Basics in Primary Knee Arthroplasty

Roland Becker
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Editors

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Foreword

A book in which all aspects for the understanding of total knee arthroplasty are gathered can be considered a real treasure.

Knowledge is essential in order to be able to perform surgery correctly and to handle unexpected problems.

Prosthetic knee surgery requires not only manual skills but also good tools, reliable instruments, computer assistance or robotics, but above all, a real understanding of knee surgery. The correct placement of the knee prosthesis is not simply replacing the worn articular surfaces with metal implants and polyethylene inserts. It must also integrate into the general architecture of the entire lower limb and the ligament structures. The knee surgeon cannot do without fundamental knowledge about the bony and soft-tissue anatomy, function, and the entire biomechanics of the knee, especially appreciating the work by Werner Muller.

As important as they are, tools do not detract from well-constructed reasons. Questions replace doubts and trust takes precedence over hesitation. The supported choice gives way to employed methods and certainties. Instruments, computers, or even robots are able to improve the faculties of the surgeon's hands. However, they do not replace the complexity of the human brain.

Knee prosthesis has become the most common treatment offered to patients who have a painful knee and limited activity generally caused by osteoarthritis. Focusing on the success of primary knee replacement, the decision to perform a partial or total replacement is a deliberate choice and depends on numerous aspects. If the "how" is one of the keys to success, the "who" and the "when" have not been overlooked in this book. These prevent complications that still occur too often.

This book also makes us aware of the virtues of evaluation. The use of current data and the development of new, more sensitive and specific parameters remains one of the keys to future progress.

Regardless of whether a young or an experienced surgeon, performing a few dozen or a few hundred knee surgeries each year, practicing within or outside Europe, the foundation of knowledge is essential for the success of the treatment and thus for the greatest satisfaction of patients.

Surgical hands are augmented nowadays by novel tools and digital assistance, helping to improve the precision and surgical quality of the traditional knee surgeon. These qualities have crossed and will continue to cross the generations: human qualities, limitless dedication in the service of a well-organized brain and nourished by basic knowledge formidably recalled in this work on the transmission of knowledge.

This book was edited by three top-quality surgeons, Roland Becker, Michael T. Hirschmann, and Nanne P. Kort, driven by their passion for knee surgery, and they have succeeded in this happy marriage of technical or technological knowledge and well-understood surgery. They were able to bring together the best European and international surgeons around them.

Lyon, France Philippe Neyret

Preface

Knee arthroplasty has been one of the most challenging innovations of the last century to preserve patients' mobility and to improve their quality of life.

Despite the unique success of knee arthroplasty, there is still need for further improvement in terms of correct indication, awareness of patients' comorbidities, alignment philosophy, enabling technology and surgical technique.

The surgery itself is one major piece of a huge puzzle to achieve optimal outcome in knee arthroplasty. New technologies such as patients-specific instrumentation, patient-specific knee arthroplasty and robotics promise help for the knee surgeon, but the understanding of the basics in total knee arthroplasty remains of utmost importance. Technology does not replace the surgeon's capability and skills, but only helps in improving accurate and reliable component position. Surgery is and will still remain an art. Some surgeons are more talented than others, but as in professional sports steady training will improve everyone's skills. However, understanding the basic principles of knee arthroplasty helps to stay out of trouble and when getting into trouble it helps to get out of it.

The basics of total knee arthroplasty start even well before surgery. The surgeon needs to identify the appropriate patients for each procedure and establish the perfect indication. Only then the patient will benefit from the surgery. Not everybody suffering from knee osteoarthritis requires knee arthroplasty. A meticulous diagnostic algorithm and pathway will help to identify the patients for surgery and will answer the question about the type of implant, partial or total and the degree of constraint. The surgeon should not only understand the patient-specific knee morphology but also the pathology in order to partly customise surgery for each patient.

Knee arthroplasty is more than a bony surgery meaning the accurate placement of the implants onto the bone. It is rather a soft-tissue procedure as nociception and proprioception originates from the soft tissue such as the ligaments and joint capsule. Appropriate ligament balancing is hardly visible on radiographs, but crucial for good knee function.

All aspects related to knee arthroplasty are covered in this book combining eminence-based and evidence-based medicine. Evidence-based analysis of questions related to knee arthroplasty is very important in order to identify the most scientifically based guidelines for our clinical practice. However, eminence-based knowledge is very helpful from experts who have gained a vast experience over a long period in surgical practice. Tips and tricks may help to overcome difficult clinical situations, all active surgeons face sometimes even unexpectedly.

We hope you will enjoy reading our comprehensive book about basics in knee arthroplasty.

Brandenburg an der Havel, Germany — Roland Becker
Bruderholz, Switzerland — Michael T. Hirschmann
Roosteren, The Netherlands — Nanne P. Kort

Contents

About the Editors

Roland Becker was born in 1963 in Magdeburg, Germany. He was qualified as an Orthopaedic Surgeon in 1998 at the University of Magdeburg and specialised in knee surgery and sports traumatology.

Prof. Becker is the Head of the Department of Orthopaedics and Traumatology, Centre for Joint Replacement Westbrandenburg and Medical Director of the University Hospital of Brandenburg/Havel. Besides his clinical work, he is very active in research and published over 120 peer-reviewed manuscripts focused on the knee. He also published seven books about knee arthroscopy and arthroplasty.

Prof. Becker was the Deputy Editor in Chief of *Journal of Knee Surgery, Sports Traumatology and Arthroscopy* (KSSTA) from 2012 to 2019.

He has always been active in national and international societies and was the president of the German Speaking Society of Arthroscopy and Joint Surgery (AGA) between 2014 and 2016. He was the Chairman of the European Knee Associates (EKA) and is currently the President of the European Society of Knee Surgery, Sports Traumatology and Arthroscopy (ESSKA).

Michael T. Hirschmann is an affiliated professor at Basel University and head of orthopaedic surgery and traumatology at Kantonsspital Baselland, Bruderholz, Switzerland. He is also the medical director of the Center for Musculoskeletal Diseases at Bruderholz and serves as head of a research group in the Department of Clinical Research (DKF) at the University of Basel, Switzerland, focusing on the knee joint. He has published over 300 academic publications in knee surgery as well as several textbooks focused on knee-related research. His research focus has been on diagnostics and treatment of knee injuries involving the cartilage, meniscus or ligaments, diagnostics and treatment of patients with OA and in particular on unhappy patients after knee arthroplasty surgery. Another major research focus lies on the evaluation and development of 3D imaging such as CT, MRI and SPECT/CT on orthopaedic purposes.

He is considered a leading authority on knee injuries and degenerative knee problems as this is a substantial portion of his clinical practice. He has spoken widely across the globe on evidence-based approaches to diagnose and treat knee-related problems such as knee injuries or osteoarthritis.

For his research and contributions Prof. Hirschmann has received more than 50 national and international awards, among those the Swiss Quality Award, the ESSKAR or AAOS best scientific exhibit award.

Nanne P. Kort was born on July 16, 1969, in Curaçao, The Netherlands Antilles, and is an orthopaedic surgeon and medical director of CortoClinics in Nederweert, The Netherlands. CortoClinics is the first orthopaedic clinic in Europe dedicated exclusively to hip and knee osteoarthritis. At CortoClinics, clients are the top priority. The approach is to think of them as individuals, not merely a "patient file" with a protocol to be followed. The focus is to look at the client's needs and desires and provide advice and explanations about their unique situation options. They determine the course of action.

Dr. Nanne P. Kort attended medical school at the University of Utrecht and did his orthopaedic residency at Groningen. In 2007 he defended his PhD on unicompartmental knee arthroplasty. He is a board-certified orthopaedic surgeon specialising in adult hip and knee reconstruction. Dr. Nanne P. Kort is active within ISAKOS, ESSKA and European Knee Associates, which he chaired from 2018 to 2020. Dr. Nanne P. Kort is an authority on hip and knee osteoarthritis's conservative and operative treatment. He also gives lectures throughout Europe on digitisation in orthopaedic healthcare and optimising care plans.

In 2018, he realised his dream of establishing his orthopaedic centre: CortoClinics.

1 Anthropometry of the Native Knee

Christopher L. McCrum, S. Joseph de Groot, Justin W. Arner, Robert Smirgelski, and Volker Musahl

Keynotes

1. The knee is a hinged diarthrodial joint which also allows some rotation, comprising the bony articulation between the femur and tibia, as well as the patellofemoral joint.
2. Stability of the knee is imparted by several structures, including the anterior and posterior cruciate ligaments, medial and lateral collateral ligaments, posteromedial and posterolateral corner structures, and the capsule, in conjunction with the bony articulation and dynamic actions of the surrounding musculature.
3. The chapter aims to discuss the anthropometry of this complex joint, as well as the implications on total knee arthroplasty.

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1.1 Introduction

At its very basic, the knee is a diarthrodial joint comprising the bony articulation between the femur and tibia as well as the femur and the patella. Despite its relative bony simplicity, it is responsible for not only flexion and extension, but it also allows internal and external rotation, abduction and adduction as well as translation [1]. In order to fully understand the intricacies of performing a total knee arthroplasty (TKA), it is paramount to have a good understanding of the knee's bony anatomy. A profound knowledge of the anthropometry of the knee will lead to a more individualized and better fitting TKA design in the future. Besides bony anatomy, it is the interplay of several structures, including the anterior and posterior cruciate ligaments, medial and lateral collateral ligaments, posteromedial and posterolateral corner structures, and the capsule, in conjunction with dynamic actions of the surrounding muscles, which determines joint laxity and stability.

1.2 Distal Femur

The distal femur terminates into a medial and lateral condyle. The medial and lateral condyles are the epiphyseal ends of the femur that articulate with the tibia and the patella. Both condyles are smooth and rounded posteriorly to allow for

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motion and level out inferiorly allowing for articulation with the tibia [1].

The medial condyle is convex in shape with a width around 25–32 mm, while the lateral condyle, also convex, is between 25 and 31 mm wide [2, 3]. Posteriorly, the intercondylar notch helps delineate the medial and lateral condyles and provides room and the attachment site for the ACL and PCL on the anteromedial and posterolateral wall, respectively [2]. Notch anatomy has been studied extensively with regard to ACL injury, but it also plays an important role in understanding the overall anatomy of the knee and how it differs between men and women. For instance, women, on average, have a more narrow notch measuring 16 ± 2 mm, while men have an average notch width of 19.3 ± 2.3 mm [4]. The width of the intercondylar fossa varies in size from around 18–21 mm [2, 3]. The increased width of the intercondylar notch does not predict an increased size of the ACL; however, it does lead to a larger insertion site at both the tibia and femur [5]. Despite the differences between men and women with concern to notch size and the variability that exists between individuals, there is a strong symmetric relationship between notch sizes of the left and right knee [4].

Anteriorly, the condyles come together to form the trochlear groove, a shallow groove usually 3.7–4.3 mm deep that allows the patella to glide through as the knee moves between flexion and extension [2, 6]. The trochlear groove is "V-shaped" and forms an average angle of 148–151° with the lateral aspect of the groove being longer than the medial side [6]. This increase in the lateral side of the trochlear groove prevents lateral subluxation of the patella.

Other important structures adjacent to the femoral condyles are the medial and lateral epicondyles, which are small bony prominences on the medial and lateral aspects of the distal femur. The medial and lateral epicondyles serve as the attachment sites of the medial and lateral collateral ligaments, respectively [2]. The medial epicondyle is on average 29 mm proximal and 28.2 mm anterior to the articulating surface of the femur, while the lateral condyle sits on average 24 mm proximal and 24.4 mm anterior to the articular surface of the femur [7].

Side Summary

- The medial and lateral femoral condyles are convex in shape and are between 25 and 32 mm and 25–31 mm wide, respectively.
- The trochlear groove is "V-shaped" and forms an average angle around 150° with the lateral aspect of the groove being longer than the medial to prevent lateral subluxation.
- The medial and lateral epicondyles serve as attachment sites for the medial and lateral collateral ligaments, respectively.

The epicondyles not only serve as intraoperative landmarks to help locate the joint line via the transepicondylar axis (TEA), but they too are used pre-operatively to help determine the rotation of the femur as well as approximate the position of the posterior femoral cut [8]. The TEA has compared favorably to other intraoperative and pre-operative markers for femoral rotation such as Whiteside's line and posterior condylar axis (PCA) [9] (Table 1.1).

Table 1.1 Reliability as defined by the percentage of knees using a particular method that fell within 3° of flexion gap symmetry. From Olcott and Scott (Olcott, C.W., Scott, R.D., 2000)

Reliability of three different intraoperative landmarks to produce flexion gap symmetry in TKA	
Intraoperative method	Percentage of knees within 3° of flexion gap symmetry
Whiteside's line	83%
Posterior condylar axis	70%
Transepicondylar axis	90%

Table 1.2 The angle formed between the posterior condylar axis and the epicondylar axis and Whiteside's line expressed in degrees of external rotation. From Loures et al. (Loures et al. 2015)

The angle between the posterior condylar axis and the epicondylar axis and Whiteside's line			
Angle (degrees)	Mean (in degrees of external rotation)	Standard deviation	Range (degrees of external rotation)
Epicondylar axis	2.89	3.25	−2.23 to 7.86
Whiteside's line	4.77	2.80	−2.09 to 12.2

The TEA is believed to be the functional axis of the knee but due to its high intraoperative and intra-observer variability the PCA can also be used as an alternative to TEA [10]. The PCA is very easy to identify intraoperatively especially as compared to the TEA, and studies have shown the PCA to be on average 3° internally rotated compared to the transepicondylar axis [11] (Table 1.2). It can be identified intraoperatively, and the distal femur cut is made with 3° of external rotation to allow for a rectangular flexion box [11]. Careful consideration must be taken, however, when using the PCA because it can vary between 0 and 10° of internal rotation. Therefore, it is important to carefully evaluate the PCA preoperatively to prevent under- or overestimating the degree of internal rotation to ensure the ability to create a rectangular flexion box [11].

Whiteside's line can be also used to assess femoral TKA rotation. It consists of a line from the deepest part of the trochlear groove to the center of the intercondylar notch [12]. Whiteside's line, like the EA, can be inconsistent, can be difficult to determine intraoperatively, and can lead to excessive rotation of the femur with more severe varus deformity [10]. Rotation of the femur, as well as the tibia, is critical, as it has been shown to have a significant effect on the success of the implant, particularly the patella [13].

Side Summary

- The transepicondylar axis (TEA), Whiteside's Line, and the posterior condylar axis (PCA) are all used in total knee arthroplasty to help determine the axis of the femur.
- The TEA is believed to be an estimation of the functional axis of the knee and is used preoperatively to help determine the rotation of the femur as well as approximate the position of the posterior femoral cut.
- The TEA has a high intraoperative and intra-observer variability but shows the most reliability in producing flexion gap symmetry.

In addition to the medial epicondyle, the medial aspect of the knee also has the adductor and gastrocnemius tubercles where the adductor magnus and the medial gastrocnemius attach, respectively. The adductor tubercle is approximately 12.5 mm proximal and 8 mm posterior to the medial epicondyle, while the gastrocnemius tubercle is approximately 14 mm posterior and 6 mm proximal to the medial epicondyle [11] (Fig. 1.1). On the lateral side, the attachment site of the fibular collateral ligament is 1.4 mm proximal and 3.1 mm distal to the lateral epicondyle, and the lateral gastrocnemius tubercle is on average 17.2 mm proximal and posterior to the lateral epicondyle [14] (Fig. 1.2).

1.3 Patella

Understanding the anatomy of the patella is crucial for TKA as it is one of the most common causes of complications and failure [15].

The patella is a triangular-shaped sesamoid bone connected by the quadriceps tendon superiorly and the patellar tendon inferiorly with the apex of the triangle directed inferiorly [2]. The

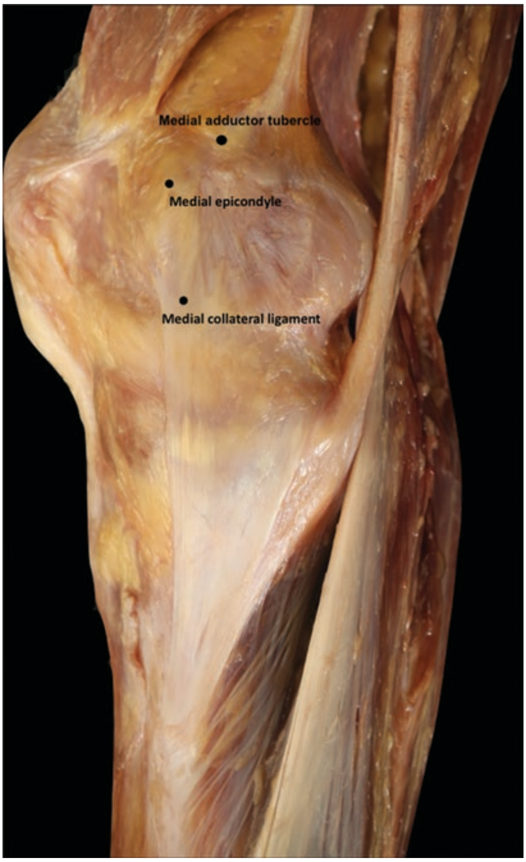

Fig. 1.1 Medial view of the knee. Soft tissue structures, medial collateral ligament, medial epicondyle, vastus medial muscle

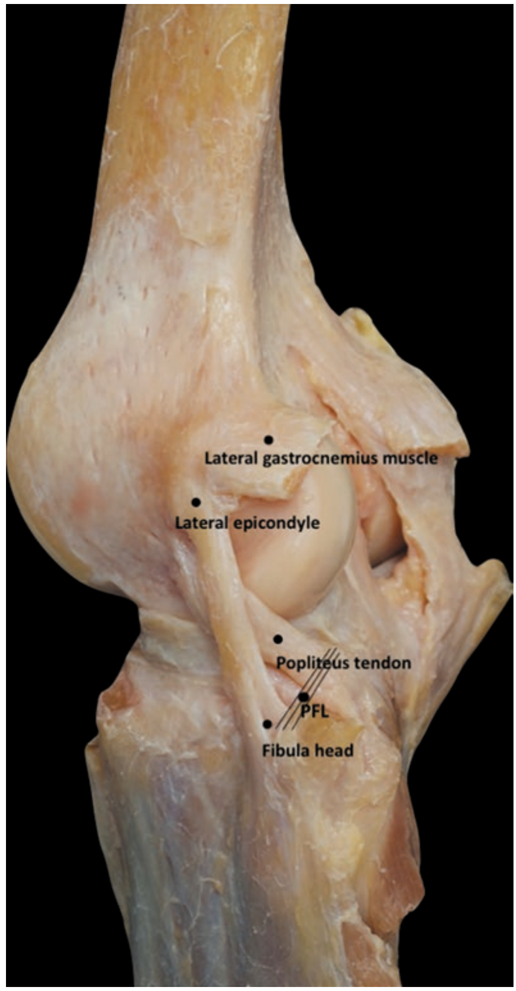

Fig. 1.2 Lateral view of the knee. The main posterolateral corner static stabilizers include the lateral collateral ligament (LCL), popliteofibular ligament (PFL), and popliteus tendon

patella has medial and lateral facets, which articulate with the medial and lateral condyles of the femur, respectively. The lateral facet is larger than the medial facet with an average width of 27.5 mm as compared to 20.5 mm for the medial facet [15]. The reason for this discrepancy is that the lateral femoral condyle is larger than the medial condyle, so the lateral facet of the patella must be larger to accommodate [15]. Despite the smaller size, however, the medial facet is thicker than the lateral facet with an average thickness of 19 mm in males and 18 mm in females compared to 18.4 mm in males and 16.7 mm in females, respectively [15].

Also important is the thickness of the patella as it is crucial to guiding how much bone should be resected during patellar resurfacing. Men tend to have a thicker patella as compared to women with an average patellar thickness of 25.3 mm compared to 22.5 mm [16]. Men also tend to have wider patellae with an average width of 50.3 mm compared to 43.5 mm in women [15]. The height is also larger in males with an average height of 38.6 mm in males and 33.9 mm in females [15]. However, despite women having smaller patellae in height, width, and thickness, they have near-identical width/height ratios as men [15].

Side Summary
- The patella is one of the most common causes of complications in total knee arthroplasty.
- The lateral facet is larger than the medial facet due to the lateral femoral condyle being larger.
- Men tend to have thicker patellae as compared to women with an average thickness of 25.3 and 22.5 mm, respectively.

1.4 Proximal Tibia and Menisci

The articulating surface of the tibia consists of a convex lateral compartment and a concave medial compartment [2]. The medial tibial plateau is on average larger than the lateral plateau in both the anterior to posterior direction and the medial to lateral direction [17, 18]. In the anterior–posterior direction, the medial plateau averages 45–78 mm, while the lateral plateau averages between 41 and 48 mm [17]. Further, the area of the medial plateau is approximately 1.4–1.9 cm^2, while the lateral plateau is between 1.25 and 1.67 cm^2 [18] (Fig. 1.3). The tibia is sloped posteriorly which is paramount to knee flexion and stability. The higher the posterior tibial slope, the more flexion the knee is capable of [19]. The slope is different medially and laterally. It is on average between 4.6 and 8.2° medially and 5° laterally [19]. Women show higher posterior slope than men. It is on average 8.6° medially and 8° laterally [20]. The tibial slope is also important to consider when making the tibial cut in a TKA as a decreased angle leads to increased strain on the PCL and a decrease in knee flexion [21–24].

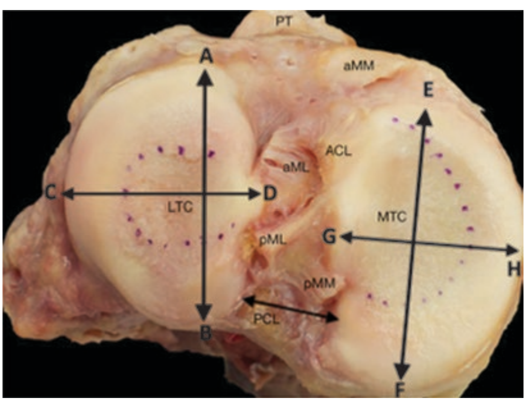

Fig. 1.3 Superior view of the proximal tibia and its measurements. AB and CD: AP and transverse measurements of superior articular surface of medial condyle, EF and GH: AP and transverse measurements of superior articular surface of lateral condyle

Side Summary
- The tibia consists of a convex lateral compartment and a concave medial compartment.
- The tibia is sloped posteriorly which is paramount to knee flexion and stability.
- The higher the posterior tibial slope, the more flexion the knee is capable of.
- A decrease in the tibial slope during the tibia cut leads to increased strain on the PCL and a decrease in knee flexion.

The intercondylar area resides between the medial and lateral condyles and is the attachment site of the ACL and PCL as well as the medial and lateral meniscus [2]. The intercondylar area is formed by the medial and lateral intercondylar eminences, which are bony prominences arising from the most lateral aspect of the medial epicondyle and the most medial aspect of the lateral epicondyle, respectively [2]. The intercondylar area is on average 43–49 mm from anterior to posterior; however, it varies in size from medial to lateral as it is wider anteriorly than it is posteriorly [18]. Anterior to the intercondylar area is the anterior intercondylar fossa, which is the attachment site of the ACL, which is on average 22–25 mm from medial to lateral [25, 26]. The PCL attaches posteriorly in the smaller posterior intercondylar fossa, which is on average 6.5–7.5 mm from medial to lateral.

The medial and lateral menisci cover the medial and lateral tibial plateau. They are

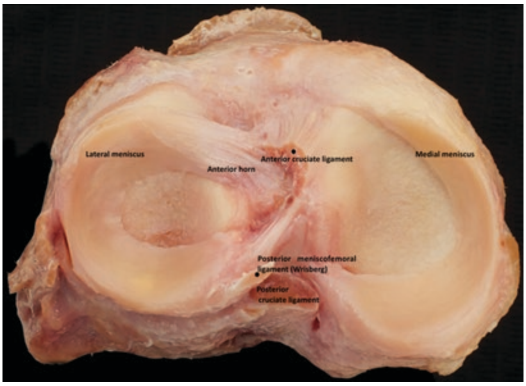

Fig. 1.4 Tibial insertion site of the ACL, with related landmarks such as the anterior horn of the lateral meniscus, and their relationship to the insertion site indicated

C-shaped wedges of fibrocartilage, which predominantly consist of water and collagen allowing for a smooth articulation between the concave femoral condyles and the relatively flat surface of the tibial plateau (Fig. 1.4) [27].

The medial meniscus covers approximately 60% of the medial joint surface [27]. The anterior horn is thinner and attaches to the tibia just anterior to the ACL attachment site in close proximity to the intercondylar fossa. The posterior horn, which is thicker than the anterior horn, attaches anterior to the insertion site of the PCL, and peripherally, the medial meniscus merges with the knee capsule. The medial meniscus is less mobile than the lateral meniscus as it most commonly has a bony attachment to the intercondylar area of the tibia laterally and the superficial medial collateral ligament medially.

The lateral meniscus is more uniformly C-shaped than the medial meniscus and, despite being smaller, covers 80% of the lateral joint surface [27]. The lateral meniscus is more mobile than the medial meniscus with the anterior horn attaching to the intercondylar fossa near the attachment site of the ACL and the posterior horn attaching to the PCL and medial femoral condyle [27]. The posterior meniscofemoral ligament (Wrisberg ligament) lies posterior, while the anterior meniscofemoral ligament (Humphrey) is anterior to the PCL. Both serve as anchor of the posterior horn of the lateral meniscus to the medial femoral condyle [27].

Side Summary

- The intercondylar area is the attachment site of the ACL and PCL as well as the medial and lateral meniscus.
- The menisci are C-shaped wedges of fibrocartilage, which predominantly consist of water and collagen allowing for a smooth articulation between the concave femoral condyles and the relatively flat surface of the tibial plateau.
- The medial meniscus is less mobile than the lateral meniscus as it most commonly due to bony attachments laterally and the superficial medial collateral ligament medially.

1.5 Ligamentous Structures

1.5.1 Anterior Cruciate Ligament (ACL)

The anterior cruciate ligament (ACL) provides primary restraint to anterior tibial drawer, as well as conferring rotational stability to the knee. This structure is broken into two distinct functional bundles from early in embryogenesis [28]: the anteromedial (AM) bundle and the posterolateral (PL) bundle, based on the orientation of each bundle on the tibial footprint [29–34]. These bundles are covered with synovial tissue, which also separates the AM and PL bundles [25, 35, 36].

Although classically the AM bundle is described to be tight in flexion and the PL bundle is described to be tight in extension [34], this relationship has been noted to be non-isometric and more complex in vivo. More recent evidence has demonstrated that the PL bundle is taut in full extension, 5–6 mm of slack in mid-flexion, and taut again in flexion beyond 90°, while the AM bundle is relatively taught throughout the flexion–extension arc, with only 2–3 mm length changes throughout motion [37–39].

The tibial insertion site of the ACL, also known as the tibial footprint, is located anterior and between the intercondylar eminences on the tibial plateau (Fig. 1.4). Fibers of the ACL, including direct and indirect fibers [33], fan out over this insertion site, and this area is about 120% the size of the femoral insertion of the ACL [40]. The anterior-most aspect of the AM bundle of the ACL is at the level of the anterior border of the lateral meniscus, and it is bound by the posterior aspect of the intermeniscal ligament [34]. Relative to the peak of the medial tibial spine, the center of the AM bundle is about 8.6 ± 1.0 mm away and the center of the PL bundle is about 1.4 ± 0.7 mm away [33]. The ACL is located about 7 mm from the anterior-most aspect of the PCL insertion at the top of the notch [41, 42]. The area of the tibial insertion site of the ACL is about 136 ± 33 mm^2 [40], with an average length of 18.1 ± 2.8 mm and a width of 10.7 ± 1.9 mm [33, 43]. The AM bundle ranges from 7.9 to 12.0 mm in length and 8.2 to 15.3 mm in width, while the PL bundle ranges from 6.3 to 10.0 mm in length and 5.4 to 11.4 mm in width [33, 43].

The femoral insertion site of the ACL is associated with several significant bony landmarks on the lateral aspect of the notch. The ACL insertion site is found posterior to the lateral intercondylar ridge, also known as resident's ridge, and the AM and PL bundles are separated by the lateral bifurcate ridge, which runs in an anterior–posterior direction [43]. The AM bundle attachment to the femur is posterior and superior within the notch, while the PL bundle is more anterior and inferior [37] (Fig. 1.5). The femoral insertion site is about 113 ± 27 mm^2 [40]. The AM bundle ranges in length from 6 to 12 mm and in width from 6 to 10 mm, while the PL bundle ranges in length from 4 to 10 mm and in width from 4 to 10 mm [43].

The anatomy of the ACL varies between the tibial and femoral insertion sites and the midsubstance and is shaped like an hourglass. The insertion sites can be up to 3.5 times as large as the midsubstance of the ACL [40]. The ACL insertion site has been evaluated in vivo, and there is variation between individuals. However, in general, relative to the size of the tibial insertion site, the femoral insertion site is about 70% of the size, and the midpoint between the tibial and femoral insertion sites is about 50% of the size [44].

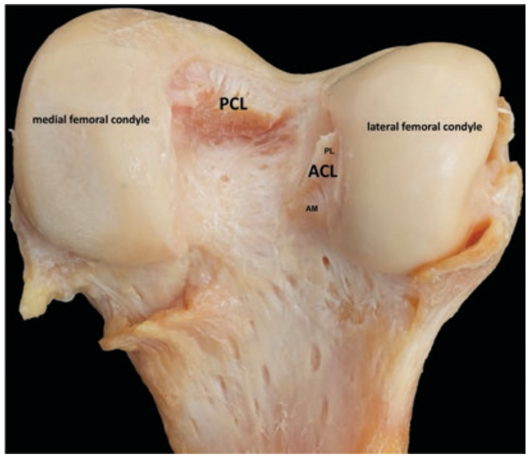

Fig. 1.5 Posterior view of the notch, showing the femoral insertion of both ACL and PCL

Side Summary
- The ACL is hourglass in shape and consists of an anteromedial and posterolateral bundle.
- The AM bundle is tight in flexion, and the PL bundle is tight in extension.
- The tibial insertion site of the ACL is anterior and between the intercondylar eminences on the tibial plateau.
- The femoral attachment site of the ACL is posterior to the lateral intercondylar ridge.

1.5.2 Posterior Cruciate Ligament (PCL)

The posterior cruciate ligament (PCL) is the structure responsible to be the primary restraint to posterior tibial translation, and it also serves as a secondary restraint to external rotation, valgus, and varus stress [26, 45, 46]. The PCL is composed of two functional bundles: the anterolateral bundle (ALB) and the posteromedial bundle (PMB) (Fig. 1.6). The ALB of the PCL is the larger bundle in cross-sectional area, and it is taut in knee flexion and relatively loose in knee extension. The PMB is smaller, taut in extension, and loose in knee flexion [34, 40, 47] (Table 1.3). While the tensioning of the bundles differs depending on knee flexion angles, biomechanical studies have shown these bundles to work synergistically in order to confer stability to the knee [48–50].

The PCL spans from the anteromedial aspect of the articular margin of the medial femoral condyle to the posterior aspect of the tibia on the posterior tibial sulcus (Fig. 1.6). Each bundle composes about 50% of both the tibial and femoral insertion sites [40]. Much like with the ACL, the size of the PCL varies between the insertion sites and the midsubstance. The insertion sites are about three times larger than the midsubstance [40], with the midsubstance measuring about 12.2–13 mm [34, 51]. The average length of the PCL is about 38 mm [34].

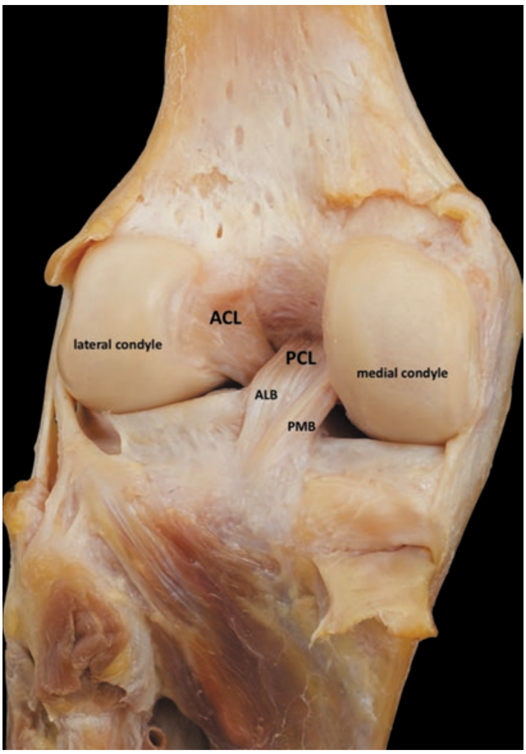

Fig. 1.6 Posterior view of the notch with the knee in extension showing the relationship between ACL and PCL and the anterolateral (ALB) and posteromedial (PMB) of the PCL

Side Summary

- The posterior cruciate ligament (PCL) is the primary restraint to posterior tibial translation, and it also serves as a secondary restraint to external rotation, valgus, and varus stress.
- The PCL is composed of two functional bundles: the anterolateral bundle (ALB) and the posteromedial bundle (PMB).
- The ALB of the PCL is larger and is taut in knee flexion, while the PMB is smaller and taut in extension.

Table 1.3 The anatomy and function of the posterior cruciate ligament

Posterior cruciate ligament (PCL)	
Origin	Articular margin of medial femoral condyle
Insertion	Posterior aspect of tibia on tibial sulcus
Role	Restraint to external rotation, valgus, varus
Bundles	Anterolateral (AL) and posteromedial (PM)
Roles	AL: Larger, taut in flexion/loose in extension
	PM: Smaller, taut in extension/loose in flexion

The PCL insertion site on the femur spans all the way to the articular surface and varies in specific shape between individuals (Fig. 1.5). The insertion site has been noted to be elliptical [51, 52], semi-circular [34], half-moon [40], and quarter elliptical [53] in shape. The insertion site of the PCL on the femur is about 128–232.2 mm^2 in area [40, 45, 53] (Fig. 1.7). On a lateral radiograph of the knee, the center of the ALB can be located at the point 62% from the posterior to anterior, along Blumensaat line, and 16% from Blumensaat line to the articular surface of the knee. The PMB is located about 51% from posterior to anterior on Blumensaat line and 35% posterior between Blumensaat line and the artic-

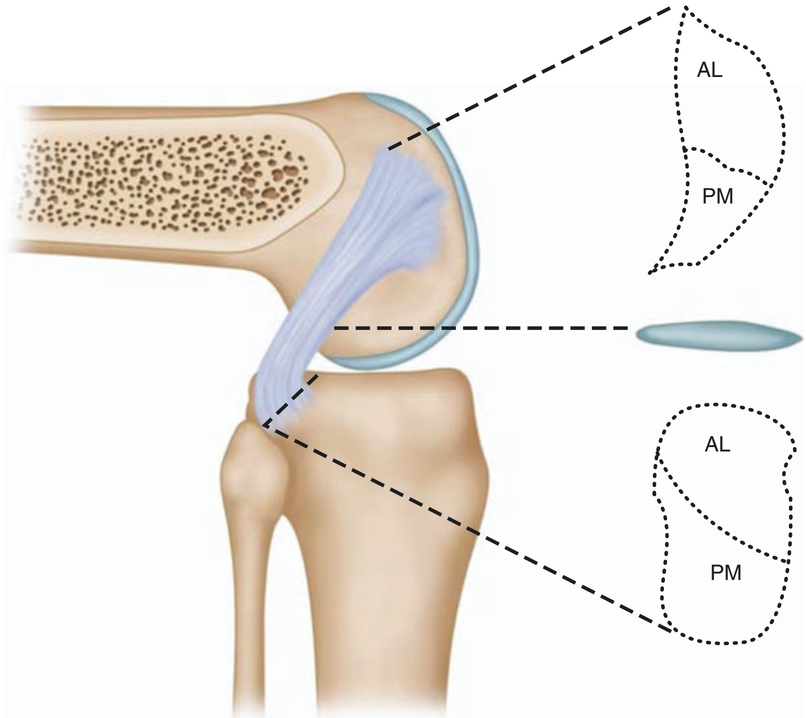

Fig. 1.7 Anatomical footprint of the anterolateral bundle (ALB) and posteromedial bundle (PMB) of the PCL ligament on both the proximal tibia and distal femur

ular surface [54]. When viewing the knee operatively, the center of the ALB is located 1.5 mm from the articular cartilage at the apex of the notch and 7.9 mm from the articular cartilage distally, while the center of the PMB is located 5.8 mm from the articular cartilage at the level of the apex of the notch and 8.6 mm from the articular edge of the cartilage distally, and they are separated by about 12.1 mm [55]. There is a small "bundle ridge" that separates the ALB and the PMB, and this separation runs from proximal to distal [40, 55].

On the tibial side, the insertion site on the tibia is larger than that on the femur, measuring about 153–243.9 mm^2 in area [40, 56]. The anterolateral aspect of this insertion site has been reported to be 46.7–93.1 mm^2, while the posteromedial aspect of the insertion site has been reported to be between 62 and 150.8 mm^2 [40, 56, 57]. The wide range of these studies may be due to the inclusion or exclusion of all of the large number of indirect fibers of this ligament—the lower end of this range may represent mainly the direct fibers of each individual bundle, which do not significantly differ from each other, while the larger aspect of the range includes all of the indirect fibers [56]. The PCL attaches to the posterior intercondylar fossa between the tibial plateaus, with the anterolateral bundle attaching to the superolateral aspect of the fossa, while the posteromedial bundle attaches to the inferomedial aspect of the fossa [40, 56].

Relevant to the PCL is the proximity of the popliteal artery posteriorly during surgery (Fig. 1.8a,b). The relationship between these structures varies based on the knee flexion angle, with increasing knee flexion positively correlating to distance to the artery. In the axial plane, the artery is located about between 3 and 10 mm from the PCL at 0° flexion, 2–11 mm at 45°, 4–13 mm at 60°, 4–16 mm at 90°, and 5–15 mm from the PCL at 100° flexion. In the sagittal plane, the popliteal artery is found 3–11 mm from the PCL at 0° knee flexion, 4–10 mm at 45°, 4–13 mm at 60°, 2–15 mm at 90°, and 6–18 mm from the PCL at 100° knee flexion [58].

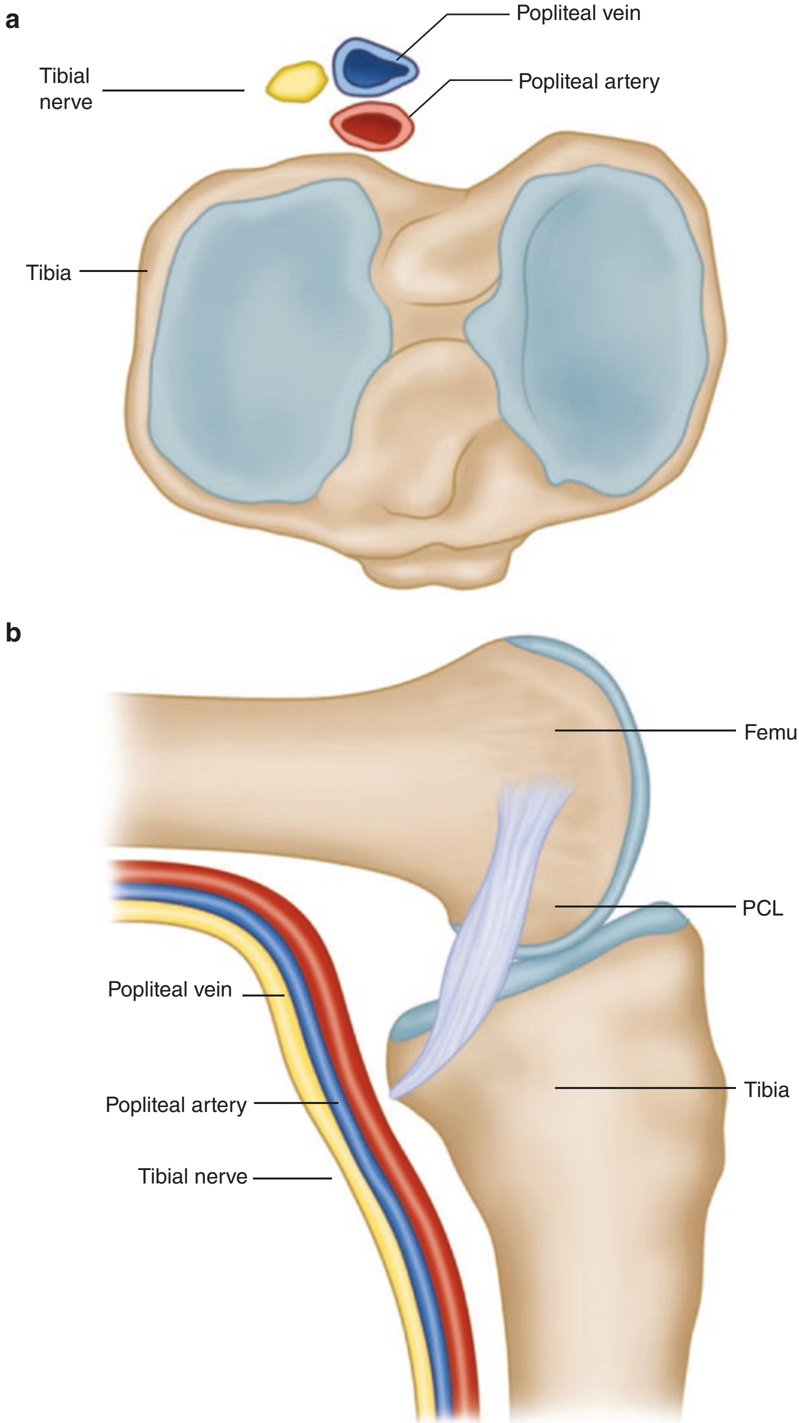

Fig. 1.8 (**a**, **b**) The femoral bony landmarks with attachment locations of medial knee structures. ME (medial epicondyle), AT (adductor tubercle), GT (gastrocnemius tubercle), sMCL (superficial MCL), dMCL (deep medial collateral ligament), AMT (adductor magnus tendon), MGT (medial gastrocnemius tendon), MPFL (medial patellofemoral ligament), POL (posterior oblique ligament), SM (semimembranosus tendon), VMO (vastus medialis obliquus muscle)

Side Summary

- The center of the ALB is located 1.5 mm from the articular cartilage at the apex of the notch and 7.9 mm from the articular cartilage distally on the femur, while the center of the PMB is located 5.8 mm from the articular cartilage at the level of the apex of the notch and 8.6 mm from the articular edge of the cartilage distally.
- On the tibial side, the PCL attaches to the posterior intercondylar fossa between the tibial plateaus, with the anterolateral bundle attaching to the superolateral aspect of the fossa, while the posteromedial bundle attaches to the inferomedial aspect of the fossa.

1.5.3 Medial Knee Structures

Medial knee structures can be easily damaged during TKA approach and may also be partially or fully released during TKA.

The medial knee structures primarily stabilize the knee against valgus stress [59–61]. The three most important structures providing primary stability to the medial side are the superficial medial collateral ligament (sMCL), the posterior oblique ligament (POL), and the deep medial collateral ligament (dMCL) [59–62]. Other structures also play important roles in patellar alignment and stability, mainly the medial patellofemoral ligament (MPFL). Other structures include the posterior oblique ligament (POL), adductor magnus tendon (AMT), the medial hamstring tendons (pes anserinus), the vastus medialis obliquus muscle, and the medial gastrocnemius tendon (MGT) [62].

The medial epicondyle is an essential landmark on the medial femoral condyle and is the most anterior and distal prominence (Fig. 1.1). The medial supracondylar line is just proximal and posterior to the medial epicondyle and is made up of a thin ridge of bone with the adductor tubercle being at its distal edge. The medial epicondyle is 12.6 and 8.3 mm anterior to the adductor tubercle. A third bony prominence, which is more difficult to identify, is the gastrocnemius tubercle, which is just distal and posterior to the adductor tubercle and adjacent to a small bony depression. This is adjacent to the actual insertion of the origin of the medial head of the gastrocnemius [14]. The locations of these three bony prominences are essential to understand soft tissue attachment locations and their role.

The sMCL is 10–12 cm in length and is the largest structure of the medial knee, and its protection during knee arthroplasty is essential [14, 63]. It attaches in a small depression 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle on the femur and has two attachments to the tibia. The more distal attachment is 6 cm from the joint line, while the proximal attachment is on the soft tissues just over the semimembranosus tendon [14]. Without this structure being competent, a constrained total knee arthroplasty must be used.

Side Summary

- The medial knee structures stabilize the knee against valgus stress with the three most important stabilizers being the superficial and deep MCL and the posterior oblique ligament.
- The sMCL is 10–12 cm in length and attaches to a small depression just proximal and posterior to the medial epicondyle on the femur.
- On the tibial side, it attaches approximately 6 cm from the joint line and in the soft tissues just over the semimembranosus tendon.
- Without this structure being competent, a full constrained total knee arthroplasty must be used.

The dMCL is actually a thickening of the joint capsule just deep to the sMCL (Fig. 1.9). It consists of the meniscotibial and meniscofemoral parts, the first being thicker and shorter and attaching 3.2 mm distal to the joint. The menisco-

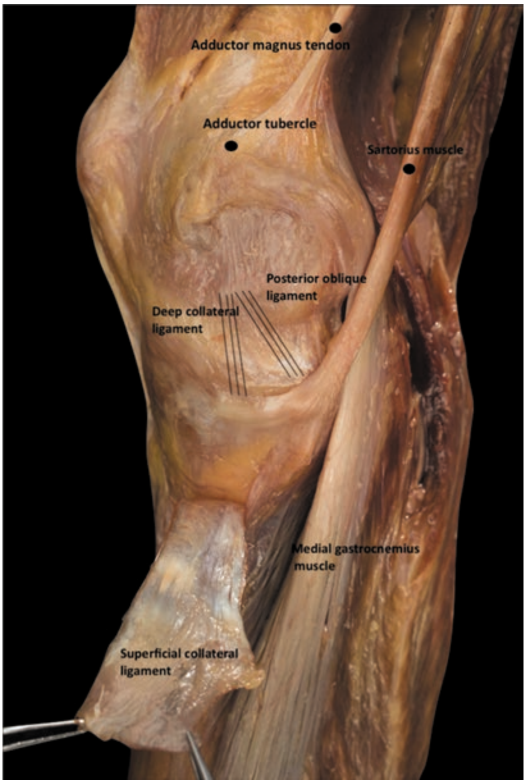

Fig. 1.9 Attachment locations of the LCL (also known as the fibular collateral ligament or FCL), popliteofibular ligament (PFL), popliteus tendon (PLT), and lateral gastrocnemius tendon (LGT)

femoral portion is thinner and longer and attaches 15.7 mm proximal to the joint line [14].

Other secondary stabilizers exist, as mentioned previously. The POL is actually three bands that originate from the semimembranosus tendon and help support the posteromedial capsule in a fan-like manor posterior to the sMCL and attach to numerous soft tissue structures of the medial knee described previously [14, 64] (Fig. 1.9). The AMT inserts posterior and proximal to the adductor tubercle and has attachments to the MGT and posteromedial joint capsule as well as the vastus medialis obliquus. The MPFL originates anterior and distal to the adductor tubercle and runs transversely like a fan to the medial patella [14].

The pes anserinus tendons are made up of the sartorius, gracilis, and semitendinosus from proximal to distal. They attach to the anteromedial aspect of the proximal tibia. The semimembranosus inserts more posteriorly into a horizontal groove on the posterior medial aspect of the medial condyle of the tibia [14]. It is an important landmark to identify during tibial preparation, particularly in revision total knee arthroplasty. The POL has important attachments to this structure as well. The MGT attaches proximal and posterior to the gastrocnemius tubercle (Fig. 1.9) and has attachments to the POL as well. Finally, the vastus medialis obliquus originates from the AMT as well as the adductor longus. It also has attachments to the MPFL, making it clear it plays a role in patellar stabilization [14].

The saphenous nerve is a branch of the femoral nerve and lies between the gracilis and semitendinosus tendons. It divides into the main saphenous branch and infrapatellar branch. The infrapatellar branch is important, as it is a sensory nerve of the anterior knee and anterolateral aspect of the proximal lower leg. Its course is variable but generally runs through the sartorius muscle, and then travels distal and anterior and crosses horizontally over the patellar tendon [65].

The superior and inferior medial genicular arteries lie on the medial aspect of the knee and both meet their lateral genicular partners superior and inferior to the patella, respectively. The superior genicular arteries meet anterior to the quadriceps tendon while the inferior geniculates meet in the fat pad posterior to the patellar ligament [66].

Side Summary

- The deep MCL is a thickening of the joint capsule deep to the superficial MCL.
- The POL is three bands originating from the semimembranosus tendon, and it helps support the posteromedial capsule.
- The pes anserine is made up of the sartorius, gracilis, and semitendinosus, and they attach to the anteromedial aspect of the proximal tibia.

1.5.4 Lateral Knee Structures

The lateral knee structures primarily resist varus forces. Other important lateral structures are the iliotibial band (ITB), long and short heads of the biceps femoris, lateral gastrocnemius tendon, fabellofibular ligament, proximal tibiofibular ligaments, and coronary ligament of the lateral meniscus [67]. The common peroneal nerve and lateral inferior genicular artery are also vital to understand anatomically and assess, as injury can be catastrophic.

Lateral knee bony anatomy is important in order to understand the soft tissue relationships. The convex surface of the native tibia makes the lateral knee less stable and makes healing of injuries difficult. For this reason, pre-operative evaluation for lateral knee stability is important to rule out previous lateral knee injuries, which may have led to end-stage osteoarthritis necessitating a knee replacement. The lateral epicondyle, popliteal sulcus, Gerdy's tubercle, and fibular head are key bony landmarks [68].

The most important structure in static lateral knee stabilization is the LCL, which originates 1.4 mm proximal and 3.1 mm posterior to the lateral epicondyle in a small bony depression [68]. This actually is proximal and posterior to the attachment of the popliteus tendon, which is important in ligament reconstruction surgery (Fig. 1.10). The distal LCL attachment is the lateral fibular head 8.2 mm posterior to the anterior margin and 28.4 mm distal to the tip in a small depression [68].

Side Summary

- The key bony landmarks to the lateral knee are the lateral epicondyle, popliteal sulcus, Gerdy's tubercle, and the fibular head.
- The LCL is the most important static stabilizer of the lateral knee and originates just proximal and posterior to the lateral epicondyle and attaches to the lateral fibular head.

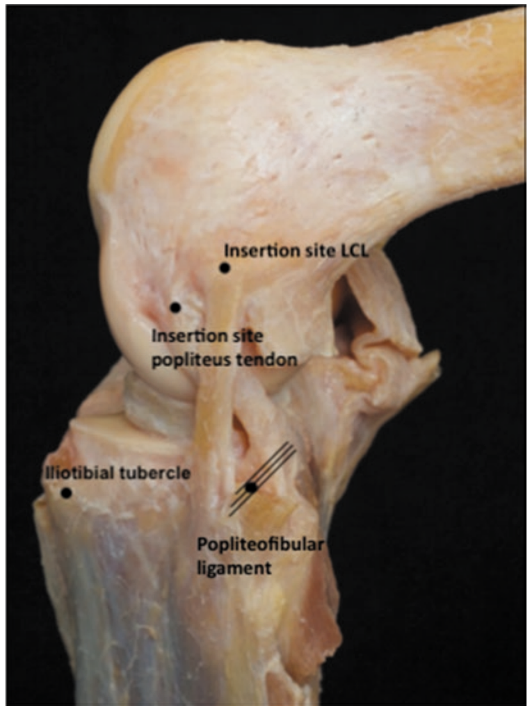

Fig. 1.10 (**a**) Middle, deep, and capsulo-osseous layer of the iliotibial band. A different fiber alignment of the lateral intermuscular septum (IS) compared to the Kaplan fibers (KF) becomes evident. The *asterisk* shows the accessory fiber bundles of the Kaplan fibers, inserting on the lateral superior condyle. Furthermore, the proximity of the Kaplan fibers with the branches of superior genicular artery (*white arrow-head*). (**b**) With further posterior reflection of the superficial iliotibial band (sITB) and blunt dissection between the deep ITB (*black arrow*) and the anterolateral capsule, the capsulo-osseous layer (*black arrow-head*) becomes visible. From *Herbst* et al. "The anterolateral complex of the knee: a pictorial essay. Herbst E, Albers M, Burnham JM, Shaikh HS, Naendrup JH, Fu FH, Musahl V. Knee Surg Sports Traumatol Arthrosc. 2017 Apr;25(4):1009–1014"

The popliteus muscle's origin is as a tendon on the lateral femur, posterior to the lateral femoral condyle articular cartilage at the popliteal sulcus [68]. The tendon then goes posterior and inferiorly and exits the joint at the popliteal hiatus and then travels medially to insert broadly on the posterior tibia [68]. If the knee is tight in the lateral compartment, one may release the popliteus tendon during total knee arthroplasty. The popliteal hiatus is made up of three fascicles that attach the tendon to the meniscus. The popliteofibular ligament (PFL) has two divisions that attach the musculotendinous junction of the popliteus muscle to the posterior fibular head [68].

The ITB is a broad fascia that travels from the pelvis and attaches to the anterolateral aspect of Gerdy's tubercle. The ITB can be pie crusted or lengthened as the first step if a total knee arthroplasty is too tight laterally, with the popliteus tendon being a secondary consideration. Tissue also continues to the patella and capsule-osseous layers which attach to the lateral gastrocnemius, short head of the biceps femoris, and more posteriorly on the tibia [69]. The long head of the biceps femoris has an anterior arm that attaches to the fibular head lateral to the LCL, while the direct arm attaches lateral to the fibular styloid [62]. The short head of the biceps femoris has many distal attachments including a direct arm, anterior arm, the long head of the biceps tendon, posterolateral joint capsule, capsulo-osseous layer of the IT band, and a lateral aponeurosis [70]. The direct arm attaches at the fibular head between the styloid and distal LCL attachment, while the anterior arm attaches 1 cm posterior to Gerdy's tubercle.

The lateral gastrocnemius tendon has a fabella and then attaches to the supracondylar process of the femur, posterior to the LCL and PLT attachments. Anterior and posterior tibiofibular joint ligaments make up the proximal tibiofibular joint which give stability and therefore provide stability to the structures that attach to the fibula [71]. The coronary ligament of the lateral meniscus is part of the posterolateral joint capsule connecting the lateral meniscus to the lateral tibia just distal to the cartilage surface, while the other attachment is adjacent to the PCL attachment [67, 69].

The common peroneal nerve is vital and courses along the biceps femoris then around the fibular neck and splints into superficial and deep peroneal nerves. Neurolysis typically is performed when surgery is done in this region with the thought being to decrease the risk of post-operative drop foot secondary to swelling [72]. If a drop foot or other sensory or motor issues exist after total knee arthroplasty, the knee should be bent to decrease tension on the nerve and compressive dressing removed. Post-operative hematoma also can compress the nerve and should be considered [72].

The main blood vessel in the lateral knee region is the lateral inferior genicular artery which comes from the popliteal artery along the capsule and comes anteriorly just posterior to the PFL and continues along the anterior capsule [69]. This artery should be identified during lateral knee surgery as injury can cause post-operative hematoma with outcomes as mentioned previously.

Side Summary

- If the knee is tight laterally, the IT band is often the first structure pie crusted or lengthened.
- If the knee remains tight, then the popliteus muscle may also be released.
- The common peroneal nerve courses along the biceps femoris and around the fibular head splitting into the superficial and deep peroneal nerve and damage to this nerve may lead to foot drop.

Take Home Message

- The knee is a diarthrodial joint with articulations between the femur and tibia, as well as the patellofemoral joint.
- Bony knee anatomy plays a role in stability; knowledge of specific bony relationships are key for proper treatment of knee conditions.
- Stability of the knee is also imparted by soft tissue structures including the anterior and posterior cruciate ligaments, medial and lateral collateral ligaments, posteromedial and posterolateral corner structures, the capsule, and dynamic actions of the surrounding musculature.
- Knowledge of the anatomic relationships of these soft tissue structures as well as neurologic and vascular structures are essential for a safe and properly balanced knee arthroplasty.

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2 Kinematics of the Native Knee

Ryan J. Reynolds, Aude Michelet,
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Keynotes

1. Kinematics is a branch of physics concerned with analysis of movements, in absolute or relative space, without consideration for their driving or resistant forces.
2. Knee kinematics are determined primarily by the four ligaments, the ACL, PCL, MCL, and LCL.
3. Over the past two decades, various authors reported disparate kinematic patterns, which could be attributed to the heterogeneity of knee specimens, imaging modalities, reference axes, and loading conditions.
4. The tibiofemoral joint is a bicondylar, modified-hinge joint that also exhibits rotational and linear movements, thereby allowing up to six degrees of freedom during dynamic activities. The center of the rotation is located in the medial tibiofemoral compartment.
5. The main biomechanical function of the patella is to improve quadriceps efficiency by increasing the lever arm of the extensor mechanism.
6. The knee is considered to be stable when, in response to external forces, there are no subjectively excessive rotations or displacements, and the surrounding ligaments are within their elastic ranges.
7. The extent of knee flexion required for different activities varies considerably: 67° for walking, 83° when climbing stairs, 90° when sitting down and descending stairs, 106° when tying shoelaces, and 130° when squatting.
8. A clear understanding of the interrelationship between the different structures of the native knee joint and their role in knee kinematics is required to better serve the functional needs of patients.

2.1 Introduction

The knee serves several important functions, including sustainment of body weight, transmission of forces for motion, and conservation of momentum during gait [1]. Yet the knee is the least stable joint in relation to the loads it supports [2]. Its intrinsic susceptibility to damage is mainly due to poor congruence between its

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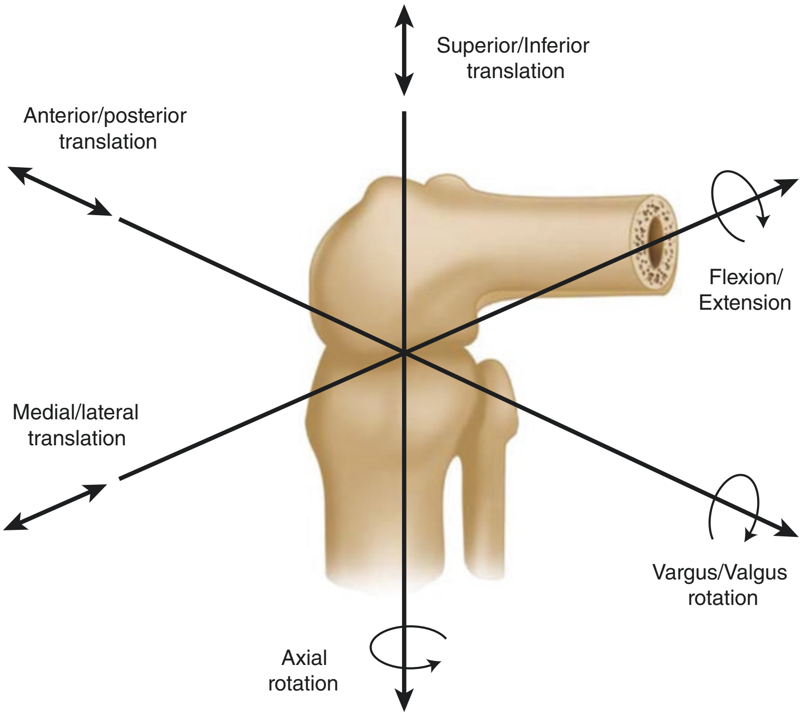


Fig. 2.1 Six degrees of freedom of the knee joint

articular surfaces and partly because of substantial dependence on its surrounding soft tissues for coherence [3].

Kinematics is a branch of physics concerned with analysis of movements, in absolute or relative space, without consideration for their driving or resistant forces [3]. In its simplest form, the knee can be represented as a simple hinge that allows pure flexion and extension about a single mediolateral axis, hence limited to one degree of freedom [4]. In reality, however, the knee is a bicondylar, modified-hinge joint that also exhibits rotational and linear movements, thereby allowing up to six degrees of freedom during dynamic activities: three rotations (flexion–extension, external–internal, varus–valgus) and three translations (anteroposterior, mediolateral, and compression–distraction) (Fig. 2.1) [1, 5].

Side Summary
In its simplest form, the knee can be represented as a simple hinge that allows pure flexion and extension about a single mediolateral axis, hence limited to one degree of freedom. In reality, however, the knee is a bicondylar, modified-hinge joint that also exhibits rotational and linear movements, thereby allowing up to six degrees of freedom.

Understanding knee kinematics is of paramount importance to clinicians and surgeons, not only to enable them to restore normal function in pathologic or injured knees, but also to help diagnose and understand knee pathologies and injuries [3]. Knowledge of knee kinematics is equally important to biomedical engineers and sports scientists, particularly those involved in design or assessment of surgical implants and techniques for ligament reconstruction, meniscal repair, bone deformity correction, as well as partial or total arthroplasty [6].

In this chapter, the authors analyze kinematics of the native knee from various perspectives, starting with some reminders of the anatomic structures and articular geometries that guide the movements, followed by detailed representations of the physiologic patterns during different activities, and ending with a review of kinematic discrepancies between individuals, genders, age groups, and ethnicities. The authors attempt to include a balance of simple and complex analyses, to cover both historical and recent literature, and to explain patterns in clear and concise terms. Throughout the chapter, the reader should remember that the distinct kinematic patterns described within the knee are interdependent and are closely related to motions and loading of the adjacent joints of the lower limb, especially the hip and ankle.

Side Summary
The knee is a bicondylar, modified-hinge joint that also exhibits rotational and linear movements, thereby allowing up to six degrees of freedom during dynamic activities: three rotations (flexion–extension, external–internal, varus–valgus) and three translations (anteroposterior, mediolateral, and compression–distraction) [1, 5].

2.2 Physiology

The knee joint consists of four bones and three articular compartments [7]: (a) the medial tibiofemoral compartment (the medial condyle of the femur and the medial side of the tibial plateau), (b) the lateral tibiofemoral compartment (the lateral condyle of the femur and the lateral side of the tibial plateau), and (c) the patellofemoral compartment (the dorsal side of the patella and the femoral trochlea, extending to the distal condyles) [7]. The lateral tibiofemoral compartment is less stable than the medial tibiofemoral compartment, but it has greater mobility that serves to increase the range of motion of the knee and allow for internal–external rotation [3]. The articular surfaces of both medial and lateral tibiofemoral compartments are incongruent; their contact areas are thus limited and change through flexion. The meniscus increases the tibiofemoral articular contact area, thereby lowering contact pressure and improving the knee's congruence [3]. The patellofemoral compartment is incongruent with the medial and lateral tibiofemoral compartments when the knee is extended but becomes more congruent as the patella engages within the trochlear groove and begins to transmit loads beyond the first 20° of flexion [8].

The knee comprises four ligaments which help ensure knee stability through their viscoelastic properties and proprioceptive stress functions, thus preventing joint injury [3, 9]. The ligaments include (a) the anterior cruciate ligament (ACL), (b) the posterior cruciate ligament (PCL), (c) the medial collateral ligament (MCL), and (d) the lateral collateral ligament (LCL). The ACL originates from the inter-condylar notch of the femur and inserts slightly anteriorly in the center of the tibial plateau. Its primary function is to prevent excessive anterior translation of the tibia [10]. The PCL also originates from the inter-condylar notch of the femur and inserts posteriorly in the center of the tibial plateau. Its primary function is to induce femoral roll-back during knee flexion and thus increase range of motion. The PCL also restrains posterior translation of the tibia especially without load-bearing [11]. Without load-bearing, the ACL resists 86% of the anterior directed force, while the PCL resists 95% of the posterior directed force [10]. The MCL connects the medial margins of the femur and tibia, while the LCL connects the lateral margins of the femur and fibula. The MCL and LCL also contribute valgus–varus torsional stability, together with the joint capsule [12, 13]. A number of tendons (gastrocnemius, hamstrings tendon, patellar tendon, etc.) attach the flexor and extensor muscles, which therefore control knee motions and provide dynamic stability [14]. Beyond external loads and muscle forces, the geometry of the knee's articular surfaces, together with the configuration of its tendons and ligaments, are the chief determinant of knee kinematics. Even the slightest disruption or deformation to any of these anatomic structures could lead to abnormal kinematics that may prevent the individual from performing basic functions or cause further damage or injury [2].

Side Summary
The knee joint comprises three compartments: (a) the medial tibiofemoral compartment (the medial condyle of the femur and the medial side of the tibial plateau), (b) the lateral tibiofemoral compartment (the lateral condyle of the femur and the lateral side of the tibial plateau), and (c) the patellofemoral compartment (the dorsal side of the patella and the femoral trochlea, extending to the distal condyles).

Side Summary
The ACL and PCL together constitute a four-link bar in the knee [15]. The elastic flexibility of the ligaments functions as proprioceptive stress transducers, which help prevent joint injury [2]. Beyond external loads and muscle forces, the geometry of the knee's articular surfaces, together with the configuration of its tendons and ligaments, is the chief determinants of knee kinematics.

Unlike the ankle and wrist joints, which allow considerable rotation about both the anteroposterior (AP) axis (inversion and eversion) and the mediolateral (ML) axis (dorsiflexion/plantarflexion), or the hip and shoulder joints, which allow free rotation about all three axes (abduction/adduction, flexion/extension, and internal/external rotation), the primary kinematic functions of the knee and elbow joints are limited to rotation about the mediolateral axis (flexion–extension) [1, 3]. This over-simplified analogy must not detract from the importance of the auxiliary rotational and linear motions within the knee, which serve to stabilize it under different loading scenarios and to maximize its range of motion when needed.

The bipedal posture of humans doubles the loads borne by the knees and destabilizes them substantially compared to quadrupedal animals [1]. The knee is therefore highly susceptible to ACL injury if the femur and tibia are subject to opposing forces or moments, causing excessive varus–valgus, internal–external rotations, or even anteroposterior translation [9, 16]. Nevertheless, constant muscular reflexes and ligament tensions compensate for its inherent instability and often prevent falls and dislocations [2]. It has in fact been shown that neuromuscular training can reduce these risks and enables the joint to move with increased stability, even when non-muscular anatomic structures are unable to [16, 17].

The kinematics of the knee can be divided into tibiofemoral (TF) kinematics (grouping both the medial and lateral compartments) and patellofemoral (PF) kinematics [3]. The former is well studied and documented in orthopedic and sports medicine literature [18–28]. Although a series of in vivo and in vitro studies have been conducted on the latter [29–37], PF kinematics are somewhat less understood, with inconsistent descriptions [38]. Interestingly, the TF and PF joints exhibit different extents of rotational laxity depending on the knee flexion angle, and both joints lock their rotational positions to grant stability when needed. The TF joint locks in a rigid rotational position between full extension and 10° of flexion, but gains considerable rotational laxity (femur rotates externally) between 30° and

140° of flexion [39]. The PF joint is conversely lax between full extension and 20° of flexion, but the patella locks securely within the trochlear groove between 30° and 140° of flexion [40]. What might seem a coincidental reversal of rotational locking versus laxity, between 20° and 30° of flexion, is an important aspect in knee physiology, crucial to preventing subluxations or dislocations between different bones [3].

Side Summary
Knee kinematics can be divided into kinematics of the medial and lateral tibiofemoral compartment and the patellofemoral compartment.

Side Summary
The TF joint locks in a rigid rotational position between full extension and 20° of flexion but gains considerable rotational laxity between 30° and 140° of flexion [39]. The PF joint is conversely lax between full extension and 20° of flexion with the patella locking securely within the trochlear groove between 30° and 140° of flexion [40].

2.3 The Lower Limb Kinetic Chain

Before studying kinematics of the TF and PF joints in detail, it is important to understand the principal loading conditions in the knee joint and to consider that the weight and motion of the body are supported and governed by the entire lower limb, of which the knee is only one of several articular joints.

The knee joint supports the body by distributing its weight over the medial and lateral TF compartments. The contact stresses in these compartments are attenuated by the menisci, which help distribute loads more evenly over a greater surface area [1, 7]. Furthermore, the anterior tibial slope and the menisci also contribute to the anteroposterior stability of the knee, although knee stability depends mostly on the soft tissues (ligaments and tendons with their respective muscles) surrounding the joint [7, 41].

It is important to note that the knee is an integral part of the body's kinetic chain which, comprised of the spine, hips, knees, and ankles, controls lower extremity movements [16, 42]. The kinetic chain model refers to the body as a linked system of interdependent segments, often working in a proximal-to-distal sequence, to achieve the desired movement in an efficient manner [43]. The proximal and distal segments of the kinetic chain have considerable effects on knee kinematics [44, 45] though these considerations will not be addressed here.

Side Summary
The kinetic chain model refers to the body as a linked system of interdependent segments, often working in a proximal-to-distal sequence, to achieve the desired movement in an efficient manner [43].

2.3.1 Tibiofemoral Kinematics

The knee moves primarily as a hinge that closes (flexion) with the contraction of the hamstrings and opens (extension) with the contraction of the quadriceps. During flexion and extension, the femoral condyles glide and roll over the tibial plateau [1, 5]. The extent of rotational and linear movement is governed by contractions of the hamstring and quadriceps muscles, and restricted by tensions within the ACL and PCL at different flexion angles [46, 47]. The posterior translation of the femur relative to the tibia or anterior translation of the tibia relative to the femur during flexion, known as *"femoral roll-back"* and "*tibial roll-forward,*" respectively, are most pronounced during midflexion (30° to 120°), and are crucial to enable deep flexion (beyond 120°) [1, 7]. Moreover, condylar asymmetry causes more roll within the lateral compartment and more glide within the medial compartment, which leads to internal–external rotation within the TF joint. The external rotation of the tibia relative to the femur as the knee extends from 30° flexion to terminal extension—also termed the *"screw home mechanism"*—contributes to the aforementioned locking of the femur and tibia in extension [1, 3, 7].

The first study of knee kinematics dates back to the early nineteenth century, whereby Weber and Weber [48] made direct visual observations on cadaveric specimens and described the medial motion of the femur onto the tibial plateau to be "cradle-like." Since then, several authors confirmed these observations using quantitative in vitro cadaver studies as well as in vivo imaging analyses. The advancement of computed tomography (CT) and magnetic resonance imaging (MRI) later enabled quantification of tibiofemoral displacements at different flexion angles and in different loading scenarios [21, 25, 27, 49, 50]. Most recent studies of TF kinematics illustrate the relative positions of the femur and tibia using two-dimensional (2D) coordinates in the sagittal [51–55] and transverse planes [18, 19, 49, 56–59].

Side Summary

The posterior translation of the femur relative to the tibia during flexion is known as *"femoral roll-back"* (or *"tibial roll-forward"*). It is most pronounced during mid-flexion (30°–120°) and is crucial to enable deep flexion (beyond 120°). The external rotation of the tibia relative to the femur as the knee extends from 30° flexion to terminal extension is termed the "*screw home mechanism*" and contributes to the aforementioned locking of the femur and tibia in extension.

2.3.1.1 Sagittal Plane

Sagittal plane representations help visualize the knee in various flexion angles, including femoral roll-back and patellar position, but do not illustrate the screw home mechanism. This view enables analysis of the flexion–extension motion of the knee, which is often divided into three arcs: (a) the "screw home arc" (0°–30°), (b) the "functional arc" (30°–120°), and (c) the "passive arc" (120°–160°), with 0° corresponding to full extension (Fig. 2.2) [60]. The screw home arc is thus termed due to the marked rotation of the femur relative to the tibia as the knee approaches full extension: The lateral femoral condyle continues

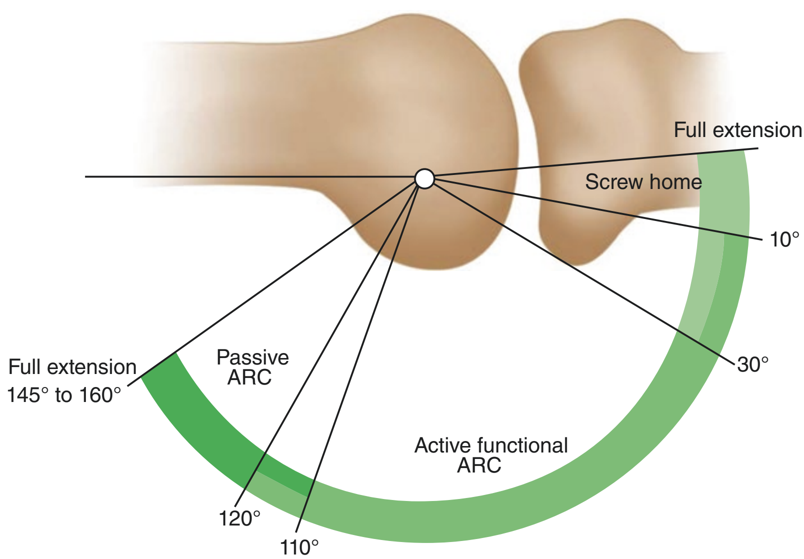


Fig. 2.2 The three arcs of the flexion–extension motion

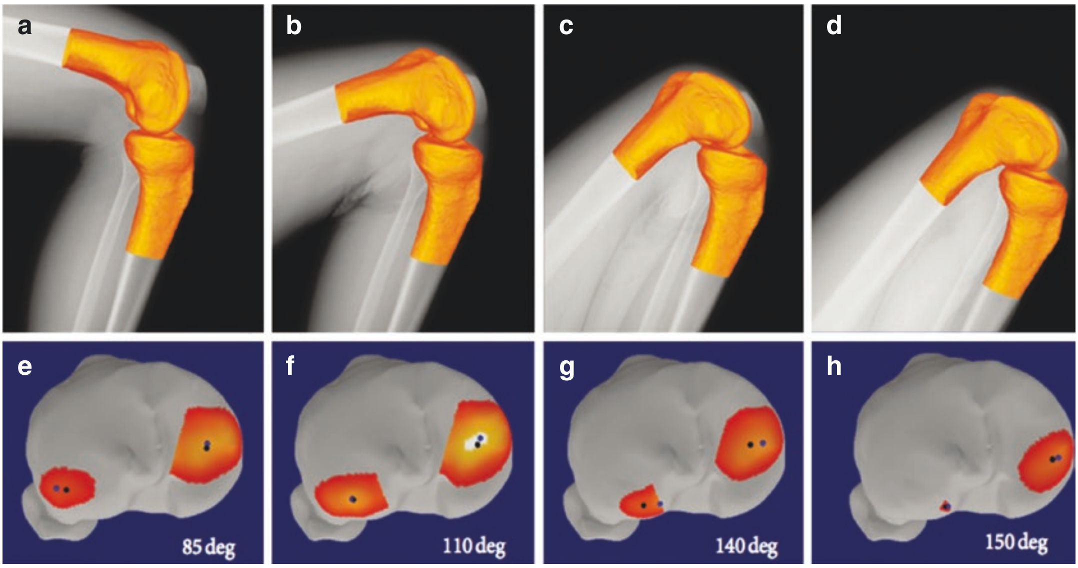


Fig. 2.3 Tibiofemoral contact areas at different flexion angles. (**a** and **e**) TF contact pattern at 85° flexion; (**b** and **f**) TF contact pattern at 110° flexion; (**c** and **g**) TF contact pattern at 140° flexion; (**d** and **h**) TF contact pattern at 150° flexion) (Adopted from Hamai et al. [41])

to translate anteriorly, while the medial femoral condyle exhibits minimal anterior displacement, thereby acting as a "medial pivot." The functional arc is the range where muscle activity and joint reaction forces are greatest: the femur continues to rotate relative to the tibia during flexion but at a much slower rate. The passive arc is so named as it cannot be reached through muscle contraction and instead requires body weight or an extrinsic force to induce flexion. At the more extreme end of flexion, the lateral side translates posteriorly to the point of subluxation (Fig. 2.3). Without this translation, deep flexion would be either impossible or painful. Frankel et al. [61] were among the first to describe the flexion–extension axis as a moving "instantaneous center of rotation." Using "true-lateral" X-rays, the authors showed how, on normal knees, the instantaneous center of rotation moves through a semi-circular pathway (Fig. 2.4) [1]. Several authors built on this model to determine precise locations of the flexion–extension axis at different angles [51–54]. The limitations of studies based on "instantaneous centers of rotation" include lack of a consistent Cartesian coordinate system, definition of the flexion–extension axis in two dimensions only, and inability to make continuous measurements.

Side Summary
Sagittal plane representations enables analysis of the flexion–extension motion of the knee, which is often divided into three arcs: (a) the "screw home arc" (0°–30°), (b) the "functional arc" (30°–120°), and (c) the "passive arc" (120°–160°), with 0° corresponding to full extension. True-lateral X-rays reveal that the knee instantaneous center of rotation moves through a semicircular pathway.

2.3.1.2 Transverse Plane

Transverse plane representations help to illustrate femoral roll-back and the screw home mechanism but require superimpositions of a line connecting the medial and lateral tibiofemoral contact points or projected centers of the femoral condyles on the surface of the tibia, plotted as a function of the flexion angle. This permits simultaneous visualization of femoral roll-back and screw home rotation during flexion (Fig. 2.5). Tanifugi et al. [62] reported that between full extension and 140° of flexion, the medial condyle translates over 20% along the tibial plateau (between 40% and 60% of the AP dimension), while the lateral condyle translates over 60% along the tibial plateau (30–90% of the AP dimension). Most other studies concur that knee flexion induces rotation of the tibia relative to the femur; in full extension, the tibia is externally rotated by up to 23°, while in full flexion, the tibia is internally rotated by up to 12° [18, 19, 49, 56–59]. They also agree that flexing the knee to 120° causes posterior translation of the lateral femoral condyle by up to 45 mm, and of the medial femoral condyle by up to 30 mm [19, 49, 56, 57, 59]. Despite considerable discrepancies, most authors agree that the medial femoral condyle has a relatively stable position [63]. By contrast, Feng et al. [64] and Pinskerova et al. [50] observed some initial anterior translation of the medial femoral condyle, followed by gradual posterior translation. In high flexion (>120°), Hamai et al. [41] reported a paradoxical "lateral pivot," while Johal et al. [22] emphasized that the medial and lateral condyles had equal posterior translations. The results are dependent on how the experiments were conducted, whether with or without axial loads, and how the knee was flexed, either passively or under quadriceps contraction. High flexion kinematics are also variable according to the activity that is performed [65].

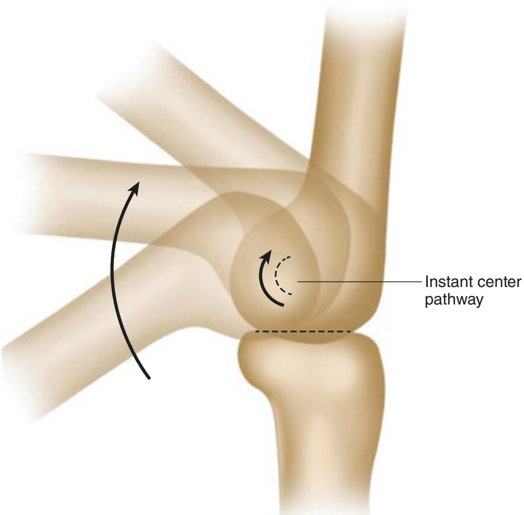
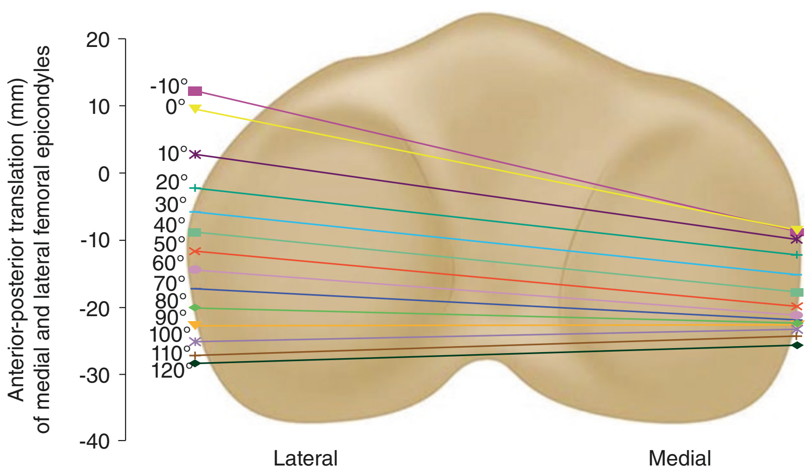


Fig. 2.4 The semi-circular pathway of the instantaneous center of rotation during knee flexion

Over the past two decades, various authors reported disparate kinematic patterns, which could be attributed to the heterogeneity of knee specimens, imaging modalities, reference axes, and loading conditions. On the one hand, in vitro cadaver studies enable fitting bones within sophisticated experimental rigs or optical trackers [21, 24, 46, 52, 66], which grant high accuracy. On the other, in vivo patient studies allow simulation of real loading with natural muscle contractions but require advanced imaging technologies [25, 49, 62, 64, 67]. Fluoroscopy enables real-time observation of in vivo knee kinematics [25, 26, 49] but does not reveal soft-tissue structures, while MRI provides excellent volumetric detail but is typically restricted to static analyses, with only a few studies describing methods for dynamic acquisition [68–70]. Even when taking measurements on the same specimen, using identical imaging techniques and loading

Fig. 2.5 Anteroposterior translation of the medial and lateral femoral epicondyles during knee flexion, projected in the transverse plane on the tibial reference system



conditions, a number of studies highlighted how the choice of reference axis could considerably alter findings [62, 64, 67]. For instance, Tanifugi et al. [62, 67] reported femoral rotation during flexion to be about 26° when using the geometric center axis (GCA), and about 17° when using the clinical transepicondylar axis (cTEA). They further showed that while GCA and cTEA offer approximately similar measurements on the lateral side, they differ significantly on the medial side because the two axes have different starting positions and paths during flexion (Fig. 2.6). Feng et al. [64] demonstrated similar findings but emphasized that on the medial side the use of the cTEA or GCA reveals some anterior translation of the medial condyle prior to its posterior translation. Victor et al. [71] illustrated the noticeable effect of contractions within the hamstrings and quadriceps on TF translations and rotations, which can be attenuated or reversed depending on loading conditions. The variability of TF kinematics depends on the flexibility allowed by the surrounding soft tissues, which provide multiple motion paths within certain boundaries.

Side Summary
Transverse plane representations help illustrate the femoral roll-back and screw home mechanism but require superimpositions of a line connecting the medial and lateral tibiofemoral contact points or projected centers of the femoral condyles on the surface of the tibia, plotted as a function of the flexion angle. Knee flexion induces rotation of the tibia relative to the femur; in full extension the tibia is externally rotated by up to 23°, while in full flexion, the tibia is internally rotated by up to 12°.

Side Summary
Over the past two decades, various authors reported disparate kinematic patterns, which could be attributed to the heterogeneity of knee specimens, imaging modalities, reference axes, and loading conditions.

2.3.2 Patellofemoral Kinematics

The main biomechanical function of the patella is to improve quadriceps efficiency by increasing the lever arm of the extensor mechanism (Fig. 2.7) [72]. The patella does so by displacing the patellar tendon away from the tibiofemoral contact point, thereby increasing the mechanical advantage of the quadriceps during knee extension [73–79]. The position and orientation of the patella relative to the tibiofemoral joint determine the lever arm of the extensor mechanism and therefore influence required quadriceps forces [74, 78], joint reaction forces [75, 80, 81], and the level of contact with the femoral trochlea and condyles [82–84]. Patella tracking refers to the articulation pattern of the patella relative to the trochlear groove during knee flexion. Although the patella has six degrees of freedom, the patella tracking parameters of interest are patella shift, patella height, and patella tilt (Fig. 2.8) [85]. Consensus between studies reporting on patella tracking is largely affected by the inconsistent definitions of the applied coordinate systems, reference points, and the experimental protocols [38, 86].

Side Summary
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Side Summary
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2.3.2.1 Patella Tracking

In full extension, the distal attachment of the patellar tendon on the tibial tubercle is positioned laterally in relation to the trochlear groove [8],

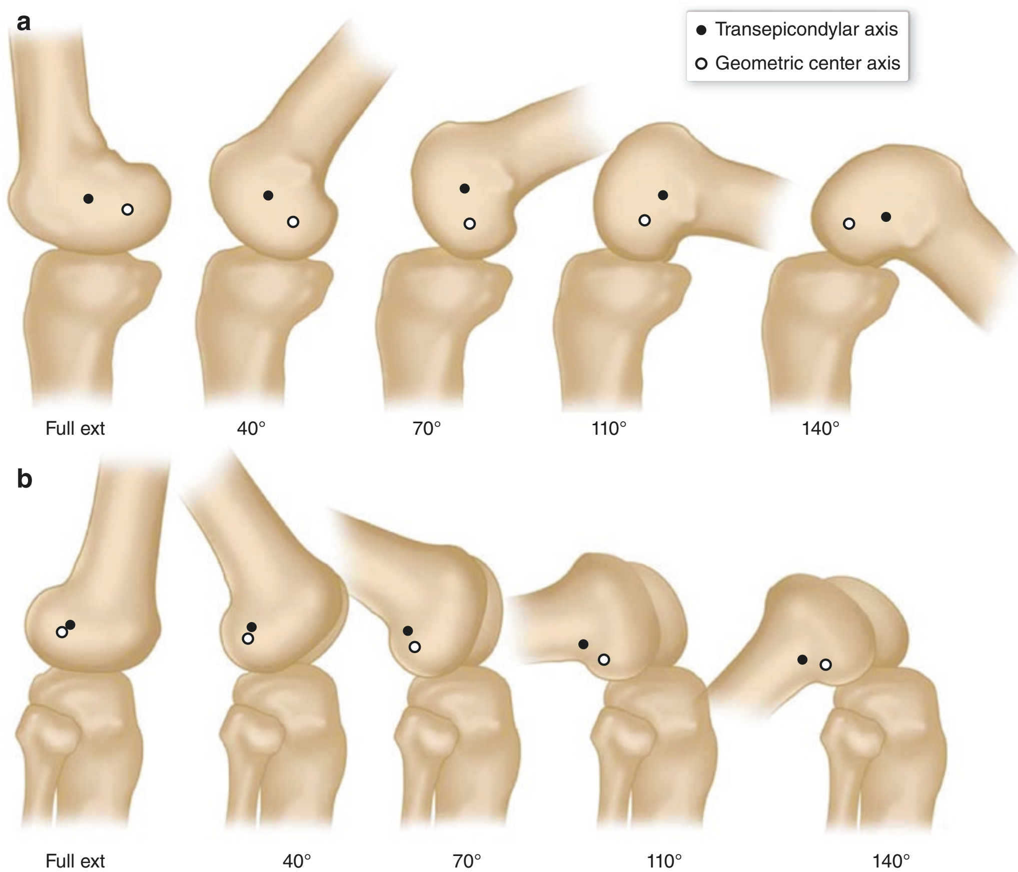

Fig. 2.6 Comparison of geometric center axis (GCA) and clinical transepicondylar axis (cTEA). (**a**) medial view; (**b**) lateral view

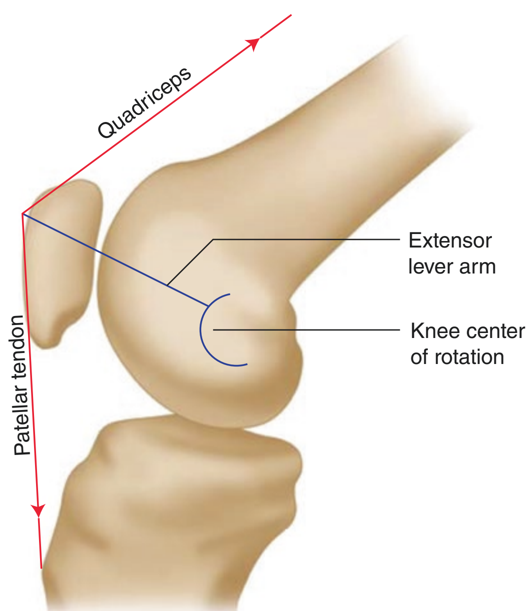

Fig. 2.7 The biomechanical advantage of increasing the extensor mechanism lever arm with the aid of the patella

and the patella is not congruent with the trochlear groove [38]. The angle forming between the effective quadriceps vector and patellar tendon vector is referred to as the Q-angle and leads to a lateral pull on the patella in full extension (Fig. 2.9). This lateral force is resisted by the oblique vastus medialis muscle, medial patellofemoral ligament, and the lateral trochlear facet. As the knee starts to flex, the tibia rotates internally relative to the femur, thereby decreasing the Q-angle, and the patella enters the trochlear groove from the lateral side [8].

After engagement with the trochlea, the patella will shift medially between 10° and 30° of knee flexion, after which it translates laterally again [38]. Some studies [87–89] indicate that the patella will shift medially beyond flexion angles of 80°, but there are limited data available beyond 90° of flexion since few studies consider deep flexion [88, 90]. There is no guidance on the clinical diagnosis and management for patellar proximal–distal and anterior–posterior displacement; hence, research on these two degrees of freedom is scarce [91]. Between full extension and 90° flexion, the patella will tilt medially between 1° and 3° and laterally between 1° and 15.5° [38]. During knee flexion, studies [88–90, 92, 93] indicate that the patella flexion angle will range between 60 and 70% that of the knee flexion angle [38]. The average curve derived from studies [92, 94–96] shows that the patella will rotate slightly medially at the beginning of flexion before its long-term lateral rotation with transient fluctuation [38].

Side Summary
As the knee starts to flex, the tibia rotates internally relative to the femur, thereby decreasing the Q-angle, and the patella enters the trochlear groove from the lateral side [8].

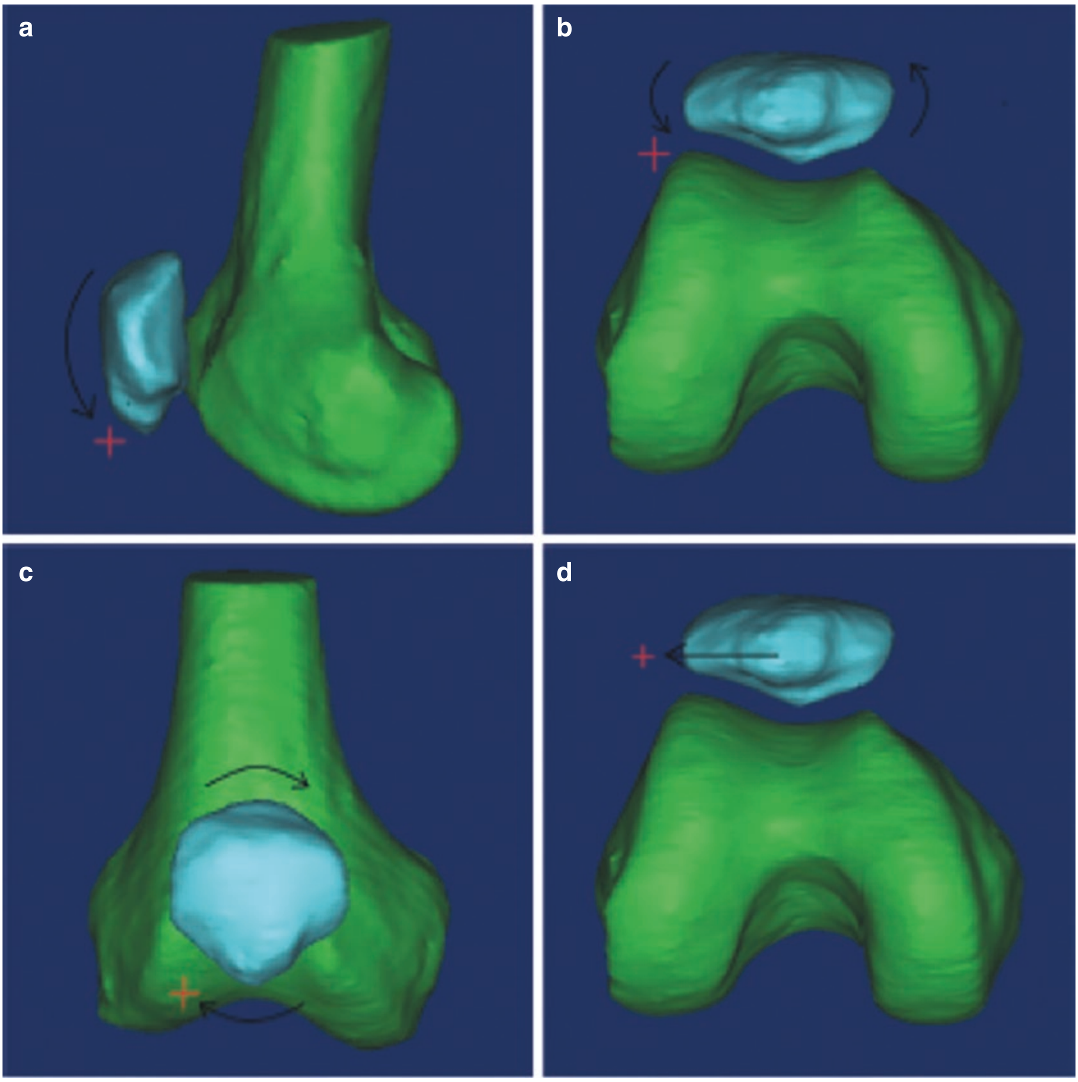

Fig. 2.8 Six degrees of freedom of the patella illustrated on a right knee joint. (**a**) Flexion–extension; (**b**) tilt; (**c**) rotation; (**d**) medial–lateral shift; (**e**) anterior–posterior translation; (**f**) proximal–distal translation (Adopted from Yu et al. [38])

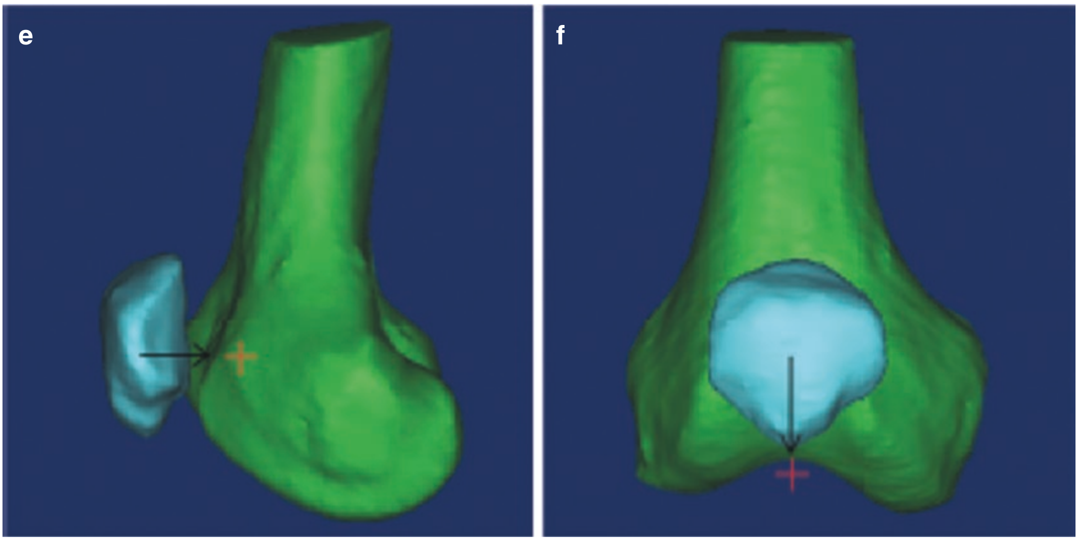

Fig. 2.8 (continued)

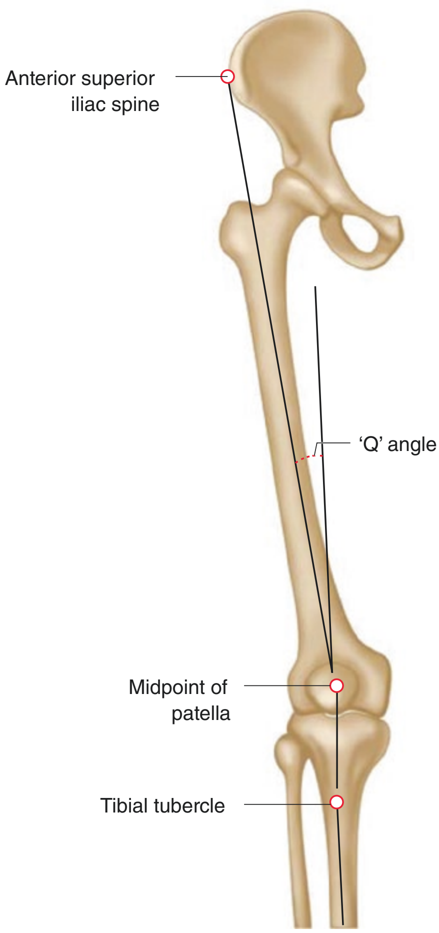

Fig. 2.9 Orientation of the effective quadriceps tendon and patella tendon force vectors to form the Q-angle

2.3.2.2 Patellar Height

The height of the patella relative to the trochlear groove is an important orthopedic measurement [85]. Although various methods to quantify patellar height have been proposed, there is no consensus in the literature on the most appropriate method or cut-off values [97]. The five most popular methods include the Insall–Salvati ratio [98], the Blackburn–Peel ratio [99], the Caton–Deschamps ratio [100], the modified Insall–Salvati ratio [101], and the Patellotrochlear index [102] (Fig. 2.10). In a recent comparison between the five methods, use of the Insall–Salvati ratio delivered better intra- and inter-observer reliability, whereas the use of radiographs and CT also provided better reliability in comparison to MRI [97].

Side Summary

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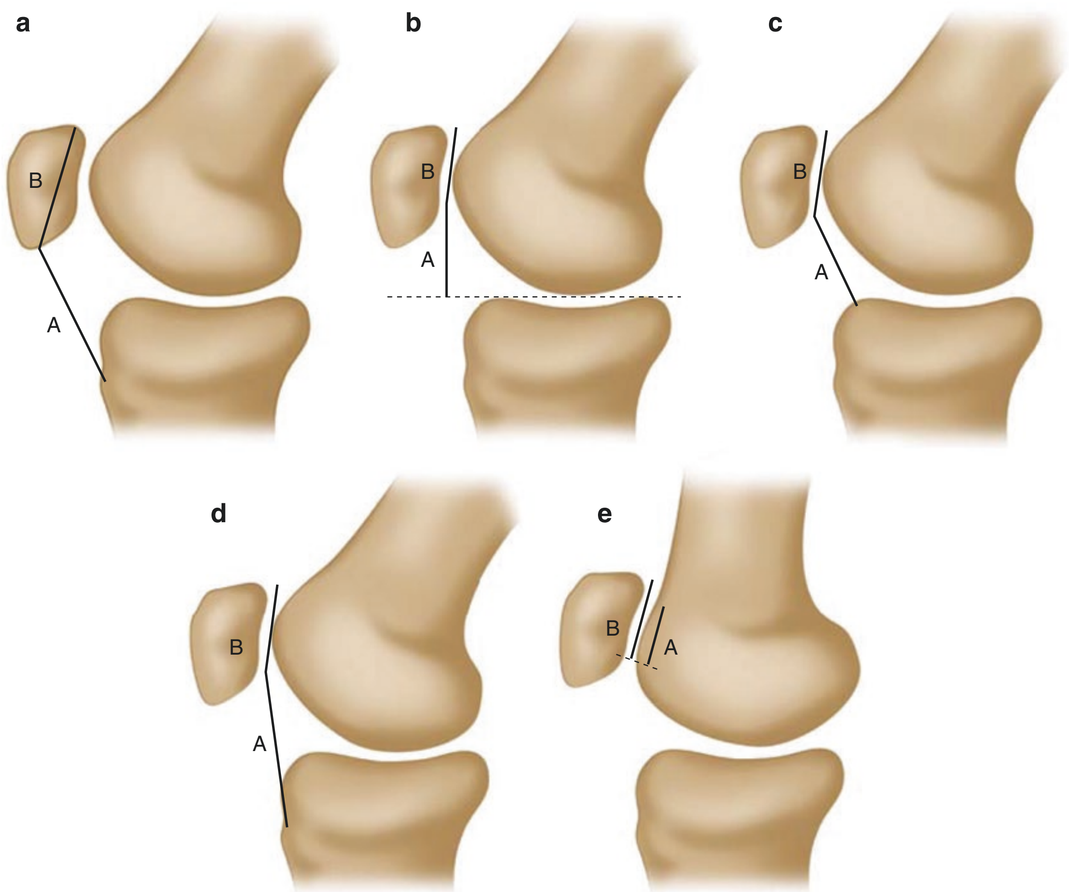

Fig. 2.10 The measurement of patella height = A/B. (**a**) Insall–Salvati ratio; (**b**) Blackburn–Peel ratio; (**c**) Caton–Deschamps ratio; (**d**) modified Insall–Salvati ratio; (**e**) Patellotrochlear index

2.3.2.3 Tibial Tubercle–Trochlear Groove Distance

The tibial tubercle–trochlear groove distance (TT-TG) is the measurement of the deepest point on the trochlear groove and central position of the patella tendon insertion on the tibial tubercle along the medial–lateral dimension (Fig. 2.11) [103]. Measurement of the TT-TG was originally defined using CT scans [104], but the use of MRI has also been described in the literature [103, 105, 106]. Although values reported in the literature show a high degree of variability [105], there is consensus that values exceeding 15 to 20 mm are pathological [103, 105]. It is known that the TT-TG will also vary between flexion angles and load-bearing conditions [105]. In a recent systematic review and meta-analysis comparing TT-TG measured with CT or MRI, the results indicated that TT-TG was a reliable measurement to differentiate between patients with and without patella instability [103]. TT-TG measured on CT was, however, significantly greater than the TT-TG measured on MRI, which suggest that different cut-off values should be used.

2.3.3 Stability

Due to the poor congruence of its articular surfaces, the knee is a relatively unstable joint in relation to the loads it supports [2]. Because it depends heavily on soft tissues to maintain

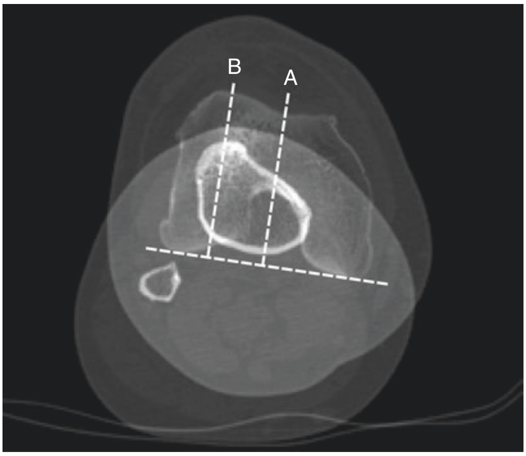

Fig. 2.11 The tibial tuberosity–trochlear groove (TT-TG) distance is measured using two superimposed CT slices: the first (A) through the most proximal part of the trochlear groove, where the notch looks like a Roman arch, and the other (B) through the most proximal part of the tibial tuberosity. The two reference points are projected perpendicularly to the bicondylar line. The distance between their projections is the TT-TG value

coherence, the knee is susceptible to injuries, particularly tears of the ACL [9, 16]. To prevent or repair injury, one must understand the mechanics of knee stability. In their seminal observational studies, Brantigan and Voshell [107] and Abbott et al. [108] introduced the general concepts of laxity and stability by describing the loosening and tightening of knee ligaments during flexion, their elongation when shear or torque loads were applied, and the effect of the interacting bearing surfaces on ligament lengths. The knee is considered to be stable when, in response to external forces, there are no subjectively excessive rotations or displacements and the surrounding ligaments are within their elastic ranges. Knee stability can be quantified in terms of knee laxity, evaluated by measuring the displacement (anterior–posterior, mediolateral, internal–external) or rotation relative to a neutral position when applying a force (or torque) to the femur or tibia. In a recent study, Marouane et al. [109] showed that the neutral position depends upon the posterior tibial slope and varies from one subject to another. The total laxity is determined by the net amount of displacement when applying a force in one direction and then applying the force in the opposite direction after returning to neutral.

Laboratory studies have focused on the primary roles of the different structures in providing stability. Girgis et al. [110] and Furman et al. [111] studied the anatomy of the cruciate ligaments to understand their ability to restrain anterior–posterior shear forces and identified two bands (or major fascicles) of each cruciate ligament, which loosened and tightened at different flexion angles. They used the method of selective resection of ligaments, which entails resecting one ligament at a time and testing the knee after each resection. By applying forces, they determined the relative contribution of each knee ligament to the general stability of the knee. Their study found that anterior translation increased most when the anteromedial band was severed, and further translation was seen with the severing of the posterolateral band and the medial collateral ligament (MCL). This study also highlighted that while the knee was in extension, the ACL limited both internal–external rotation and hyperextension. Finally, they found that during flexion there were fibers that stretched and contracted, and others that remained at constant length. These findings were confirmed by several other studies on knee stability, usually in the context of diagnosing soft-tissue injuries [10, 112–115].

A limitation with many of these early studies is that the knee was not axially loaded as it usually is in activity. Thereafter, Wang and Walker [116] showed that a compressive load substantially reduced rotary laxity and attributed to the geometrical interaction between the bearing surfaces. This work was followed up with a study of anterior–posterior and rotational laxity using selective cutting of ligaments and menisci to show their limited role in stabilizing the knee under load [117]. Knee stability under load was largely explained by the "uphill mechanism" where the femur would distract from the tibia in displacement or rotation. This is seen on the medial condyle as it has to climb out of the depression in the medial tibial compartment when experiencing shear forces, while the lateral condyle rests on the flat or convex surface of the lateral tibial compartment [118].

The reduction of laxity when the knee is loaded was confirmed in clinical studies. Markolf et al. [118] observed that AP laxity reduced by up to 50% when the patients tensed their muscles. Markolf et al. [119] later found that AP laxity reduced by only 30% in an unconstrained dissected cadaveric knee under load (925 N). These studies thus highlight the contribution of muscle contractions to knee stability, in addition to strains within the ACL [120], meniscus [13, 121], and cartilage [122].

Side Summary
The knee is considered to be stable when, in response to external forces, there are no subjectively excessive rotations or displacements, and the surrounding ligaments are within their elastic ranges. Knee stability can be quantified in terms of knee laxity, evaluated by measuring the displacement (anterior–posterior, mediolateral, internal–external) or rotation relative to a neutral position when applying a force (or torque) to the femur or tibia.

2.4 Kinematics during Different Activities

The extent of knee flexion required for different activities varies considerably: 67° for walking, 83° when climbing stairs, 90° when sitting down and descending stairs, 106° when tying shoelaces, and 130° when squatting. The loads transmitted through the knee at each flexion angle also vary depending on these activities, during which the native knee joint has variable degrees of congruency and stability [26]. A number of authors investigated how knee kinematics vary during different common activities. Their interesting observations are reported in the remainder of this section.

2.4.1 Walking

Walking, also termed “gait,” has two principal phases: the stance phase and the swing phase. The stance phase is when the foot is on the ground, and the swing phase is when the foot is in the air. Each phase can be described in multiple parts. The stance phase includes initial contact, loading, mid-stance, terminal stance, and pre-swing. The swing phase includes initial swing, mid-swing, and terminal swing. The terminal swing ends with the initial contact portion of the stance phase. During the stance phase, the knee has a limited flexion of less than 10°, while during the swing phase, the knee flexes up to 55° (Fig. 2.12).

2.4.2 Stair Climbing and Descent

When climbing stairs, the knee has a maximum flexion ranging from 79° to 97°, a minimum flexion of 17°, and an internal rotation up to 15° [26, 123]. While descending stairs, the medial condyle translates anteriorly about 3 mm and the lateral condyle translates posteriorly approximately 7 mm [49]. The flexed knee and shifting body weight cause a slight paradoxical (anterior) motion on the medial side. Similar to gait, the majority of translation of the lateral condyle seemed to occur from heel strike to 66% of stance phase (average, 3.9 mm) as the lateral condyle moved in the posterior position [49].

2.4.3 Sitting Down and Standing from Seated

Sitting down has specific knee kinematics. The maximum flexion is slightly over 90° (94–97°), and the minimum angle is with the knee slightly

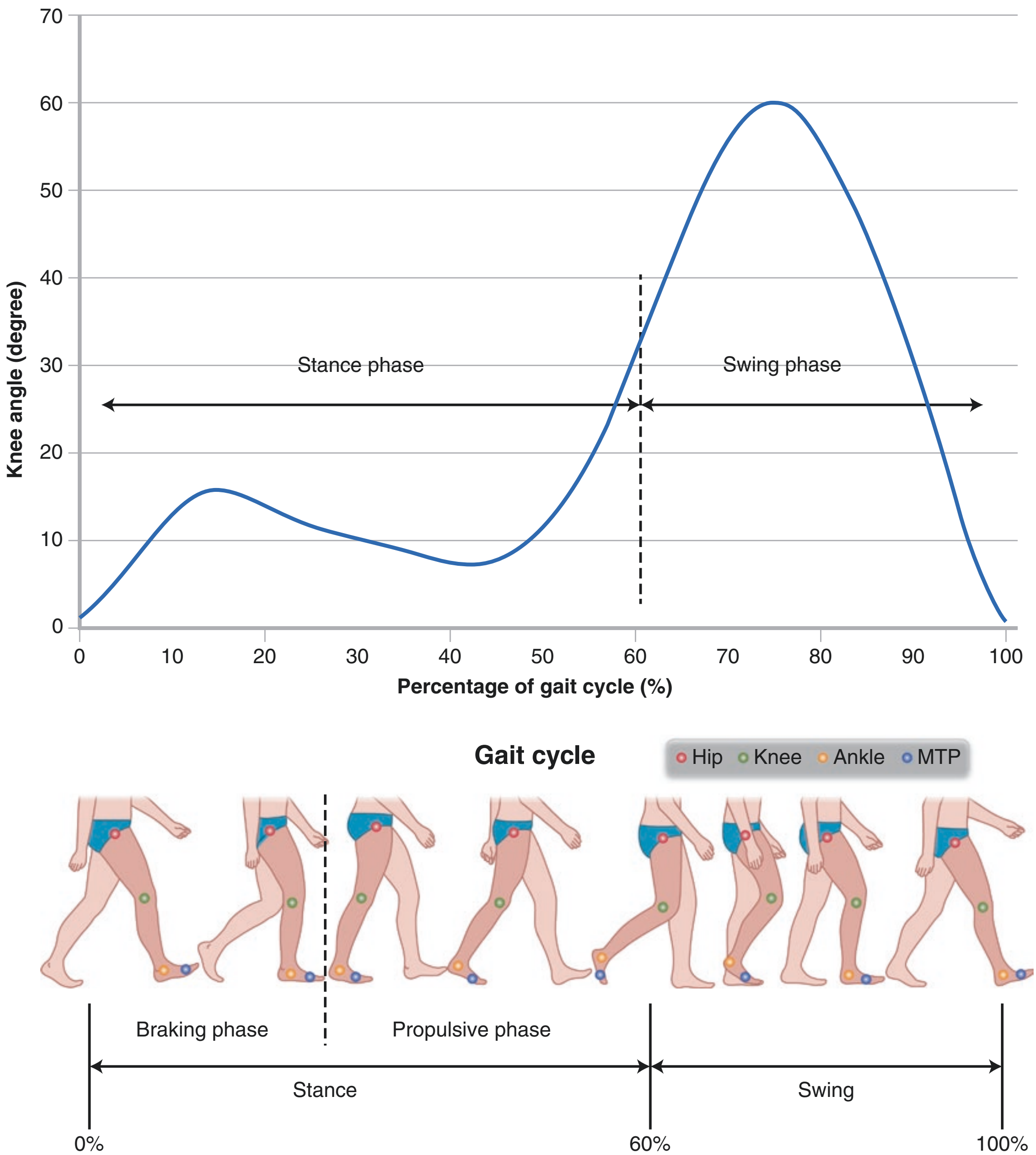

Fig. 2.12 Stance and swing phases of gait cycle

flexed (6°–8°) [49, 124]. Translation of the medial femoral condyles is greater while sitting into a chair (3 to −9 mm) than while rising up from a chair (0.5–5.9 mm). The decreased translation demonstrates the increased knee stability due to muscle action required to overcome gravity.

2.4.4 Squatting, Lunging, and Kneeling

During squatting, lunging, and kneeling, the knee flexion reaches its greatest extent [65]. Hamai et al. [125] had healthy individuals perform a lunge, enabling a single knee to be in view of the radiograph, flexing from the middle of the functional arc into the passive arc (85–150°). Their study evaluated the medial and lateral TF compartments, as well as femoral valgus rotation. Over the range of flexion, the medial side displaced anteriorly about 3 mm and then posteriorly about 4 mm, while the lateral side consistently displaced posteriorly about 8 mm. The knee externally rotated from 15° to 30° and moved from a slight varus rotation of 1° to a valgus rotation of 5°.

2.4.5 Vertical Drop Jump

One test of the ACL's condition is to perform a vertical drop jump (VDJ), where the subject jumps to the floor from a box 30 cm high. The medial–lateral motion of the knee is observed in assessing the status of the ACL. Krosshaug et al. [126] and Leppanen et al. [17] both detailed the VDJ, with Krosshaug et al. [126] evaluating a cohort of female handball and soccer players and Leppanen [17] evaluating both male and female floorball and basketball players. Krosshaug et al. [126] report that a VDJ was not able to establish risk of ACL injury, and that the only factor that was associated with risk of injury was medial knee displacement. Across all participants the average medial knee displacement observed for those that had a new ACL injury was 2.7 cm, while those that had no injury was 2.2 cm. The difference between other kinematic data was insignificant, and therefore one can expect to see about 2° valgus at initial contact and a peak knee flexion of 90° while performing a VDJ.

2.4.6 Sports

The majority of knee surgeries happen following sports injuries [127]. The knee and body go through more dynamic and aggressive motions than the controlled motions often reported. Steiner et al. [128] found that while 90 minutes of playing basketball or 10 km of running increased knee laxity by about 20%, squatting had almost no effect on AP laxity. Similarly, basketball players had greater valgus laxity after performing a jump landing compared to floorball players (−3 and −1 mm, respectively) [17].

Murakami et al. [28] evaluated the knee kinematics of five healthy males' golf swings, utilizing single-plane radiographs taken at 10 Hz. They found that the trailing knee rotated significantly more (26° on average) than the leading knee (18° on average) during a golf swing. Interestingly the external rotation of the left and right knee essentially mirrored each other; where there is external rotation of the left knee, the right knee will have internal rotation, and vice versa.

> **Side Summary**
> The extent of knee flexion required for different activities varies considerably: 67° for walking, 83° when climbing stairs, 90° when sitting down and descending stairs, 106° when tying shoelaces, and 130° when squatting.

2.5 Inter-Individual, Gender, Age, and Ethnic Variations

Komistek et al. [49] were among the first to highlight remarkable inter-individual variability of AP translations on the medial and lateral femoral condyles during flexion. Since then, numerous studies have investigated potential variations in knee kinematics across sex, age groups, and ethnicities.

2.5.1 Sexual Variations

There is some controversy as to whether there are meaningful differences in knee kinematics between men and women [17, 22, 23, 28, 129]. Nevertheless, it is worth noting the established differences in lower limb kinematics and muscle control between the sexes [16]. For instance, Leppanen et al. [17] found that a greater proportion of men had better knee control (75%) than women (21%), regardless of their sports activities, and that men's knees exhibited peak knee varus of 3.4° while women's knees exhibited peak valgus of 7.5°. Sheu et al. [130] found in a study testing side-cutting manoeuvres that men had greater flexion than women when entering a cutting motion. This difference could explain the greater susceptibility of women to ACL injuries. Mendiguchia et al. [16] observed that when performing sports manoeuvres, women had increased hip adduction and internal rotation. It is important to note that knee kinematics do not depend on the knee joint exclusively but also on the kinetic chain that controls lower extremity movements together with the spine, hips, and ankles. Thus, understanding knee kinematics requires having a systemic view of the lower limb, taking into account proximal and distal factors to the knee joint. For instance, women's altered spine and hip flexion angles, more lateral spine displacement, and larger ranges of spine motion when compared to men help explain their increased risk of ACL injury relative to males [16].

Side Summary
There are established differences in lower limb kinematics and muscle control between the sexes [16].

2.5.2 Age Variations

Age increases the risk for developing osteoarthritis and lowers muscle strength, both of which alter knee kinematics [20, 131–133]. Moreover, the recommended treatment for osteoarthritis is often total knee arthroplasty (TKA), so that studies comparing the performance of healthy knees to TKA knee are especially relevant for elderly patients.

In essence, aging normally slows knee motion and positions the knee in slight varus, both of which factors result in more work being required from adjacent joints to accomplish a task. In a study on 22 patients aged between 21 and 75, Fukagawa et al. [20] found that valgus angle and squat time significantly increased with age, and maximum flexion occurred later in the gait cycle. Likewise, Hortobágyi et al. [131] reported that elderly patients (mean 77 years) did more hip-positive work and less ankle-positive work during gait.

Side Summary
Age increases the risk for developing osteoarthritis and lowers muscle strength, both of which alter knee kinematics [20, 131–133].

2.5.3 Ethnic Variations Differences

In a study of healthy individuals of Japanese and Caucasian origin, Leszko et al. [23] evaluated whether sex or ethnicity had a greater effect on knee kinematics. They found that Caucasian men were limited in their maximum flexion compared to Caucasian women (respectively, 146° versus 152°), while Japanese men and women had similar ranges (respectively, 151° versus 153°). The authors also found that Caucasian men had their knees positioned more posteriorly, and as a result underwent less internal–external rotation, than the three other groups. In another study comparing Chinese, Malay, and Indian patients requiring TKA, Siow et al. [134] found small but significant differences in each ethnicity's preoperative range of motion.

Take Home Message
A clear understanding of the interrelationship between the different structures of the native knee joint and their role in knee kinematics is to be recognized. It can be expected that new rehabilitation protocols, surgical techniques, and treatment regimens will be developed based on this

understanding, to better serve the functional needs of the patient. The hypothesis of better functionality through kinematic normality has still not been achieved, primarily due to inconsistencies in coordinate reference frames, differences in measurement techniques, and inconsistent experimental protocols. There is a need for more guidelines like the ISB recommendations for joint coordinate systems [135] to reduce variability between different studies on kinematics.

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3 Kinematics of the Knee After Partial and Total Knee Arthroplasty

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Keynotes

1. Loss of the ACL, as in the cruciate-retaining (CR) TKA, allows the femur to shift more posteriorly when the knee is extended. With flexion, the femur may displace anteriorly before undergoing rollback. When this "paradoxical motion" occurs, quadriceps efficiency decreases and the range-of-motion of the knee is reduced.
2. The kinematics of posterior-stabilized (PS) TKA is determined by the geometry and location of the post and cam mechanism which engages between 60° and 90° of flexion and displaces the femur posteriorly in a manner similar to the intact PCL.
3. Some TKA designs have a "deep dished" tibial insert which conforms to the shape of the femoral component medially ("medial-pivot" TKA), laterally ("lateral pivot" TKA) or both medially and laterally ("ultracongruent" TKA). This provides resistance to anterior translation of the femoral component and increases the AP stability of the knee compared to CR and PS designs.

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3.1 Modalities for Studying Knee Kinematics After Arthroplasty

Numerous studies have described the kinematics of the knee after TKA during controlled motions (e.g., flexion-extension) and functional activities (e.g., walking, squatting, lunging, and stair-climbing). In these accounts, the relative displacements and rotations of the tibia, femur, and/or patella have been derived from several different settings, most commonly experimental studies performed in cadaveric specimens, motion analysis studies performed in the gait laboratory, or from in vivo imaging modalities (e.g., radio stereophotogrammetric analyses (RSA), quasi-dynamic MRI testing, or video fluoroscopy) [1–5].

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Each of these methods has some limitations. Studies done on cadavers do not simulate in vivo conditions given that the actuators used to apply joint loads are unable to reproduce dynamic in vivo motions. Studies performed with RSA are often performed under non-weight-bearing conditions and are quasi-dynamic [5]. Gait analysis also presents some limitations. Several studies have evaluated the accuracy of kinematic measurements reported by gait laboratories, and have shown that conventional marker-based methods are subject to significant errors in out-of-plane rotational and translational measurements due to motion between skin markers and underlying osseous structures [6]. Video fluoroscopy has also been used to study knee kinematics in both the native and implanted knee [7]. Fluorokinematic studies can be completed under in vivo, weight-bearing, and fully dynamic conditions, while subjects perform various activities. The two-dimensional images from the fluoroscopic studies are matched with three-dimensional models of normal or prosthetic knees, thereby accurately measuring in vivo knee kinematics.

3.2 The Kinematics of Total Knee Replacements

There are different design concepts in total knee replacement. The CR (cruciate retaining) designs preserve the posterior cruciate ligament, PS (posterior-stabilized) designs replace the posterior cruciate ligament with a cam/post mechanism, and medial-pivot (MP) designs stabilize the medial compartment with a highly conforming (ball-in-socket) articulation while allowing translation of the lateral condyle. Bicruciate-retaining designs have also been developed in which both the anterior and posterior cruciate ligaments are preserved.

Knee kinematics is also guided by different inlay designs, including the mobile, fixed bearing and deep dished (ultracongruent) designs. Multiple parameters define the kinematics of TKA and there is no general consensus on which design of artificial knee best restores the kinematics of the native joint. For instance, designs that allow less varus/valgus angulation may be favorable in the event of injury or insufficiency of the collateral ligaments. Several total knee implant designs have focused on the role of the posterior cruciate ligament (PCL) (Fig. 3.4). Some TKA implants, referred to as cruciate-retaining (CR) TKA designs, are designed to retain the PCL and display kinematics that are dependent upon contributions from both this ligament, the collateral ligaments and the implant surfaces. Other knee prostheses are designed to function without the PCL and have mechanical features that guide the motion of the tibia with respect to the femur. These designs are referred to as posterior-stabilized (PS) or cruciate-substituting implants (Fig. 3.1). Several studies have evaluated these two designs and reported on the advantages and disadvantages of each.

3.2.1 Cruciate-Retaining TKA Designs

In the CR TKA design, the PCL is preserved, which, in theory, allows increased control of knee flexion and retention of proprioception due to the presence of mechanoreceptors within the ligament [9]. As the PCL is preserved, CR designs are thought to display kinematics that is more similar to a native knee. Cruciate-retaining TKR designs have evolved from flat-on-flat articulations offering minimal inherent constraint to more conforming designs with some design features that attempt to guide femoral-tibial motion, especially internal tibial rotation with flexion. To this end, it has been reported that TKA patients display similar anteroposterior knee stability when compared to normal controls at 3 years after receiving a PCL-retaining TKA, whereas those undergoing PS TKA have significantly less AP stability [10]. Although preservation of the PCL in the CR knee is designed to reduce poste-

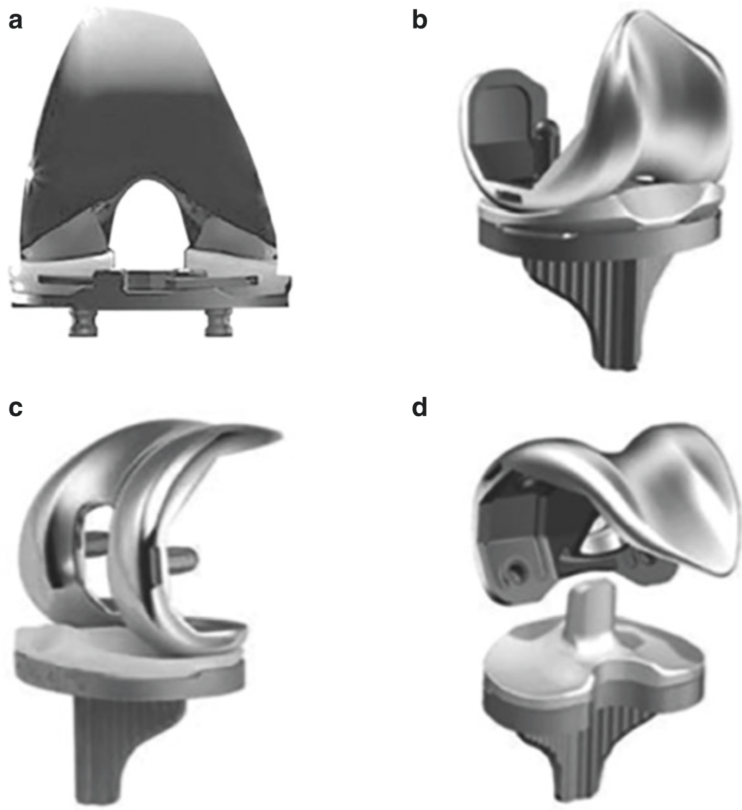

Fig. 3.1 Different designs of total knee prostheses. (**a**) bicruciate-retaining, (**b**) posterior-cruciate-retaining, (**c**) posterior-cruciate substituting, (**d**) posterior stabilized [8]

rior translation of the tibia and contribute to femoral rollback during deep knee flexion, loss of ACL function causes the femur to shift posteriorly in extension. With flexion, the femur may slide anteriorly forward with increasing flexion, thereby limiting the range-of-motion of the knee through premature impingement of the posterior tibia and femur [11, 12] (Figs. 3.2 and 3.3). This paradoxical translation decreases the quadriceps moment arm, increases muscle forces needed to stabilize the knee, and accelerates polyethylene wear by increasing loading of the articular surface [14, 15].

The polyethylene tibial insert of many CR designs has a reduced anterior edge to limit anterior translation of the medial condyle, rather like the "anterior extension facet" of the normal knee. Theoretically, the PCL retention of the PCL in CR TKA drives posterior translation of the femur on the tibia ("femoral rollback") as the knee flexes which increases the mechanical efficiency of the extensor mechanism [16]. However, in a video-fluoroscopy study of TKA patients during stair-climbing, Banks and Hodge [17] reported that 63% of patients with cruciate-retaining implants exhibited a lateral center of rotation with flexion, corresponding to anterior sliding of the medial femoral condyle.

In terms of maximum knee flexion after TKA, Yamakado et al. [18] reported that CR TKA led to a reduction in knee motion from 124° preoperatively to 112° at an average follow-up of 7.1 years, while IIshi et al. [19] found no difference in the median ROM of contralateral PS

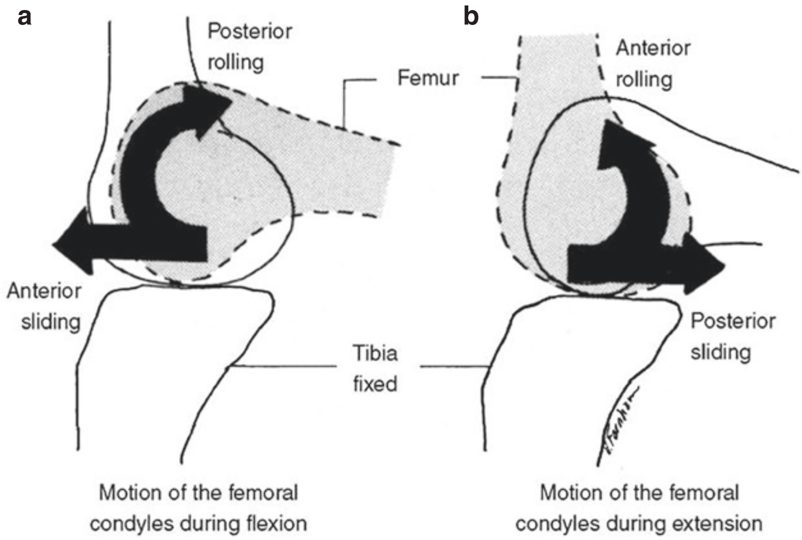

Fig. 3.2 Patterns of paradoxical motion observed during flexion (**a**) and extension (**b**) in some TKR patients, especially with CR designs [13]

Fig. 3.3 Sagittal radiograph of a CR TKR with a non-functional PCL. The femur has translated anteriorly with flexion in contrast to the posterior “roll-back” observed in the normal knee. The anterior margin of the femoral component abuts the anterior lip of the tibial insert

and CR knee replacements (both 115°), at an average follow-up of 9.8 years. In a fluoroscopic study, it was found that during single-leg deep knee bend, the maximum flexion for CR TKA knees was 98° and several patients could not flex beyond 70° [20]. Also, CR TKA knees did not reproduce the kinematics of the normal knee, as the point of tibio-femoral contact was located posterior to the tibial mid-line at the commencement of flexion and then translated anteriorly with flexion [20]. As the range-of-motion of the knee after CR TKA is affected by the posterior offset of the femoral condyles [21, 22], over-resection of the posterior condyles may lead to premature impingement between the posterior surfaces of the tibia and the femur compromising terminal flexion. However, the relationship between posterior condylar offset and maximum knee flexion after TKA remains controversial [22, 23]. Moreover, several other variables (e.g., tibial slope [24], implant design, function of PCL after surgery) may also play a role in the amount of flexion obtained.

3.2.2 Posterior-Stabilized TKA Designs

Potential benefits of the PS design include more predictable restoration of knee kinematics, improved range-of-motion, decreased polyethylene wear because of more congruent articular surfaces, easier correction of severe deformities,

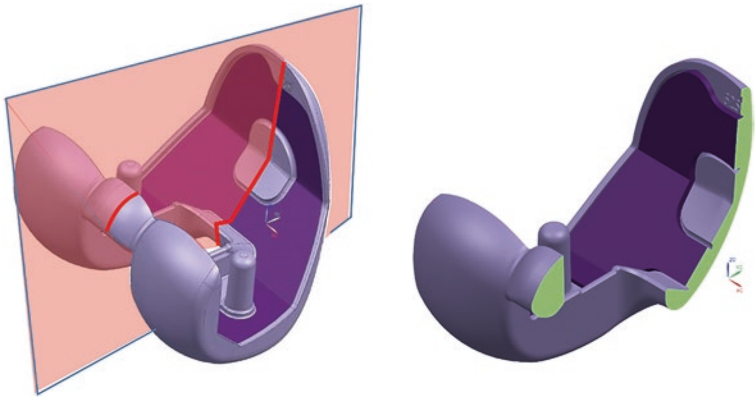

Fig. 3.4 Section through a posterior-stabilized femoral component taken along the sagittal mid-line, bisecting the intercondylar notch. (L) Location of Section plane, (R) Cross-sectional geometry of the cam and the anterior flange

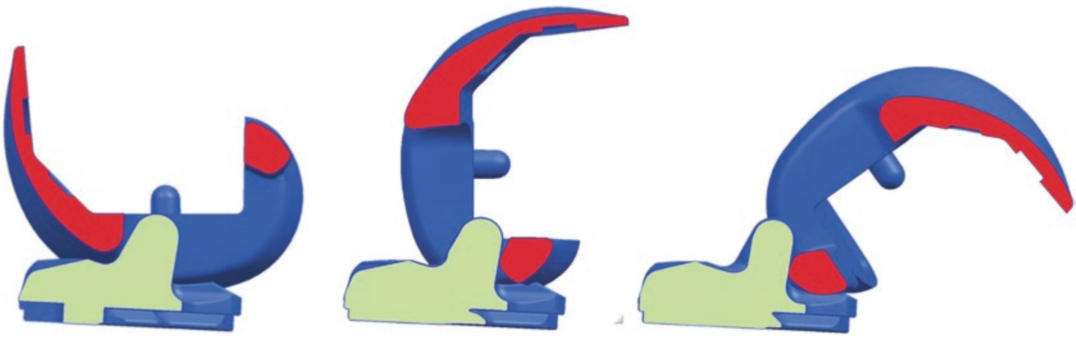

Fig. 3.5 Sagittal mid-line sections taken through a posterior-stabilized TKA in 3 different degrees of flexion, showing the location of the contact point between the femoral cam and the tibial post

and easier ligament balancing [25]. The PS knee is designed with a tibial post and cam mechanism which drives the posterior translation of the femur with respect to the tibia during flexion. This is achieved by an axle with a cam-shaped cross-section that bridges the intercondylar space of the femoral component and engages with a mating prominence of the tibial insert that is located along its medial-lateral mid-line between the bearing surfaces (Fig. 3.4).

Multiple design parameters influence the mechanical function of different post-cam designs and hence the kinematics of PS knee replacements. The shapes (including cam radius and post depth) of the post and cam and their anterior-posterior (AP) locations within the TKA primarily determine: (i) the angle of knee flexion at engagement and (ii) the magnitude of femoral rollback occurring from impingement to the maximum flexion (Fig. 3.5). Other design variables, including the size of the post (i.e., its height, width, and depth) and the location of the impingement point determine the strength, stiffness, and stability of the cam-post mechanism. In most designs, the cam and post engage at knee flexion angles between 60° and 90°. Thus, joint stability at flexion angles of less than 60° relies on soft-tissue balancing and so is similar for both CR and PS TKA designs [14]. Beyond 90° of flexion, PS knees show significant posterior

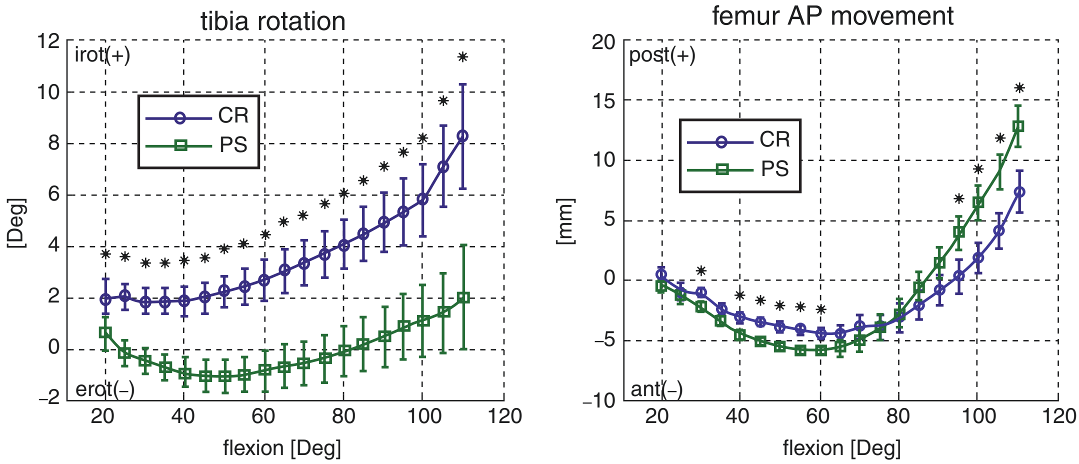

Fig. 3.6 Internal/external rotation and AP translation of cadaveric knees after implantation of a PS and a CR TKR during flexion from 20° to 110° [28]

translation and more closely replicate the kinematics of the intact knee [26]. Post-cam contact forces in PS TKA approximate the loads borne by the PCL in the intact knee, though there are still some differences in joint motion [27] (Fig. 3.6).

A fluoroscopic study [17] demonstrated that 75% of PS implants rotated about a medial pivot during stair-stepping activity (70° of flexion), indicating posterior femoral translation with flexion. Another fluoroscopic study of PS TKA [29] showed that there was posterior condylar translation from 80° to 120° flexion, and anterior translation beyond 120°. Implants with PS design allow for easier ligament balancing as distraction of the joint space generates tension in the collateral ligaments without the surgical challenge of tensioning of the oblique PCL [30]. The mechanical enforcement of femoral rollback via the cam-post articulation generally leads to greater femoral translation but less internal rotation in PS knees compared to CR TKA [28]. The range-of-motion of PS TKR is also generally larger than CR designs. In one study of 20 patients who underwent bilateral total knee arthroplasties, Maruyama et al. [31] found that PS knees had significantly greater flexion than CR knees (131° vs. 122°) at an average follow-up of 30 months. Similar differences (131° ± 12° vs. 121° ± 16°) were reported by Yoshiya et al. [14]. In addition, the PS knees showed no anterior translation of the femur under weight-bearing conditions, whereas it was observed in the CR knees between 30° and 60°. The same conclusion was obtained by Harato et al. [32] for 99 CR and 93 PS TKAs at a minimum follow-up of 5 years. However, in a study by Kolisek et al. [33], contrary to previous studies, CR knees (45 patients) showed a 7° higher mean range-of-motion than PS knees (46 patients) at a mean follow-up of 60 months.

The cam and post mechanisms of PS knees have varying shapes and positions which affect the guided or constrained motion of the femur on the tibia and also the amount of congruency and wear of the tibial polyethylene [34]. In designs in which the cam is positioned more anteriorly, contact occurs at lower angles of flexion and once engaged, the height of the contact point remains within the mid-portion of the post [35] (Fig. 3.7). More posterior cam placement yields post contact later in the flexion arc, with a point of contact that becomes closer to the tray as flexion

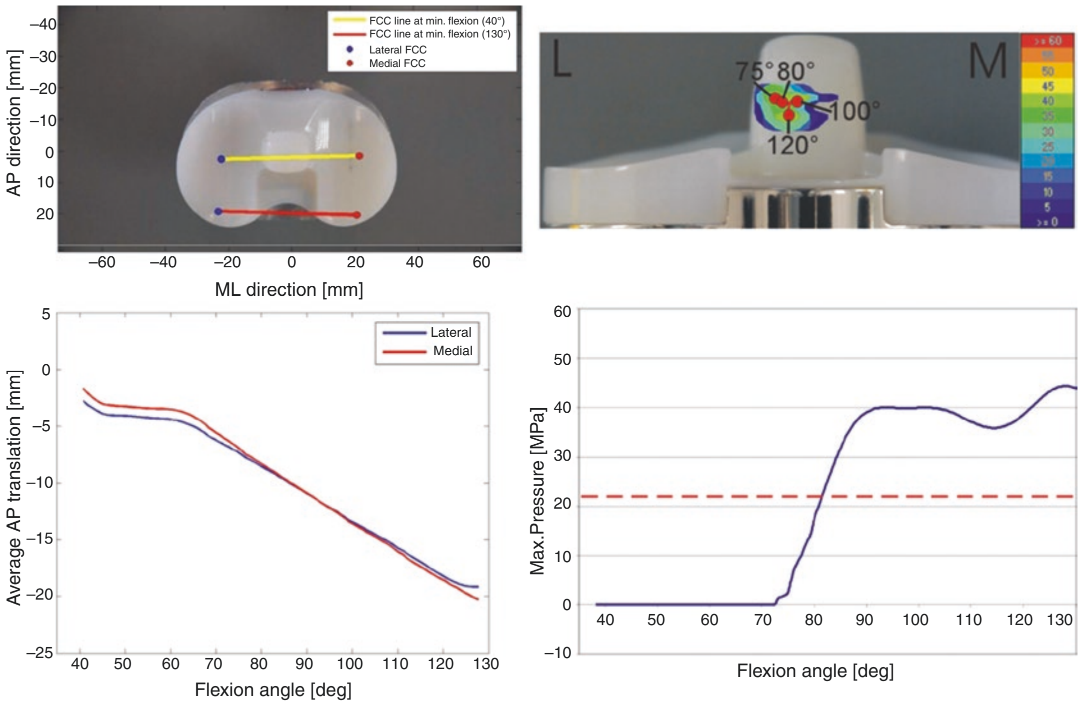

Fig. 3.7 Motion of the centers of the lateral and medial femoral condyles during flexion of a typical PS TKR from 40° to 130°. The location of cam-post contact and the magnitude of the contact pressure are also shown [36]

increases. This provides increased stability in deep flexion and maximizes the vertical excursion (the "jump height") required for tibio-femoral dislocation [34, 37]. Certain PS knees are designed with articulating features on the anterior aspect of femoral box and the mating surface of the post to guide tibio-femoral motion in extension.

The shape of the post in the transverse plane also influences joint kinematics during functional activities [34]. Posts that are rectangular in cross-section constrain rotation of the femoral component, depending on the overall width of the post and the size of the cam. During tibio-femoral rotation, cam-post loading is concentrated along the corners of the post leading to localized deformation, wear and, in some cases, fatigue fracture. On the other hand, if the post is more cylindrical in design, there will be less limitation of internal or external rotation, less wear on the post, and greater reliance upon soft tissues for rotational stability. The height of the post has also been known to affect the kinematics following TKA [34]. Tall posts with a more anterior position have an inferior aspect of the patellar. This phenomenon is called post-patellar conflict. It can limit deep flexion and cause pain as the post contacts the patella increased risk of impingement between the top of the post.

Certain cams are designed with asymmetric geometries, including different diameters medially and laterally [34]. In these designs, the medial end of the cam has a relatively smaller diameter compared to the lateral end to guide internal rotation during flexion. The wider diameter of the cam on the lateral side pushes the lateral femoral condyle posteriorly to affect rollback, whereas the smaller medial diameter keeps the medial femoral condyle centrally located with more sliding motion.

Fig. 3.8 A medial-pivot TKA with a congruent ball-in socket-like medial articulation [40]

In the PS design, the post contacts the cam causing posterior displacement during flexion with the resultant stress transferred to the bone implant interface. Theoretically this added constraint can increase the incidence of aseptic loosening with this design. Also, the PS design calls for more bone cuts to allow the space for the cam on the femur. The increased femoral bone loss and added implant constraint can possibly increase the risk of aseptic loosening. However, there have been multiple studies comparing survivorship of PS vs. CR TKA and the results have shown similar outcomes with regard to aseptic loosening [33].

3.2.3 Medial-Pivot Design

The "medial pivot" design of TKA is part-way between the UC and the CR and has a highly conforming medial compartment which resembles a ball-and-socket joint, combined with a non-conforming lateral compartment that allows unrestricted posterior rollback [38] (Fig. 3.8). The AP stability of this design stems from the raised anterior lip of the medial compartment of the polyethylene insert. Only the lateral femoral condyle is allowed to translate posteriorly as the knee flexes [39]. Radiologic findings of patients with medial-pivot CR implants demonstrated posterior femoral translation with rolling and sliding of the lateral femoral condyle during knee flexion [21]. Cadaveric studies have also shown less medial and more lateral anterior-posterior motion in the medial-pivot knees, which is similar to that of intact knees. Also, there was no difference in quadriceps forces required for extension [22]. Bae et al. showed no clinical difference in outcomes of medial pivot TKA with PCL-retaining or sacrificing techniques, and suggested sacrificing the PCL in cases where balancing the soft tissues proved difficult [23].

3.2.4 Lateral-Pivot Design

Another TKA design that has a conforming articulation within a single compartment is the "lateral-pivot" knee which is similar in design to the medial-pivot knee with reversal of the medial and lateral articulations. In the lateral-pivot design the lateral compartment has a "ball-in-socket" configuration while the medial condyle is free to translate posteriorly. This design concept has been developed on the basis of kinematic studies demonstrating a shift in the center of rotation of the knee from medial to lateral after loss of the ACL [41]. The congruent lateral compartment provides AP stability, while the less-conforming medial compartment allows for femoral rollback and translation [42]. The combination allows the use of a wider medial condyle which increases the tibio-femoral contact area and reduces contact stresses compared to other fixed-bearing, CR, and PS TKA designs [43].

3.2.5 Bicruciate-Retaining TKA Designs

In an effort to utilize the stabilizing effects of both the anterior and posterior cruciate

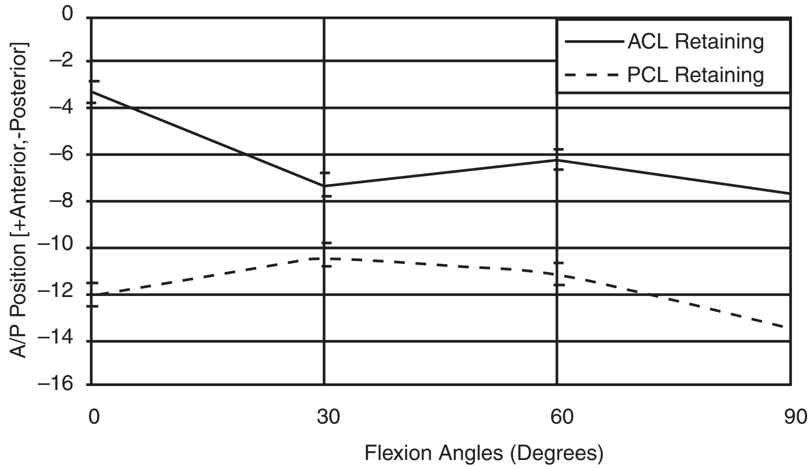

Fig. 3.9 In vivo comparison of the average AP position of the lateral femoral condyle after bicruciate retaining TKR vs. a CR TKR during a deep knee bend [44]

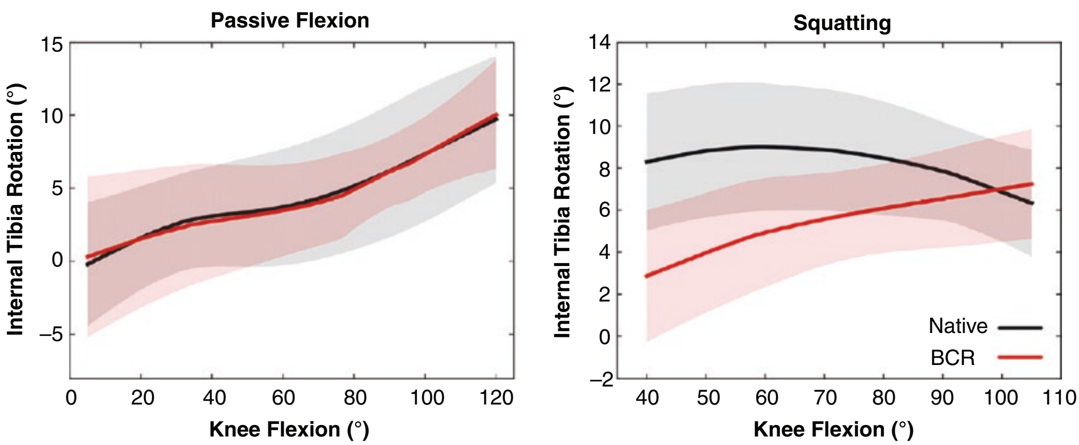

Fig. 3.10 Internal tibia rotation for the native and BCR conditions as a function of knee flexion angle during passive flexion and squatting. *Solid lines* represent the average values and shaded regions the standard deviations [55]

ligaments, "Bicruciate Retaining" TKA designs have been developed. In vitro and early in vivo results show better simulation of natural knee kinematics by the bicruciate-retaining knees compared to the regular CR or PS TKA [1, 44–49]. Fluoroscopic kinematic analysis revealed a more posterior contact point during deep knee bending and greater AP laxity in the CR design as compared to bicruciate-retaining knees [44]. When the ACL is sacrificed, the dwell point (neutral location) of the femur moves posteriorly which increases terminal flexion at the cost of reduced ease of extension and less efficient patellofemoral function. Maintenance of the normal physiologic balance of the extension and flexion mechanics of the knee during dynamic motion is critical if patients are to retain the ability to run after TKA [36, 50]. Preserving ACL function allows the femur to move anteriorly during extension by maintaining the

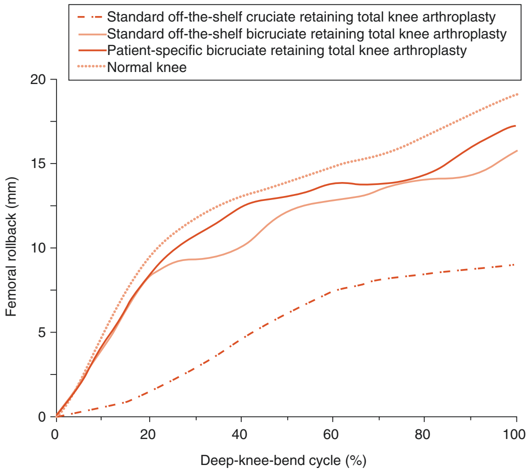

Fig. 3.11 Comparison of femoral rollback of a standard CR TKR, a standard bicruciate-retaining TKA, a patient-specific bicruciate-retaining TKA, and the normal knee during a deep knee bend [56]

physiologic relationship between the patella and the tibia. After CR TKA, tibio-femoral contact is displaced posteriorly in extension, and, at 60° of flexion, the lateral femoral condyle remains more posteriorly displaced compared to the native knee and the bicruciate design [44] (Fig. 3.9).

The absence of the ACL may also lead to loss of proprioception [51]. Reports have shown that the ACL and capsular mechanoreceptors respond mostly when the knee is in terminal extension where these receptors have the greatest proprioceptive sensitivity [52]. Balance testing has demonstrated impairment of normal knee proprioception in patients with ACL-deficient knees, and in patients who underwent ACL reconstruction, compared to healthy controls [53]. Fuchs et al. [54] evaluated proprioception in 15 patients who underwent unilateral bicruciate-retaining TKA, and demonstrated that there were no significant differences in balance measurements between the patients who received a bicondylar prostheses compared to both the contralateral limb, and normal controls. These findings help support retention of the ACL during TKA in maximize knee stability, proprioception, and balance.

The kinematics of bicruciate TKA have been characterized also using fluoroscopic examination of TKR patients [20, 44, 47, 48, 55] (Fig. 3.10) and sophisticated computer simulations of knee motion during functional activities [56]. Stiehl et al. [44] compared two designs (bicruciate-retaining vs. regular CR) for knee bending motions at 0°, 30°, 60°, and 90° flexion.

Bicruciate-retaining TKAs showed gradual posterior femoral rollback and limited anterior–posterior translation, with the femoral contact point remaining posterior to the sagittal mid-line throughout. In a fluoroscopic imaging study, Moro-oka et al. compared the in vivo kinematics of a PCL preserving TKA with a bi-cruciate-sparing design during kneeling, stair-stepping and squatting and found that in the stance and swing phases of gait, posterior translation of both femoral condyles was greater for the bicruciate-retaining compared to the PCL preserving design [48]. Additionally, during deep flexion activities and stair stepping from 30 to 70° of knee flexion, the increase in posterior translation of the lateral condyle was up to 6 mm greater in patients receiving bicruciate-retaining implants (Fig. 3.11).

3.2.6 Fixed and Mobile-Bearing Designs in TKA

Two primary failure mechanisms challenge the durability of TKA—wear and oxidation of the polyethylene insert on the one hand and aseptic loosening of the tibial tray or the femoral component on the other. Wear and mechanical failure of the bearing inserts can be increased by reducing the peak stresses developed during articulation, primarily through maximizing the area of contact, and hence the conformity of the tibio–femoral interface. This approach was adopted in early designs of knee implants in which the crucite ligaments were sacrificed and

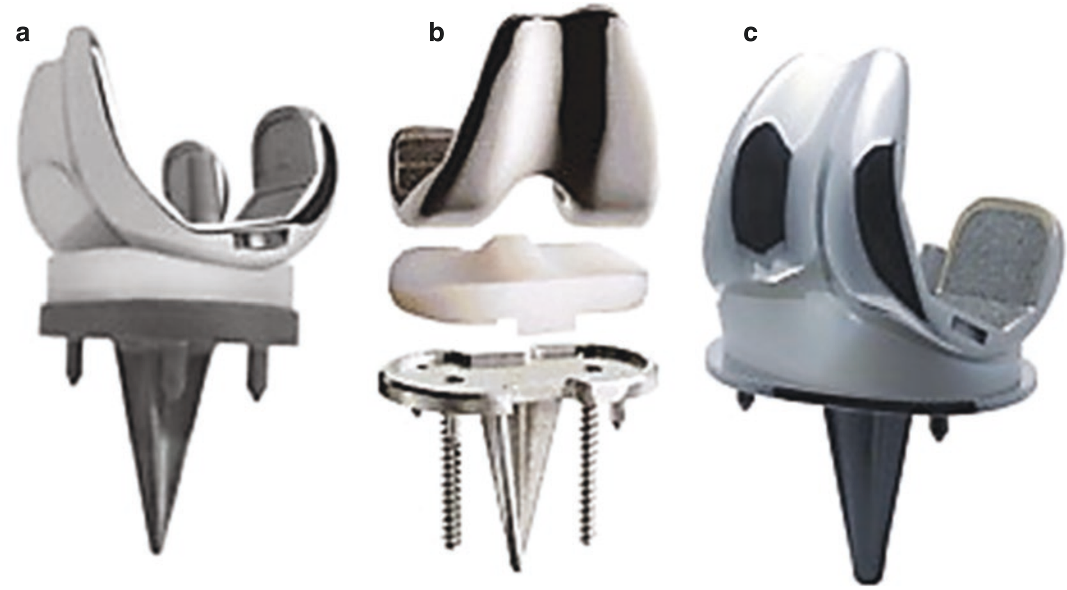

Fig. 3.12 A single TKA design supplied in fixed bearing (**a**, **b**) and mobile-bearing (**c**) options designed for cemented (**a**, **c**) or cementless (**b**) modes of fixation [60]

the constraint forces provided by the soft tissues of the knee were borne by the articular surfaces and subsequently transferred to the fixation interfaces of the femoral and tibial components and the supporting bone. In an unacceptable percentage of cases this ultimately led to premature failure secondary to aseptic component loosening [57]. To minimize load transfer to the implant–bone interface, newer designs were developed with less-conforming round-on-flat or flat-on-flat articular geometries [58]. However, this led to a reduction in the true area of contact at the bearing surface, a drastic increase in the contact stresses with resultant premature mechanical failures secondary to polyethylene damage and wear. This problem was especially common when polyethylene inserts were sterilized with gamma radiation and then stored in air-permeable packaging [59].

Before the advent of new designs balancing conformity with bearing stresses, one approach to this dilemma was the introduction of "mobile bearing tibial inserts" that articulated with the tibial tray (Fig. 3.12). These inserts were of several different designs that differed in their mobility:

i. "rotating-platform" designs allowed free rotation of the tibial polyethylene insert about the central axis of the tibia,
ii. "meniscal-bearing" designs attempted to mimic the natural meniscus with independent movement of medial and lateral bearings, and
iii. "AP glide-and-rotation" designs allowed the insert to move in an AP direction, with some rotation about the central axis of the tibia [61].

A fundamental advantage of the mobile-bearing configuration is that the two articulating surfaces can provide separate components of the net motion of the joint. Thus, the upper surface of the liner can be designed to closely conform to the femoral component while the undersurface can allow all of the internal/external rotation required to simulate normal knee kinematics. In this way, the contact area between the articulating surfaces can be increased, substantially reducing contact stresses and polyethylene wear, while simultaneously protecting the implant–bone interfaces from repetitive overload. However, despite these potential benefits, evidence of long-term benefit of mobile-bearing TKA implants vs. fixed-bearing designs is lacking [62].

3.2.7 Highly Conforming Designs in TKA

In published studies, patients with bilateral TKAs have evaluated the relative performance of implants with different degrees of tibio-femoral conformity [63]. These studies suggest that patient satisfaction with knee function after TKA is primarily a question of tibio-femoral stability in resisting AP translation. This conclusion is borne out by the emergence of implants with highly conforming articulations on one (medial-pivot or lateral-pivot TKA) or both (Ultracongruent, UC) sides of the knee.

One design of tibial insert, which is supplied as an option with many TKA designs, is the "deep-dish" or "ultracongruent" design which provides greater conformity between the tibial bearing and the medial or lateral femoral condyles. The UC insert design is characterized by an elevated anterior lip and deeper weight-bearing surfaces to prevent anterior subluxation of femoral condyles during flexion [64, 65]. A concomitant benefit is increased area of tibio-femoral contact, at least when the knee is in extension. This is expected to lead to reduced wear and increased knee stability, however, this may come at the cost of reduced posterior rollback and posterior impingement at the end of the flexion arc with some loss of terminal flexion [66]. One study comparing mobile-bearing PS UC and standard mobile-bearing PS inserts showed increased anterior translation of the femoral component in the UC TKA from 80° to 120° of knee flexion. Furthermore, patients with UC inserts displayed less paradoxical internal rotation of the femur from 40° to 120° compared to patients with the PS design [67].

3.3 The Kinematics of Unicondylar Knee Replacement

3.3.1 Introduction

Unicondylar knee arthroplasty (UKA) is a surgical procedure in which only one of the tibio-femoral compartments is replaced with an artificial joint with preservation of both the ACL and PCL [68–71]. The primary objectives of UKA are pain relief, improvement in function, and correction of lower extremity alignment. This procedure is recommended in selected patients with painful focal arthritis or unicompartmental osteonecrosis of the knee [68, 70, 72–74]. Many authors have reported that UKA provides better physiological function and quicker recovery than TKA [68, 70, 74–76]. Furthermore, recent innovations in implant designs, bearing materials, rapid recovery protocols, surgical techniques, and patient selection criteria have all led to a resurgence of interest in UKA in clinical practice [69, 70].

The goal of UKA is to restore the tibio-femoral joint by replacing the diseased compartment of the joint with a prosthesis that matches the thickness of the bone and cartilage lost or resected [70, 74]. In cases with minimal bony deformity, this procedure leads to a joint that is balanced throughout the full range-of-motion with restoration of "natural" kinematics, though the specific patterns of implant motion may vary substantially from patient to patient [74].

Despite reports of higher revision rates after UKA compared to TKA, independent of the age and gender of the patients (Australian Joint Arthroplasty Registry, 2017 Annual Report), UKA presents some advantages, including decreased blood loss, faster recovery, higher patient satisfaction, smaller incision, preservation of bone stock, ease of revision, superior range-of-motion, and a reduced rate of readmissions after surgery [68–70]. In addition, the restoration of more normal kinematics may slow progression of joint degeneration in the non-diseased compartments of the knee, provided that the UKA is implanted in correct alignment [72, 77–80].

3.3.2 The Kinematics of UKA

After UKA, patients display knee kinematics closer to the native knee than is generally possible with TKA [72, 79]. In one comparative study, Laurencian et al. reported that UKA led to a 17° improvement in the range-of-motion of the knee (106°–123°), compared to an average increase of only 5°after TKA [81]. Cadaveric studies have also shown similar patterns of tibial rotation (15°–30°) and femoral rollback in UKA compared with intact knees [82]. This is primarily because the cruciate ligaments are retained and one compartment, typically the lateral, remains intact [83]. Also, the walking speed in UKA patients (2.2 m/s) has been reported to be significantly faster than is normally observed in TKA patients (1.6 m/s) [75]. This is consistent with the significantly larger improvements in outcome and function scores reported after UKA vs. TKA [84–86].

While many hypothesize that resection of the meniscus and part of tibial plateau increase the mobility of the knee, thereby altering joint kinematics, many characteristics of native knee motion are preserved after UKA, including femoral rollback and the medial-pivot/screw-home mechanism seen during flexion [72, 77, 88, 89] (Fig. 3.13). Nonetheless, compared to the normal

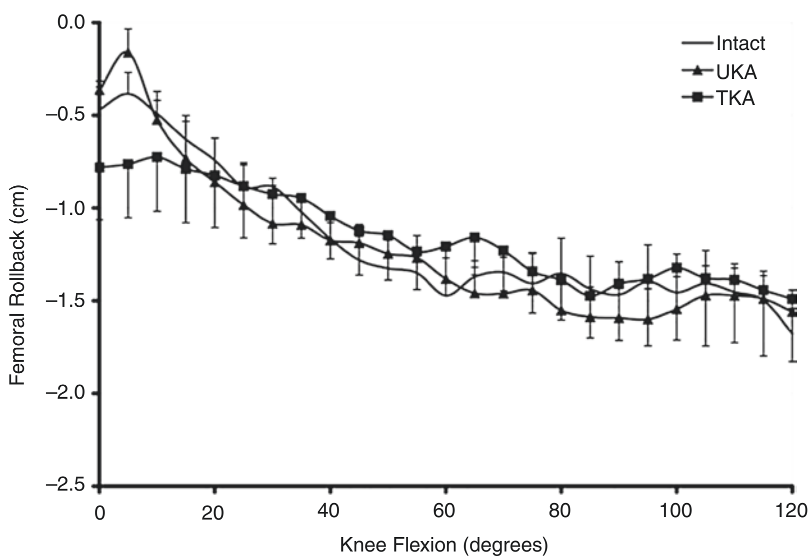

Fig. 3.13 Femoral rollback with knee flexion in intact cadaver knees and after medial unicondylar knee replacement and a total knee replacement. Rollback is measured with respect to the ML midpoint of the transepicondylar axis [82]

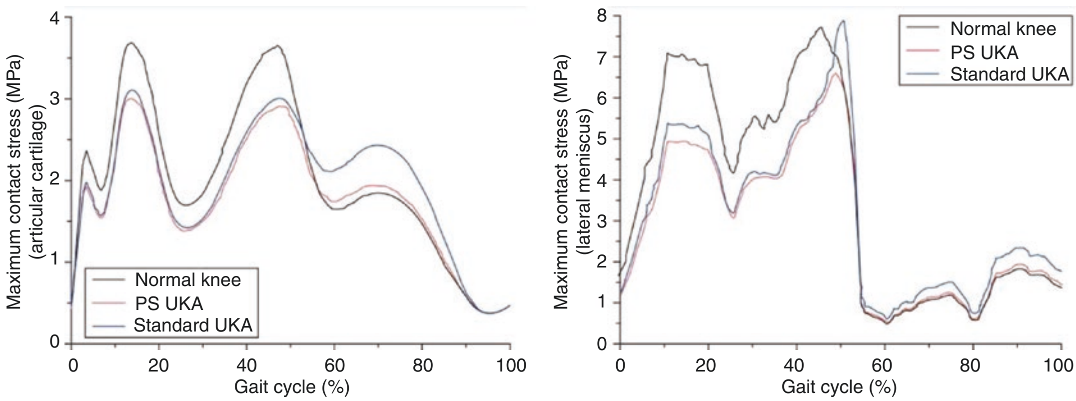

Fig. 3.14 Maximum contact stress on (**a**) the articular cartilage of the lateral compartment (L) and; (**b**) the lateral meniscus in the normal knee, patient-specific (PS) unicompartmental knee arthroplasty (UKA), and standard UKA [87]

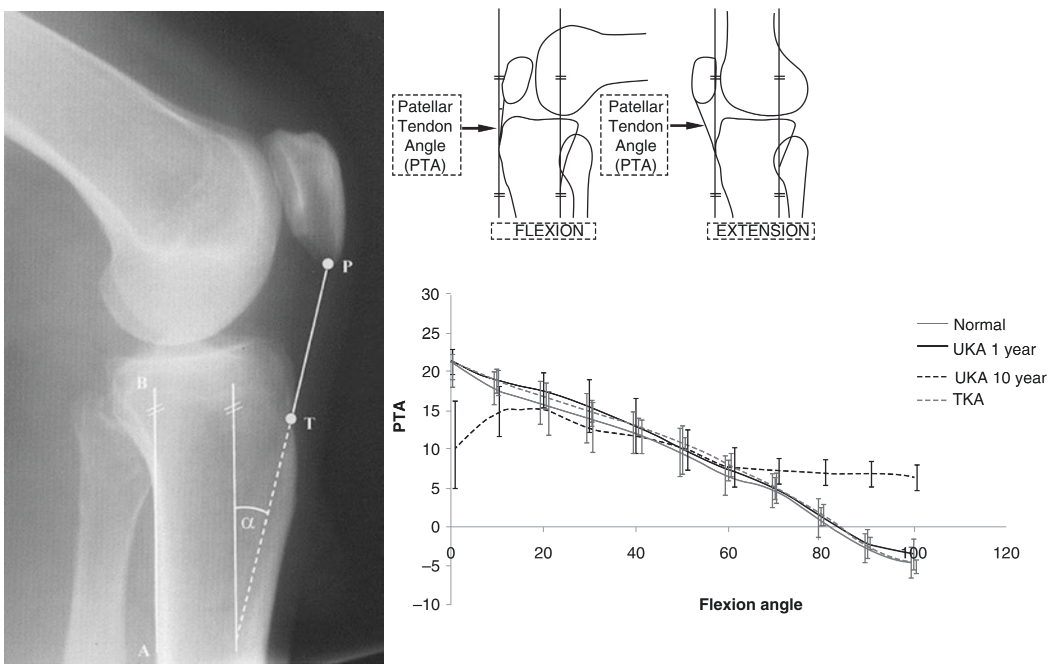

Fig. 3.15 (L) The PatellarTendon Angle (PTA,α) is defined by the angle between the patellar tendon and the longitudinal axis of the tibia [91]. (R) Published values of the PTA as a function of knee flexion angle [91, 94]

knee, UKA is unable to completely restore normal gait patterns, as indicated by a significantly slower walking speed and cadence and a shorter stride length [90] (Fig. 3.14).

One parameter used to assess knee kinematics in the sagittal plane is the Patellar Tendon Angle (PTA), which is the angle formed between the patellar tendon and the longitudinal axis of the tibia. The PTA varies with knee flexion [71, 91, 92], and is influenced by both the AP displacement of the femur on the tibia and the inclination of the patella in the sagittal plane [93] (Fig. 3.15).

The utility of the PTA as an indicator of knee kinematics stems from its ease of use in the analysis of sagittal plane video fluoroscopy, and its relative insensitivity to internal/external rotation of the knee during flexion [91, 93]. In the native knee, the patellar tendon is directed posteriorly from the inferior patella to the tibial tubercle at an angle of approximately 20° in terminal extension, decreasing linearly with flexion until the patellar tendon and the tibial shaft become parallel when knee flexion reaches approximately 75°. Values of the PTA in patients after UKA (especially the Oxford mobile-bearing UKA) have been shown to be the same as in the normal, intact knee, primarily due to the normal AP location of the tibia on the femur when the cruciate ligaments are retained [91]. Moreover, Price et al. have shown that this equivalence after UKA remains unchanged for up to 10 years postoperatively [91].

Despite "average" kinematic values, considerable variations in knee kinematics after UKA have been reported by different authors, possibly due to differences in surgical techniques, implant designs, and individual anatomy [72, 77, 88]. Akizuki et al. reported wide variations within their own study population [77]. It was found that 70% UKA implants experienced paradoxical rotation during flexion. Moreover, while several in vitro studies demonstrated that UKA displays relatively physiologic sagittal plane kinematics [72, 82, 89, 95], abnormal knee motion was seen in vivo, most frequently anterior femoral translation at either 30° or 60° of flexion [96]. Also, in lateral UKA, the lateral condyle moved minimally with increasing knee flexion, instead of posteriorly as in the normal knee [73].This may due to the fact that many in vitro studies do not assess knee function under normal weight-bearing conditions, despite known differences between unloaded and load joint kinematics in vivo [73].

3.3.3 Mobile vs. Fixed-Bearing UKA

There are mobile-bearing (MB) and fixed-bearing (FB) articulation options in UKA, similar to TKA designs (Fig. 3.16). The MB option has a high conformity between the femoral component and the polyethylene insert, as coupled AP translation of the femur on the tibia during flexion is

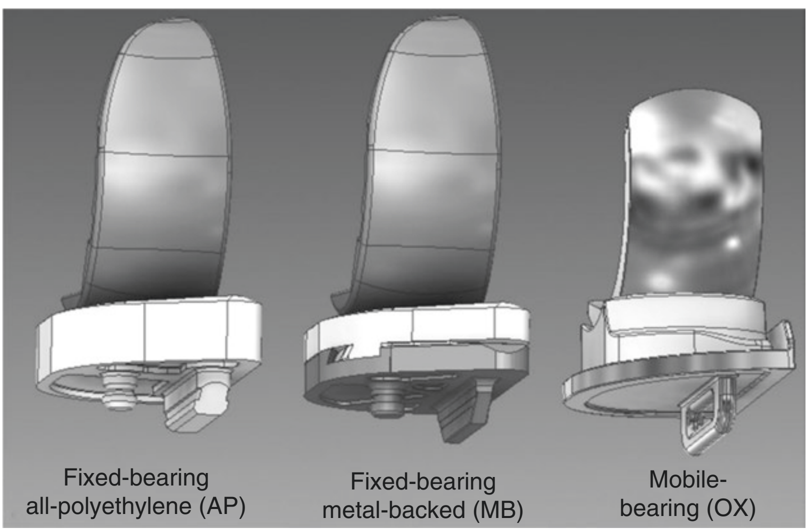

Fig. 3.16 Three configurations of a unicompartmental knee replacement (UKR), where the material and constraints vary

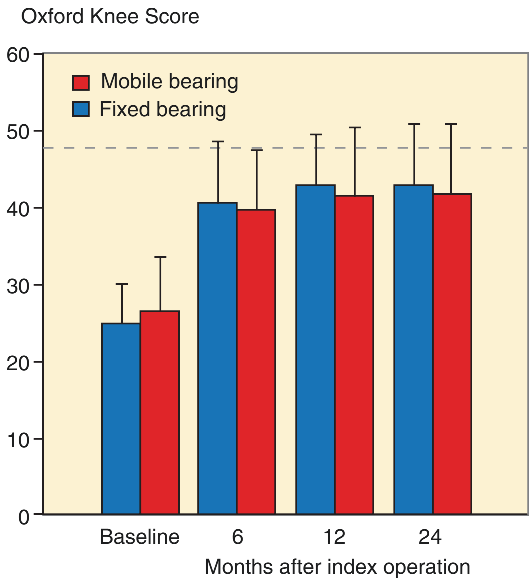

Fig. 3.17 Oxford Knee Scores reported after fixed-bearing and mobile-bearing UKR at 6-, 12-, or 24-months post-operatively [99]

accommodated by the articulation between the mobile insert and the tibial tray [83, 97]. In contrast, in the FB design, the articulation is of low conformity so that the condylar runner may move posteriorly as the knee flexes. The higher contact stresses present over the articulating surface of the FB design increases the theoretical risk of increased polyethylene wear. In contrast, the high congruency of the spherical MB articulation minimizes contact stresses, potentially eliminating wear and increasing survivorship [89, 98]. Bearing dislocation was the predominant mechanism of failure in MB design, whereas polyethylene wear and aseptic loosening remain the main cause of failure of FB design.

Past studies have noted no difference between MB and FB designs of medial UKA in terms of joint kinematics, specifically anterior translation and internal rotation [89] or in clinical outcomes, as measured by the Oxford Knee Score [99] (Fig. 3.17).

Moreover, the fixed-bearing components exhibited greater migration at 2 years postoperatively when compared to the mobile-bearing design (0.30 ± 0.22 mm vs. 0.17 ± 0.09 mm, $p = 0.04$) [99]. However, mobile-bearing components are not recommended for replacement of the lateral compartment due to the increased laxity of lateral collateral ligament (LCL) in flexion. This allows greater AP translation of the lateral tibio-femoral compartment in flexion and may lead to dislocation of the polyethylene bearing insert [83, 89].

3.3.4 Medial vs. Lateral UKA

The kinematics of medial and lateral UKA has been studied using both cadaveric testing ex-vivo and clinical studies, with contradictory results. Wada and colleagues reported measurements of the internal rotation of the tibia before and after medial and the lateral UKA in paired cadaveric tibias [100]. All measurements were performed with a surgical navigation system under non-weight-bearing conditions. The results were highly variable, especially after medial UKR, but showed that both medial and lateral UKR fairly closely restored the "screw-home" pattern of tibial rotation with flexion, though paradoxical rotation was seen both before and after lateral UKA. In vivo knee kinematics were reported by Argenson et al. in 20 patients on the basis of fluoroscopic measurements, 17 after medial UKA, and 3 after lateral UKA. In this study, medial UKA replicated the pattern of AP translation of the native knee during flexion, though with significantly less internal/external rotation [73]. They also observed paradoxical anterior translation of the femur during flexion and a posterior shift of the femur on the tibia when the knee was placed in full extension. This is in contrast to the kinematics of the native knees of their study subjects, half (53%) of whom had anterior tibio-femoral contact in extension. The kinematics of 3 patients with lateral UKA was even more variable than those with medial UKA [73].

3.3.5 The Importance of the Anterior Cruciate Ligament in UKA

The functional role of the ACL in maintaining satisfactory knee kinematics after UKA has been previously demonstrated both in cadaveric and clinical studies [73, 80, 94, 100]. The ACL provides primary constraint to anterior tibial translation/posterior femoral translation and also serves as a secondary stabilizer to resist tibial rotation [80, 100]. Several cadaveric studies demonstrated that, with an intact ACL, UKA provides similar AP stability and axial rotation compared to the native knee [80, 100]. However, ACL-deficient UKAs may lead to poor survivorship and component loosening, one of the most common mechanisms of failure after UKA [69, 80, 93]. When the ACL is absent or deficient, the kinematics of a medial UKA is similar to those observed after TKA [71, 80, 94], with paradoxical anterior translation of femur on the tibia in low flexion angles (30–60°), larger variations in knee kinematics between subjects than is seen in the native knee, and a broader range of contact locations over the surface of the bearing insert. Subclinical deficiency or incompetence of the ACL may explain the variability in knee kinematics reported in several UKA studies, both in vivo and in vitro [72, 73, 77, 79, 93, 101]. For example, while the ACL may be visually intact intraoperatively, it could be chronically attenuated by notch osteophytes or by iatrogenic means, which may not be recognized post-operatively [73].

Several authors have reported success in restoring normal kinematics to the ACL-deficient arthritic knee by combining ACL reconstruction and UKA. In series performed using both fixed-bearing [102] and mobile-bearing [71] implants, a dramatic reduction in the rate of revision UKA has been reported in ACL-deficient knees after ligament reconstruction (2.8%) vs. remaining ACL deficient (12.3%) [94]. While ACL-deficiency has been a classic contraindication of UKA in the arthritic knee, several authors have advocated UKA/ACL reconstruction as an alternative to TKR due to advantages of UKA [93, 94]. In addition, Engh et al. and Boissonneault et al. reported that there was no difference in survivorship between ACL-deficient UKAs and ACL-intact UKAs [103, 104]. These studies, however, have relatively short-term follow-up of 6 and 5 years, respectively. In conclusion, UKA with an intact and functional ACL produces knee kinematics more similar to the normal knee than TKA, leading to superior outcome scores with quicker and more functional recovery. However, abnormal kinematic patterns can be also found in patients with UKA, these can be attributed to ACL insufficiency or surgical/technical errors. Technological advances, such as navigation and robot-assisted surgery, can increase the reproducibility of UKA as well as improve the functional outcomes and survivorship of UKA.

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4 Loading of the Knee Joint After Total Knee Arthroplasty

P. Moewis, A. Trepczynski, A. Bender, G. N. Duda, and P. Damm

Keynotes

1. In principle, all external forces, such as ground reaction forces, masses, and acceleration forces of foot and shank, act at the knee joint. The forces acting across the joint (tibiofemoral contact forces, muscle forces, and forces in soft tissue structures) counterbalance those external loads.
2. For most activities, resultant forces are typically between 220 and 350% BW. The impact of co-contractions is present if a subject loses balance during one-leg stand, leading to forces of more than 550% BW.
3. The highest adduction moments (−My see below) were observed in knees with a varus alignment and therefore a medial load transfer. Highest abduction moments (+My) and a lateral load transfer were observed in knees with a valgus alignment. The varus/valgus alignment may further influence the mediolateral shear forces Fx. There was no evident correlation between the axis alignment and the axial force (Fz).
4. PF forces can reach the level of TF forces (of above 300% BW), even though the body's weight is directly supported by the TF joint, while the PF force is a result of muscle action only. The peak PF forces even exceeded the TF forces during activities with high knee flexion. This demonstrates that the in vivo loading conditions of the knee can only be fully understood if the interaction between the TF and the PF joints is considered.
5. Malalignment of more than 3°–5° has been associated with increased wear of the polyethylene tibial insert and also an increased risk of implant loosening.
6. The mediolateral force distribution in the knee joint is influenced by limb support and by overall leg alignment. The force distribution changes throughout the activity.
7. Overall leg alignment is a critical factor for the force distribution in the knee joint

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and can be influenced during TKA. The actual trend toward a "constitutional varus," for the overall tibiofemoral alignment, should be reconsidered due to the resulting increased medial force ratio monitored in the instrumented patient cohort.

4.1 Introduction

Total knee arthroplasty (TKA) is a widely used and successful surgical procedure, which provides pain relief as well as restoration of function in most patients. Although high patient's satisfaction rates (up to 89% at 15 years) have been reported after TKA, a substantial number of patients remain unsatisfied with the outcome [1, 2].

Non-physiological kinematics, surgical technique, soft tissue balancing, and implant geometry are considered to be frequent causes of such remaining patients' dissatisfaction [3, 4].

Frequently, the resulting mechanical forces acting within the joint are considered to play a relevant role in those cases with unsatisfactory outcomes. Thus, a more detailed knowledge of the in vivo loads acting in a knee joint after TKA would help to judge whether such forces and moments could be linked to functional deficits or postoperative pain. Such knowledge is in addition key to preoperative planning and intra-operative placement of implants, in which postoperative physiotherapy treatments would impact the joint loading most.

4.2 Technical Capabilities: How to Measure Knee Loading in Vivo?

4.2.1 Tibial Tray Design

A telemetric tibial tray [5] with a measurement accuracy of 3% was developed to measure the knee joint loads in vivo. The tibial tray consists of two plates which are separated by a small gap. The necessary snaplock mechanism for the tibial is positioned in the proximal plate, while the distal plate is cemented onto the resected tibia. The design is a cruciate substituting, compatible with a proven TKA system (INNEX, Zimmer GmbH, Winterthur, Switzerland). On this basis, standard ultracongruent tibial inserts, femoral components, and instruments are used in combination with the instrumented baseplate. All electronics and strain gauges are positioned in the cavity of the inner stem. A polyetheretherketone (PEEK) cap is used to protect the antenna against mechanical damage. To avoid ingrowth of connective tissue, a plastic sealing is incorporated along the circumference of the tibial tray (Fig. 4.1a).

4.2.2 Coordinate System and Nomenclature

The origin of the coordinate system (Fig. 4.1, right) is at the level of the lowest part of the polyethylene insert. Force components Fx, Fy, and Fz act in the lateral, anterior, and superior directions, respectively. Moments Mx, My, and Mz act in the sagittal, frontal, and horizontal planes and are termed after the tibial rotation they counterbalance (Fig. 4.1b). Considering this, the moments are named flexion/extension moment = +Mx/−Mx, abduction/adduction moment = +My/−My, and external/internal rotation moment = +Mz/−Mz. Peak forces are stated in percent of the body weight (%BW) and peak moments in percent body weight times meter (%BWm).

4.3 In Vivo Loading in Activities of Daily Living

In principle, all external forces, such as ground reaction forces, masses, and acceleration forces of foot and shank, act at the knee joint. The forces acting across the joint (tibiofemoral contact forces, muscle forces, and forces in soft tissue structures) counterbalance those external loads. Additionally, the "net moment" caused by the external forces is counterbalanced by the moments exerted by muscles, soft tissues, contact forces, and frictional forces.

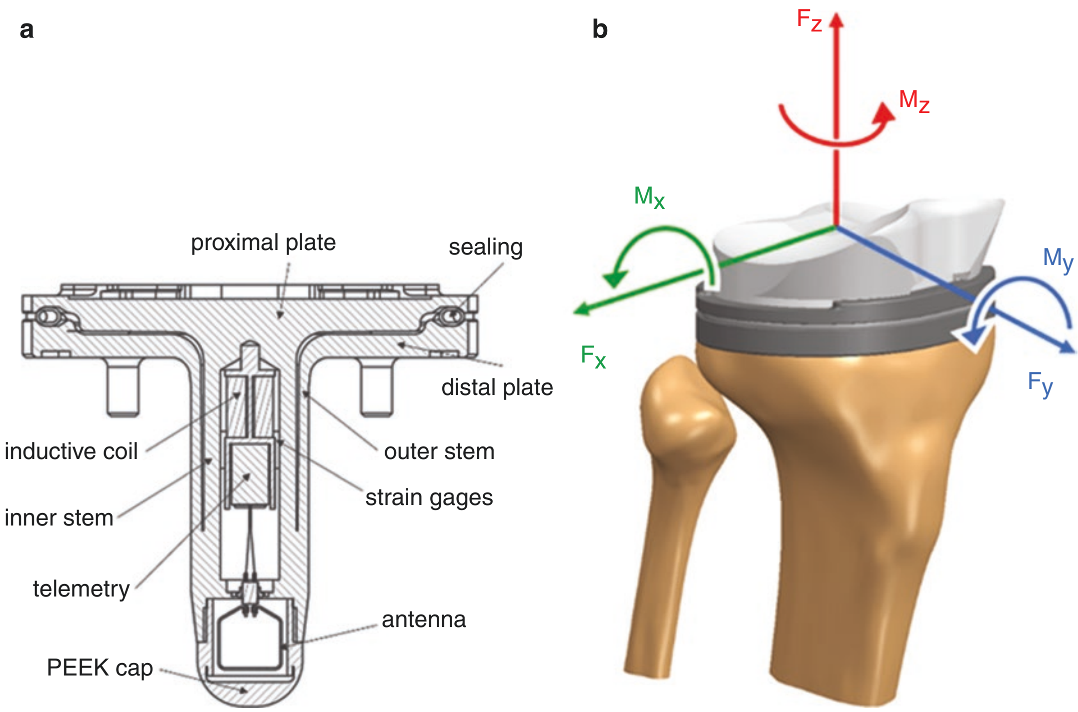

Fig. 4.1 (**a**, **b**) Schematic drawing of the tibial component with the sensor system (**a**). Telemetric tibial tray and coordinate system (**b**)

Gait analysis and musculoskeletal models are the usual methods to analyze muscle and joint contact forces. However, large variations of the reported forces and moments do exist. In order to gain a more profound understanding of the role of muscle and contact forces as well as the force distribution across the lateral and medial condyles, a number of activities of daily living were analyzed [6]: (a) Two-legged stance (2LegSt, Equal load distribution), (b) sitting down (SitD, Seat height 45 cm, no support at armrest), (c) standing up (StUp, Seat height 45 cm, no support at armrest), (d) knee bend (KneeB, Self-selected flexion angle), (e) one-legged stance (1LegSt, No or minimal support at fingertip), (f) level walking (LevWalk, Self-selected comfortable speed on level ground), (g) ascending stairs (AscSt, Stair height 20 cm, no support at handrail), and (g) descending stairs (DesSt, Stair height 20 cm, no support at handrail). Selected examples of such in vivo loads measurements are shown and can be downloaded at the public database www.OrthoLoad.com.

4.3.1 The Observed Peak Loads

4.3.1.1 Resultant Forces F

Smallest peak resultant forces of 107% BW were measured during 2LegSt. During SitD, the values were two times higher (225% BW). StUp, KneeB, 1LegSt, and LevWalk caused approximately the same forces (246–261%BW). The highest forces were present during AscSt (316% BW) and DesSt (346% BW) (Fig. 4.2a).

> **Side Summary**
> Over 300% body weight during ascending and descending stairs.

4.3.1.2 Shear Forces

Shear forces in the transverse plane were approximately 10–20 times smaller than the axial force Fz. The largest shear forces Fx and Fy were found during LevWalk, AscSt, and DesSt. Medial shear forces (-Fx) ranged between −1% and − 18%

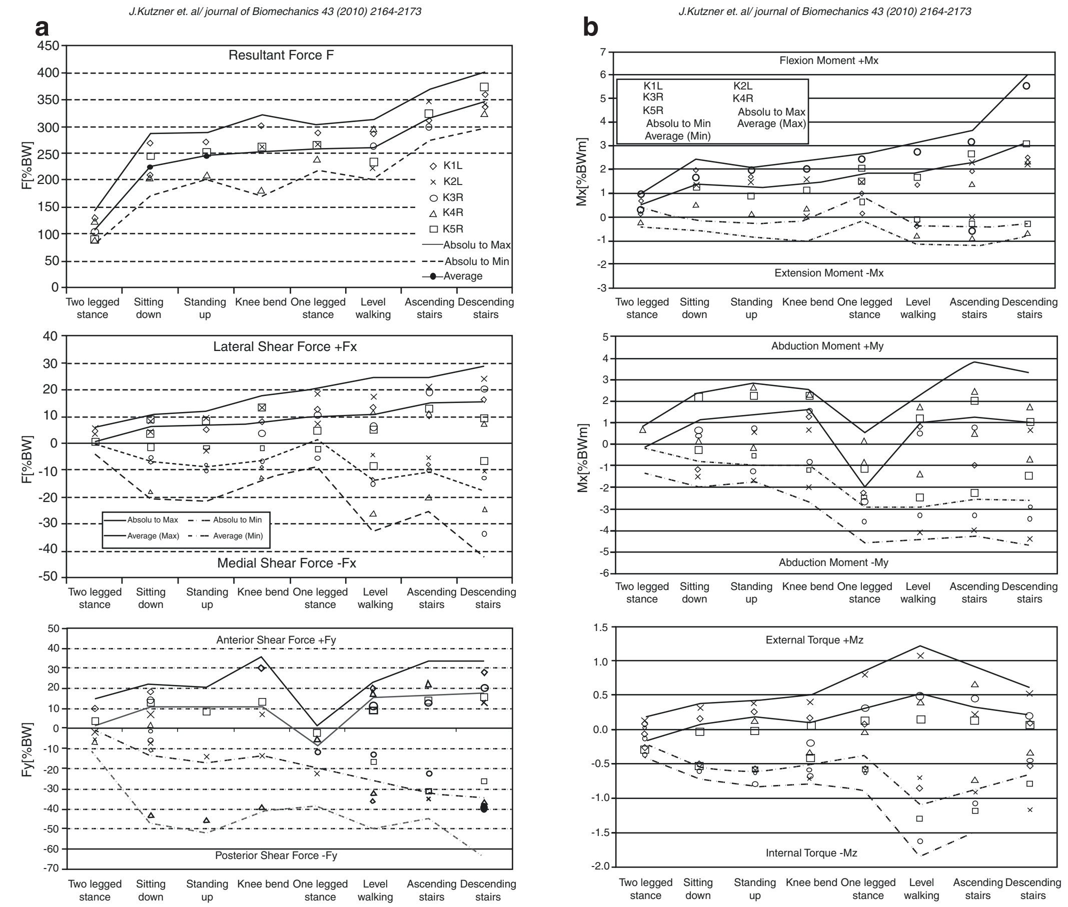

Fig. 4.2 Knee joint loading during different activities of daily living, forces (**a**), moments (**b**). Reproduced with permission from Elsevier - License Number 5157051249765

BW and forces in lateral direction (+Fx) between +1% and +16% BW. Shear forces -Fy in posterior direction were highest for LevWalk (−26% BW), AscSt (−32% BW), and DesSt (−34% BW) (Fig. 4.2a).

4.3.1.3 Flexion–Extension Moments

In the sagittal plane, high flexion moments +Mx (+0.53% to +3.16% BWm) but only small extension moments -Mx (−0.14% to −0.44% BWm) were observed. Flexion moments +Mx were highest during DesSt (3.16% BWm), followed by AscSt (2.29% BWm), LevWalk (1.92% BWm), and 1LegSt (1.81% BWm). Slightly lower flexion moments occurred during high flexion and two-legged activities: StUp (1.24% BWm), SitD (1.35% BWm), and KneeB (1.39% BWm) (Fig. 4.2b).

4.3.1.4 Abduction–Adduction Moments

In the frontal plane, abduction moments (+My) were highest during KneeB (1.61%BWm) followed by StUp (1.39% BWm), AscSt (1.26% BWm), DesSt (1.04%BWm), SitD (1.14% BWm), and LevWalk (1.0% BWm). High adduction moments (−My) were present during all activities which include temporary single-legged stance. AscSt/DesSt led to moments of −2.58/−2.57% BWm. During 1LegSt/LevWalk, slightly higher values of −2.88/−2.91% BWm were measured. Smaller moments acted during

StUp (−0.97% BWm), KneeB (−0.91% BWm), and SitD (−0.77% BWm) (Fig. 4.2b).

Side Summary
High abduction moments during level walking, knee bend, stand up, and going up and downstairs. High adduction moments during single-leg activities.

4.3.1.5 External–Internal Rotation Moments

LevWalk showed the highest rotation moments. They typically changed from +0.53% BWm during the early stance phase to −1.1% BWm at late stance. AscSt led to high internal rotation moments -Mz of −0.92% BWm. For all other activities, internal rotation moments -Mz were between −0.22% and −0.66% BWm. External rotation moments +Mz were usually smaller and reached values between 0.07% and 0.53% BWm (Fig. 4.2b).

4.3.2 Load Patterns

4.3.2.1 Two/One-Legged Stance

Changing from 2LegSt to 1LegSt led to about 2.5 times increased axial forces −Fz as well as an increase of the adduction moment −My and flexion moment +Mx. This gives a good insight into the influence of the muscle forces on the resultant in vivo knee joint loads. During 1LegSt, the entire body weight will be transferred to the knee joint. However, also much more muscle activity is needed to balance the body than during 2LegSt. Thus, it is followed by a clear increase of the resultant knee joint load. Shear forces Fx and Fy remained small during one- and two-legged stances.

4.3.2.2 Knee Bend, Standing Up, and Sitting Down

During high flexion activities, highest peak forces were reached at the instant of higher flexion, specifically after losing contact with the chair and before the seated position. During high flexion, particularly the abduction moments +My as well as the flexion moments +Mx were high. These high values of +My indicate a pronounced load shift toward the lateral compartment.

4.3.2.3 Level Walking

Two main force peaks took place at the instant of contralateral toe-off (CTO) and also before contralateral heel strike (CHS). A much smaller force peak was observed immediately before heel strike (HS). At CTO, small shear forces −Fy and +Fx were acting in posterior and in lateral directions, respectively. In contrast to the high flexion activities and similar to 1LegSt and 2LegSt, an adduction moment (−My) acted in the frontal plane during stance phase, which indicates a medial load shift. Flexion moments (+Mx) reached their peak values around CTO and CHS. The axial torque changed from an external rotation moment (+Mz) at CTO toward a pronounced internal rotation moments (−Mz) at CHS (Fig. 4.3).

4.3.2.4 Ascending/Descending Stairs

Peak forces took place at CTO and also during or shortly after contralateral stair contact (CSC). In the frontal plane, adduction moments (−My) acted between CTO and CSC and abduction moments (+My) after CSC. The two peak values of My occurred subsequently to CTO and CSC. The signs' change of My indicate an initially predominant force transfer by the medial compartment toward a shift to the lateral side. During AscSt and DesSt, predominantly internal rotation moments -Mz acted at the tibia.

4.3.3 Force Directions

In general, both shear forces Fx and Fy were rather at small values during all activities compared to the vertical contact one, leading to resultant forces acting almost vertically on the tibial plateau. This was especially the case for

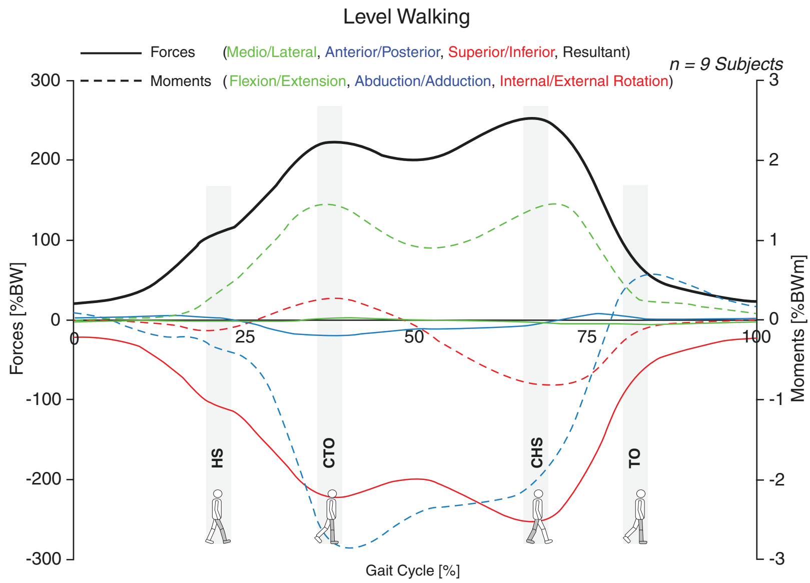

Fig. 4.3 In vivo measured knee joint loads during level walking (average subject)

high resultant forces and surprisingly also seen to be the case during the high flexion activities KneeB, StUp, and SitD. In the frontal plane, only small direction differences within activities were observed.

For most activities, resultant forces were typically between 220 and 350% BW. The impact of co-contractions is present if a subject loses balance during 1LegSt, leading to forces of more than 550% BW. During 2LegSt the joint force is also higher than required statically. While only approximately 44% BW would be required to support the body weight by both legs, additional 60% BW act due to the muscle activities required to maintain equilibrium.

For the high flexion activities (StUp, SitD, KneeB), typical forces between 210% and 260% BW were measured though the body is supported by both knee joints. During high flexion, mainly abduction moments (+My) acted in the frontal plane, whereas adduction moments −My prevailed during all activities that included temporary single-legged stance.

The highest adduction moment (−My) and therefore a mainly medial load transfer were observed in knees with a varus alignment. Highest abduction moments +My and a lateral transfer were observed in knees with a valgus alignment. The varus/valgus alignment may further influence the mediolateral shear forces Fx. There was no evident correlation between the axis alignment and the axial force (Fz).

> **Side Summary**
> Highest adduction moment in varus aligned knees and highest abduction moment in valgus aligned knees.

4.4 The Third Player: The Patellofemoral Joint Contact during High Knee Flexion

The patellofemoral (PF) joint plays a crucial role in knee function, particularly during stair climbing or sit-to-stand activities which require considerable quadriceps activation. In vitro experiments have improved the understanding of the mechanisms critical for load sharing between the active and passive structures of the PF joint, but knowledge of the actual in vivo PF joint forces during activities involving high knee flexion remains limited.

In order to access the PF forces, a gait analysis was performed on two subjects with the previously described telemetric knee implants during walking, stair climbing, sit-to-stand, and squat [7]. Patient-specific musculoskeletal models of the lower limb bones and muscles were created from post-op CT scans and a reference muscle model based on the visible human dataset. The position of muscle attachment as well as via points of the muscle paths were determined for every frame, based on the segment and joint kinematics, allowing the calculation of muscle lever arms at the joints. Segment and joint kinematics, inertial parameters and ground reaction forces, were used as the inputs to an inverse dynamic approach to yield the intersegmental resultant moments and forces at the ankle, knee, and hip. The physiological cross-sectional area (PCSA) of each muscle was collected from the literature and adjusted to the patients using their body weight as reference. The muscle forces were added to the intersegmental resultant forces from the inverse dynamics to determine the total joint contact forces. The PF contact force was defined as the vector sum of the forces acting on the patella by the quadriceps and the patellar tendons. Analyses were performed for 46 trials (23 per patient; 12 walk, 7 stair climbing, 9 sit-to-stands, 18 squats).

Peak in vivo measured tibiofemoral (TF) forces averaged for each activity across both patients ranged from 2.9 BW during walking to 3.4 BW during stair climbing (Fig. 4.4). The knee flexion angles during peak forces for the two subjects were 90.3 ± 3.5° and 89.4 ± 0.8° during sit-to-stand, 48.2 ± 1.8° and 45.0 ± 2.9° during stair climbing, and 93.5 ± 5.2° and 89.0 ± 5.5° during squatting. The resultant TF contact forces predicted by the model were generally in good agreement with the in vivo measured data across all activities for both subjects (avg. error: 14%), which lends credibility to the predicted PF forces.

PF peak contact forces of <1 BW were determined during walking at ~18° knee flexion. Considerably larger PF forces were found during activities requiring knee extension from a more flexed position: 2.8 BW in stair climbing (at 53° flexion), 3.1 BW in sit-to-stand (at 90° flexion), and 3.2 BW in squatting (94° flexion). During walking and stair climbing, the peak PF forces were smaller than the peak TF forces by 74% and 16%, while for the sit-to-stand and squatting activities, the PF forces were ~ 3% and 5% higher than the TF contact forces, respectively.

The results demonstrated that the PF forces can reach the level of TF forces (of above 3BW), even though the body's weight is directly supported by the TF joint, while the PF force is result of muscle action only. The peak PF forces even exceeded the TF forces during activities with high knee flexion. This demonstrates that the

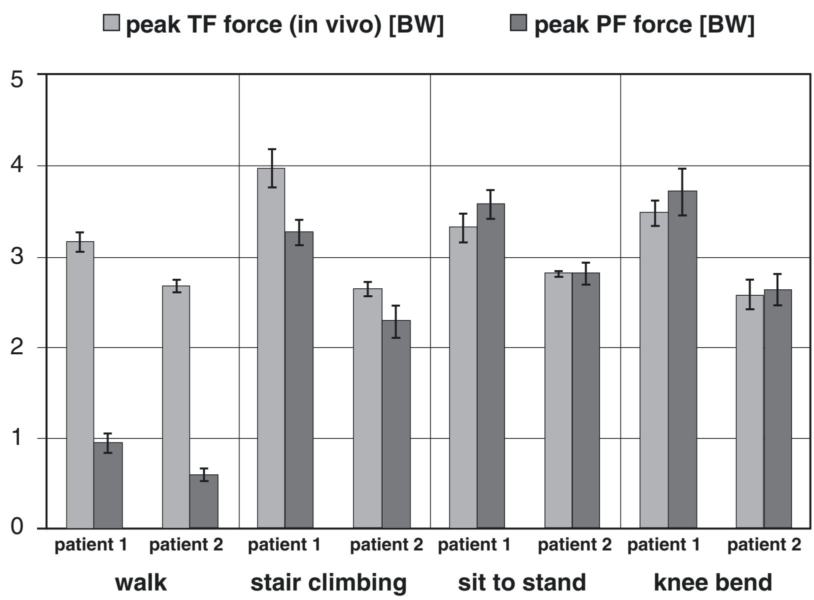

Fig. 4.4 Peak in vivo measured TF and numerically determined PF forces (in body weight, BW) for two patients and four activities. Trepczynski et al. 2012, ©2011 Orthopaedic Research Society. Reproduced with permission from John Wiley and Sons - License number 5147630383935

in vivo loading conditions of the knee can only be fully understood if the interaction between the TF and the PF joints is considered.

4.5 Mediolateral Force Distribution: Shifts across Activities and Is Driven by Tibiofemoral Alignment

Tibiofemoral leg alignment is directly related to the progression of knee joint osteoarthritis as well as implant survival following total knee arthroplasty (TKA). In a neutral tibiofemoral alignment, the static mechanical axis passes through the center of the knee joint. In a varus or valgus malalignment, the mechanical axis shifts in the medial or lateral direction, increasing the forces passing through the respective compartment. Malalignment of more than 3°–5° has been associated with increased wear of the polyethylene tibial insert and also an increased risk of implant loosening. In general, tibiofemoral alignment in healthy adults is slightly varus, and it has been hypothesized that restoration of this "constitutional varus" following TKA could be desirable to creating a neutral postoperative alignment. It has been also demonstrated that static leg alignment does not reflect the loads experienced by the joint during dynamic weight-bearing activities.

In order to gain a deeper understanding of this matter, the mediolateral force distribution in the knee joint was determined throughout a variety of daily tasks [8, 9] in order to assess if the static alignment of the leg can be considered a valid predictor for the mediolateral force distribution and medial force magnitude during static and dynamic weight-bearing activities. The activities were categorized as "single-limb" (walking, one-legged stance, ascending and descending stairs, and jogging) and "double-limb" support (knee bend, standing up, sitting down, and cycling).

Side Summary
Malalignment of 3–5° after TKA is associated with increase in polyethylene wear.

4.5.1 Determination of Medial Force and Medial Force Ratio

The axial force −Fz, which is transferred by the medial and lateral compartment, is composed of the sum of the medial (F_{med}) and lateral (F_{lat}) axial force components (Fig. 4.5). F_{med} and Flat are positive when acting in inferior direction, and F_z is defined as positive in superior direction:

$$-F_z = F_{med} + F_{lat} \tag{4.1}$$

F_{med} is calculated using the abduction/adduction moment My, which is caused by the axial force acting eccentrically in the mediolateral direction onto the tibia, and l being the distance between the medial and lateral femoral condyles. The medial force ratio (MR) represents the percentage of the axial force that is transferred through the medial compartment:

$$F_{med} = \frac{-F_z}{2} - \frac{M_y}{l} \tag{4.2}$$

$$MR = \frac{F_{med}}{-F_z} * 100 \tag{4.3}$$

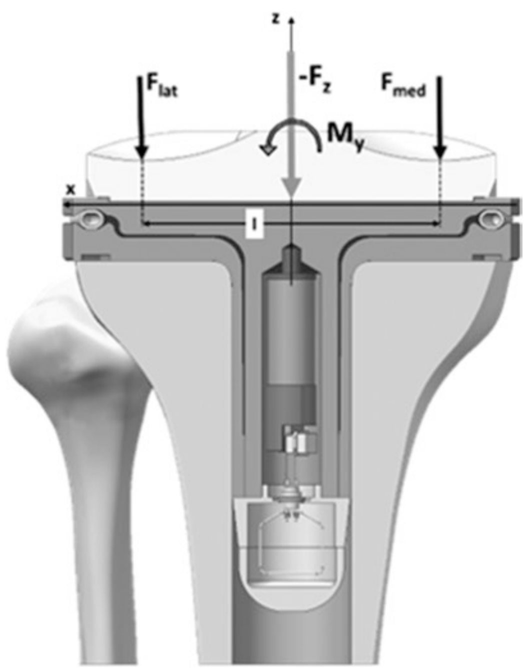

Fig. 4.5 Principe to calculate mediolateral force distribution

4.5.2 Determination of Static Leg Alignment

Pre- and postoperative frontal plane tibiofemoral alignment was analyzed using standing full-leg anteroposterior radiographs. The hip–knee–ankle (HKA) angle was determined using the mechanical axes of the femur (center of femoral head to center of tibial plateau) and tibia (center of tibial plateau to center of talus). Neutral limb alignment was expressed as 0°, and positive and negative values indicate varus and valgus alignments, respectively.

4.5.3 Variation of the Medial Force Ration (MR) and Medial Femorotibial Force (F_{med})

The MR varied within and between activities. During the stance phase of single-limb activities, a shift of the axial force toward the medial compartment was observed (Fig. 4.6). On the other hand, a shift of the lateral force was then observed during the loading phase of the double-limb activities. While in general peak values of F_{med} happened at the same time as or close to the peak values of F_{res}, the highest MR values did not always occur at F_{res} max. The highest MRs (up to 88%) were observed during activities with single-limb support. In contrast, an MR < 50% was found during most activities with double-limb support.

Among all activities, those involving higher knee flexion angles tended to have more equal mediolateral force distributions. MR values of 0% or 100%, which represent a medial and lateral lift-off, respectively, were not observed in any of the analyzed trials.

4.5.4 Influence of Leg Alignment on MR and F_{med} during Static One-Legged Stance [9]

During static load-bearing activities in one-legged stance, the HKA angle was a robust predictor for MR. The axial force was transmitted

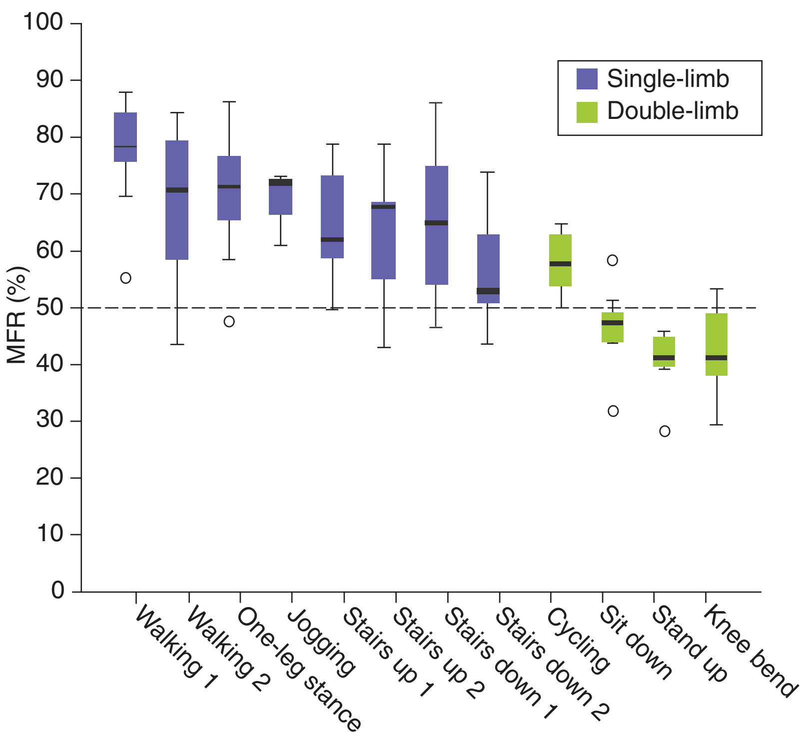

Fig. 4.6 Box and whisker plots of medial force ratio (MFR) during various activities of daily living. Values taken at peak resultant forces (the transverse line shows the median value, with the box representing the 25th to 75th percentile range. Data falling outside 1.5× interquartile range are plotted as outliers). Reproduced with permission from British Editorial Society of Bone & Joint Surgery - License number 1150663-1

more medially (greater MR) in patients with varus alignment, while it was more lateral in patients with valgus alignment. For a neutral leg alignment (HKA = 0°), the linear regression analysis indicates an MR of 63%. Although still statistically significant, the correlation between HKA angle and Fmed was less pronounced.

4.5.5 Influence of Leg Alignment on MR and F_{med} during Dynamic Limb Loading

Significant correlations between HKA angle and MR were observed during dynamic activities with single-limb support (Fig. 4.7). There was no significant correlation between HKA angle and MR or F_{med} during activities with double-limb support.

The mediolateral force distribution in the knee joint is influenced by limb support as well as by overall leg alignment and is not constant during different activities. Therefore, the MR cannot be generalized to a distinct value. During the static condition of one-legged stance and dynamic single-limb loading, the HKA angle was found to be a strong predictor for the mediolateral force distribution, which indicates that varus malalignment leads to an increased loading of the medial compartment. However, there was little correlation between the alignment of the leg and the magnitude of the medial contact force. This indicates that other unmeasured variables such as joint stability or muscle status as well as the level of muscle co-contraction could play an important role in joint force magnitudes.

During the planning of a TKA, the intention is in most cases to restore neutral tibiofemoral alignment with the mechanical axis of the leg passing through the center of the knee joint. However, it has been shown that the mean alignment of the leg is slightly varus, with 32% of investigated men and 17% of women having a mechanical alignment of 3° varus or more. These findings have led to a constant debate as to whether the incorporation of a "constitu-

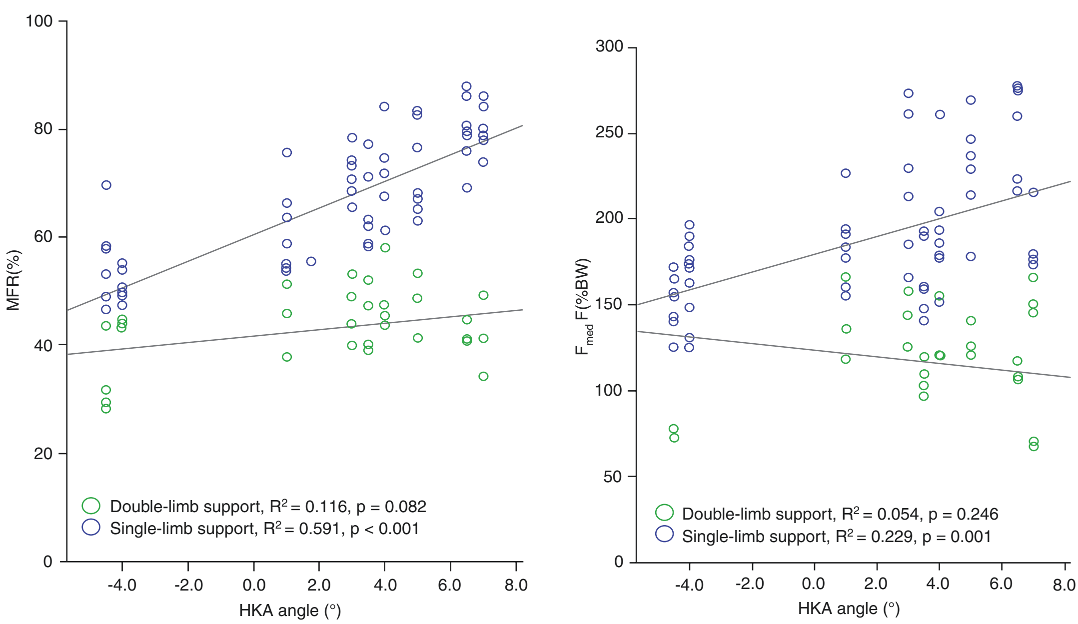

Fig. 4.7 Linear regression analysis between hip–knee–ankle (HKA) angle and medial force ratio (MFR) (left) or medial force magnitude (F_{med}) (right) during dynamic daily activities with single-limb support (walking, stair ascending, stair descending) and double-limb support (standing up, sitting down, knee bend). Pearson's coefficients of correlation are given (%BW, percentage body weight) [9]. Reproduced with permission from British Editorial Society of Bone & Joint Surgery - License number 1150663-1

tional varus" would lead to improvements in function after TKA. Our analysis in the telemetric patients showed a clear correlation between tibiofemoral alignment and mediolateral force distribution, with varus alignment leading to high MR values. Also for an HKA angle of only 3° varus, a medial force ratio of 70% to 80% could be expected. To prevent high MRs following TKA, varus malalignment should then be avoided. On the other hand, slight valgus alignment of 3°–4° leads to an equal distribution of force. Accordingly, clinical results have shown that polyethylene (PE) wear of the medial and lateral compartment increased with varus and valgus alignment, respectively. Minimal PE wear of both compartments was found for a tibiofemoral alignment of about 3° valgus.

The results show that the mediolateral force distribution depends on tibiofemoral alignment and varies between as well as within different weight-bearing activities. Overall the leg alignment is a critical factor for the force distribution in the knee joint and can be influenced during TKA. The actual trend toward a "constitutional varus," for the overall tibiofemoral alignment, should be reconsidered due to the resulting increased medial force ratio monitored in the instrumented patient cohort.

Take Home Message

- TKA is a widely used and very successful surgical procedure, which provides pain relief as well as restoration of function in patients suffering from knee joint degeneration. Despite the high patient's satisfaction rates reported, a substantial number of patients remain unsatisfied with the outcome. Such reported dissatisfactory results are frequently linked to mechanical conditions. Using an instrumented knee replacement implant, we were able to analyze the resulting in vivo forces across multiple activates and report these here as indicators for the resulting knee joint loading after TKA: For most analyzed activities, the forces acting across the joint range between 220% and 350% BW. Hence, the impact of co-contractions can lead to forces of more than 550% BW. The patellofemoral joint plays also a crucial role in knee function requiring considerable quadriceps activation. These muscle activations reached the level of tibiofemoral forces. Furthermore, the peak values even exceeded the tibiofemoral forces during activities with high knee flexion.
- Malalignment of more than 3°–5° has been associated with increased wear of the polyethylene tibial insert and also an increased risk of implant loosening. It could be shown that varus/valgus alignment together with the performed activity directly influences the mediolateral shear forces. The mediolateral force distribution in the knee joint is influenced by limb support as well as by leg alignment and that is not constant throughout the activity. Therefore, the medial ratio cannot be generalized to a distinct value. In general, leg alignment is one of the main critical factors for the force distribution in the knee joint and influences the outcome of TKA. The actual trend toward a "constitutional varus," for the overall tibiofemoral alignment, should therefore be reconsidered with special attention to the increased medial force ratio.

Example of the in vivo load measurement, available at the OrthoLoad.com database

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5 The Optimal Indication for Unicompartmental Knee Arthroplasty

Michael Clarius

Keynotes

1. The classic and optimal indication for unicompartmental knee arthroplasty is isolated bone-on-bone osteoarthritis on either the medial or lateral compartment of the knee with full-thickness cartilage loss, intact collateral ligaments, intact cruciate ligaments, and a passive correctable varus or valgus deformity of the knee.
2. Due to excellent clinical outcome and immediate pain relief, avascular necrosis of the medial femoral condyle is also a very good indication for unicompartmental knee arthroplasty.
3. Minimal degenerative changes in the patellofemoral joint are acceptable. More severe lateral OA of the patella is known to result in inferior outcomes and hence should be considered as exclusion criteria.
4. Contraindications are inflammatory arthritis as the disease affects the whole knee. Also, patients with previous high tibial or distal femoral osteotomy should not be operated with a unicondylar knee prosthesis as their outcome is significantly worse due to overload of the not affected side.

5.1 Introduction

Unicompartmental knee arthroplasty (UKA) has been described as a very successful alternative for the treatment of osteoarthritis (OA) of the knee [1–4]. However, success is highly dependent on a careful selection of patients that are suitable for this operation [5]. The pertinent question to be answered is: How can we identify these patients?

Three different criteria are important for the indication of UKA:

1. The patients' subjective symptoms and complaints,
2. The objective clinical examination, and.
3. The results of radiological investigations.

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5.2 Indication for UKA in Medial Femorotibial OA

The classic indication for a UKA is an isolated compartment OA, mainly located on the medial side with severe damage of the cartilage on the femoral as well as on the tibial side resulting in a bone-on-bone contact. The cartilage on the other compartments should not be affected, and the ligaments, particularly the cruciate ligaments, should be functionally intact. Patients should have had failed appropriate conservative treatment, and the symptoms should be severe enough for such surgery.

Typically, the knees present with a so-called anteromedial OA show a bone defect in the anteromedial tibial plateau and severe cartilage loss at the medial femoral condyle [6]. Clinically, these patients show a varus deformity and complain of pain during standing and walking, while pain is relieved by sitting (Fig. 5.1). When the anterior cruciate ligament (ACL) is functionally intact, the cartilage in the posterior aspect of the medial tibia and in the posterior part of the medial femoral condyle is also intact. When intact cartilage of the dorsal part of the medial femoral condyle articulates with intact cartilage of the dorsal tibia plateau in 90° knee flexion, the varus deformity is corrected in knee flexion and prevents contraction of the medial collateral ligament [7]. Usually, these knees will not fully extend but flexion deformity is seldom more than 10° and mostly caused by an osteophyte at the tibial footprint of the anterior cruciate ligament and by a shortening of the posterior capsule. More than 15° flexion contracture is considered as a contraindication, because the medial OA is too far advanced and might have damaged the cruciate complex.

In contrast, 5°–15° of varus deformity in full extension and without the possibility of correction, the posterior capsule, and posterior osteophytes will prevent the maneuver. With the knee in 20° flexion, the varus can be corrected as the posterior capsule is loose and with the knee flexed to 90°, the varus corrects spontaneously. Anteromedial OA in varus aligned knees is predominantly a disease of the extension gap (Fig. 5.2).

Fig. 5.1 Ideal indication: A 65-year-old male patient with varus deformity and painful medial OA of both knees

Fig. 5.2 A resected left medial tibial plateau showing the typical anteromedial osteoarthritis of the knee with a deep grooving and exposed bone in the anteromedial part of the tibia but intact cartilage at the back of the tibia

Side Summary
The anteromedial OA of the knee is predominantly a disease of the extension gap.

The severity of the disease can be identified on a standing anterior–posterior (AP) radiography (Fig. 5.3) or a 30°–45° flexed posterior–anterior view (Rosenberg view) [8]. We recommend to perform routinely lateral view and varus and valgus AP stress radiographies to confirm the diagnosis of anteromedial OA (Figs. 5.4a,b and 5.5a–d) [9]. The technique is simple and reproducible. For varus and valgus AP stress radiographies, the patient lies supine on the X-ray table with a support under the knee to flex it 20°. The X-ray beam is aligned 10° from the vertical and 15 kp varus or valgus stress is applied.

Varus stress radiographies confirm the full-thickness cartilage loss and the bone-on-bone contact on the medial side, and valgus stress radiographies demonstrate that the intraarticular varus deformity is correctable and also proof normal thickness of the articular cartilage in the lateral compartment. As long as the thickness of the lateral joint space is intact, osteophytes of the lateral femoral condyle or the lateral tibial plateau can be ignored [10].

Side Summary
Varus and valgus stress X-rays are recommended for proper assessment of the joint space configuration.

Patients with partial-thickness loss of femur and or tibia are not a good indication as outcome and revision rate are significantly worse [11, 12]. Hence, we cannot recommend UKA in these patients [13, 14].

Due to excellent clinical results and immediate pain relief, avascular necrosis of the medial or lateral femoral condyle is a secondary, very good indication for UKA, whether spontaneous or following previous surgical intervention [1, 15, 16].

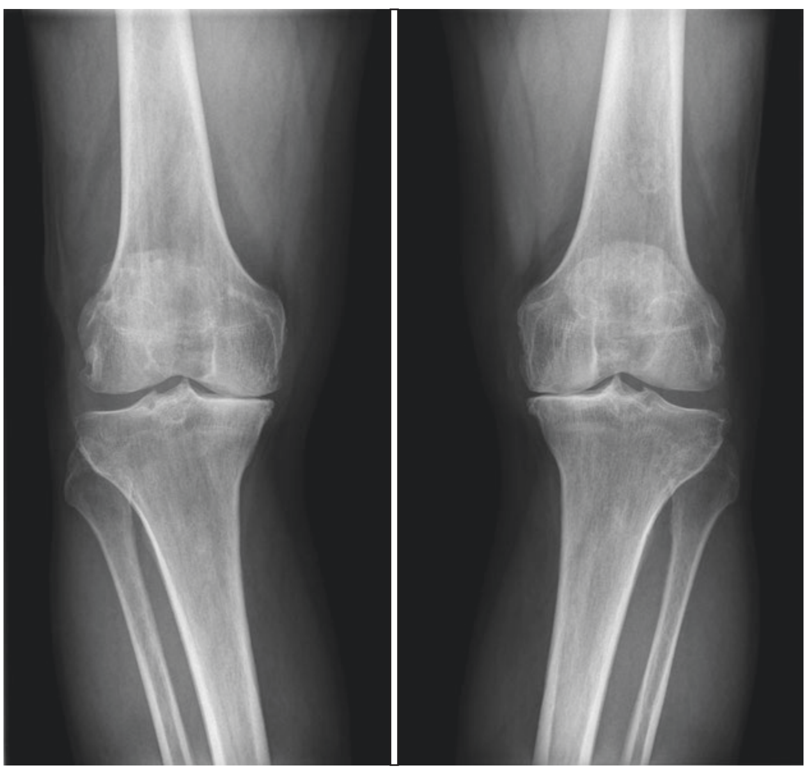

Fig. 5.3 Bilateral anteroposterior weight-bearing radiographies show bone-on-bone contact at the medial femorotibial compartment

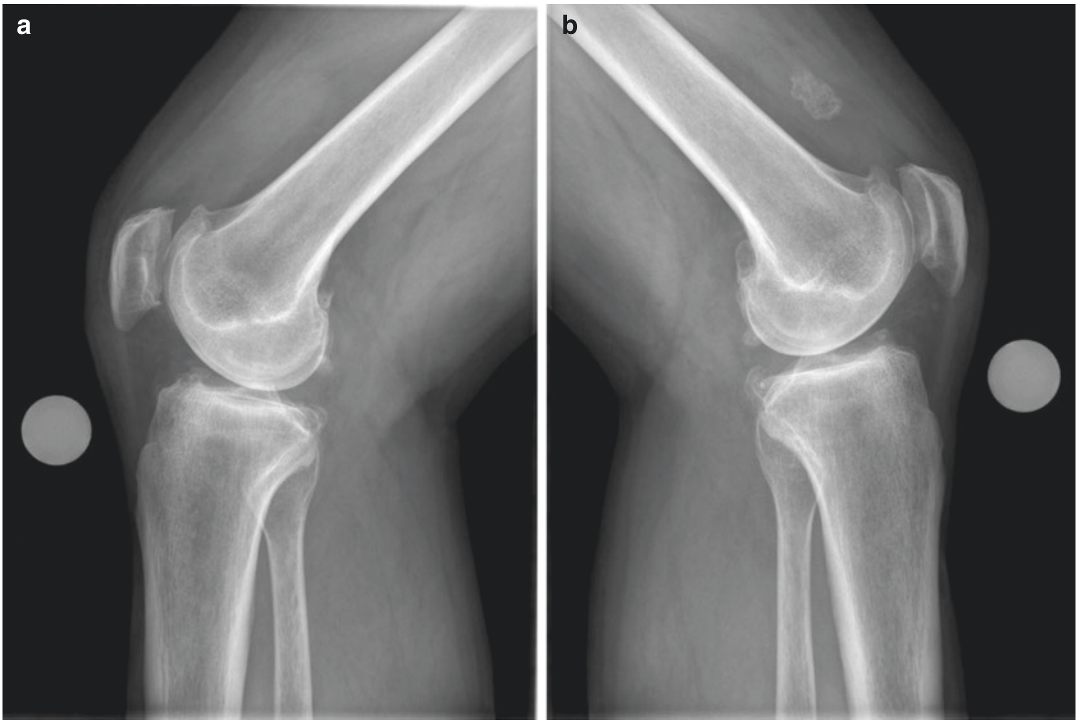

Fig. 5.4 (**a**, **b**) The bone defect is anteromedial indicating that the anterior cruciate ligament is intact (**a**-right knee, **b**-left knee) as shown in the lateral radiographies. A large osteophyte at the footprint of the anterior cruciate ligament prevents the knee from full extension

5.3 Indication in Lateral Femorotibial OA

Lateral unicompartmental OA represents a good indication for UKA. However, the normal anatomy and the pathological lesions of the lateral compartment are completely different [5, 17]. Lateral OA of the knee is relatively rare accounting for less than 10% of all unicompartmental arthritis. Most of these patients are female. Flexion deformity is less common, and hyperextension is sometimes seen. The valgus deformity is usually correctable manually (Video 5.2). A lot of these patients had previous open or arthroscopic lateral meniscectomy in the past. The cartilage and bone defects are usually in the center of the lateral tibial plateau and not anteriorly, and the posterior lateral condyle is usually involved [18]. The radiological diagnosis remains to be a challenge because regular AP X-rays may look nearly normal. Due to described pathological changes, the bone-on-bone contact is usually seen in 30°–40° of flexion of the knee under valgus stress. Clinical examination in the same position under valgus stress reveals crepitation due to bone-on-bone contact indicating severe lateral osteoarthritis.

Side Summary
The lateral OA of the knee is diagnosed in 30° to 40°flexion of the knee.

Magnetic resonance imaging (MRI) is an important diagnostic tool to show cartilage defects and bone reactions. However, MRI has not been validated to set indication or contraindication for UKA. It is therefore not particularly helpful to identify optimal candidates for UKA [5, 19].

Kozinn and Scott [20] are frequently cited as the gold standard for the indications and contra-

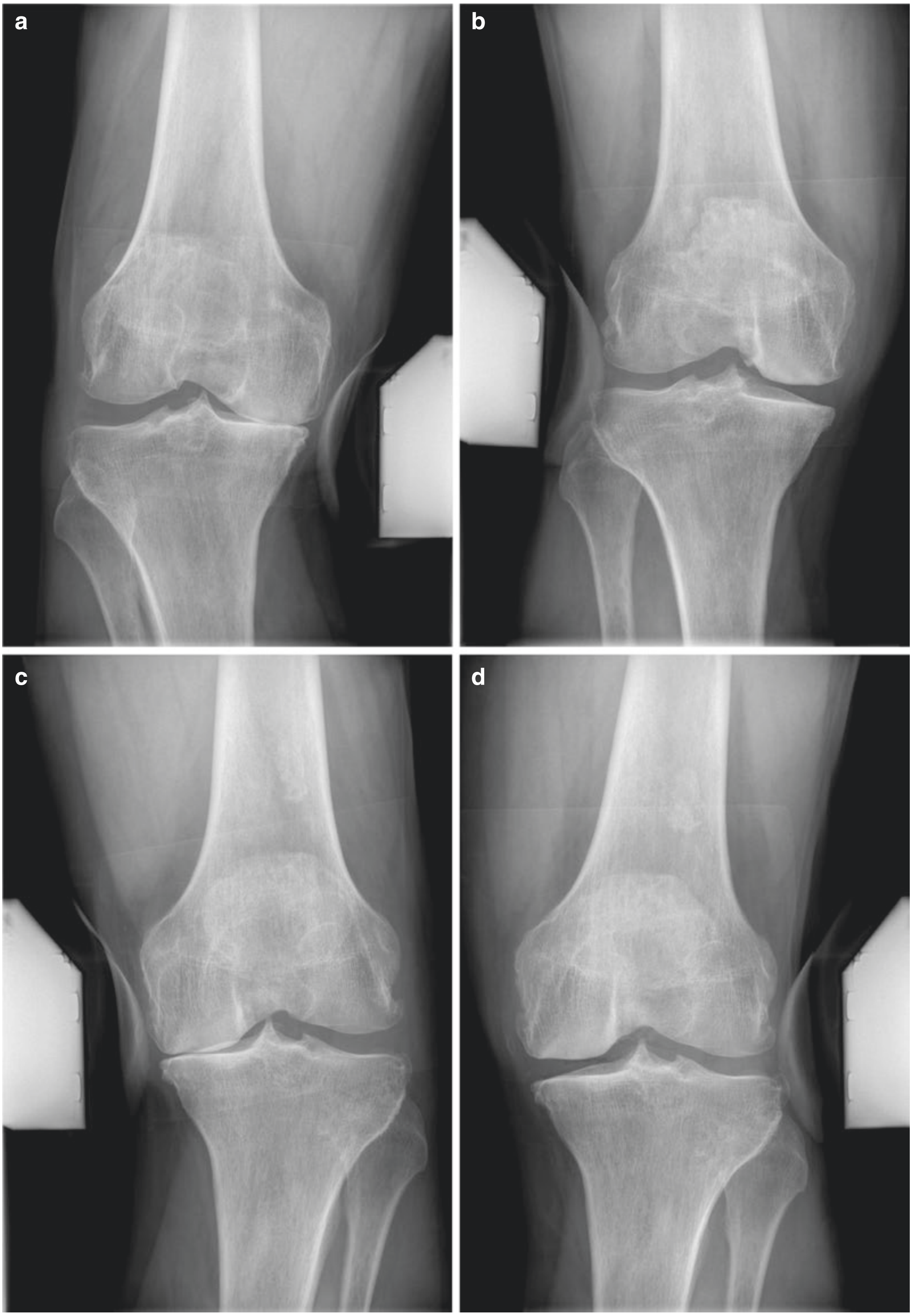

Fig. 5.5 (**a**–**d**) Varus and valgus stress X-rays of both the right and left knees using a Telos® device to confirm the diagnosis of bone-on-bone arthritis on the medial side (**a**, **c**) and the passive correction of the varus deformity in valgus stress (**b**, **d**). The lateral compartment should show under valgus stress an intact joint space indicating full-thickness cartilage of the lateral condyle and tibia

indications for UKA. However, some of their recommendations given nearly 30 years ago were not evidence based. Enough evidence has now been provided that obesity [13, 21, 22], younger or older age [22–24], and chondrocalcinosis [22, 25] are no longer contraindications for UKA.

5.4 The Impact of Patellofemoral OA on the Indication for UKA

The skyline view provides information about the patellofemoral compartment (Fig. 5.6). In the past, a lot of authors have included patellofemoral OA in the list of contraindications to UKA [20, 26], whereas others completely ignored the status of the patellofemoral joint [22, 27, 28]. In a consensus conference, it was stated that in the presence of full-thickness cartilage loss within the lateral facet and/or lateral trochlea with eburnation, grooving, with or without the presence of lateral patellar subluxation, is a contraindication to UKA [5]. However, all other conditions of the patellofemoral joint are acceptable and not considered contraindications. In the presence of anteromedial OA of the knee, the patellofemoral compartment commonly comes along with chondromalacia, fibrillation, and cartilage erosions. These lesions are mainly on the medial facet of the patella and the equivalent surface of the femoral trochlea. The explanation why these lesions can be ignored is simple. The genu varum tends to overload the medial patellofemoral facet; the most commonly damaged surfaces and osteophytes can impinge on the medial facet in flexion of the knee. After medial UKA, the varus deformity is corrected, and therefore the medial patellofemoral joint decompressed. Correction of the varus deformity unloads the medial patellar facet, and the osteophytes that may have caused clinical symptoms are removed [7, 29].

Side Summary
Presence of full-thickness cartilage loss within the lateral facet and/or lateral trochlea with eburnation, grooving, with or without the presence of lateral patellar subluxation, is considered as a contraindication to UKA.

5.5 Contraindications

Contraindications are an inflammatory disease, instability, or previous correction osteotomy.

Inflammatory disease is considered of being a systemic arthropathy, which affects the entire knee and therefore is a contraindication for UKA [30].

Instabilities due to damage to the collateral ligaments or/and the cruciate ligament complex are contraindications for UKA. However, there are cases in which ACL deficiency may be safely ignored or concomitant ACL reconstruction successfully be performed with medial UKA [24, 31–35].

Previous extraarticular alignment procedures have been considered as contraindications for UKA [36, 37] as they lead to a load transfer to the unaffected side and cause overload that may

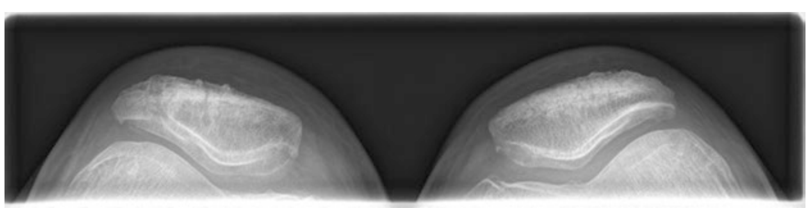

Fig. 5.6 The skyline view demonstrates no significant degenerative changes in the patella or patellofemoral joint

result in OA [38]. Patients with medial OA and undercorrection after high tibial osteotomy might be an indication for UKA. However, a consensus conference of six experienced surgeons did not reach a consensus as to the magnitude of undercorrection following high tibial osteotomy that may be acceptable. Two authors noted that in cases of undercorrection, high tibial osteotomy may not be a contraindication. Consensus was reached that neutral or overcorrection is an absolute contraindication [5].

Side Summary
Contraindications are an inflammatory disease, instability, or previous correction osteotomy.

Take Home Message
- UKA is an ideal implant for isolated osteoarthritis of the medial or lateral femorotibial compartment. Minor changes of the medial facet of the patella can be accepted.
- Knee stability is essential for UKA showing intact collateral ligament and cruciate ligaments. ACL deficiency is a contraindication but can be addressed in selected cases with a combined procedure (UKA with ACL reconstruction).
- Inflammatory diseases or previous osteotomies are contraindications for UKA.

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6 The Optimal Indication for Patellofemoral Arthroplasty

Stefano Pasqualotto, Marco Valoroso, Giuseppe La Barbera, and David Dejour

Keynotes

1. Patellofemoral (PE) osteoarthritis is a relatively common disease whose signs are observed in 39% of patients aged over 30 suffering from knee pain.
2. Patient's related risk factors are female gender and age, whereas increased body mass index (BMI) is not considered a specific risk factor even though it is frequently encountered in patients with patellofemoral osteoarthritis.
3. Four different etiologies have been identified: primary osteoarthritis, osteoarthritis secondary to the presence of predisposing factors for patellofemoral instability, posttraumatic osteoarthritis, and osteoarthritis secondary to chondrocalcinosis or rheumatic diseases.
4. Knee-related risk factors include trochlear and patellar dysplasia, whereas the effects of patellar height and lower limb malalignment on the pathogenesis of patellofemoral osteoarthritis are still debated.
5. Quadriceps and gluteal muscles, hip abductors, hamstrings, and iliotibial band have also been implicated in the genesis of increased patellofemoral joint stress.
6. Conservative treatment should always be the first option, while non-prosthetic treatment represents a valid alternative in case of mild-to-moderate arthritis.
7. The presence of disabling pain and severely reduced knee function due to high-grade isolated patellofemoral osteoarthritis represents the optimal indication for patellofemoral arthroplasty.
8. The ideal patient for patellofemoral arthroplasty is a non-obese patient, aged less than 60, with severe isolated patellofemoral osteoarthritis secondary to patellofemoral instability or trochlear dysplasia.
9. In case of isolated patellofemoral osteoarthritis associated with predisposing factors for patellofemoral instability, the aim of the patellofemoral replacement is to eliminate osteoarthritis and correct predisposing factors, as in the "menu à la carte" described for objective patellar instability.

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6.1 Introduction

Although prosthetic replacement of the patellofemoral joint represents the logical treatment for end-stage disease of the patellofemoral joint, it still remains a controversial option among many knee surgeons. Despite the first successful attempt by McKeever to replace the patellar surface using a Vitallium shell in 1955 [1] and then the promising results of the first patellotrochlear replacements by Blazina, the enthusiasm of surgeons toward artificial replacement of the patellofemoral joint has always been fluctuating [2]. The outcomes of the first implants were considered too unpredictable and inconsistent in comparison to those obtained with total knee arthroplasty. Particularly, shortcomings in the available designs, difficulty in proper positioning of the implant, and failure to address correctly the underlying pathology were the main reasons for this lack of confidence.

Recently, however, there has been a renewed interest in the use of patellofemoral arthroplasty and a growing tendency in believing that patellofemoral arthroplasty has a well-defined place in the treatment of end-stage patellofemoral osteoarthritis (OA). The recent trend toward less invasive surgery as well as the revival of selective, unicompartmental resurfacing options has aroused the orthopedic industry to increase the efforts in improving patellofemoral prosthesis toward a more anatomic design. Meanwhile, a better understanding of biomechanics of patellofemoral joint and pathophysiology of patellofemoral disorders has led to a more precise definition of the proper indications for patellofemoral arthroplasty. As with other surgical interventions, successful clinical outcome for patellofemoral arthroplasty depends on appropriate patient selection and indication, as well as surgical technique and postoperative care.

Side Summary
A better understanding of biomechanics of patellofemoral joint and pathophysiology of patellofemoral disorders has led to a more precise definition of the proper indications for patellofemoral joint and a renewed interest in the use of patellofemoral arthroplasty.

6.2 Epidemiological Data

Epidemiological studies reported an overall prevalence of patellofemoral OA of 25% in asymptomatic population, while this percentage increases to 39% in people aged over 30 who suffer from knee pain [3].

Like OA of the femorotibial compartment, patellofemoral OA is found predominantly in females (72%) with 51% of the patients having bilateral symptoms, starting at the age of 46. Taking into account other risk factors, even though BMI is not statistically correlated with this type of arthritis, 38% of patients with patellofemoral OA are overweight and 29% are obese [4].

Side Summary
Overall prevalence of patellofemoral osteoarthritis is about 39% in people older than 30 years suffering from knee pain. Higher incidence is found in female, elderly, and overweight patients.

6.3 Etiology of Patellofemoral OA

Four different etiologies [5] have been identified for patellofemoral OA:

1. Primary patellofemoral OA.
2. OA secondary to the presence of predisposing factors for patellofemoral instability.
3. Posttraumatic patellofemoral OA.
4. Patellofemoral OA secondary to chondrocalcinosis or other rheumatic diseases.

Side Summary
Four different etiologies have been identified: Primary patellofemoral osteoarthritis, osteoarthritis secondary to the presence of predisposing factors for patellofemoral instability, posttraumatic patellofemoral osteoarthritis, patellofemoral osteoarthritis secondary to chondrocalcinosis, or other rheumatic diseases.

Fig. 6.1 Primary isolated patellofemoral arthritis

6.3.1 Primary Patellofemoral OA

Primary OA population (49%) incorporates patients without any orthopedic antecedent and especially any history of patellar dislocation (Fig. 6.1). This kind of OA is often bilateral, with a greater prevalence in women and a mean age at surgery of 58 years [6, 7]. It tends to be well tolerated for a long time, with patients being able to walk normally on level ground, whereas walking on uneven ground, ascending and descending stairs, and steep slopes become progressively more difficult to negotiate. Moreover, patients could complain of a sense of instability, generally due to reflex quadriceps inhibition because of painful stimuli. Catching and locking sensations as the knee flexes are due to patellar osteophytes impinging on the lateral facet of the trochlea and to the bony spurs on the trochlea.

From a radiological point of view, generally both knees are involved. The skyline view shows narrowing of joint space, with bony contact between the lateral patellar facet and the trochlea and patellar subluxation, mainly due to cartilage wear, rather than to extensor mechanism malalignment. Osteophytes are typically on the lateral border of the patella and on the trochlea. A lateral radiograph shows osteophytes at the proximal part of the trochlea, as well as subchondral sclerosis of the patellofemoral joint, and joint space narrowing.

Side Summary
Primary patellofemoral osteoarthritis is often bilateral and tends to be well tolerated for a long time. Symptoms generally comprise progressive impairment in ascending and descending stairs associated with catching and locking sensation and a sense of instability.

6.3.2 OA Secondary to Presence of Predisposing Factors for Patellofemoral Instability

The prevalence of patellofemoral OA is about 33% in patients with a history of objective patellar dislocation (Fig. 6.2). In comparison to primary patellofemoral OA, patients in this group are slightly younger, with a mean age at time of surgery of 54 years. The percentage of patients with patellofemoral OA and a history of objective patellar instability is variable in the literature, ranging from 8% to 53% [8–10]. A deeper understanding of biomechanics and anatomical abnormalities of patellofemoral joint in patients with objective patellar instability allowed some deductions on the etiology of osteoarthritic lesions.

Fig. 6.2 Isolated patellofemoral OA secondary to patellofemoral instability

6.3.2.1 Dislocation

Recurrent lateral patellofemoral dislocation has been identified as a significant risk factor for the development of patellofemoral OA [11, 12].

Whenever the patella dislocates, a damage in the patellar cartilage may occur, sometimes producing small articular fractures. Cartilage lesions could be found also on the lateral aspect of the trochlea or even on the lateral condyle, creating mirror-image lesions.

6.3.2.2 Extensor Mechanism Malalignment

Extensor mechanism malalignment is due to an increased distance between the tibial tubercle and the deepest part of the trochlear groove (TT-TG) [13], which increases the dislocating force acting on the patella (Fig. 6.3). In the case of extensor mechanism malalignment, asymmetrical pressure peaks develop on the lateral facet of both the patella and femoral trochlea.

6.3.2.3 Lack of Congruency between the Patella and the Trochlea

Trochlear dysplasia and, to a lesser extent, patellar dysplasia may be responsible for a lack of congruency between the two articular surfaces, making the joint unstable [14–17]. In this scenario, two factors may cause OA.

- Trochlear prominence, in high-grade (B or D) dysplasia according to Dejour classification [18], is responsible for impingement between the patella and femoral trochlea whenever the knee flexes and increases the patellofemoral contact pressures with the knee flexion. Grade 3 and 4 kissing cartilage lesions, typically involving the entire length of the patella, are often found and represent the precursor of OA.
- The asymmetry of trochlear facets, as seen in grade C and grade D of trochlear dysplasia, is responsible for a permanent tilt of the patella, which, in turn, exacerbates the unbalanced

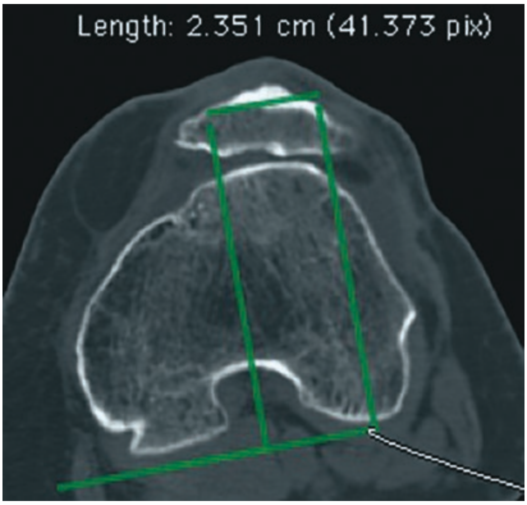

Fig. 6.3 Extensor mechanism malalignment, measured with the distance between the trochlear groove and the tibial tubercle (TT-TG)

contact stress distribution in the patellofemoral joint [14].

Therefore, whenever a young patient shows up with patellofemoral OA, a detailed investigation about any episodes of dislocation should be conducted, and X-rays should be analyzed in depth in order to search for any anatomical abnormalities that may be responsible for patellar instability. Trochlear dysplasia [4] is defined as the most common predisposing factor, and a correlation between higher grade of trochlear dysplasia and higher grade of patellofemoral OA was also found [19].

Side Summary
Osteoarthritis secondary to the presence of predisposing factors for patellofemoral instability is generally found in younger patients. Risk factors are incongruency between trochlea and patella, with high-grade trochlear dysplasia representing the most important predisposing factor, extensor mechanism malalignment, and also number of previous dislocations.

6.3.3 Posttraumatic Patellofemoral OA (9%)

The posttraumatic population (9%) refers to patients with a previous articular patellar fracture. Patellar fractures account for 0.7–1% of all fractures [20] and typically produce patellofemoral OA in the long term [21]. Factors that may promote the development of patellofemoral OA are linked to the mechanism of fracture and accident pattern. A direct shock to the patella, which results in a comminuted fracture, is a well-known source of OA [22, 23]. In the same way, suboptimal treatment of the fracture, with unsatisfactory reduction, gaps >2 mm, and/or residual joint incongruity >1 mm, is likely to result in OA [22–24]. Two other risk factors for the development of patellofemoral OA after patellar fractures are manipulation under anesthesia to mobilize a stiff knee, which leads to diffuse cartilage damage and infections.

From a radiological point of view, the appearance is very variable even though a global patellofemoral OA associated with a patella magna (an enlarged patella overhanging the trochlea on both the medial and the lateral sides) is a common situation.

Side Summary
Posttraumatic patellofemoral osteoarthritis is typically encountered after a patellar fracture. Comminuted fracture and suboptimal treatment represent risk factor for the development of this type of arthritis, whose classic radiographic sign is patella magna.

6.3.4 Patellofemoral OA Secondary to Chondrocalcinosis or Other Rheumatic Diseases (9%)

The pathophysiology of this condition implicates the deposition of microcrystals, generally of calcium pyrophosphate di-hydrate (CPPD), within the joint. Chondrocalcinosis is a metabolic joint

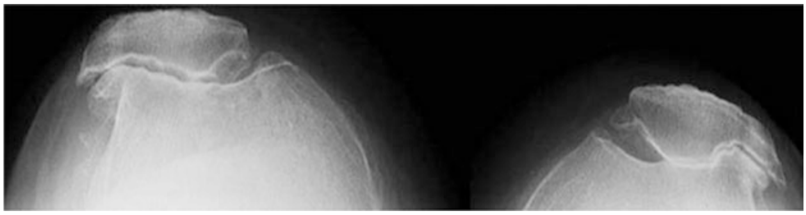

Fig. 6.4 Bilateral chondrocalcinosis

disease, which may affect any joint in the body with a particular predilection for the knee. In the patellofemoral joint, chondrocalcinosis may occur in a form that mimics OA but often occur in a destructive form. Clinical manifestations are characterized by spontaneous serosanguinous effusions of increasing frequency and severity. Otherwise, the signs and symptoms are those of primary OA.

From a radiological point of view, both knees are generally affected. First radiographic signs are represented by thin linear calcium deposit along all or part of the joint line or as distinct densities in the patellar cartilage. With the progression of the disease, the patella is thinned out overall with the lateral facet more involved. The femoral trochlea is also worn or even destroyed, resulting in patellar subluxation (Fig. 6.4). The joint surfaces are indented and irregular, and this aspect distinguishes chondrocalcinosis from primary OA.

Side Summary

Patellofemoral osteoarthritis secondary to chondrocalcinosis is related to the deposition of microcrystals of calcium pyrophosphate dehydrate (CPPD). This type of arthritis is characterized by spontaneous serosanguinous effusions and linear calcium deposits along the joint line, which progress in patellar thinning and trochlear erosion, resulting in patellar subluxation.

6.4 Predisposing Factors for Patellofemoral Osteoarthritis

An accurate radiographic analysis is an important step to identify anatomic risk factors for the development of patellofemoral OA.

6.4.1 Trochlear Dysplasia

Trochlear dysplasia represents the most important risk factor for the development of patellofemoral OA. Among patients with patellofemoral OA, trochlear dysplasia with the presence of crossing sign was found in 78% [4]. The crossing sign represents the convergence between the trochlea and the lateral femoral condyles; in case of a normal development of the knee, the line of the femoral trochlea remains separate and posterior to the projection of femoral condyles. Trochlear dysplasia is found in 96% of patients with objective patellar dislocations; meanwhile, it is detected only in 3% of a control population [25]. These data show that trochlear dysplasia represents a risk factor for the development of patellofemoral OA and moreover, a direct correlation was also found between the severity of trochlear dysplasia and severity of arthritis (Table 6.1, Fig. 6.5) [4, 26]. This was also confirmed by several studies [27, 28] in which magnetic resonance image analysis of the patellofemoral joint revealed more severe cartilage defects, a higher patellofemoral wear, and lower patellar cartilage volume in patients with trochlear dysplasia, confirming how trochlear dysplasia represents a risk factor for the development of patellofemoral OA.

From a biomechanical point of view, indeed, the trochlear spur increases the contact pressure on the patellofemoral joint in flexion performing a so-called "anti-Maquet effect," whereas the asymmetric trochlear facets are responsible for an unbalanced kinematic of the patellofemoral joint with a permanent patellar lateral riding. Consistent with this, a recent cadaveric study with simulated trochlear deformities [29] showed that the patellofemoral joint in case of trochlear dysplasia, especially types B and D of Dejour classification, presented increased internal rotation with lateral patellar tilt and translation and increased contact pressures with decreased contact areas and stability when compared with a normal anatomy. This finding could explain the short-term effects (maltracking, increased pressures, and instability) and long-term effects (OA) of different types of trochlear dysplasia.

Table. 6.1 Type of trochlear dysplasia and isolated patellofemoral arthritis

	Primary PF arthritis		OA secondary to PF instability	
No dysplasia	44	27%	6	5%
Type A	58	35%	35	29%
Type B	24	14%	44	36%
Type C	21	13%	16	13%
Type D	19	11%	20	17%

6.4.2 Dysplasia of the Patella

Patellar dysplasia is another important risk factor for the development of patellofemoral osteoarthritis. Patellar dysplasia type II of Wiberg classification [17] was found in 42% of patients with patellofemoral OA secondary to instability. This is the framework of a dysplastic patellofemoral joint with a significant relationship between the presence of trochlear dysplasia and a dysplastic patella.

6.4.3 Other Factors

Patellar height represents a determining factor in the development of patellofemoral arthritis, which is still a matter of debate. While some authors did not find any correlation between patella alta and

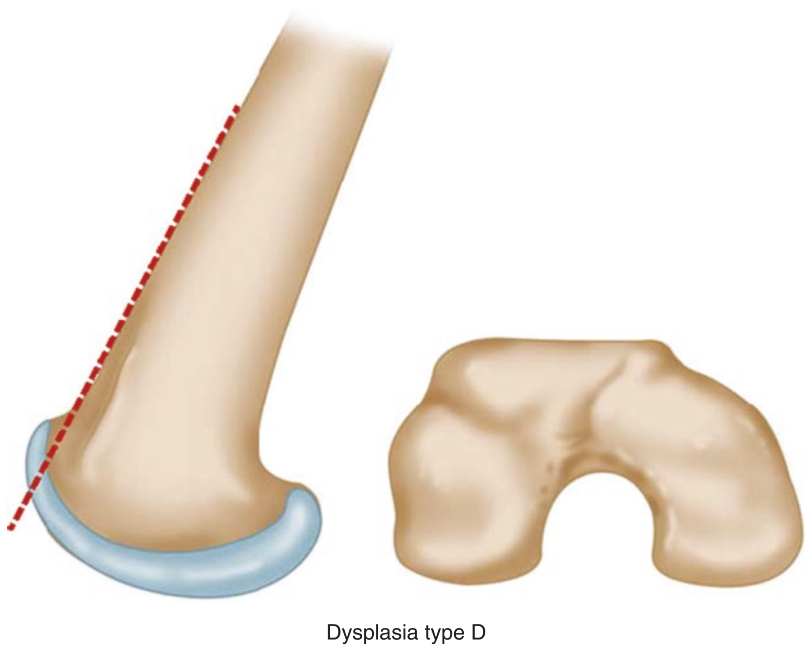

Fig. 6.5 High-grade trochlear dysplasia (type B and type D) is correlated to more severe patellofemoral osteoarthritis

higher risk of developing patellofemoral OA [4], some others reported that patella alta is associated with increased cartilage damage of the patellofemoral joint [30]. Moreover, a recent biomechanical study [31] shows that patellofemoral contact stress increased progressively with knee flexion until contact occurred between quadriceps tendons and the femoral trochlea, inducing load sharing. Patella alta delays this contact until higher grade of flexion, increasing maximal patellofemoral contact force and pressure, whereas the presence of a patella infera significantly rises the contact pressure with the knee extension.

The effect of femoral and tibial rotation on the pathogenesis of patellofemoral OA is still debated. Whereas Dejour and Allain [4] in a computed tomography (CT) scan study did not found a significant correlation between these parameters and arthritis, other biomechanical studies [32, 33] revealed how external tibial rotation increases lateral patellar shift and tilt increasing patellofemoral contact pressure in the lateral compartment.

Influence of limb alignment on patellofemoral OA is also a matter of debate. In the literature, several studies reported that valgus alignment was associated with increased odds of lateral patellofemoral OA [34, 35], whereas other authors did not find any significant correlation between coronal malalignment of the lower leg and increased risk of patellofemoral OA [4].

Quadriceps muscles, hip abductors, gluteal muscles, hamstrings, and iliotibial band (ITB) have also been implicated, in different ways, in the genesis of increased patellofemoral (PF) joint stress. Hart et al. [36] noted a significant reduction in the cross-sectional areas of the vastii and rectus femoris in individuals with patellofemoral OA, suggesting a reduced force-generating capacity. These findings have been also supported by other studies reporting that individuals with patellofemoral OA negotiate stairs with decreased quadriceps force [37] and that lateral cartilage damage and bone marrow lesions were positively associated with quadriceps weakness [38], whereas a strong quadriceps represents a protective factor [39].

The analysis of gluteal muscles in patients with patellofemoral OA revealed that this population showed lower force value in gluteus medius and minimus during level walking and descending stairs in comparison to healthy controls [37]. Moreover, patients with patellofemoral OA also exhibit significantly reduced hip abductor strength [40], which may be responsible for an increased femoral internal rotation with a resultant increased lateral displacement of the patella in the trochlear groove.

The presence of tight hamstrings and a tight ITB have negative consequences on patellofemoral biomechanics. Tight hamstrings, indeed, could contribute to overload the lateral cartilage of the patellofemoral joint, especially in patients with a concomitant extensor mechanism malalignment [41]. In a study of 16 healthy men, those with tight hamstrings exhibited significantly greater lateral patellofemoral compartment joint stress and significantly reduced medial PF compartment contact area during a squat task [42].

The ITB also influences the kinematics of the patellofemoral joint. A tight ITB, indeed, increases lateral tilt and translation of the patella and tibial external rotation, increasing patellofemoral contact pressure [43, 44].

Side Summary
Predisposing factors to patellofemoral osteoarthritis are the presence of trochlear and/or patellar dysplasia, whereas the effects of patellar height and axial and coronal malalignment of the lower limb still represent a matter of debate. Furthermore, quadriceps and gluteal muscles, hip abductors, hamstrings, and iliotibial band have also been implicated in the genesis of increased PF joint stress.

6.5 Therapeutic Consequences

6.5.1 Non-operative Treatment

Conservative treatment should always be considered as the first option. This kind of approach always represents a mixture of non-operative treatment of patellofemoral arthritis and conservative management of conditions that produce patellar pain, such as a tight lateral retinaculum, vastus medialis obliquus (VMO) dysplasia, and core deficiency. Symptoms may be alleviated by weight loss in case of overweight patients, by activity modification, such as avoiding activities like running and squatting and limiting stair climbing, by quadriceps strengthening, water exercises, bracing, non-steroidal anti-inflammatories (NSAIDs), glucosamine–chondroitin, and viscosupplementation [45]. However, in the setting of advanced arthritis, these non-operative treatment options failed to give excellent results, in particular, in a long term [45, 46].

Side Summary
Conservative non-operative treatment always represents the first treatment option. This consists of weight loss; avoidance of worsening activities such as running, squatting, and stair climbing; and promotion of quadriceps and core strengthening and stretching, cycling, and water exercises.

6.5.2 Non-prosthetic Treatment

Non-prosthetic treatment represents a valid alternative especially in case of mild-to-moderate arthritis [47].

In the setting of a primary patellofemoral arthritis without anatomical abnormalities, the results of soft-tissue realignment procedures have not been sufficiently investigated. Release of the lateral retinaculum has been widely performed in case of lateral patellofemoral pain associated with tightness or contracture of the lateral retinaculum and a lateral patellar tilt. However, the results of this procedure in relieving pain are difficult to predict [48]. Among bone procedures, the tibial tubercle osteotomy represents an alternative with the aim of correcting extensor mechanism malalignment, performing a medialization or an anteromedialization [49, 50].

Another valid option in the treatment of mild-to-moderate patellofemoral arthritis is the partial lateral facetectomy, which consists of removal of about 1–1.5 cm of the lateral border of the patella including osteophytes [51]. Partial lateral facetectomy is indicated in case of lateral isolated patellofemoral arthritis and could be associated with lateral release in case of patellar tilt or with internal procedures like medial reefing or an Insall proximal realignment.

Side Summary
Non-prosthetic operative treatment is indicated in case of failure of non-operative treatment in the presence of mild-to-moderate arthritis. Tibial tubercle medialization or anteromedialization has the purpose of correcting extensor mechanism malalignment and reducing patellofemoral pressure, whereas partial lateral facetectomy represents a good solution in case of isolated lateral patellofemoral arthritis.

6.5.3 Patellofemoral Arthroplasty

6.5.3.1 Indication and Contraindications

The best indication for a patellofemoral arthroplasty is the presence of an isolated, degenerative patellofemoral arthritis resulting in persistent pain and functional limitations, which affects daily activities, despite a period of 3–6 months of non-operative treatments. Posttraumatic OA, diffuse grade 3 cartilage degeneration involving the entire trochlea, the medial facet, or proximal half of the patella, and failure of previous extensor unloading surgical procedures represent additional indications [52, 53].

Contraindications to patellofemoral arthroplasty are represented by the presence of tibiofemoral arthritis, a systemic inflammatory arthropathy, such as chondrocalcinosis or rheumatoid arthritis, obesity, the presence of a complex regional pain syndrome, and the presence of psychogenic pain. Moreover, patellofemoral arthroplasty is not indicated in case of severe coronal plane tibiofemoral malalignment (valgus >3 ° or varus >5°), history of meniscal surgery, fixed flexion contracture greater than 10°, limited flexion (< 120°), and a patella infera [52–54].

Moreover, when interviewing and examining patients with patellofemoral arthritis, it is mandatory to look for factors that may adversely influence clinical outcomes and failure rates. The etiology itself represents an influencing factor in the results of this procedure. Several studies [4, 55] reported significantly higher incidence of failure because of progression of femorotibial OA in case of primary arthritis in comparison to arthritis secondary to patellofemoral instability.

Considering patient's risk factors, it is well known that obesity is associated with lower postoperative functional improvement and patient satisfaction and higher failure rate due to progression of tibiofemoral arthritis [56–58]. On the other hand, the presence of trochlear dysplasia is considered a protective factor for the progression of tibiofemoral OA. Several studies in the literature, indeed, showed that patellofemoral OA in the presence of trochlear dysplasia is significantly associated with less progression of tibiofemoral OA and that patellofemoral arthroplasty performed on these patients is correlated with higher patient-reported outcome scores postoperatively [55–57, 59, 60].

Finally, a history of previous multiple knee interventions is reported to adversely affect the outcome of patellofemoral arthroplasty, increasing the risk of stiffness and the need for postoperative manipulations and arthrofibrotic debridement [52, 53].

Side Summary
The optimal indication for patellofemoral arthroplasty is the presence of high-grade, isolated patellofemoral osteoarthritis secondary to the presence of predisposing factors for patellofemoral instability, which severely affects daily activities of a non-obese patient, aged less than 60 years.

6.5.3.2 Technical Considerations

When facing patellofemoral arthritis, two anatomic situations could be encountered; the first is when patellofemoral arthritis develops in a context of normal patellofemoral anatomy, whereas the second is when patellofemoral OA is associated with patellofemoral dysplasia.

Patellofemoral Osteoarthritis without Dysplasia

In the setting of high-grade isolated patellofemoral OA, patellofemoral joint replacement represents the best therapeutic option. In the absence of anatomical abnormalities, the arthroplasty does not need the association of other procedures, like osteotomy of the tibial tubercle.

Patellofemoral Osteoarthritis with Dysplasia

Since the dysplasia of patellofemoral joint has not been corrected, the instability of the patellofemoral joint persists associated with chronic retraction of lateral retinaculum and loosening of the medial one. In this setting, a partial or total arthroplasty represents an interesting solution since it allows the correction of both trochlear and patellar dysplasia. Therefore, the application of a trochlear cutting patellofemoral arthroplasty allows the correction of trochlear dysplasia by removing the whole supratrochlear prominence and the correction of the extensor mechanism malalignment by setting the mediolateral and rotational positioning of the component. In this way, the TT-TG may be diminished by a slight lateralization of the femoral component without any procedure on the tibial tubercle (Fig. 6.6).

Concerning the patellar correction, it is mandatory to preserve an acceptable thickness of the patella with a minimum of 13–14 mm, in order to reduce the risk of patellar fracture. Moreover, if prosthetic patella is slightly undersized, it permits to correct both patella alta and patella infera by placing the prosthetic button relatively at the most distal or proximal part of the native patella and the malalignment by setting the mediolateral positioning of the patellar implant. During the resurfacing of the patella, a lateral release is not always necessary because generally lateral osteophyte removal is sufficient, since it constitutes a sort of a lateral facetectomy from the inside, allowing decompression of the lateral compartment.

Side Summary
In the presence of osteoarthritis secondary to patellofemoral instability or associated with predisposing factors for patellofemoral instability, the aim of a patellofemoral arthroplasty is not only to treat the arthritis but also to perform a "metallic trochleoplasty," correcting the trochlear dysplasia and the extensor mechanism malalignment.

Fig. 6.6 Treatment of patellofemoral OA and correction of trochlear dysplasia and extensor mechanism malalignment with a trochlear cutting patellofemoral arthroplasty

Take Home Message

A better understanding of pathophysiology of patellofemoral disorders has led to a renewed interest in the use of patellofemoral arthroplasty. A very careful patient selection is mandatory in order to reduce failure rate. The optimal indication for patellofemoral arthroplasty is the presence of high-grade, isolated patellofemoral osteoarthritis secondary to the presence of predisposing factors for patellofemoral instability, which severely affects daily activities of a non-obese patient, aged less than 60. In the presence of predisposing factors for patellofemoral instability, the aim of a patellofemoral arthroplasty is not only to treat the arthritis but also to perform a "metallic trochleoplasty," correcting the trochlear dysplasia and the extensor mechanism malalignment.

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7 The Optimal Indication for Combined Patellofemoral and Unicondylar Knee Arthroplasty

Johannes Beckmann and Malin Meier

Keynotes

1. Bicondylar knee arthroplasty (BKA) as a combination of patellofemoral arthroplasty (PFA) and unicondylar knee arthroplasty (UKA) is technically demanding as it requires experience in both.
2. It is a promising solution especially for young active patients suffering from bicompartmental osteoarthritis; however, selection of patients is crucial as well as the precision of the surgical procedure in terms of technique and correct knee balance.
3. The ideal patient or indication will be described and is of utmost importance.

7.1 Introduction

Traditional total knee arthroplasty (TKA) is still the most common way to treat end-stage degenerative changes of the knee even when associated with uni- or bicompartmental disease. Although TKA is widely reported in the literature as giving reliable and long-lasting results [1–3], patient satisfaction, however, does not always meet expectations: 20% of patients receiving TKA (in younger patients up to 30%) are not satisfied with their surgical intervention [4–6], supporting the view, that new concepts and, nowadays, surgical solutions alternative to TKA must be taken into consideration, exploiting the technical possibilities offered by the new designs of prostheses which show results superior to results of already used, old-fashioned implants [7]. It was common to implant a TKA in patients having not only one but two compartments of the knee affected by osteoarthritis (OA). This might be considered an overkill, since three-compartmental OA occurs only in 30% of patients scheduled for knee replacement, whereas 30–60% suffer from bicompartmental OA [8–11].

Nevertheless, BKA is not very often performed, because surgeons are more in favor of performing TKA. Implanting a TKA in patients with bicompartmental OA, one healthy compartment and one or both cruciate ligaments need to be sacrificed. That approach is in contradiction of the concept of preserving intact anatomical structures in arthroplasty. Furthermore, it has been shown that sacrificing both the unaffected compartment and at least one or both cruciate ligaments leads to altered knee kinematics and gait [12, 13].

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Side Summary
Up to 60% of patients scheduled for TKA suffer from bicompartmental osteoarthritis. In those patients with TKA, one healthy compartment and one or both cruciate ligaments need to be sacrificed which might be unnecessary.

7.2 Concepts of Combined Patellofemoral and Medial Unicondylar Knee Arthroplasty

Partial OA of the knee can be treated with partial resurfacing prosthetic solutions such as unicompartmental, bi-unicompartmental, or PFA alone or unicompartmental combined, which respects the cruciate ligaments and achieves maximal bone preservation, essential particularly for young patients [13, 14].

UKA is a well-accepted surgical option for medial or lateral osteoarthritis of the knee. However, osteoarthritis typically progresses from the medial (or less frequent from the lateral) tibiofemoral compartment to the patellofemoral compartment [15, 16], leading to the question of the impact of patellofemoral osteoarthritis after UKA: whereas medial cartilage lesions of the patellofemoral joint seem to be well-tolerated, lateral cartilage lesions can negatively influence the outcome of medial UKA [17]. Further, Berger et al. found patellofemoral arthritis to be the primary mode of failure in UKA [18]. Thus, BKA as a combination of UKA and PFA appears to be an appropriate remedy (Fig. 7.1).

Side Summary
Knee OA typically progresses from the medial (or less frequent lateral) tibiofemoral compartment to the patellofemoral compartment. Patellofemoral OA can be a mode of failure in UKA. BKA as a combination of UKA and PFA appears to be an appropriate remedy.

Fig. 7.1 Monolithic customized bicompartmental knee prosthesis for the patellofemoral and medial femorotibial compartment

On the other hand and just relying on registry data, it is hard to justify the combination of two procedures (UKA and PFA) in knee arthroplasty which both fail earlier compared to TKA [15, 19, 20] (Fig. 7.2a–c).

Former implants (particularly monolithic) were controversially discussed with poor outcomes and partially disappointing high revision rates [15, 21, 22]. However, it is difficult to assess BKA survivability, since especially young patients choose this kind of implant due to its less-invasive and joint-preserving nature. Those patients continuing active lifestyles increase the risk of requiring revision because of loosening, fracture, and normal wear [23].

Side Summary
BKA is technically demanding as it requires experience in both PFA and UKA.

Newer solutions (monolithic or modular/two-piece) show very promising results which are comparable to TKA (Figs. 7.2a–c and 7.3a–c) [24–26]. There are even studies describing BKA as superior to TKA in terms of function and biomechanics [27]. BKA facilitates the restoration of normal knee mechanics and gait kinematics [28], due to the preservation of intact cruciate ligaments. Some other authors found the BKA having a better range of motion compared to the TKA [29], which might be due to the retention of the anterior cruciate ligament, which reduces stiffness plausibly by

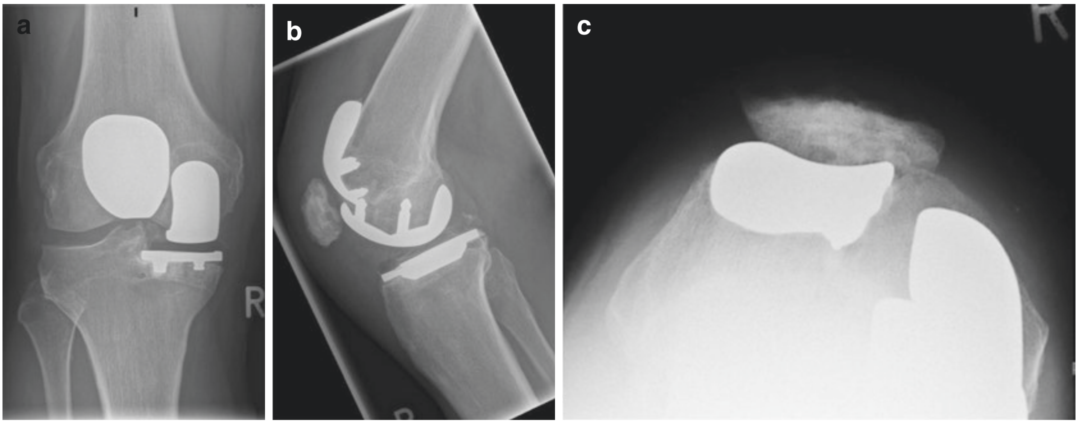

Fig. 7.2 Radiographs in antero-posterior (**a**) and lateral (**b**) and Merchant view (**c**) of bicompartmental replacement of a right knee using a patellofemoral implant and unicondylar implant separately

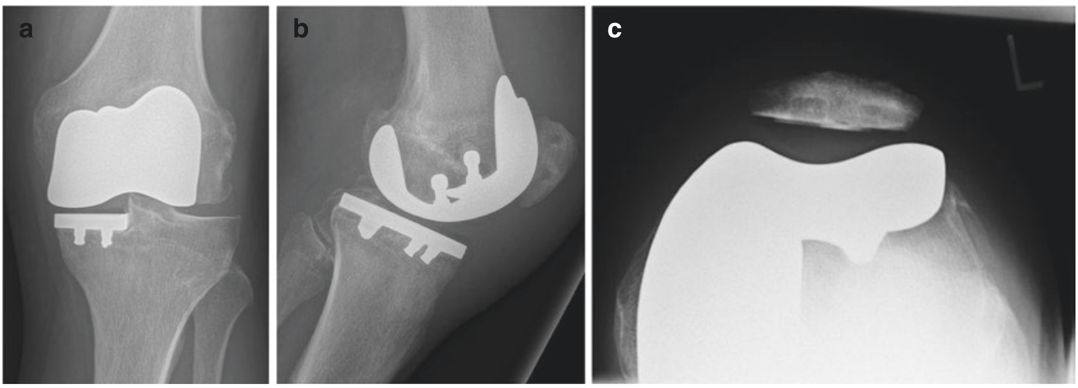

Fig. 7.3 (**a**–**c**) Postoperative radiographs after implantation of the monolithic customized bicompartmental arthroplasty (anteroposterior (**a**), lateral (**b**), Merchant view (**c**)) of the case presented in Fig. 7.1

providing a protective mechanism against the limited flexion [15]. One study showed that in vivo knee joint kinematics in BKA limbs are found to replicate, for a large range of daily-life motor tasks, the kinematics of the contralateral non-affected limbs and healthy controls to a similar extent (despite the presence of differences indicative for retention of preoperative motion patterns and/or remaining compensations) [30]. Another study compared clinical scores such as knee society score (KSS), knee injury and osteoarthritis outcome score (KOOS), and activities of daily life between BKA and TKA and found that the BKA group had a significantly greater range of motion compared to the TKA group, whereas no significant differences were found in clinical and functional scores in short term [29].

Because of its bone-preserving property, BKA is an attractive solution for especially young patients, who bear a high risk of requiring future revision. Further, the preservation of the cruciate ligaments is of crucial importance for younger and active patients, since these structures play an important role in proprioception and normal knee kinematics.

Side Summary

BKA appears to have certain advantages over TKA. Its bone- and ligament-preserving property renders BKA attractive for especially younger and active patients.

Although newer standardized BKA are showing a good functional outcome, there is still a high revision rate [31], which might be due to the technical complexity but also due to the insufficient variety of implant sizes, which does not cover the high variety of patient individual anatomy. Recently, interest has grown in patient individual knee arthroplasty. It is obvious that an optimal fit and anatomic congruence of a knee arthroplasty are difficult to achieve with fixed geometry implants in a population with a widely varying knee anatomy. Individual implants, on the other hand, are showing very promising results with increasing range of motion and good patient satisfaction [32, 33]. A study by Wang et al. showed good results of BKA in terms of walking speed, peak knee extensor moment, and power, and also showed that there was no significant difference between individual BKA and normal healthy knees [34]. However, long-time data need to be awaited.

Side Summary
A high revision rate might be due to the technical complexity but also due to the insufficient variety of implant sizes. Individual implants could be a solution to achieve optimal fit and anatomic congruence in a population with widely varying knee anatomy.

The ideal indication for combined UKA and PFA might be

- Tibiofemoral unicompartmental disease (medial or lateral) with just or mild or even no degeneration of the other compartment, associated with patellofemoral OA with evident clinical symptoms, both subjective and objective (positive signs of patellofemoral pain) (Fig. 7.4a–d).
- Osteoarthritis of the lateral patellar facet associated with even poor/mild symptoms in association with tibiofemoral unicompartmental disease (e.g., arthritis of the medial tibiofemoral compartment combined with arthritis of the lateral patella) (Fig. 7.4a, c, d).
- Deformity of the anatomical axis of the limb due to intraarticular disease (narrowing of the joint line caused by degenerative disease), not extraarticular (e.g., deformity of the tibia), with evident patellofemoral incongruency due to patellar misalignment but unrelated to the deviation of mechanical and anatomical axis of the limb. Osteoarthritis in the medial tibiofemoral compartment is associated with varus alignment of the knee joint. This deformity can be corrected with implantation of a UKA. However, correcting a varus deformity in a patient with medial tibiofemoral osteoarthritis in combination with lateral patellofemoral osteoarthritis will further transfer the patella toward the lateral femur condyle, thereby aggravating the lateral patellofemoral osteoarthritis.
- Further conditions are analogous to unicompartmental treatment [35]:
  - Varus/valgus deformity <10°.
  - Flexion contracture <10°.
  - ROM >90°.
  - Intact anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL).

Side Summary
The ideal indication for BKA comprises arthritis of the medial tibiofemoral compartment combined with symptomatic arthritis of the lateral patella (or lateral tibiofemoral compartment combined with arthritis of the medial patella).

Typical contraindications are

- Involvement of all three compartments.
- Tibial lateral thrust.
- Unstable situation (other than opening of tibiofemoral narrowed joint).
- Relatively or controversial: rheumatoid arthritis, BMI [36], contact sports, or heavy professional activity.

Fig. 7.4 (**a**–**e**) Long-leg weight-bearing view (**a**), lateral view (**b**) and Merchant view (**c**), coronal and sagittal planes of magnetic resonance imaging (MRI) (**d**, **e**) of a patient with bicompartmental disease (tibiofemoral medial and lateral patellofemoral) with intact lateral femorotibial compartment and both of the cruciate ligaments

Take Home Message

BKA is a promising solution especially for young active patients suffering from bicompartmental osteoarthritis. This approach could preserve more natural kinematics. However, the selection of patients is a key factor, and contraindications have to be considered. Further, long-time data need to be awaited to decide whether BKA or TKA has a better outcome.

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8 The Optimal Indication for Total Knee Arthroplasty

Mahmut Enes Kayaalp and Roland Becker

Keynotes

1. Pain, reduction in knee function and quality of life are the most common reason for total knee arthroplasty (TKA) surgery.
2. Degree of osteoarthritis does not correlate well with pain and knee function.
3. Good muscle function seems to cause less pain and disability in osteoarthritic knees.
4. It remains unclear what amount of improvement in muscle strength may show an impact on patient symptoms.
5. Indication for TKA remains a very individual decision process based on patient symptoms and expectation and the severity of radiological signs of osteoarthritis.

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8.1 Introduction

There is a large variety in severity and history of OA in patients presenting for TKA. In addition, there are patients who are able to get along well with the limitations during daily life, whereas others request surgery.

Most indication criteria consider the following three pillars: pain, function and radiological changes, with the prerequisite that pain could not be controlled by conservative therapy. Specific cut-off values or ranges for pain and function are not established. For radiological changes, only the British Orthopaedics Association (BOA) indication criteria reported a cut-off value of grade ≥ III according to Kellgreen and Lawrence. However, these criteria are based on low-level evidence (level IV) [1].

Pain and poor function due to the OA are the main indication criteria for TKA [2].

Side Summary
Pain and Poor Function are the Main Indicators for TKA

Conservative treatment should be performed before surgery is considered [3]. It has been shown that conservative treatment will relieve pain and improve function in patients suffering from OA. Radiographs of the knee including full-leg weight-bearing view, Rosenberg's view, lat-

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eral view and skyline view should be taken routinely in order to receive important information about degree of degeneration of the three compartments and the alignment in general as well. The sensitivity of medial or lateral joint space narrowing is much higher when Rosenberg's view is used (Figs. 8.1 and 8.2). It is very important to be aware of intra-articular and extra-articular deformities. Sometime stress radiographs may provide better information about cartilage loss and collateral ligament insufficiency due to unnatural opening of the contralateral compartment.

Side Summary
Weight-bearing radiographies are important for proper assessment of the joint space

Radiographs provide additional information underlining the clinical-based indication for TKA.

The Kellgren and Lawrence grading is the most accepted radiographic assessment of OA [4]. The classification has been modified in 2011 taking the development of joint space narrowing beside the osteophytes more into consideration [5].

The optimal indication for total knee arthroplasty (TKA) is one of the major challenges for successful outcomes after TKA. Numerous studies have shown that the optimal outcome does not solely depend on a well-performed surgery, which includes correct implant placement, perfect ligament balancing and correct alignment. These surgical-related factors are very important, but, in addition, there are patient-related factors that matter.

As a knee surgeon, one should aim for the perfect indication. However, in reality, one has to make numerous compromises with regards to the ideal patient in mind. This chapter aims to report and discuss the optimal indication for TKA.

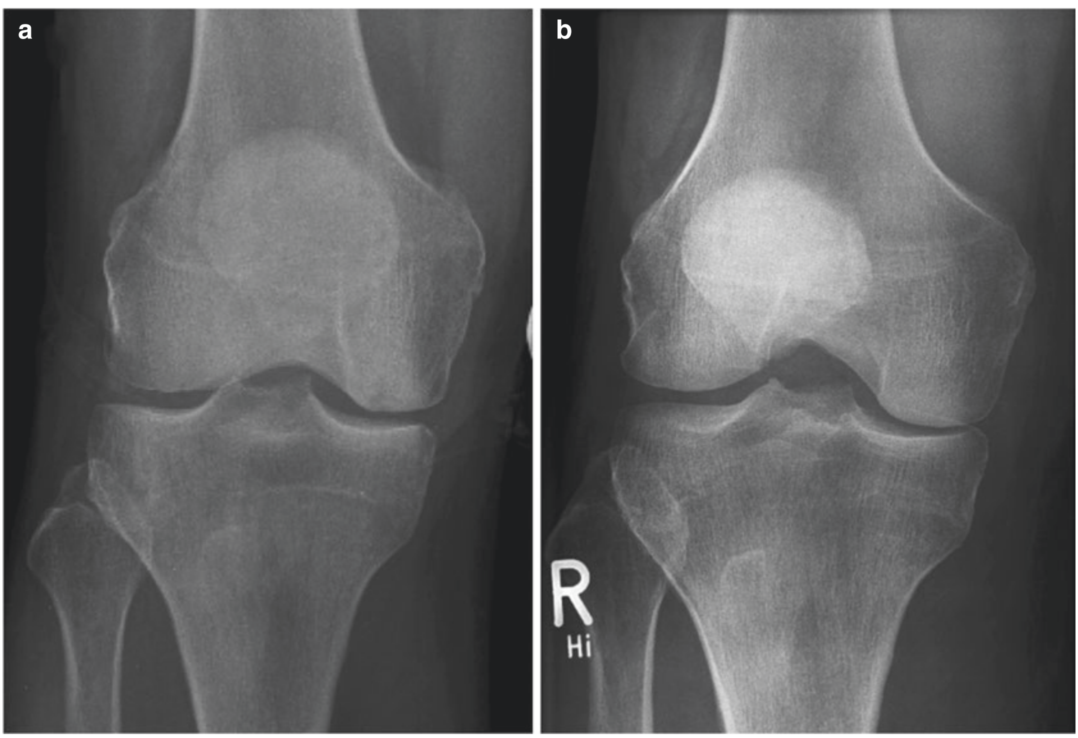

Fig. 8.1 (**a**, **b**) Standard anteroposterior (**a**) view and Rosenberg's view (**b**)

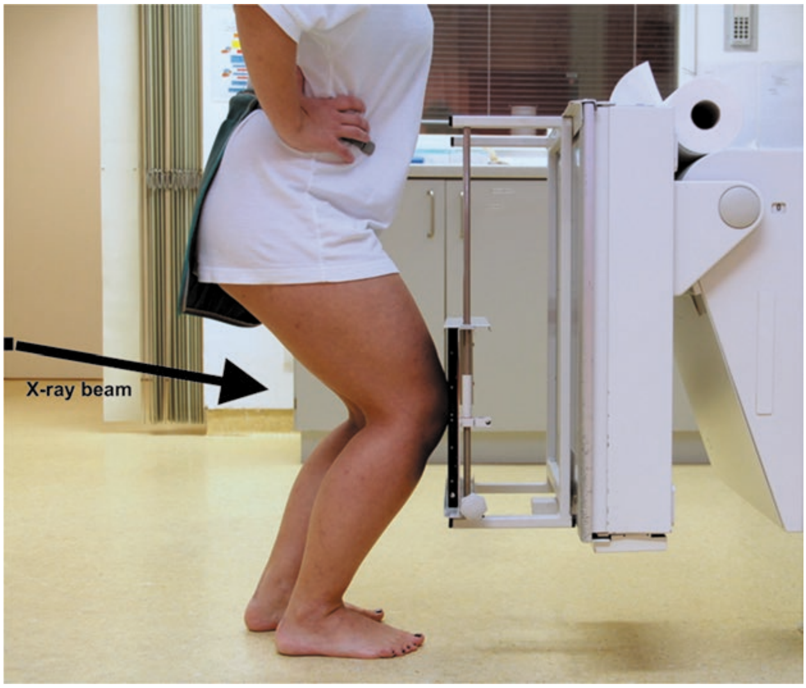

Fig. 8.2 Radiographic technique for Rosenberg's view or 45° weight-bearing view (45° of knee flexion and posterior-anterior beam 10° towards the floor)

8.2 Indication for Total Knee Arthroplasty (TKA)

Six guidelines from different countries of Europe are available concerning the indication for TKA.

1. S2 guidelines by the German Society of Orthopaedics and Orthopaedic Surgery: https://www.awmf.org/leitlinien/detail/ll/033–004.html
2. Guidelines by the British Orthopaedic association: http://www.boa.ac.uk/pro-practice/painful-osteoarthritis-of-the-knee-commissioning-guide-2
3. National institute for care and health excellence. [http://www.nice.org.uk/guidance/cg177].
4. New Zealand guide to good practice [http://nzoa.org.nz/ system/files/total_knee_replacement_practice_guidelines.pdf].
5. Osteoarthritis Research International (ORSI) [6].
6. European League Against Rheumatism (EULAR) [7].

All guidelines show level IV of evidence and are based on the criteria: pain, function radiographic changes and other criteria such as quality of life and progression of loss of function or deformity.

The German Society of Orthopaedics and Orthopaedic Surgery released the S2 guidelines for 'Working Group of Scientific Medical Societies' (AWMF) regarding the indication for total knee arthroplasty (TKA).

A group of 20 experts were involved in the development of this guideline. There was a 100% consensus between all participants on 5 main criteria and 13 additional criteria.

Main criteria indicating TKA are as follows:

1. Knee pain.
2. Destruction of the knee (osteoarthritis and osteonecrosis).
3. Failure of conservative therapy.
4. Reduction in quality of life directly relating to pathology of the knee.
5. Psychological strain.

Pain, reduction in function and quality of life are the most common criteria for TKA. However, pain with joint discomfort is highly variable. Symptoms of OA show weak correlation with degenerative changes in radiography. A systematic review of the literature revealed that patients suffering from knee pain showed radiographic signs of knee OA 15–76% of the time. Those patients with radiographic knee OA complained about knee pain 15–81% [8]. However, an association has been reported between loss of cartilage volume and knee pain [9]. While some studies have shown a positive correlation between the increase in the K&L grading and decrease in the Hospital for Special Surgery scoring, others did not [8, 10, 11]. Symptoms seem to increase when joint space narrowing is underway, but no correlation has been reported between the severity of symptoms and growth of osteophytes [12]. Thus, radiographic changes should be considered as a kind of additional information during the clinical assessment of the patients.

One reason for poor correlation between the degree of structural damage and pain is caused by the neuroplastic changes occurring in the central and peripheral nervous system and may have an impact on patient's experience of pain [13].

Besides joint degeneration, muscle strength seems to have a direct impact on clinical symptoms. Lower strength for knee extension and flexion shows reduction in muscle function and functional capacity in osteoarthritic patients [14, 15]. Greater hip abductor strength was associated with reduced risk of progression in patellofemoral and lateral tibiofemoral cartilage damage and the outcome regarding the chair to stand rate [16].

Improvement in muscle strength does not automatically mean improvement in function. A 15% gain in quadriceps muscle strength, for instance, showed no effect on walking pace and chair stand up performance in male patients [17]. Thus, it remains unclear how much improvement in muscle strength is required in order to show an improvement in the symptoms. But quadriceps weakness correlates with increase in incidence of OA without progression of OA in woman and men [18]. In conclusion, higher muscle strength may prevent degenerative radiographic changes in the knee.

However, the length of conservative treatment remains unclear and depends on the symptoms and severity of OA. Pre-rehabilitation and exercise training do not improve the outcome in terms of function and pain after TKA [19–21].

Side Summary
Preoperative training and rehabilitation does not improve functional outcome and pain after TKA

Bedson et al. discuss three particular reasons after analysing the literature as to why discordance between radiography and symptoms arise [8]. Firstly, there might be an insufficient number of views in order to estimate the association between the radiography and pain. Therefore, an appropriate set of radiographies are essential (Fig. 8.3).

Secondly, the grading of pain and radiographic chances have an important influence upon estimating the association. Finally, the nature of the study population is important. Variation in knee pain and radiological signs might be influenced by age, ethnicity and other characteristics.

A literature review has been performed recently in order to search for evidence-based indication for TKA [22]. The authors concluded that more systematic reviews are needed to explore the following questions:

What are the treatment goals for TKA?
For whom are the treatment goals measured?
How are the treatment goals measured?

Beside the five main criteria for indication for TKA, additional criteria may help in the decision process such as:

1. Limitation in walking distance.
2. Limitation in standing for long periods of time.
3. Limitation in going up and down stairs.
4. Deformity.

5. Instability.
6. Limitation in range of motion.
7. Reduction in quadriceps strength.
8. Difficulties in sitting down, kneeling or personal hygiene.
9. Support given by another person.
10. Difficulties to manage housework.
11. Difficulties in using public transport facilities.
12. Limitation in participating in social life, professional work and sports activities.

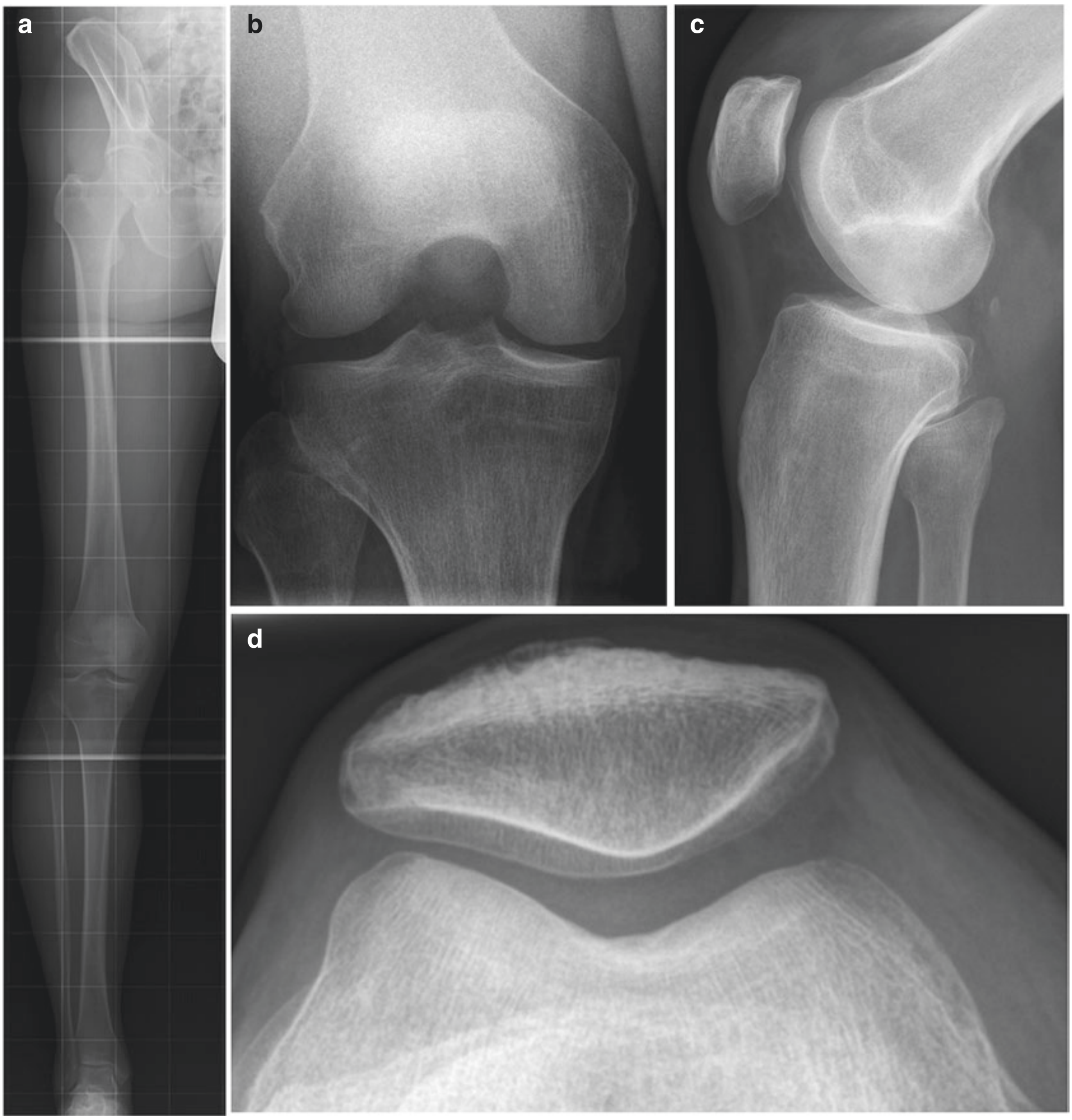

Fig. 8.3 (**a**–**d**) Standard set of radiographies for complete knee assessment including full-leg anteroposterior weight-bearing view (**a**), Rosenberg's view (**b**), lateral view (**c**), Merchants view (**d**) and sometimes stress radiographies are helpful in case of mediolateral instability

8.3 Prediction for Outcome after TKA

The predictors of elective total knee arthroplasty by the patients were analysed [23]. The authors found that age, knee extension and KOS-ADLS significantly predict whether or not a patient would like to undergo TKA. Factors such as gender, BMI, degree of knee flexion and unilateral versus bilateral OA did not show significant impact on decision-making. Dissatisfaction was seen in patients who have more stiffness, less pain and a lower quality of life [24]. Based on the finding, a predictive model was developed using 10 questions regarding gender, age, pain, knee stiffness, grinding or clicking during knee motion, knee feeling, awareness of knee problems and anxiety or depression in order to foresee patients' satisfaction and dissatisfaction.

Side Summary

It is essential to analyse patients' expectation prior to surgery. Mental factors have to be taken into consideration when TKA surgery is considered

Early satisfaction rate after 3 months was compared with the outcome after 12 months [25]. There was no difference between the satisfied and dissatisfied group prior to surgery. The outcome in the dissatisfied group was significantly lower in pain score, SF-12 and OKS without improvement in any of the scores at 12 months of follow up. Demographic parameters such as age, BMI, gender, length of stay and diagnosis did not show any impact on the outcome.

A preliminary predictor rule has been introduced based on the Western Ontario and McMaster Osteoarthritis Index (WOMAC) [26]. Five questions drawn from the WOMAC at baseline were identified from all potential predicts such as:

1. Difficulty in taking off socks
2. Getting on and off the toilet
3. Performance of light domestic work
4. Rising from the bed
5. Degree of morning stiffness after awakening

Take Home Message

- One should take as many aspects as possible into consideration in order to identify a patient for TKA.
- The five main criteria, such as pain, osteoarthritis grade III–IV according to K/L, failed conservative treatment, reduction in quality of life and psychological strain, seem to be the most important ones.
- Additional examinations should be considered when necessary, including consultation of a psychiatrist or pain specialist [27].
- Conservative management should be the first choice of treatment; however, in some cases, immediate surgery will be necessary.

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9 Partial Resurfacing Implants

Martin Lind

Keynotes

1. Localized cartilage injury in middle-aged patients can be treated with focal resurfacing implants.
2. Two implant systems for the knee exist today: the HemiCAP® implants from Arthrosurface® and the Episealer® implants from Episurf®. Both systems utilize an alloy metallic cap to replace the injured cartilage but have different principles for subchondral bone anchorage. Both systems have differently sized implants for both femoral condyle and trochlea cartilage lesions.
3. Literature on clinical outcome after resurfacing implant treatment is limited.
4. For HemiCAP® implants, case series have demonstrated good short-term symptom reduction and improved knee function for both femoral and trochlear implant types. Reoperation rates with conversion to conventional arthroplasty types are, however, high and resurfacing implantation probably should be considered as a temporary surgical management for symptomatic cartilage pathology in middle-aged patient who will eventually progress to more generalized osteoarthritis.

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9.1 Introduction

Treatment of symptomatic, isolated, localized, full-thickness, femoral cartilage defects in middle-aged active patients is a challenge due to poor cartilage healing capacity and frequently disabling symptoms [1]. Also such cartilage lesions can progress into osteoarthritis (OA) [2]. Biological treatment options such as marrow stimulation and chondrocyte transplantation are influenced by patient age and have less favourable outcomes with increasing patient age [3, 4]. Total and unicompartmental knee arthroplasty are typically not indicated for these patients due to only a limited area of the knee having significant cartilage loss [5, 6]. Normally non-operative treatment modalities are employed for these patients with physiotherapy, weight loss, analgesics and activity modification. But non-operative management is in some cases ineffective or fails over time. In these cases surgical treatment with a resurfacing implant is a potential treatment option.

Isolated femoral condylar cartilage lesions in middle-aged patients can be managed by numer-

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ous strategies. These are: non-operative treatment with activity modification, weight loss, physiotherapy, pharmacological measures or surgically with various cartilage repair techniques such as microfracture, chondrocyte transplantation or osteochondral transplantation. And in case of lower limb axis malalignment, correction osteotomies can be used to offload the affected cartilage. For isolated patellofemoral OA, many surgeons prefer TKA rather than PFA in order to achieve predictable clinical outcome. Some of the current issues about isolated PFA are the fact that extensive exposure is necessary, a lack of evidence for long-term outcome and the variable success rate of this procedure. To overcome this treatment gap for some cartilage pathologies, a minimally invasive, anatomic, joint preserving, PFJ resurfacing component may provide some of the solutions required to succeed in this area [7].

In order to manage symptomatic isolated cartilage lesion in these younger and more active patients, it makes some sense to limit the surgical reconstruction to the area of the cartilage defect. With regards to this background, small implants which only address the cartilage defects have been developed. In the knee joint, implants have been developed to address cartilage lesions in the patellofemoral joint and at the femoral condyles. Such implants have been given numerous names over time, such as resurfacing implants, resurfacing arthroplasty, prosthetic inlay resurfacing and condylar implants. In this book chapter, the term condylar or resurfacing implant will be used.

This chapter will describe the present implants on the market, the potential indication for the use of resurfacing implants, the surgical techniques for implantations and the clinical outcome after use of resurfacing implants.

9.2 Knee Resurfacing Implant Types

9.2.1 HemiCAP® Implants

HemiCAP® Focal Femoral Condyle Resurfacing Prosthesis (Arthrosurface Inc., Franklin, MA, USA) was introduced in 2003 for treatment of full-thickness femoral chondral lesions. Both femoral condyle and a trochlear implant have been designed. This device consists of a bone fixation component and an articular component connected by a Morse taper. The fixation component is a cannulated cancellous screw with a tapering distal tip made of titanium alloy (Fig. 9.1). The articular dome-shaped component is available in two diameters, 15 mm and 20 mm, for which there are various convex surface sizes in order to match the curvature at the implant site. This bearing surface is a cobalt–chromium–molybdenum alloy with titanium plasma spray underside for bone ingrowth.

For larger condylar cartilage defects, a bicircular implant (UniCAP®), and for trochlear defects, two concave implant exist: the patello-

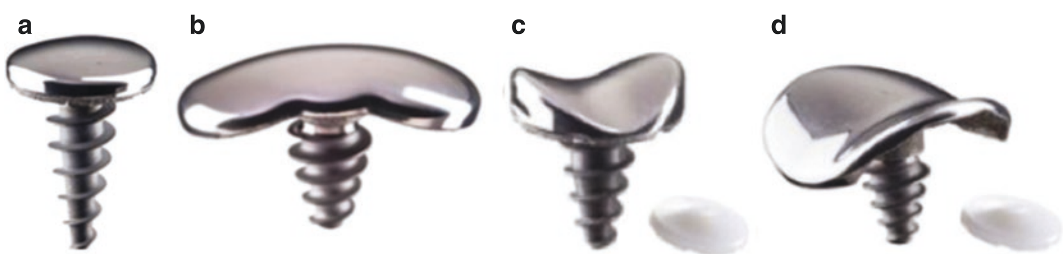

Fig. 9.1 The HemiCAP® implant types. (**a**) Femoral HemiCAP®. (**b**) UniCAP®. (**c**) HemiCAP® trochlea. (**d**) HemiCAP® wave

femoral HemiCAP® and the larger-wave implant (Table 9.1) (Fig. 9.1).

> **Side Summary**
> Treatment of local defects of 15–20 mm in size at the femoral condyle or trochlea defects.

9.2.2 The Episealer® Implant

The Episealer implant is special in the sense that it is uniquely designed to fit a patient's condylar anatomy. The cartilage and bone damage are assessed on 3D-MRI for optimal planning. The Episealer implant is a one-piece design with two functions: a hat that sits within the subchondral bone bed, loading in a physiological manner with the chondrophilic edges bonding to the patient's healthy cartilage; and a peg that gives initial stability and press fits into the subchondral cortex allowing stable fixation and rapid recovery post-operatively.

An Episealer implant can be produced for defects on the medial femoral condyle, lateral femoral condyle and within the femoral trochlea. The Episealer product line consists of three implant types, the Episealer Condyle Solo for femoral condyle defect, the Episealer Femoral Twin for large femoral condyle lesion and the Episealer Trochlea Solo for trochlea lesions (Table 9.1) (Fig. 9.2).

9.3 Indications for the Use of a Resurfacing Prosthesis

The indications for treatment with femoral resurfacing implants are symptomatic focal chondral and osteochondral defects in femoral condyles or trochlea for which standard non-operative treatment measures such as physiotherapy, weight loss, activity modification and pharmaceutical treatment have failed (Fig. 9.3) [8]. The lesion can be traumatic and degenerative due to osteochondral pathology or after failed previous cartilage repair such as microfracture or chondrocyte transplantations [9, 10]. If osteochondral pathology is the cause of cartilage lesion in case of osteochondritis dissecans or spontaneous osteonecrosis of the knee, then the subchondral bone lesion should be limited to 3–4 mm in order to have sufficient subchondral bone support for the resurfacing implant.

Table 9.1 Knee resurfacing implants

Company	Femoral condyle	Femoral condyle large	Trochlea	Trochlea large
Arthrosurface®	HemiCAP® (15 & 20 mm)	UniCAP®	Patellofemoral HemiCAP®	Patellofemoral HemiCAP® XL (wave®)
Episurf®	Episealer solo (12–20 mm)	Episealer twin (15–25 mm width, 23–35 mm length)	Episealer trochlea solo (20–29 mm)	

Fig. 9.2 The Episealer® implant types. (**a**) Episealer® femoral solo. (**b**) Episealer® femoral twin. (**c**) Episealer trochlea

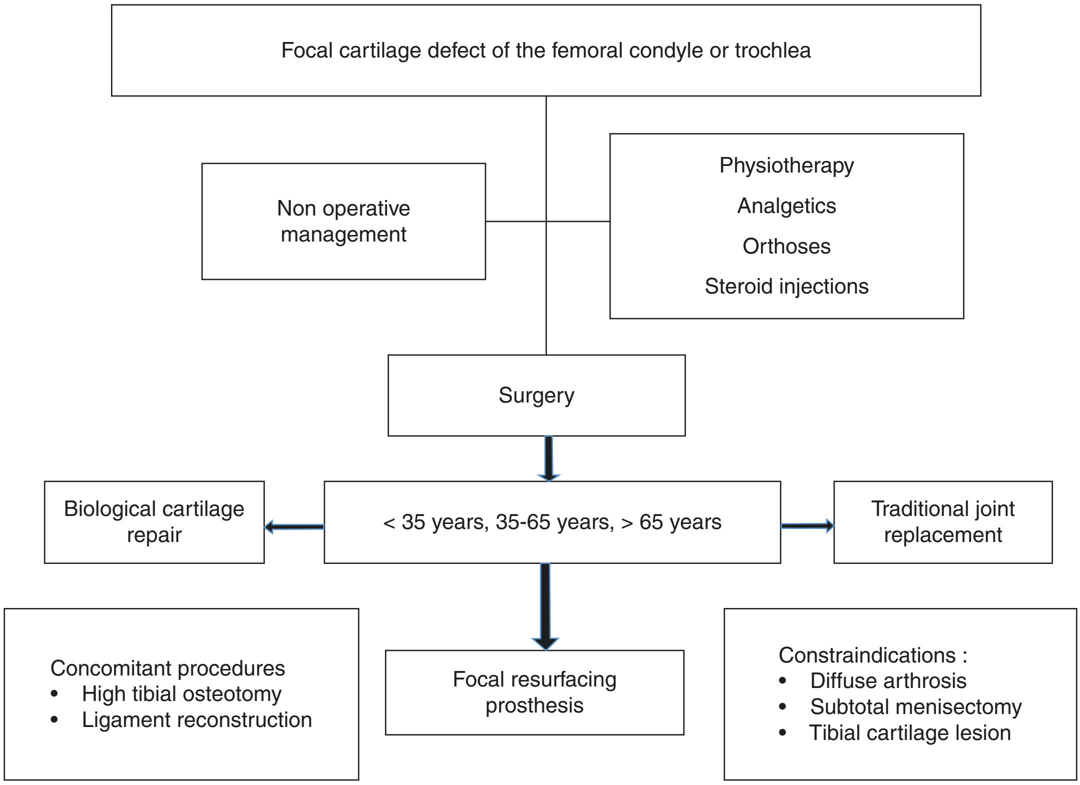

Fig. 9.3 Algorithm for treatment focal resurfacing prostheses

The age of the patient is a key issue. In younger patients below 35 years, with good healing potential for biological cartilage repair, such treatment methods should be used. In older patients above 65 years, where traditional arthroplasty treatment had consistent and well-proven clinical outcome and the risk of revision arthroplasty is limited, traditional arthroplasty should be used. In case of symptomatic ligament lesions, these should be additionally managed by reconstruction. In case of coronal plane axis deviations such as valgus or varus deformity then these should be corrected surgically with osteotomies. This is the case for patients with valgus or varus deviation of more than 5° from the weight-bearing axis.

Contraindications for choosing focal resurfacing prosthesis treatment are the following conditions: non-focal cartilage lesions and generalized osteoarthritis, tibial cartilage lesions grade 3 or 4 and subtotal meniscectomy of more 75% loss. In these patients, it is highly likely that there would be an insufficient positive response to focal treatment of femoral cartilage pathology.

Side Summary
Indications for partial resurfacing implant treatment

- Focal chondral and osteochondral defects in femoral condyles or trochlea with significant pain symptoms is which non-operative treatment measures have failed.
- Age between 35 and 65.

Side Summary
Contraindications

- Non-focal cartilage injuries.
- Osteoarthritis.
- Tibial cartilage lesions.
- More than 75% loss of meniscus tissue.

9.4 Surgical Techniques

9.4.1 HemiCAP®

The procedure is initiated with a standard arthroscopy to identify cartilage status, confirm the indication and treat any concomitant intra-articular pathology. The cartilage lesion is exposed using a small parapatellar incision. The cartilage lesion is measured. A special centralized drill guide is used to place a K-wire perpendicular and central to the articular cartilage surface. Over the k-wire, the reaming for the fixation screw is performed. The fixation screw is implanted into the bone. Mapping instruments measure the surface curvature. A matching surface reamer then prepares the inlay implant bed. Sizing trials are used to confirm an accurate fit to the surrounding cartilage. The resurfacing implant is fixed press fit onto the fixation screw and seated flush or slightly recessed 0.5 mm to the surrounding articular cartilage surface. A standardized rehabilitation protocol with free range of motion is allowed starting immediately after surgery. For the first 2 weeks, patients use touch weight bearing. Then, full weight bearing is allowed.

9.4.2 Episealer®

Via a small parapatellar incision, the cartilage defect is inspected. The capsular incision can be extended in a subvastus direction to accommodate the drill guide (Epiguide). The Epiguide is placed flush over the cartilage lesion according to MRI planning map and fixed with surgical pins to the condylar bone (Fig. 9.4a).

A drilling socket is placed on the Epiguide (Fig. 9.4b). The drilling socket guides the precutting of cartilage and the first drill step. The Epicut is used to pre-cut the cartilage before drilling by turning the Epicut one turn clockwise pushing it slightly downwards (Fig. 9.4c). Then, the first drilling step is performed with the Epidrill (Fig. 9.4d). Next, the drilling socket is removed and the adjustment socket inserted, which is used for drilling to the final subchondral depth (Fig. 9.4e). The adjustment socket is used

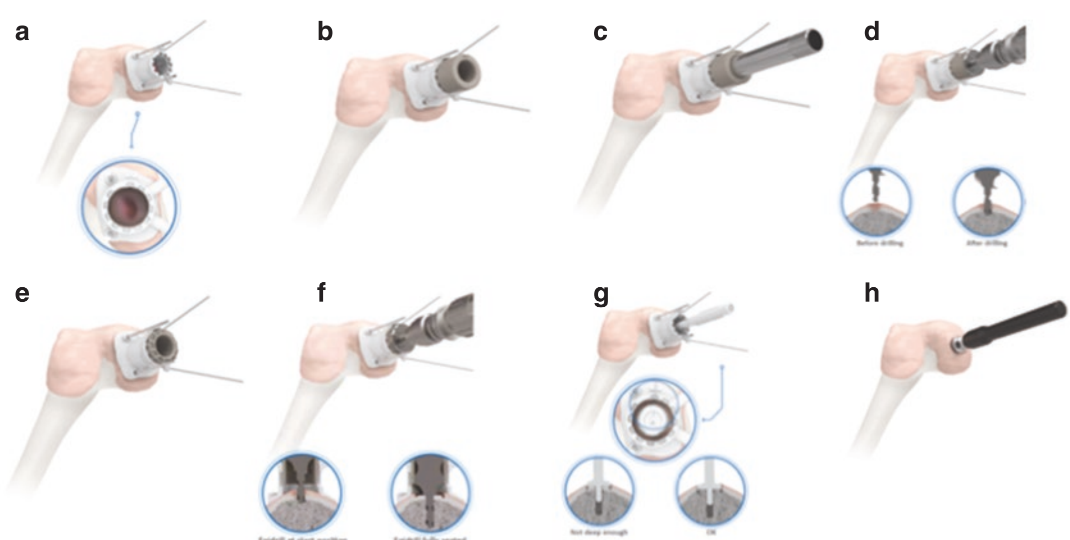

Fig. 9.4 Surgical technique for Episealer implantation. (**a**) Positioning and fixation of the Epiguide. (**b**) The drilling socket in place onto the Epiguide. (**c**) The Epicut used to pre-cut the cartilage before drilling. (**d**) The first drilling step is performed with the Epidrill. (**e**) Next, remove the drilling socket and insert the adjustment socket, which is used for drilling to the final subchondral depth. (**f**) Subsequently regulate the adjustment socket for deeper drilling in 0.2 increments until the drill-hole depth fits the trial implant (Epidummy). (**g**) When the Epidummy top surface is positioned approximately 0.51 mm below the adjacent articular cartilage surface, the drilling is finished. (**h**) Gently tap the Episealer implant into the final seated position

for deeper drilling in 0.2 mm increments until the drill-hole depth fits the trial implant (Epidummy) (Fig. 9.4f). After noting the position of the adjustment socket, it is removed from the Epiguide. All debris is cleared from the drill hole using adequate lavage. After positioning of the Epidummy top surface approximately 0.5–1 mm below the adjacent articular cartilage surface, the drilling is finished (Fig. 9.4g). The proximal direction is marked on the cartilage edge using a sterile pen. This marking is necessary for correct rotational placement of the implant.

Then, the Episealer is inserted into the drilled hole. After checking for correct rotation, the Episealer® is aligned to the rotation mark on the cartilage. Finally, the Epimandrel and a hammer are used to gently tap down the Episealer® into the bone (Fig. 9.4h). When fully seated, the top surface should be approximately 0.5–1 mm below the adjacent articular cartilage surface.

9.5 Biological Response to Resurfacing Implants

Biomechanical studies have demonstrated that the HemiCAP® implants did not result in increased deleterious loading to opposing cartilage surfaced [11]. Biological response to femoral resurfacing implants has been tested in animal studies, in which the HemiCAP® implant was investigated in a goat model. The prosthesis was inserted into the medial femoral condyle with the contralateral joint acting as a control. Normal weight bearing had returned by 4 weeks with a full range of movement. Arthroscopy performed 14 weeks after implantation revealed a moderate synovial inflammation but no tibial plateau defects or meniscal lesions were present. Typically, at the edge, synovial overgrowth and good trabecular bone ingrowth to the fixation anchors were seen. No evidence of implant failure or loosening or gross degenerative changes were radiographically demonstrated. Histological analysis revealed new trabecular bone abutting the implant in all specimens 1 year postoperatively [12].

The bone integration of the Episealer implant, which has a hydroxyapatite coating for enhanced bone ingrowth, has been investigated in a sheep model. It demonstrated more than 90% of bone ingrowth to the implant surface, which was in contact with condylar bone at both 6 and 12 months follow-up [13]. Finite-element analysis of the Episealer implant demonstrated that implants should be placed slightly recessed under the native cartilage surface in order to avoid damage to the opposing cartilage [14]. This finding was also confirmed in a sheep animal model, in which resurfacing implants recessed 0.5 mm did not produce significant injury to opposing cartilage at 12 months follow-up [15].

9.6 Clinical Outcome

9.6.1 Case Series (Table 9.2)

Only limited evidence with regards to clinical outcome and failure rates has been presented to date. The literature mainly consists of case series with small samples and short-term follow-up. For femoral condyle resurfacing arthroplasty of small-sized cartilage lesions, the following studies have presented clinical outcome data.

Bollars et al. studied 27 patients treated with the HemiCAP prosthesis with 34 months follow-up. Hospital for Special Surgery Score improved from 61 to 86. The Knee Osteoarthritis Outcome Score (KOOS) was comparable with published data for normal populations [16]. Becher et al. presented results in 21 patients with average 5.3 years follow-up. These knees operated with HemiCAP® implants demonstrated significant improvement in KOOS scores, knee function and quality of life. Furthermore, no OA progression within 5 years follow-up was seen [17]. Recently, two cases from this study cohort have been presented with excellent outcome 12 years after surgery [18]. Laursen and Lind presented the largest case series (61 patients) and followed these for up to 7 years. They demonstrated significant improvements in Knee Society Score (KSS) and reduced pain scores within the first 2 years.

Table 9.2 Case series clinical outcome after treatment of cartilage lesions with resurfacing implants

Author (year)	Implant	No. of patients	Follow-up	Outcome
Bollars (2011)	HemiCap	27	34 months	Increased HSS: 61–86
Becher (2011)	HemiCap	21	5 years	Increased KOOS pain: 51–78 SF36: 15–47
Laursen (2015)	HemiCap	61	2 years PROM 7 years for revision	Increased KSS (54–91) Revision rate 24%
Laursen (2016)	UniCap	64	2 years PROM 7 years for revision	Increased KSS (49–88) Revision rate 50%
Laursen (2016)	HemiCap wave	18	2 years PROM 6 years for revision	Increased KSS (49–88) Revision rate 28%
Patel A (2017)	HemiCap wave	16	24 months	Increased KOOS Tegner: 1.5–40 SF36: 15–47

Failure rate defined as revision to TKA was 25% within 7 years [19].

For larger and more degenerative defects treated with the UniCAP® implant, Laursen et al. followed up 64 patients for 7 years and demonstrated significant improvements in KSS score and reduced pain score within the first 2 years. However, failure rate defined as revision to TKA was 50% within 7 years [20].

For the trochlear cartilage lesions, the Wave® implant has been investigated in two case series. Laursen followed up 18 patients for 6 years and demonstrated significant improvements in KSS score and reduced pain score within the first 2 years. Failure rate defined as revision to TKA was 28% within 7 years [21]. A study by Patel et al. assessed 16 patients with patellofemoral cartilage injuries and followed up for average 24 months. They demonstrated both improvements in subjective symptoms levels and quality of life [22]. No studies have so far presented clinical outcomes in patients with combined condylar and trochleal resurfacing implantations. Overall, treatment with resurfacing implants for cartilage lesions in the knee demonstrates good early clinical outcomes with reduced pain and improved knee function.

9.6.2 Failure after Resurfacing Implant Treatment

A relatively high failure rate of 24–50% was found. These patients needed reoperation with revision to some type of knee arthroplasty [19]. Such high revision to TKA reoperation rate has also been demonstrated in national knee arthroplasty registries. The Australian Arthroplasty registry has presented revision rates of 28% [23, 24]. In 50% of these revisions, the cause was OA disease progression. This could indicate that the cartilage pathology of early degenerative changes in many instances is a progressive condition that continue despite local resurfacing implant treatment.

9.7 Discussion

Treatment of symptomatic focal cartilage defects with resurfacing implants has been introduced as a treatment modality over the last decade. Implants can be used in both the femoral condyle and trochlea. These implants have different sizes offering relatively minimal invasive procedures compared to unicompartmental arthroplasty and patellofemoral arthroplasty.

The middle-aged patient (35–65 years) with symptomatic early OA cartilage defects is a demanding patient group, expecting pain-free activities of daily living and high activity levels at work and for recreational activities. As conventional knee arthroplasty is often not offered to patients when only focal and early osteoarthritic changes exist despite often severe symptoms, there exists a treatment gap. Recent studies have estimated that 20% of symptomatic knee OA patients in USA fall into this treatment gap [25]. The good results from several case studies demonstrating clinically relevant improvement in function and pain reduction suggest that femoral resurfacing treatment can be used with predictive outcome in patients between 35 and 65 years with localized femoral condyle cartilage lesions. Since degenerative cartilage pathogy tend to progress resulting in a need for revision surgery in 23–50% of patients within 7 years, it is important to consult with patients that the treatment primarily is aimed at providing temporary pain relief and function improvement rather than a permanent solution for early degenerative cartilage pathology. A careful indication and patients` selection are of utmost importance. The implant should only be used for younger patients with isolated deep cartilage lesions, and not suitable for biological repair in knees without generalized degenerative changes. Most likely deep osteochondral pathology such as old osteochondritis dissecans and osteonecrosis should not be treated with a resurfacing implant due to insufficient subchondral bone quality.

There are currently no long-term follow-up data for the use of resurfacing implants. In addition, there are only limited data from joint registries that can elucidate the failure profile of the treatment principle. Although short- and medium-term results appear promising, these need to be confirmed with larger patient cohorts in order to better define when good results can be expected.

Take Home Message

- In conclusion, metallic resurfacing implants can be used to treat symptomatic.
- Focal cartilage defects localized at the femoral condyle and trochlea in middle-aged patients when non-operative treatment has failed.

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10 Patients' Evaluation Prior to Knee Arthroplasty

Michael Salzmann and Roland Becker

Keynotes

- Patients' evaluation for TKA includes:
  1. Patients-specific history.
  2. General medical history in order to identify co-morbidities and malnutrition.
  3. Clinical examination including the neurological and vascular status.
  4. Radiological assessment.
  5. Social assessment.
- Close collaboration with the cardiologist and geriatric specialist is often needed.
- Optimal preparation of the patients for TKA surgery is essential in order to minimize the risk of surgical-related complications.

10.1 Introduction

Musculoskeletal pathologies are on the third position in frequency of medical care worldwide. Partial or total knee replacement belongs to a major intervention with high risk of complications, especially in terms of wound healing, infection and cardiovascular problems. The following factors were associated with an increase in 30 days resubmission rate, such as age below 50 years and above 70 years, congested heart failure (OR = 1.64), diabetes (OR = 1.19), anaemia (OR = 1.19), renal failure (OR = 1.33) and chronic obstructive pulmonary disease (OR = 1.29) [1]. The risk of complication can be minimized when patient' assessment is taken in detail prior to surgery. Surgery should be postponed in patients where optimization of the general medical status can be achieved.

Knee arthroplasty surgery means elective surgery and the risk of complications needs to be minimized as much as possible. Life expectation in Germany has increased from 76.4 years of age in 1995 to 80.6 years in 2016. Patients have become more demanding in terms of daily activity of life. These may explain partially the rising number of patients scheduled for arthroplasty. However, co-morbidities are more likely and may have a significant negative impact on clinical outcome.

The goal is to receive the maximal amount of information about the medical status of the patients prior to surgery. Patients' social status and demand should be exactly known in order to be able to recommend the best individual treatment.

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10.2 Patients' Evaluation

Patients' evaluation includes:

1. Specific history of the knee.
2. General medical history.
3. Clinical examination.
4. Radiological assessment.
5. Social assessment.

10.2.1 Specific History of the Knee

Pain is the major cause when patients ask for medical advice. Pain during daytime and activity is typical for symptomatic osteoarthritis. Patients also report about morning stiffness and pain during the first couple of steps after getting out of bed. In contrast, pain at night is rather characteristic of synovitis of the knee commonly in conjunction with effusion. These patients present less pain during daily activity. This information is of importance, especially for the conservative management. Steroid injection may help to treat the synovitis in combination with non-steroidal anti-inflammatory drugs. The literature has shown that intraarticular steroid injection prior to arthroplasty surgery does not increase the risk of infection [2, 3]. However, Marsland et al. [4] stated that most of the studies seem to be underpowered and there is a risk of selection bias. A more recent study based on a national database showed that steroid injection within 3 months prior to knee arthroplasty is associated with increased rate of periarticular joint infection [5].

Arthroscopy 6 months prior to total knee arthroplasty did not show an impact on early infection [6].

> **Side Summary**
> No injection within 3 months prior to arthroplasty surgery is recommended due to increased risk of periarticular joint infection

Previous surgery such as high tibial or distal femoral osteotomy may have had an impact on outcome after knee arthroplasty. A multicentre analysis of the French Society of Orthopaedics and Traumatology showed slightly higher complication rate at the early post-operative phase in patients with TKA after open-wedge osteotomy. However, late complication such as component loosening or infection was more frequent in the closed-wedge group [7]. Another study based on a computer model using the dataset of 40 patients showed that the tibial component placed closer to the cortical bone after closed than after open-wedge osteotomy [8]. No clinical impact was noticed whether open- or closed-wedge osteotomy was performed prior to total knee arthroplasty [9].

A systematic review of the literature did not find difference in clinical outcome but stated that total knee arthroplasty after closed-wedge osteotomy shows more surgical concerns [10].

> **Side Summary**
> TKA after closed-wedge osteotomy seems to be of more technical concern than after open-wedge osteotomy

Infection prior to knee arthroplasty is always an aspect of major concern. There is a potential risk of developing periarticular joint infection (PJI) after TKA. Biopsies should be taken when unsure about the situation prior surgery.

10.2.2 General Medical History

The medical history of the patients is very important in order to detect potential risks and complications for surgery. The most frequent co-morbidities are as follows: diabetes mellitus, anaemia, cardiovascular diseases, renal failure, neurological diseases, nutrition status and obesity.

The American Society of Anesthesiologists Classification (ASA Class) (https://www.asahq.org). The patients are classified into groups I to V.

ASA PS classification system: Last approved by the ASA House of Delegates on October 15, 2014

ASA PS classification	Definition	Examples including but not limited to
ASA I	A normal healthy patient	Healthy, non-smoking, no or minimal alcohol use
ASA II	A patient with mild systemic disease	Mild diseases only without substantive functional limitations. Examples include (but not limited to): Current smoker, social alcohol drinker, pregnancy, obesity (30 < BMI < 40), well-controlled DM/HTN and mild lung disease
ASA III	A patient with severe systemic disease	Substantive functional limitations; one or more moderate-to-severe diseases. Examples include (but not limited to): Poorly controlled DM or HTN, COPD, morbid obesity (BMI ≥40), active hepatitis, alcohol dependence or abuse, implanted pacemaker, moderate reduction in ejection fraction, ESRD undergoing regularly scheduled dialysis, premature infant PCA < 60 weeks, history (>3 months) of MI, CVA, TIA or CAD/stents
ASA IV	A patient with severe systemic disease that is a constant threat to life	Examples include (but not limited to): Recent (<3 months) MI, CVA, TIA or CAD/stents, ongoing cardiac ischemia or severe valve dysfunction, severe reduction in ejection fraction, sepsis, DIC, ARD or ESRD not undergoing regularly scheduled dialysis
ASA V	A moribund patient who is not expected to survive without the operation	Examples include (but not limited to): Ruptured abdominal/thoracic aneurysm, massive trauma, intracranial bleed with mass effect, ischemic bowel in the face of significant cardiac pathology or multiple organ/system dysfunction
ASA VI	A declared brain-dead patient whose organs are being removed for donor purposes	

Please find more details at the following website: (https://www.asahq.org).

The following blood parameter should be analysed prior to surgery.

Parameter	Reference
Haemoglobin	Male: 13–17 g/dL Females: 10–16 g/dL
Haematocrit	Male: 0.4–0.6 Females: 0.35–0.48
Leukocytes	3.5–10 × 10^9/L
Mean platelet volume (MPV)	7.2–11.7 fL
Mean cell volume (MCV)	Male 76–102 fL Female 78–102 fL
Sodium	135–147 mmol/L
Potassium	3.5–5 mmol/L
Chloride	95–105 mmol/L
Glomerular filtration rate	90 mL/min/1.73m^2
HbA1c	28–38 mmol/Mol
C-reactive protein	<5 mg/L
Transferrin	190–360 mg/dL
Ferritin	Males 12–300 μg/L Females 27–650 μ/L

10.2.2.1 Diabetes Mellitus (DM)

DM shows a direct impact on clinical outcome after TKA. A systematic review of the literature reported an increased risk of periarticular joint infection (OR = 1.61), deep vein thrombosis (OR = 2.57), prosthetic fracture (OR = 1.89) and aseptic loosening (OR = 9.36) [11]. Lower functional scores based on the knee society score (KSS) after 1 and 10 years of follow up was found in a matched pair study [12]. Lower range of motion was reported throughout the entire follow-up time. The comparison of patients with and without controlled DM showed longer stay in hospital and more frequent cardiovascular accidents or events of pneumonia, haemorrhage and infection in patient with uncontrolled DM.

Patients who need insulin or oral anti-diabetic medication and patients with hyperglycaemia have a significant higher risk of PJI [13]. The effect was attenuated when adjusted for BMI, ASA and operating time. No correlation between HbA1c and PJI has been shown. However, other studies reported about increase in PJI and wound complication in patients with increased HbA1 level [11, 14–16].

Side Summary

Diabetes mellitus and increased HBA1c level cause increased risk of complications and lower functional outcome after TKA

HbA1c level may serve as a predictor. Uncontrolled diabetes in patients should be of concern when presenting blood glucose levels greater than 200 mg/L or haemoglobin Hba1c of greater than 7% [17, 18]. These patients require optimization in treatment of the DM.

Side Summary
HbA1c level should be lower than 8% prior to surgery.

10.2.2.2 Anaemia

Anaemia is defined as a blood condition of decrease in number of erythrocytes. The prevalence of pre-operative anaemia in orthopaedic surgery ranges from 7% to 35% [19]. An observational study showed that 14% of patients awaiting elective orthopaedic surgery were anaemic and 85.7% became anaemic after surgery.

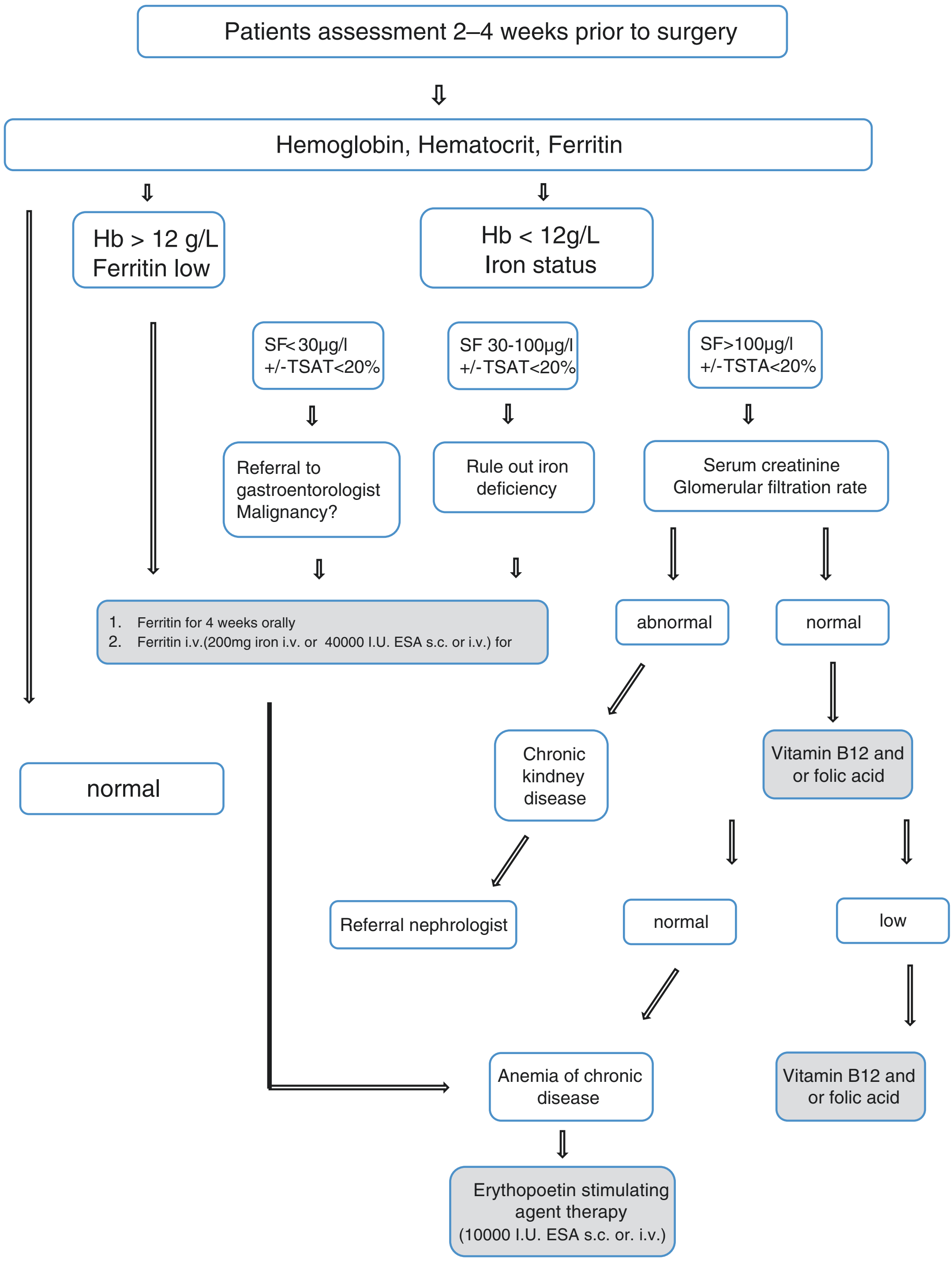
Anaemia is considered when the haemoglobin level is below 12 g/L in female and below 13 g/l in male patients according to the recommendations by the World Health Organization (http://whqlibdoc.who.int/publications/2008/9789241596657_eng.pdf). The estimated and average loss of haemoglobin during primary TKA surgery is about 3.8 g/dL [20].

The prevalence of asymptomatic gastric and duodenal lesions is about 78% and 26%, respectively, and may cause potentially anaemia [21, 22]. Pre-operative anaemia is associated with an increased risk of morbidity and mortality after surgery [23]. The transfusion rate and re-admission rate to hospital increase within the first 30 days after surgery [24].

Pre-operative anaemia can be caused by:

1. Decreased production of red blood cells (disorder of proliferation and differentiation of the erythropoetic stem cells).
2. Increased destruction of red blood cells (decrease in lifetime of the erythrocytes).
3. Loss of erythrocytes due to bleeding (e.g. gastrointestinal bleeding).

The network for advancement of transfusion alternatives (NATA) has developed practical guidelines for the evaluation and management of pre-operative anaemia in orthopaedic patients [25].


Patients assessment 2–4 weeks prior to surgery
Hemoglobin, Hematocrit, Ferritin
Hb > 12 g/L
Ferritin low
Hb < 12g/L
Iron status
SF< 30µg/l
+/-TSAT<20%
SF 30-100µg/l
+/-TSAT<20%
SF>100µg/l
+/-TSTA<20%
Referral to
gastroentorologist
Malignancy?
Rule out iron
deficiency
Serum creatinine
Glomerular filtration rate
1. Ferritin for 4 weeks orally
2. Ferritin i.v.(200mg iron i.v. or 40000 I.U. ESA s.c. or i.v.) for
abnormal
normal
normal
Chronic
kindney
disease
Vitamin B12 and
or folic acid
Referral nephrologist
normal
low
Anemia of chronic
disease
Vitamin B12 and
or folic acid
Erythopoetin stimulating
agent therapy
(10000 I.U. ESA s.c. or. i.v.)

Pre-operative pathway for patients scheduled for TKA surgery, adapted from [25].

Iron deficiency and anaemia due to chronic diseases are the major causes of anaemia prior to surgery. Anaemia should be treated with erythropoiesis-stimulating agent in combination with intravenous iron supplementation [26]. Based on a Cochrane analysis, red blood cell transfusion should be restricted to haemoglobin concentration less than 7 or 8 g/dL [27].

A consensus statement recommends that patients who may face post-operative anaemia receive i.v. iron [28]. However, the evidence for the recommendation is rather moderate to low.

Side Summary

Ion and ferritin should be measured prior to arthroplasty in order to diagnose and sufficiently treat patients with anaemia.

10.2.2.3 Cardiovascular Diseases

Hypertension, chronic ischemic cardiac disease, history of myocardial infarction, stent implantation and arrhythmia are the most common cardiac co-morbidities of the patients scheduled for TKA. The risk of cardial complications after TKA is 0.33% [29]. Age over 80 years (OR = 27.95), hypertension with medical treatment (OR = 4.74) and history of cardiac disease (OR = 4.46) were the most significant predictors of development of cardiac complications after surgery. A systematic review and meta-analysis of the literature have shown that cardiac disease increases the risk of surgical site infection (OR = 1.92), short-term mortality (OR = 2.9) and re-admission to the hospital (OR = 1.6) [30].

To improve the predicting capacity of existing cardiac risk factors for non-cardiac surgery, guidelines have been released by the American College of Cardiology and American Heart Association [31]. A simple joint arthroplasty cardiac risk index has been introduced [32]. The index is based on the predictive factors of hypertension, a diagnosis of cardiac disease and age of 80 years or older; and thus, ranges from 0 to 3. A strong correlation has been seen between the index and cardiac complications after surgery. In case there is one factor positive, the OR shows 2.2; and in case of all three factors, the OR increases to 11.19.

There is a risk for cerebrovascular accident of 0.08% after TKA. Independent risk factors for patients older than 75 years of age are insulin-dependent diabetes mellitus (OR = 3.08), hypertension (OR = 2.71), history of transient ischemic attack (OR = 2.83), dyspnoea (OR = 2.51) and operating time over 180 min [33].

10.2.2.4 Chronic Renal Disease (CRD)

It has been estimated that there is a prevalence of chronic renal disease (CRD) of 35% in adults with diabetes disease and over 40% in individuals over the age of 60 years [34]. Patients suffering on CRD have a 1.9 times (95% CI: 1.1–3.5) higher risk of superficial site infection (SSI), 1.3 times (CI: 1.1–1.6) higher risk of hospital re-admission within 90 days and 1.5 times (CI: 1.2–1.8) higher risk of mortality at any point after the procedure after adjustment for confounding variables [35].

Kidney function changes with increase in age and a cross-sectional study showed a constant decline in renal function of patient between ages of 30 and 92 years [36].

The assessment of renal function prior to surgery should include creatinine concentration and glomerular filtration rate.

10.2.2.5 Neurological Diseases

Neurological assessment of the lower limb should be performed prior to surgery in order to exclude pathology at the lumbar spine. The Oswestry Disability Index (ODI) is a well-validated instrument to perceive levels of disability in 10 different everyday activities [37]. The prevalence of significant low back pain in patients scheduled for total knee arthroplasty is 16% [38]. Surgeons should be aware that functional outcome is worse in patients suffering with chronic back pain [39, 40].

Patients with both osteoarthritis of the knee and low back pain show increased asymmetry in hip adduction and flexion patterns [41]. Patients with knee pain may present pathologies caused by nerve root L3 or L4. Quadriceps atrophy is caused by L4 radiculopathy [42].

10.2.2.6 Rheumatoid Arthritis (RA)

The American College of Rheumatology and the American Association of Hip and Knee Surgeons released guidelines for the perioperative management of patients with rheumatic diseases [43].

Eighty per cent of the patients have cervical spine involvement and need to be taken into consideration when the patient will be positioned on the operating table. Radiographies prior to surgery should be considered in these patients. Evaluation of the joints for swelling and destruction is mandatory.

Based on a national database, it has been shown that patient with rheumatoid arthritis, psoriatic arthritis and ankylosing spondylitis had higher perioperative complication rate such as infection, systemic complication and 90-day readmission rate to the hospital after TKA in comparison with osteoarthritic patients [44]. There is also an increase in the revision rate of these patients after mid- and long-term follow up [45]. Late revision shows an OR of 2.5.

No difference was found in 90-day mortality rate or thrombosis. Revision due to infection is significantly higher in rheumatoid patients compared to osteoarthritic patients [46].

Methotrexate should be continued perioperatively. A 2% infection rate was demonstrated when methotrexate was continued compared to 15% of infection when the treatment was stopped as shown in a prospective randomized study [47].

Poor bone stock, significant deformity and contraction may cause higher constrained implants. Mostly patients present severe valgus deformity and stretching of the medial collateral ligament. A higher risk of instability has been reported when posterior cruciate preserving implants were used [48].

10.2.2.7 Malnutrition

'Malnutrition is a state of disordered nutrition, in which a combination of varying degrees of over- or undernutrition and inflammatory activity has led to a change in body composition, diminished function and outcome' [49]. Malnutrition may be assessed by nutrition balance, body composition (muscle mass), inflammatory activity (plasma albumin and C-reactive protein), muscle endurance and force [50].

An analysis of 600 revision knee arthroplasties showed a prevalence of malnutrition in 38% of the patients [51]. Malnutrition causes regularly poor wound healing and prolongation in oozing [52].

Malnutrition also causes decrease in total protein, albumin and vitamin B1, B12 and D.

The vitamins are important for biological function of the body.

	Reference	Function
Total plasma protein	60 g/L	• Create and maintain the oncotic pressure • Transport of lipids, vitamins, steroid hormones and minerals • Function of the immune system
Albumin	35–55 g/L (60%)	• Carrier protein for steroids, fatty acids and thyroids hormones • Maintains oncotic pressure
Vitamin B1	2.5–7.5 μg/dL	• Impact on carbon hydrate metabolism • Important for the function of the thyroid • Important for function of the nerves
Vitamin B12	200–900 pg/ml	• Regeneration and formation of red blood cells • Important for function of the nerves • Improvement in appetite
Vitamin D (cholecalciferol)	20–70 ng/ml	• Improvement of calcium uptake
Zinc		• Essential tracer element • Catalytic agent in hydroxylation • Acts as a messenger in signalling pathways • Important for reading DNA sequences

	Reference	Function
Selenium	60–150 ng/mL	• Tracer element • Essential micronutrition • Co-factor for reduction in antioxidant

Malnutrition may cause:

- Changes in the body composition
- Disturbance of the immune response
- Decrease in physical activity
- Decrease in cardiac function
- Decrease in pulmonary function
- Decrease in the visceral protein synthesis
- Apathy and depression

Side Summary
Malnutrition is often underestimated not only in elderly patients but also in obese patients.

10.2.2.8 Obesity

A BMI between 25 and 30 kg/m^2 is defined as overweight, and obesity when the body mass index (BMI) exceeds 30 kg/m^2. According to the report of the World Health Organization, 39% of woman and men aged 18 and over are overweight. It has been estimated that in 2013 more than 2 billion people were overweight and 671 millions of them obese [53]. Obesity has an important contribution to the incidence of osteoarthritis, cardiovascular disease and type 2 diabetes [54]. Overweight and obesity have a 40 to 100% increased risk of surgery [55].

Patients with a body mass index of over 40 kg/m^2 were matched with a group of non-obese patients BMI < 30 kg/m^2 in a prospective matched pair study [56]. Lower outcome according to the Knee Society Score and a higher incidence of radiolucent lines (29% vs. 7%), a higher rate of complication (32% vs. 0%) and inferior survivorship were found in the obese group. It has been advised that obese patients should lose weight prior to TKA surgery. Obese patients showed higher risk of early infection (OR = 1.3), deep infection (OR = 2.38), wound dehiscence and genitourinary infection [57, 58].

10.2.2.9 Smoking

The median smoking prevalence of the world population is 17.8% (3–70%) [59].

Smokers have a higher risk of wound complication (OR = 1.47) [60]. Cigarette smoking reduces blood flow by up to 40% due to vasoconstriction [61]. Higher tissue lactate level has been reported and prolonged tissue acidosis increases the risk of infection. Hypoxia promotes the colonization of bacteria in the tissue. Smoking also effects the proliferation and remodelling of wound healing. Inhibition occurs in fibroblast chemotaxis, migration and proliferation. The collagen I and III production is reduced.

Smokers show an increased risk of revision [62]. Bone healing is affected similar to wound healing due to smoking. The likelihood of malunion after fracture is about 37% and there is a significantly prolonged time for fracture union [63]. Smoking is associated with decrease in bone mineral density and may occur indirectly due to altered calciotropic hormone metabolism, which reduces calcium absorption. Osteoblast like cell proliferation and differentiation is inhibit due to alteration of the RANK–RANKL–OPG system, which promotes osteoclast formation and activation.

Side Summary
Be aware of inferior wound and bone healing in smoker

10.2.2.10 Alcohol Misuse

Alcohol misuse is an independent factor for poor outcome after total knee arthroplasty [64]. Higher surgical-related complications (OR = 1.334) and general medical complications (OR = 1.3) have been reported.

Alcohol misuse is beside chronic pulmonary disease, depression, renal disease, hemiplegia or paraplegia, and obesity one of the most significant independent risk factors for early revision after TKA [65].

10.2.2.11 Depression

Patients' satisfaction should be considered as the predominant parameter for successful TKA. Patients' satisfaction is influenced by surgical-related and patients-related factors. Pain, mental health and emotional role have significant impact on patient's outcome [66]. A logistic regression analysis was performed in order to identify factors, which may influence patient satisfaction [67]. Depression, diabetes, back pain, WOMAC stiffness score and SF-12 physical and mental components negatively influenced patient satisfaction. A clinical prediction model was introduced recently [68]. Low pre-operative Oxford knee score, obesity and patients reported anxiety or depression were associated with worst outcome. Clinical factors such as worse pre-operative physical status, presence of other conditions affecting mobility and previous knee arthroscopy worsened the outcome. Similar findings were also reported by Hanusch et al. who also reported worse knee scores at 6 weeks and 1 year in patients suffering from depression and anxiety [69]. However, studies have also shown that TKA may cause improvement in anxiety and depression scores at 6 weeks and 1 year [70]. The scores showed a slight deterioration after 7 years but remained significantly better than prior to surgery.

> **Side Summary**
> Patients mental status needs to be assessed carefully prior to TKA.

10.2.2.12 Urinary Tract Infection

Urine analysis is performed routinely prior to TKA. Escherichia coli is the most common organism in case of urinary tract infection. Symptomatic infections should be distinguished from asymptomatic infection. The prevalence of asymptomatic urinary tract infection is between 3% and 5% [71]. The role of urinary tract infection (UTI) in the development of periarticular joint infection remains controversial. While some authors state a direct link between UTI and PJI, others have shown no association [72]. The study by Weale et al. reported PJI in 5% of patients who presented with asymptomatic urinary tract infection and in 0.61% of no infection patients [73]. In one of seven patients, the same microorganism was identified. The authors concluded that the relationship between UTI and PJI is unlikely.

Based on these findings, it has been recommended that patients with symptomatic urinary tract infection such as dysuria, urgency, frequency and more than 1×10^3 of bacteria/mL of urine should receive treatment, and surgery should be postponed. In case the patient is asymptomatic despite the presence of 1×10^3 of bacteria/mL, there is no need to postpone surgery but a routine course of antibiotics should be given after surgery [74].

It has been questioned whether routine urine analysis prior to total joint arthroplasty is beneficial [75]. It has been shown recently that asymptomatic urinary tract infection requires no delay of surgery.

10.2.3 Clinical Examination

The clinical examination is the most crucial part of patient assessment prior to surgery. The decision whether a partial or total knee arthroplasty should be implanted depends predominantly on patient symptoms and clinical findings, for instance. The constraint of the implant depends on the degree of knee instability, identified during clinical examination.

The clinical examination should be divided into four parts:

1. Inspection.
2. Feel.
3. Move.
4. Specific testing.

10.2.3.1 Inspection

The knee should be evaluated first just by looking at the lower limb. Information will be received about the alignment, muscle atrophy, intra- and/or extraarticular swelling, scares and general skin conditions. Severe atrophy of the quadriceps muscle indicates the impaired function of the knee or hip. The lumbar spine needs to be taken into consideration as well. Radicular lesion of the fourth lumbar nerve root may cause quadriceps atrophy.

10.2.3.2 Feel

Palpation is very important. You may identify swellings, which might be fixed or mobile to the bone. Scares from previous surgeries can be fixed or mobile to the underlying bone as well. Especially in traumatic patients who require total knee arthroplasty, the soft tissue needs to be evaluated very carefully. One should look for tenderness over the medial or lateral joint line. Especially when patients solely complain about pain over the medial or lateral joint line, isolated varus or valgus osteoarthritis can be considered.

Longitudinal and transvers movement of the patella will provide information about patella mobility. Crepitation behind the patella during knee movement typically for OA in the patellofemoral compartment, which does not need to be painful.

10.2.3.3 Move

The assessment of range of motion includes the documentation of the extension and flexion deficits. The zero pass method is very helpful because the documentation is very clear. All joints are defined as zero when the person stands upright. The zero pass methods provide three numbers: range of extension–zero–range of flexion. Zero always mean the physiological position of the joint.

For example:

- Knee flexion and extension of **100°-0°-0°** means: Flexion of 100°, zero position can be achieved with no extension.
- Knee flexion and extension of **90°-20°-0°** means: Flexion is 90° and zero position is 20° because the patient is unable to get to the zero position.

10.2.3.4 Specific Testing

Specific tests include the assessment of the anteroposterior and mediolateral stability. The Lachmann test, the most sensitive test to examine the function of the anterior cruciate ligament, while the knee is flexed to 20° [76]. The anterior and posterior drawer test provides information about the anteroposterior stability examined when the knee is flexed to 90°. The step-off of the tibial plateau in reference to the distal femoral condyle and serves as a good landmark to identify an increase in anteroposterior translation.

The mediolateral stability of the knee should be examined not only in full extension but also in 10° and 45° of knee flexion. The mediolateral stability in full extension is primarily provided by the posterior capsule and secondary by the collateral ligaments. The function of the collateral ligament can be assessed having the knee flexed to 10°. A lateral opening of 2 mm on the lateral site is normal. In contrast, no medial opening should be expected.

Beside the knee, assessment of the ankle and hip joint is important. The origin of pain may come from the two other joints. It should be especially taken into consideration when the weight-bearing radiographies of the knee present minor osteoarthritic changes only.

Side Summary
Use always the same algorithm during clinical examination.

10.2.4 Radiological Examination

A standard series of radiographies should be taken in order to allow proper planning including the following images:

Radiography	Information
Full-leg weight-bearing radiography	Assessment of the mechanical and anatomical alignment of the lower limb by using the centre of the hip, knee and ankle as reference points

Radiography	Information
Lateral view	Information about the trochlear groove in order to identify dysplasia Information about the posterior offset of the femoral condyle
Merchant view	Information about the patellofemoral compartment, patella tracking and the shape of the patella according to Wiberg
Patellofemoral weight-bearing view (Baldini's view [77])	Patellofemoral axial weight-bearing view taken in a semi-squatting position of the patient
Varus and valgus stress radiographies	Information about the stability of the medial and lateral collateral ligament by using the Telos® instrument

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Cardiovascular Comorbidity in Patients Scheduled for TKA

11

Oliver Ritter

Keynotes

- Presurgical evaluation should consider change in the demographics of patients (elderly patients).
- Risk assessment should be performed along with standardized risk scores and the basic evaluation in high-risk patients has to include the patient's history, electrocardiograph (ECG), echocardiography, and biomarkers.
- Beside cardiovascular evaluation, a general assessment of the pulmonary and kidney function is required, since cardiovascular patients suffer mostly from several diseases. This is especially important in heart failure patients, as heart failure is a syndrome involving all other organ compartments.
- Postpone elective surgical procedures in case of decompensated heart failure in order to avoid unnecessary complications.

11.1 Introduction

The pathophysiological reaction to a surgical insult is determined by the tissue injury and may induce sympathetic and parasympathetic imbalance. Usually, this situation is well tolerated by a healthy organism but increases in myocardial oxygen consumption occur. In patients with preexisting cardiovascular or pulmonary diseases, this might cause severe side effects or deterioration of a prior stable condition. Surgical procedures also cause alterations in the balance of thrombotic and fibrinolytic factors, potentially resulting in an increase in cardiovascular thrombogenic or thromboembolic events.

11.2 Risk Indices

Risk indices are estimated to judge perioperative complications and to help surgeons' decision process. Therefore, they represent useful tools for patient assessment, physicians' calculation of the need for cardiac evaluation, additional drug treatment, and the potential risk of cardiovascular adverse events. Risk scores offer a more or less objective overview of the side effects of a surgical procedure in the context of a cardiovascular disease and can be used for the elucidation of patients and for obtaining an informed consent. As one example, the **Lee Cardiac Risk Index** was developed to predict an array of postopera-

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tive complications, including myocardial infarction, pulmonary edema, ventricular fibrillation, or cardiac arrest and complete heart block [1]. However, as the majority of other indices it was introduced decades ago. Since then, significant changes have occurred and the current treatment of cardiovascular diseases and perioperative management of surgical patients have often changed thoroughly. A novel and currently broadly used predictive model was developed on the basis of the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) [2]. The primary end point was intra- or postoperative myocardial infarction or cardiac arrest within 30 days after the procedure. Five independent predictors of adverse cardiovascular events were identified: type of surgery, functional status, elevated creatinine, American Society of Anesthesiologists (ASA) class, and age (http://www.surgicalriskcalculator.com/miorcardiacarrest). Of note, this calculator focuses less on preexisting cardiovascular comorbidities but more on the patient's general condition and of course decisions on surgery in cardiac patients should not be made only on the basis of risk predictors. But those indices help to identify patients at high risk.

11.3 Cardiac Biomarkers

Biomarkers are used for myocardial ischemia or left ventricular (LV) dysfunction. Cardiac troponins are the preferred markers for the diagnosis of myocardial cell damage and necrosis (i.e., ischemia), as they have high sensitivity and tissue specificity. Nevertheless, elevated troponins need translation into the clinical context. Hypertension, heart failure, tachyarrhythmias, or renal failure can also cause significant elevations [3].

N-terminal pro-brain natriuretic peptide (NT-proBNP) is produced in cardiac myocytes in response to increased myocardial wall stress. NT-proBNP levels add diagnostic and prognostic value for cardiovascular mortality, recurrent heart failure decompensations, readmissions and for cardiac events after a major noncardiac vascular surgery [4–6]. But as data from controlled trials on the use of preoperative biomarkers are currently lacking, the European Society of Cardiology (ESC) does not suggest routine use in perioperative screening, unless it seems to be clinically indicated.

11.4 Noninvasive Testing of Cardiac Disease

11.4.1 Electrocardiography

The 12-lead electrocardiograph (ECG) is a long-established standard technique and is recommended as a basic part of the preoperative risk assessment for patients scheduled for surgery. It offers easy-to-obtain and important prognostic information and is predictive of long-term outcome, independent of direct clinical findings [7]. However, the ECG may be nonspecific in patients with prior myocardial ischemia and all findings need interpretation like bundle branch block or pacemaker ECGs.

11.4.2 Echocardiography

Routine echocardiography is not recommended for the normal preoperative evaluation. But in asymptomatic patients with high surgical risk or in patients with suspected heart disease, echocardiography may be performed to gain more information on the patient's status [8]. Especially, moderate-to-severe mitral regurgitation or advanced aortic stenosis are findings that are associated with major cardiac events [9].

11.4.3 Noninvasive Testing of Ischemic Heart Disease

In patients with limited exercise capacity due to joint disease, the alternative of pharmacological stress testing assessed by nuclear perfusion imaging or stress-echocardiography is the method of choice. In those patients, pharmacological stress is an established alternative to physical activity testing. The prognostic value of the extent of ischemia in the myocardium was investigated recently [10]. In this analysis, patients with an extent of the reversible ischemic defects from 20% to 50% of the total myocardium were at increased risk.

Although coronary artery disease may be present in a large number of patients requiring knee replacement especially in an older population, the indications for preoperative coronary angiography and revascularization mirror the regular indications as in any other patient [11–14]. Coronary angiography is not indicated merely to the fact that surgical procedures are planned.

Side Summary
Patient's history, physical examination, risk indices, biomarkers, and 12-lead ECG are basic tests in the preoperative evaluation of cardiovascular patients. Echocardiography, stress testing, or cardiac catheterization is only indicated in high-risk patients or if advanced heart disease is suspected.

11.5 Perioperative Management in Patients on Antiplatelet Agents or Anticoagulation Therapy

11.5.1 Aspirin

The discussion on the use of perioperative aspirin is controversial. A large meta-analysis, including 49,590 patients, compared periprocedural withdrawal vs. bleeding risks of aspirin, and found that the risk of bleeding on aspirin therapy was increased by 50%. On the other hand, aspirin nonadherence on aspirin therapy tripled the risk of major adverse cardiac events [15].

In conclusion, the continuation of low-dose aspirin (<100 mg once daily) in patients with a need for surgery should be based on an individual decision weighing bleeding risk against thrombotic complications which also includes questioning of temporal sequences of events.

Side Summary
Continuation of aspirin increases the risk of bleeding by 50% but tripled the risk of major adverse cardiac events.

11.5.2 Dual Antiplatelet Therapy (DAPT)

Approx. 20% of patients with coronary stents require noncardiac surgery within 5 years after stent implantation. Therefore, the question of dual antiplatelet therapy around surgical procedures is crucial. Among other factors, the probability of stent thrombosis varies dependent on the site of stent deployment. Accordingly, the respective management of the antiplatelet regimen in patients with recent coronary stenting is best discussed between the involved medical disciplines. To reduce the risk of surgical site bleeding, current European Society of Cardiology (ESC) Guidelines recommend delaying elective surgery whenever possible and instead performing surgery after cessation of the P2Y12 inhibitor (clopidogrel, prasugrel, and ticagrelor) but without discontinuation of aspirin [13]. While noncardiac surgery performed early after mere balloon angioplasty is not associated with an increased risk of cardiac events [16], previous stenting changes the risk.

Surgery without dual antiplatelet therapy within weeks after coronary stenting caused fatality rates of 20% [17]. After bare metal stent (BMS) implantation, elective surgery should be delayed for at least 4 weeks.

Side Summary
Interruption of dual antiplatelet therapy should be avoided after coronary stenting for at least 4 weeks

Then P2Y12 inhibitors can be withdrawn from therapy. Aspirin should be continued throughout surgery [18]. Knowledge about the stents used is important for a precise assessment of the thrombotic risk. For the first generation of drug eluting stents (DES), there was the need for prolonged DAPT (aspirin plus clopidogrel) for 12 months. For the second- and third generation of drug eluting stents, DAPT for 6 months is recommended based on the currently available data. However, observational data from the latest generation zotarolimus-eluting and everolimus-eluting stents suggest that even shorter durations of dual antiplatelet therapy might suffice [19].

To summarize current knowledge in this highly dynamic and developing field, it is recommended that DAPT is administered for at least 1 month after BMS implantation in stable coronary artery disease [19] and for 6 months after new-generation DES implantation [19]. DAPT duration is suggested for up to 1 year in patients after acute coronary syndromes, irrespective of the use of bare metals or drug eluting stents [19]. Urgent surgical procedures in those patients should be performed in hospitals where 24/7 catheterization capabilities are available to treat patients immediately in case of thrombotic events. In patients needing urgent surgery, current ESC Guidelines recommend to withhold clopidogrel and ticagrelor for 5 days and prasugrel for 7 days prior to surgery, unless there is a high risk of thrombosis [13] but individual decisions are favored.

For patients with a very high risk of stent thrombosis, there is an option of bridging with intravenous reversible glycoprotein inhibitors. However, the inhibition of platelet function is higher in those drugs compared to oral medications. Within 48 h the dual antiplatelet therapy should be continued, if possible, from a clinical point of view.

Side Summary
Dual antiplatelet therapy should be continued 48 h after surgery.

11.6 Perioperative Management in Patients on Anticoagulants

In patients under anticoagulation with a high thromboembolic risk (i.e., atrial fibrillation with a CHA_2DS_2-VASc score of ≥4; mechanical prosthetic heart valves; newly inserted biological prosthetic heart valves; mitral valve repair within the last 3 months; recent deep vein thrombosis or pulmonary thromboembolism, thrombophilia) even short cessation of anticoagulation might be harmful. These patients need bridging therapy [20]. In patients on direct novel oral anticoagulants (NOACs) bridging prior to surgery is in most cases unnecessary, due to their short pharmacological half-lives. In general, NOACs are stopped for two times their respective half-lives before surgery and up to four times the biological half-lives before surgery, if high bleeding risk is assumed [21, 22]. Because of the fast onset of NOAC effects compared to vitamin K antagonists, continuation of treatment should be delayed for 1–2 days. In some cases (recent deep vein thrombosis), prophylactic doses of anticoagulants may be enough. Similar to decision-making in patients on dual platelet therapy, team decisions between surgeons and cardiologists are strongly recommended, even more in patients with a necessity for triple therapy (anticoagulants plus dual antiplatelet therapy) (Fig. 11.1).

Side Summary
In patients on dual antiplatelet therapy (DAPT) or triple therapy (DAPT + anticoagulation) withholding one or several of the compounds depends on the respective indication (acute or stable situation), further on the type, length, size, and site of the coronary stents and the extent of the embolic risk.

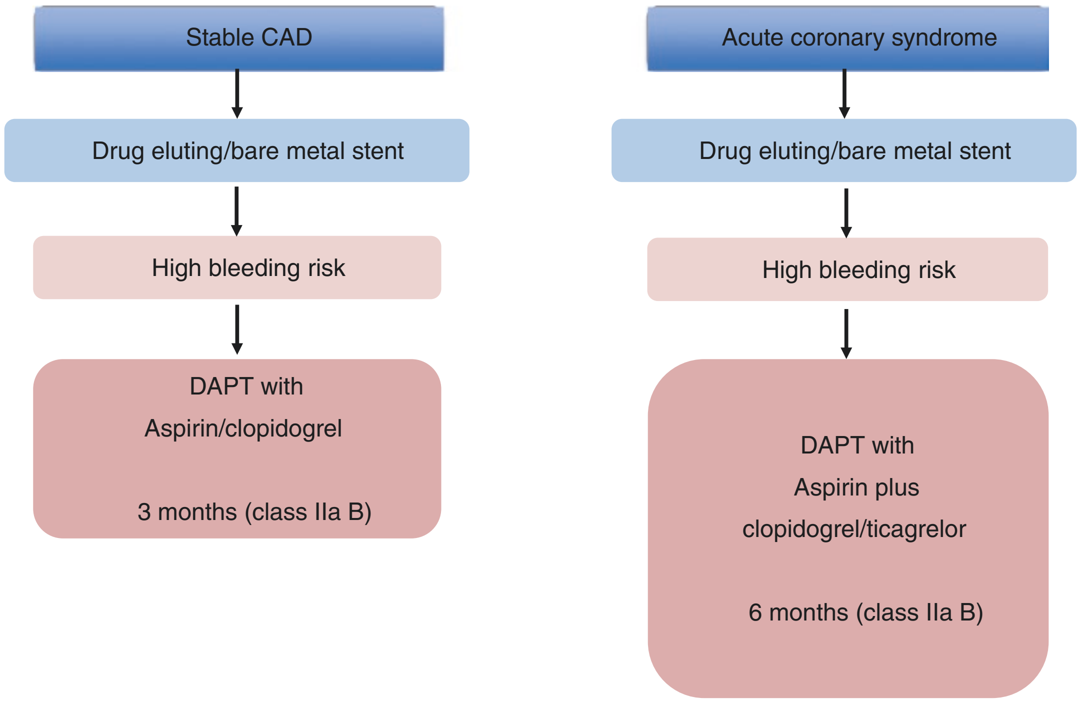

Fig. 11.1 Algorithm for dual antiplatelet therapy (DAPT) in patients treated with percutaneous coronary intervention. Stable CAD = stable coronary artery disease. High bleeding risk is considered as an increased risk of spontaneous bleeding during DAPT (e.g., PRECISE-DAPT score > _25). Simplified version of the ESC guidelines on dual antiplatelet therapy [13]

11.6.1 Chronic Heart Failure

The diagnosis of heart failure is established by symptoms, clinical signs of heart failure, and a reduction of left ventricle function, defined by a reduction of ejection fraction or by diastolic dysfunction [23]. The preoperative evaluation should include physical examination, ECG, biomarkers, natriuretic peptides, chest X-ray, and echocardiography. Special attention should be given to the patient's volume status like peripheral or pulmonary edema, since high-volume infusions are regularly needed in the intra- and immediate postoperative setting.

A reduction in the left ventricular ejection fraction (LVEF) to below 35% is a strong predictor of postoperative cardiac events [24]. In contrast, the prognostic impact of heart failure with preserved ejection fraction (HF-pEF) on perioperative morbidity and postoperative mortality is not clear. A recent trial on surgical patients found no significant differences in adverse events between controlled HF-pEF and heart failure with reduced ejection fraction (HF-rEF) [25]. With the lack of controlled trials, perioperative management is recommended to be identical in patients with HF-pEF and HF-rEF, with emphasis on general clinical status, volume overload, and levels of natriuretic peptides. Especially, the initial preoperative levels of natriuretic peptides are positively correlated to perioperative severe adverse events in both patient groups [26, 27].

In patients with heart failure on schedule for intermediate or high-risk surgery, the evaluation of LV function using echocardiography and/or assessment of natriuretic peptides has to be performed [24, 26, 27]. Therapy should be optimized as necessary, with optimal dosing of beta-blockers, angiotensin-converting enzyme inhibitors (ACEIs), angiotensin II type 1 receptor blockers (ARBs), mineralocorticoid antagonists, and diuretics, following current guidelines for heart failure treatment.

11.6.2 Hypertension

Delaying surgery in patients with hypertension is sometimes necessary, if blood pressure is poorly controlled or previously undiscovered end-organ damage is detected. In patients with only moderate elevations in blood pressure, there is no benefit from delaying surgical procedures to optimize antihypertensive therapy [28]. Blood pressure medications should be continued throughout the perioperative period. In patients with severe or badly controlled hypertension, the possible benefit of delaying surgery to optimize pharmacological treatment should be balanced against the risk and potential harm of delaying the procedure [29]. Clearly, there is no significant evidence for any special type of antihypertensive drug to control blood pressure. However, if coronary artery disease is present, beta-blockers are the drug of choice.

11.6.3 Valve Disease

The most relevant cardiac valve diseases with regard to perioperative problems are aortic stenosis and secondary mitral regurgitation both in terms of hemodynamic drawbacks and in the number of patients affected.

11.6.4 Aortic Stenosis

In aortic stenosis, the presence of symptoms is most relevant for decision-making. In symptomatic patients, valve replacement should be considered before elective knee surgery. If patients do not qualify for valve replacement, either due to high risks associated with serious comorbidities or due to refusal to undergo the valve replacement procedure, knee replacement should be performed only if essential. In patients at high risk or with contraindications for open chest aortic valve replacement, transcatheter aortic valve implantation (TAVI) may be a reasonable therapeutic option before knee surgery. In asymptomatic patients, surgery of low to intermediate risk can be performed safely [30]. If unclear, the absence of symptoms may be carefully confirmed by exercise testing. In patients at high risk, elective surgery under more invasive hemodynamic monitoring might be an option. Otherwise, aortic valve replacement should be chosen as the initial procedure.

11.6.5 Secondary Mitral Regurgitation

Left ventricular (LV) remodeling is sometimes followed by secondary mitral regurgitation caused by a dilation of the subvalvular apparatus on a structurally normal valve. Prior to surgery, these patients should undergo evaluation and eventually specific management, according to the recommendations for secondary mitral regurgitation. If this has occurred because of ischemic heart disease, the indication for cardiac catheterization has to be evaluated. Because secondary mitral regurgitation is variable depending on volume loading conditions, particular attention has to be given to the assessment of volume status and heart rhythm in the preoperative period.

11.6.6 Patients with Prosthetic Heart Valves

Patients with prosthetic heart valves can undergo knee replacement without significant risk, implied that there is no evidence of valve dysfunction or heart failure. In practice, the major problem is the need for modification of the anticoagulation regimen. Often, oral anticoagulants can temporarily be replaced by unfractionated heparins or low-molecular-weight heparins at therapeutic doses. In patients with mechanical valves in aortic position, leaving out anticoagulation for short periods of time might be an option in selected patients, but this should be decided in collaboration with the cardiologist.

11.6.7 Prophylaxis of Infective Endocarditis

Indications for antibiotic prophylaxis are limited to high-risk patients undergoing dental care. Systematic antibiotic prophylaxis is not recommended for nondental procedures. Antibiotic therapy is only needed, when invasive procedures are performed in the context of infection [31].

11.6.8 Arrhythmias

Cardiac arrhythmias are a significant cause of morbidity and mortality, even more in the perioperative period. The mechanisms for arrhythmias in patients with structural heart disease are well defined, but the impact of transient pathophysiological imbalance in patients undergoing surgery sometimes aggravates before well-controlled rhythm disorders. As such, patients with a previous history of arrhythmias should be reviewed by a cardiologist, prior to considering any surgery. Common arrhythmias as atrial fibrillation and also ventricular tachycardias often indicate underlying structural cardiac diseases and an immediate cardiac evaluation is recommended including echocardiography. The main rationale in managing perioperative atrial fibrillation is usually ventricular rate control. As recommended in the ESC Guidelines for the management of atrial fibrillation, beta-blockers and calcium channel blockers (verapamil, diltiazem) are the drugs of choice for rate control [32].

Side Summary
Patients presenting with cardiac arrhythmias should be referred to a cardiologist before surgery might be considered

In heart failure patients, amiodarone can be used as a first-line drug, since digitoxin is sometimes less effective in adrenergic states such as surgery. Beta-blockers have been shown to accelerate the conversion to sinus rhythm in the intensive care unit (ICU) after surgery [33]. Anticoagulation has to be based on the individual clinical situation.

11.6.9 Perioperative Management of Patients with Pacemakers/Implantable Cardioverter Defibrillators

Patients with a permanent pacemaker can safely undergo surgery, if appropriate precaution is taken [34]. The use of electrocautery represents a significant risk, as the electrical stimulus from electrocautery may inhibit the "demand" mode of pacemakers or may reprogram the pacemaker.

Side Summary
Do not use unipolar electrocautery in patients with pacemaker or defibrillators

These problems can be avoided or minimized by using bipolar electrocautery, correct positioning of the ground plate for the electrical circuit. Keeping the electrocautery device away from the pacemaker, giving only brief bursts, and using the lowest possible amplitude may also decrease the interference. The pacemaker should be set in an asynchronous or nonsensing mode in patients who are pacemaker-dependent. This is most easily done in the operating room by placing a magnet on the skin over the pacemaker. Patients whose underlying rhythm is unreliable should have pacemaker interrogation after surgery, to ensure appropriate programming and sensing-pacing thresholds.

Interference with the function of implantable cardioverter defibrillators (ICDs) can also occur during surgery, as a result of the electrical current generated by electrocautery. The ICD shock function (or tachycardia detection mode) should be turned off during surgery and switched on in the recovery phase before discharge to the ward. The defibrillator function of an ICD can be temporarily deactivated by placing a magnet on the skin over the ICD. While the device is deactivated, an external defibrillator should be immediately available and the patients must be monitored continuously.

Side Summary
MRI examination is not strictly forbidden anymore in patients with pacemakers or cardioverter/defibrillators. However, decision should be made in collaboration with the cardiologist

If magnetic resonance imaging (MRI) is considered in such patients, a comprehensive patient-specific risk-to-benefit analysis should be performed, with a particular focus on the available potential alternative imaging methods. Magnetic resonance imaging (MRI) has long been regarded as a general contraindication in patients with cardiovascular implanted electronic devices such as cardiac pacemakers or implantable cardioverter defibrillators (ICDs), due to the risk of severe complications and even deaths caused by interactions of the magnetic resonance (MR) surrounding and the electric devices. Over the last decade, a better understanding of the underlying mechanisms responsible for such potentially life-threatening complications as well as technical advances has allowed an increasing number of pacemaker and ICD patients to safely undergo MRI. With "MR-conditional "devices being the new standard of care, MRI in pacemaker and ICD patients has been adopted to clinical routine today.

However, specific precautions and specifications of these devices should be carefully followed if possible, to avoid patient risks that might appear with new magnetic resonance (MR) technology and further increasing indications and patient numbers. Different manufacturers offer different solutions for MRI compatibility like "full body scans," "exclusion zones," or programming features. Despite the fact that some of the measures are also mentioned in the 2013 European Society of Cardiology Guidelines on cardiac pacing [34], some further recommendations are not based on officially delivered guidelines, but rely on findings from the large set of basic research, clinical studies, and/or expert opinions [35].

11.6.10 Stroke

A recent analysis on patients undergoing noncardiac surgery reported a 0.1% incidence in perioperative stroke. Perioperative strokes are usually cardioembolic, with atrial fibrillation as the underlying condition. The withdrawal of anticoagulation and increased levels of thrombin and fibrin caused by tissue injury related to surgery may trigger thrombus formation. Additional etiologies are rare but perioperative stroke may also be caused by air, fat, or paradox embolisms.

To attenuate the risk of perioperative stroke, anticoagulation should be continued whenever possible throughout the perioperative period. If not feasible, the time without anticoagulation should be kept as short as possible.

Patients undergoing surgery should be questioned about previous neurological symptoms. In case of positive findings, a preoperative neurological consultation has to be performed. In patients with symptomatic carotid artery disease, revascularization should be performed first. Patients with carotid artery disease also have a high incidence of coronary artery disease simultaneously. As a result, statins, aspirin, and betablockers should be continued and blood pressure should be stable.

11.6.11 Peripheral Artery Disease

Patients with peripheral artery disease have usually significant atherosclerotic alterations in other vascular compartments as well. Strikingly, in patients without diagnosed coronary artery disease, peripheral artery disease is related to an increased event rate of myocardial infarctions in the perioperative setting [36]. Therefore, peripheral artery disease has to be counted as a risk factor complicating surgical procedures. In those patients, ischemic heart disease has to be assessed from the patient's history. All patients with peripheral artery disease should be treated with statins and platelet inhibitors similar as in the coronary artery disease [37]. Control of blood pressure should be achieved before surgery. However, it is not recommended to initiate a beta-blocker before surgery due to the risk of limb ischemia or at least a significant reduction in perfusion pressure [38].

11.7 Pulmonary Disease

The most common lung disease condition is chronic obstructive pulmonary disease (COPD), whereas pulmonary artery hypertension (PAH) is a rather rare condition, however accompanied with the most complications during surgery. COPD is not curable and is characterized by airflow obstruction and/or emphysema. In patients with COPD who are scheduled for surgery, the preoperative treatment goals are the optimization of pulmonary function and minimization of postoperative respiratory complications; this includes instructions on chest physiotherapy and lung expansion maneuvers. Inhaled Beta-2 agonists and anticholinergic agents should be continued until the day of surgery. In some cases, systemic steroids may be considered. In acute pulmonary infection, antibiotics should be administered for at least 10 days and, if possible, surgery should be delayed [39].

Pulmonary artery hypertension (PAH) is characterized by the presence of precapillary pulmonary hypertension. Pulmonary artery hypertension includes different forms that share a similar clinical picture [40]. A mean preoperative pulmonary artery pressure of 30 mmHg has an associated perioperative cardiopulmonary complication rate of 38% and a mortality of 7% [41, 42]. Interventions for high-risk patients should be prepared by a multidisciplinary pulmonary hypertension team. Patients receiving PAH-specific therapy may continue those drugs but may require temporary conversion to intravenous and/or nebulized treatment. As the highest mortality is in the postoperative period, it is recommended that monitoring continues for at least 24 hours. In case of progression of right heart failure in the postoperative period, inotropic support with dobutamine is recommended.

Side Summary
Pulmonary artery hypertension is a rare disease but accompanied by high morbidity and mortality rates. Close hemodynamic monitoring during the surgical procedures should be mandatory.

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12 Patient Expectations in Total Knee Arthroplasty

Holger Haas and Christian D. Weber

Keynotes

1. Preoperative patient expectations have a major impact on postoperative outcomes after total knee replacement.
2. Many total knee arthroplasty (TKA) patients have overly optimistic or unrealistic expectations regarding pain reduction, functional abilities, or duration of the recovery process.
3. In order to achieve realistic expectations, surgeons should evaluate the individual patient situation and guide or correct modifiable expectations.
4. Comprehensive patient education, a trustful communication, and the model of a shared decision-making (SDM) remain critical and helpful instruments in the management of patient expectations.

12.1 What Do Patients Expect from TKA?

Total knee arthroplasty (TKA) revolutionized the care of patients with severe and symptomatic osteoarthritis (OA) of the knee joint. In fact, over the past decades this resulted in improved functional outcomes, quality of life, and patient satisfaction [1–3].

Patients seek and expect symptom and pain relief, as well as physical and psychosocial improvements after elective TKA.

However, only 75–89% of TKA patients are truly satisfied with the final result [4, 5], and most studies suggest a lower number of satisfied patients after primary TKA, when compared to total hip arthroplasty [6–8].

Recent studies identified a major impact of preoperative patient expectations on postoperative outcome after TKA [9], suggesting that dissatisfaction may be related to unfulfilled expectations [3, 10, 11]. Furthermore, decreased patient satisfaction may also result in increased malpractice claims [12].

In order to predict dissatisfaction after TKA, many variables have been investigated. Bourne et al. identified that only 81% of patients were satisfied with their primary TKA, and the utmost important factor for patient dissatisfaction were expectations not met (10.7 times greater risk). In comparison, poor Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)

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scores or major complications requiring hospital readmission (1.9 times greater risk) had a far lower impact [5].

Side Summary
The majority of surgeons are confronted with issues regarding patient expectations, since many patients have overly optimistic or unrealistic expectations regarding pain reduction, functional abilities, or duration of the recovery process [13, 14]

In reality, patient expectations may be derived from multiple sources, including the patient's social network, interactions with general physicians, orthopedic surgeons, or other healthcare professionals, and sources may also involve marketing information distributed by the implant manufacturing industry. Before seeking surgical advice, patients might be exposed to misleading information and direct-to-patient marketing [15].

Side Summary
In order to achieve realistic expectations and prevent dissatisfaction, the surgeon should evaluate the individual patient situation, guide modifiable expectations, and therefore initiate comprehensive preoperative measures for patient education

Patient education is especially important in younger patients, since TKA patients younger than 55 years are even more highly demanding and have an increased risk of dissatisfaction [16, 17], reaching 59% in less severe OA (KL1/2).

Recent studies emphasize the need for realistic education and honest interaction between surgeons and arthroplasty candidates, to allow patients to anticipate a reasonable outcome after TKA [7]. In this context, establishing a good communication [18] remains the most critical step toward meeting or exceeding patient's expectations, and achieving a happy TKA patient.

Side Summary
The concept of a "shared decision-making" (SDM) continues to evolve as an alternative draft to the paternalistic model [19, 20]. SDM includes sharing clinical information and responsibility, and therefore increasing patient involvement

Vogl et al. proposed a personalized risk assessment approach to support shared decision-making and to predict health states and satisfaction thresholds [21].

This interesting concept requires further scientific evaluation, especially its application in various cultural and ethnic environments.

Furthermore, evaluating and addressing psychological issues might have a major impact on patient satisfaction and outcome [22–31], and is potentially more relevant than preoperative physical therapy [32] or the choice of the surgical approach [33].

Establishing a trustful communication and obtaining appropriate expectations are critical in patients preparing for TKA surgery, since preoperative patient expectations are the major determinant of satisfaction with the outcome of surgery and the adherence to postoperative recommendations [34].

12.2 Measuring and Managing Expectations—Predicting Satisfaction

Historically, the success of arthroplasty was measured by implant survivorship in arthroplasty registries, clinical analysis including range of motion (ROM), and radiographic evaluation. All these parameters did not sufficiently consider the patient's perspective.

In the past decades, the failure to measure the patient's perspective (e.g., quality of life, functional abilities, pain) led to the focus on *Patient-Reported Outcome Measures* (PROMs). Some registries have already started to include PROMs today [35, 36]. In the current literature, patient expectations and satisfaction are increasingly proposed as patient-centered quality measures after total joint arthroplasty [22, 37–52].

Lange et al. performed a Delphi Consensus Study in order to define patient treatment goals and use these items for patient-centered education and decision-making. The authors defined main treatment goals when more than 70% of participants achieved consensus and voted for the specific goal (Table 12.1).

However, when employing PROMs (Table 12.2) and satisfaction as an outcome measure for successful TKA, the intrinsic and extrinsic factors must be known by the surgeon and communicated to the patient, before proceeding with surgery [53].

Patient expectations and satisfaction are diverse and influenced by age, socioeconomic factors, sex, and race [54]. Mancuso et al. developed and validated a survey to evaluate patient expectations, and the authors identified pain relief, improved walking ability, and return to sport among the highly rated expectations [34].

Weiss et al. investigated which functional activities are important to patients with knee replacements [55]. The most prevalent activities included stretching and strengthening exercises, as well as kneeling and gardening.

Table 12.1 Main treatment goals after elective TKA surgery [47]

- Symptom reduction: Pain reduction, improvement of stability
- Functional improvements: Improvement of physical function, ROM, walking distance, walking stairs, physical activity
- Improvement of quality of life
- Prevention and safety concerns: Prevention from secondary impairments, long implant survival

Table 12.2 Common patient-reported outcome measures in TKA

- Oxford Knee Score (OKS)
- Knee Society Score (KSS)
- Knee injury and Osteoarthritis Outcome Score (KOOS)
- Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)
- Visual Analog Scale (VAS)
- EuroQol-5D Score (EQ-5D)

Of course, patient expectations are highly variable, age-dependent, and potentially change over time. In order to measure individual expectations, the *Goal Attainment Scale* (GAS) has been proposed and investigated in the context of younger TKA patients [56]. Further studies are required to elucidate whether the GAS is a valid method to measure and improve patient satisfaction.

Schilling et al. investigated 488 TKA patients in order to identify predictors of long-term gains in quality-adjusted life years (QALYs) from TKA. Patients with severe OA of the knee and poor preoperative quality of life but little comorbidities (e.g., obesity) were likely to achieve good long-term QALY outcomes [57]. There is good evidence that the absence of severe OA in the ipsilateral knee is a predictor of poor outcome after arthroplasty (Table 12.3).

Peres-da-Silva et al. analyzed factors associated with patient satisfaction and reported higher levels of satisfaction after knee arthroplasty in male patients, African American, lower socioeconomic status, and shorter length of stay [58].

Van Onsem et al. proposed a new prediction model for patient satisfaction, which allows surgeons to evaluate individual risks and benefits of surgery and help in patient selection [37]. The model also includes mental comorbidities, for example, depression and anxiety. The authors recommend 10 simple but robust questions,

Table 12.3 *Yellow* and *Red Flags*[a] during preoperative workup

- Early stage (mild/moderate) osteoarthritis [16, 17, 50, 66–68]
- Depression or psychological disorders [24–26, 29, 31, 69]
- Obesity (body mass index (BMI) 27 or ≥ 30 kg/m^2) [54, 66, 70, 71]
- High *Charlson comorbidity index* (CCI) [72]
- Poor preoperative Knee Society or WOMAC score [72]
- Pain catastrophizing [60, 62, 73]
- Age below 55 years [16]
- Low back pain [63, 64]
- Opioid use [65, 74]
- Diabetes [70]

[a]Risk factors with minimal or poor chance for preoperative modification

achieving a sensitivity of 97% with a positive-predictive value of 93%.

Eymard et al. described variables interfering with the acquisition of a "forgotten knee" after TKA. The authors analyzed a prospective cohort including 510 TKAs in 423 patients followed up for 76.6 ± 28.5 months and confirmed the negative impact of a concomitant depression [59].

Another factor associated with poor outcome after TKA was suggested for pain catastrophizing. Feldman et al. evaluated the association between socioeconomic status (SES), pain, function, and pain catastrophizing in 316 individuals [60]. The group found a significant relationship between higher education and lower pain catastrophizing, reflecting superior psychological health or coping abilities.

As an adverse coping mechanism, pain catastrophizing has been described as a well-described phenomenon with unpredictable outcome for patients undergoing surgery for lumbar spinal stenosis [61], and this personality trait is likely to affect a fair number of TKA patients as well. Burns et al. performed a systematic review to analyze pain catastrophizing as a risk factor for chronic pain after TKA [62]. The authors identified six prospective longitudinal studies, all with small to midsized samples. In conclusion, the review provides moderate-level evidence that pain catastrophizing is an independent predictor for chronic pain after TKA surgery.

Lewis et al. included almost 30,000 patients from 32 studies in their systematic review and meta-analysis. They identified catastrophizing, mental health, preoperative knee pain, and pain at other sites as the strongest predictors of persistent pain after TKA.

Staibano and coauthors evaluated the impact of low back pain (LBP) in hip and knee arthroplasty candidates in a prospective cohort. The authors recommended advising TKA candidates who are suffering from concomitant LBP that this may adversely impact the outcome of TKA [63]. Clement et al. identified LBP as an independent predictor of a worse outcome and dissatisfaction after TKA [64].

Furthermore, opioid use must warrant caution when evaluating TKA candidates, because of an increased risk of revision surgery during the first year [65].

Side Summary

Successful TKA surgery remains complex and involves the right selection of patient (Table 12.4), Indication and implant, a thorough clinical and radiographic workup, meticulous planning, surgical technique, interdisciplinary perioperative management, and rehabilitation protocol

However, the successful management succeeds the well-performed surgery with ideal alignment, because it involves the evaluation and guidance of patient expectations, which are often highly demanding, in order to anticipate overly optimistic results and ensure satisfaction. Therefore, intrinsic and extrinsic variables predicting poor outcome measures should be discussed with the patient and optimized preoperatively, whenever possible.

Side Summary

Our most important instrument to oppose dissatisfaction from excessive patient expectations remains the empathic and trustful communication with potential TKA candidates, and if applicable, the concept of a shared decision-making.

Table 12.4 Patient safety protocol [4]

- Correct patient selection
- Setting appropriate patient expectations
- Avoiding preventable complications
- Technical standards during operation
- Using pre- and postoperative pathways

Take Home Message

To identify other problems conflicting with postoperative satisfaction (e.g., mental issues, pain catastrophizing, low back pain, opioid use, etc.), patients should be asked whether they have “any issues besides their painful knee joint.” In this context, many potential problems (Table 12.3) are easily identifiable when counseling TKA candidates. Surgeons obtaining informed consent for TKA must be familiar with realistic, achievable levels of pain reduction and residual functional limitations, potential pitfalls, and need to educate patients in order to establish realistic expectations before TKA.

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13 Basic Principles of Partial Knee Arthroplasty

Justin Cobb

Keynotes

1. Pathology of the medial and lateral unicompartmental osteoarthritis is different.
2. Five key points should be considered prior to unicondylar knee arthroplasty (UKA):
   – Cartilage and bone loss in the medial compartment.
   – Cartilage and bone loss in the lateral compartment.
   – Integrity of ligaments.
   – Soft tissue laxity.
   – Patellofemoral compartment.
3. Exact planning and component placement are important. Especially, the joint line and the posterior tibial slope need to be preserved.
4. One has to distinguish resection from resurfacing UKA.
5. In UKA, one can differentiate mobile bearing from fixed bearing and all-poly from metal-backed unicondylar prostheses.
6. Surgical tips and tricks are presented for the medial and lateral UKA.

13.1 Introduction—Anthropology and Partial Knee Arthroplasty

As alternate bipedal hominids, our way of life places specific demands upon our knees. In particular, we need to be able to undertake two distinct activities: standing and squatting. Each of these can lead to distinct patterns of wear that may be restored by partial knee arthroplasty.

Standing needs stability in or near extension. This position of stability is achieved by slight hyperextension, so that the weight of the body is brought in front of the mechanical axis, with extension being limited by increasing tension in the anterior cruciate ligament (ACL) and the coronary ligaments of both menisci. Failure of the medial meniscal coronary ligament causes meniscal extrusion leading to edge loading and runaway wear of the medial compartment, which will progress slowly posteriorly, allowing progressive medial subluxation of the femur on the tibia [1]. The lateral tibial spine prevents this, so will erode into the femoral condyle, allowing an abnormal translational force across the ACL, leading to fatigue failure, and eventually a knee that has lost its soft tissue constraints [2, 3]. If the medial joint height is restored, stability in extension is regained, so even substantial medial translation may be correctible [4] (Fig. 13.1a–c).

The lateral meniscus is not strained in extension, but is absolutely needed for deep flexion,

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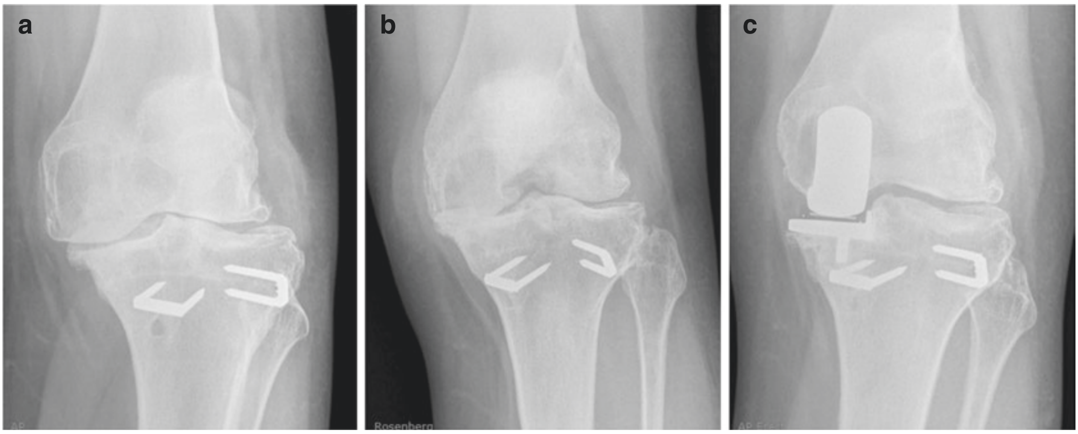

Fig. 13.1 (**a**–**c**) Medial subluxation of the femur in the frontal plane in severe OA: (**a**) standing AP view, (**b**) Rosenberg view confirming the extent of the subluxation, (**c**) 4-years postoperative view, showing the correction of translation

with the meniscofemoral ligaments constraining the posteroinferior subluxation of the lateral femoral condyle. Loss of lateral meniscal competence will lead to a feeling of instability when twisting or bending. It further results in an edge loading with runaway wear of the chondral surfaces [5]. A progressive valgus in flexion can be seen in these cases, with the wear scar slowly progressing anteriorly. Restoration of lateral joint height restores stability in flexion, allowing patients to regain agility and mobility.

Bone morphology differs between varus, straight and valgus knees on both sides of the joint. The lateral distal femoral angle (LDFA) reduces from (89° ± 1°) in varus knees to (88° ± 1°) in straight legs, while it is lowest in valgus knees at (85° ± 1°) [6]. The medial proximal tibial angle (MPTA) is in slight varus even in the valgus knee (89° ± 1°), a little more varus in the straight knee (88° ± 2°) while in the varus knee it is more oblique (85° ± 2°), as illustrated in Fig. 13.2 [6, 7]. Varus knees also show less femoral anteversion and a larger extension facet of the medial femoral condyle [8].

Side Summary
Bone morphology differs in varus and valgus knees.

13.2 Indication

13.2.1 Medial Femorotibial Osteoarthritis

The principal indication for medial unicondylar knee arthroplasty (UKA) is osteoarthritis (OA) secondary to meniscal failure in a varus knee [9]. In this instance, the UKA aims to reconstruct the knee, leaving the joint kinematics as they were prior to meniscal failure [10, 11]. So, the joint line is left in varus, with the mechanical axis also left somewhat in varus (Fig. 13.3).

Side Summary
No changes in joint kinematics after UKA. The mechanical axis should be left somewhat in varus

In older or lower demand patients, who have no symptoms of instability, a UKA might also be used in the absence of an ACL [12]. Typically, in older patients, stiffness is common, while instability is an unusual symptom [13]. A direct correlation between the increase in degree of osteoarthritis and decrease in anteroposterior laxity has been reported. So as long as the knee is left in varus, the lateral compartment is unlikely to deteriorate, and the lack of ACL is seldom a problem.

The principal symptom of anteromedial arthrosis is pain, felt medially [14]. It is worse on walking, and worse on walking down steps or slopes. Pain may also be felt anteriorly and laterally in patients whose primary diagnosis is anteromedial arthrosis. The pattern of pain is the key element: it should be produced on weight-bearing activity, and with a clear relationship to the load involved: increasing activity leads to greater pain experienced. Meniscal injury may be a discrete event, reported as a sports injury decades earlier, or a chronic fatigue failure without injury [15, 16].

Side Summary
Lack of ACL function is no contraindication for UKA.

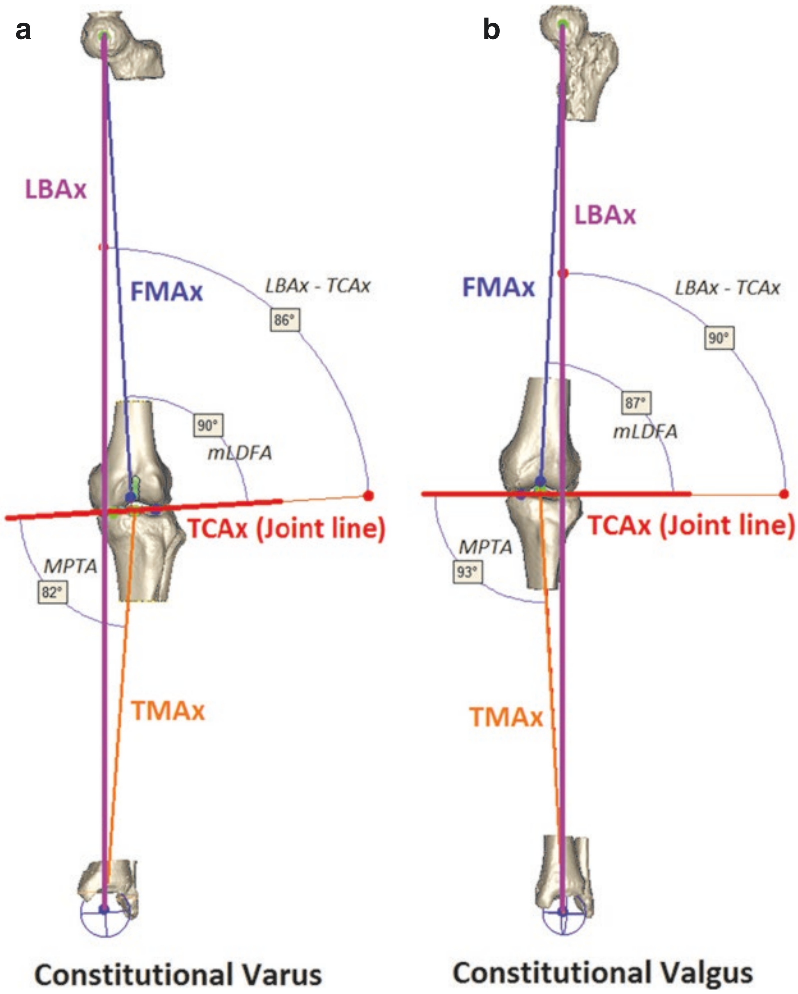

Fig. 13.2 The angular differences between varus and valgus knees (courtesy of Anthony Leong PhD thesis Imperial College 2016)

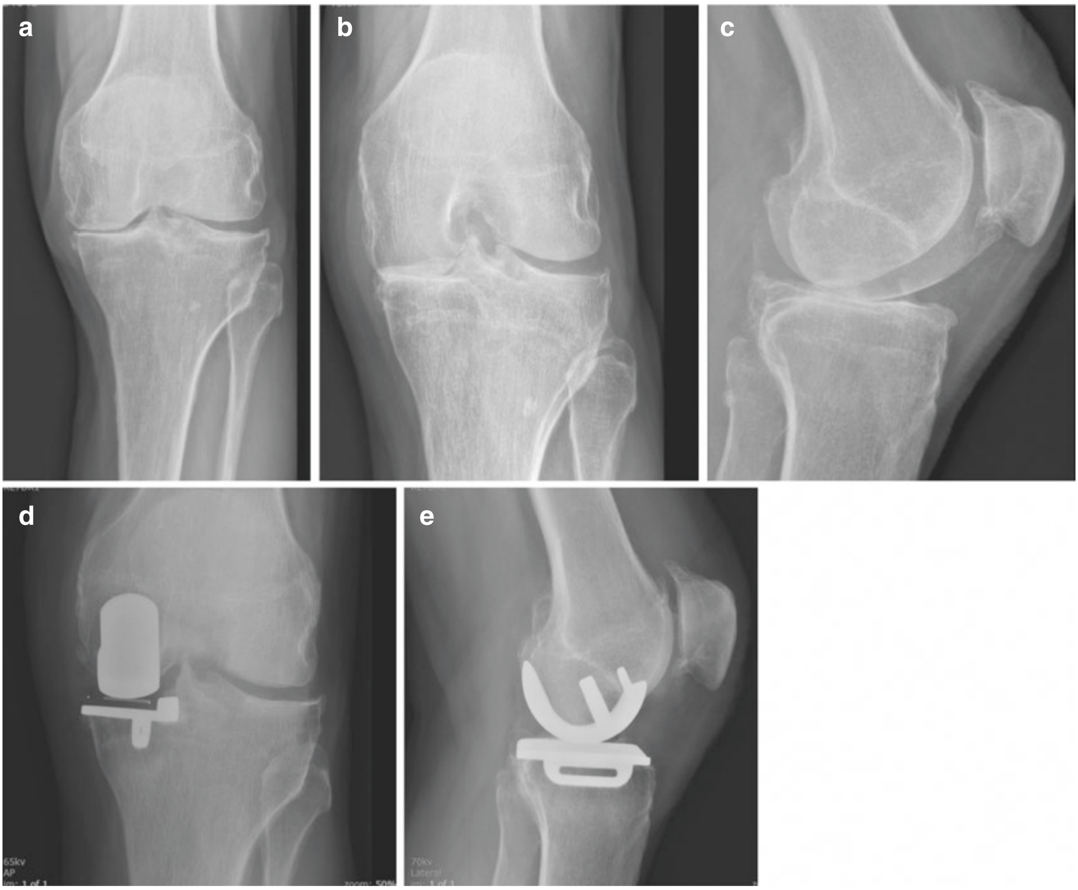

Fig. 13.3 Standing AP (**a**), Rosenberg view (**b**), lateral view preoperatively (**c**), postop ap (**d**), postop lateral (**e**)

13.2.2 Lateral Femorotibial Osteoarthritis

Lateral femorotibial OA has a completely different symptomatology. Lateral femorotibial OA occurs commonly in taller and slimmer people of either gender, the reduced Q-angle that naturally accompanies longer limbs predisposes to greater loading on the lateral compartment. A valgus malalignment of 1°–3° shows significant increase in lateral femorotibial OA (OR 2.5) [17].

The principal symptoms relate to difficulty loading the knee in flexion—particularly, descending stairs and slopes, while strolling on flat ground is often not a problem. These symptoms might be explained by the fact that valgus OA often occurs in conjunction with patellofemoral OA [18]. Both the medial or lateral facet can be affected. Thus, many straight line activities including walking and cycling are not affected, but twisting and turning functions which are essential for tennis or ballroom dancing, skiing and riding are problematic. Patients often do not complain so much about the pain, but more about the fact that they cannot use the knee. Pain is usually felt laterally and can be felt at the hip as well.

Side Summary
More symptoms in flexion than in extension in valgus OA

It is not clear to the author whether this pain referred proximally is actual hip pain. It might be caused by abnormal kinematics during gait [19]. Less hip flexion during stand phase may cause increase in loading. In any event, if the hip is normal clinically the patient can be reassured that following lateral unicompartmental knee arthroplasty, the pain will go away.

Side Summary
Valgus OA more common with patellofemoral OA.

13.3 Key Points of Examination

Examination of the knee with unicompartmental arthroplasty in mind has a number of important elements:

1. Extent of cartilage and bone loss on the medial side

   If the meniscus is still competent, the joint may open a little on valgus stressing, but without the seal being lost. On releasing the valgus stress, the medial compartment will close. There should be no bony clunk as the surfaces come together. Once the seal function is lost, the clunk is detectable on releasing the valgus stress, with discomfort felt as the damaged wear scars on femoral condyle and tibial plateau. Meet. Gentle varus stress will cause extrusion of any meniscal remnant, with joint line tenderness, and often palpable medial osteophytes. Bone-on-bone crepitus may also be felt while gently flexing and extending the knee with slight varus.

   Any loss of full extension should be noted, together with the presence of osteophytes. The so-called 'fixed' varus should be examined in 30° of flexion, where gentle valgus stress will usually correct all but the most severe fixed deformity.
2. Extent of loss cartilage and bone on the lateral side

   While stressing the knee into valgus, the lateral meniscus can be palpated. The intact meniscus will not extrude, as the extended knee is flexed in gentle valgus. Importantly, if lateral pain is reported, the examiner should note whether it is reproduced on varus stress, confirming that it is tension pain in the iliotibial band associated with medial OA. Alternatively, pain felt on compressing the lateral compartment with valgus stress, when accompanied by meniscal extrusion and bone-on-bone articulation, confirms the presence of lateral OA.
3. Soft tissue envelope intact?

   For successful partial knee arthroplasty, the soft tissue envelope needs to be intact. However, examination of this can be demanding when material loss on both tibia and femur allows pseudo-subluxation to be apparent both clinically and radiographically.

   Antero-posteriorly and medio-laterally, laxity is a key feature to be investigated. Examinations of laxity should be carried out both in neutral, and with correction of the varus deformity. With the knee in a neutral position, a greater degree of anteroposterior (A-P) glide is often observed. However, this is reduced or even abolished, when the varus is corrected by gentle valgus pressure.
4. Patellofemoral crepitus

   By starting in flexion, and slowly extending the knee, the examiner may put pressure on the lateral and then the medial patellofemoral articulation. Pain and bone-on-bone articulation may be found while carrying out this manoeuvre. If so, it is very important to identify which facet of the patella is affected. Severe OA at the lateral patella facet is of greater concern than of the medial facet in varus aligned knees.

13.4 Surgical Planning

Prior to surgery, proper planning is needed. This is mainly done for identification of the optimal size of the prosthesis, confirming that neither the tibial plateau nor femoral condyle is too small or too big for the range of implant sizes. Additional planning will help in the performance of the operation, by ensuring that the surgeon anticipates what will occur intra-operatively. Even from plain radiographs, the standing AP, Schuss and lateral views (Fig. 13.3a–c) will help in appreciating the amount of tibia vara, and intra-articular bone loss, and thus the amount of varus needed on the tibial cut, and the depth of bone needed to be resected, to ensure the minimum thickness of bearing can be accommodated, while at the same time ensuring that the prosthesis is sited on the hardest subchondral bone possible.

Posterior slope of the tibial component and flexion of the femoral component should also be planned from the lateral plain radiographs. Comparison of the planned positions and what is achieved intra-operatively is a useful audit for the surgical team (Fig. 13.3d–f). Minor changes in component placement in regard to the natural anatomy may have an effect on the clinical outcome and implant survival [20]. Tibial component obliquity of ≥5° and changes of tibial slope of ≥2° reduce survival probability after UKA. For smaller people, a higher posterior slope is common and worth preserving to ensure even soft tissue tension.

An absent or injured ACL is not a complete contraindication to UKA (Fig. 13.4a–c), which may be better managed by reducing the posterior slope of the tibial component [21]. Longstanding ACL deficiency may be confirmed by anterior tibial translation that is visible on the lateral view (Fig. 13.4d). This may correct significantly with the restoration of the joint line during the procedures (Fig. 13.4e).

Coronal plane translation of both components should also be addressed preoperatively. The aim of the tibial sagittal cut is in maximising the coverage of the bone, while the aim of the femoral

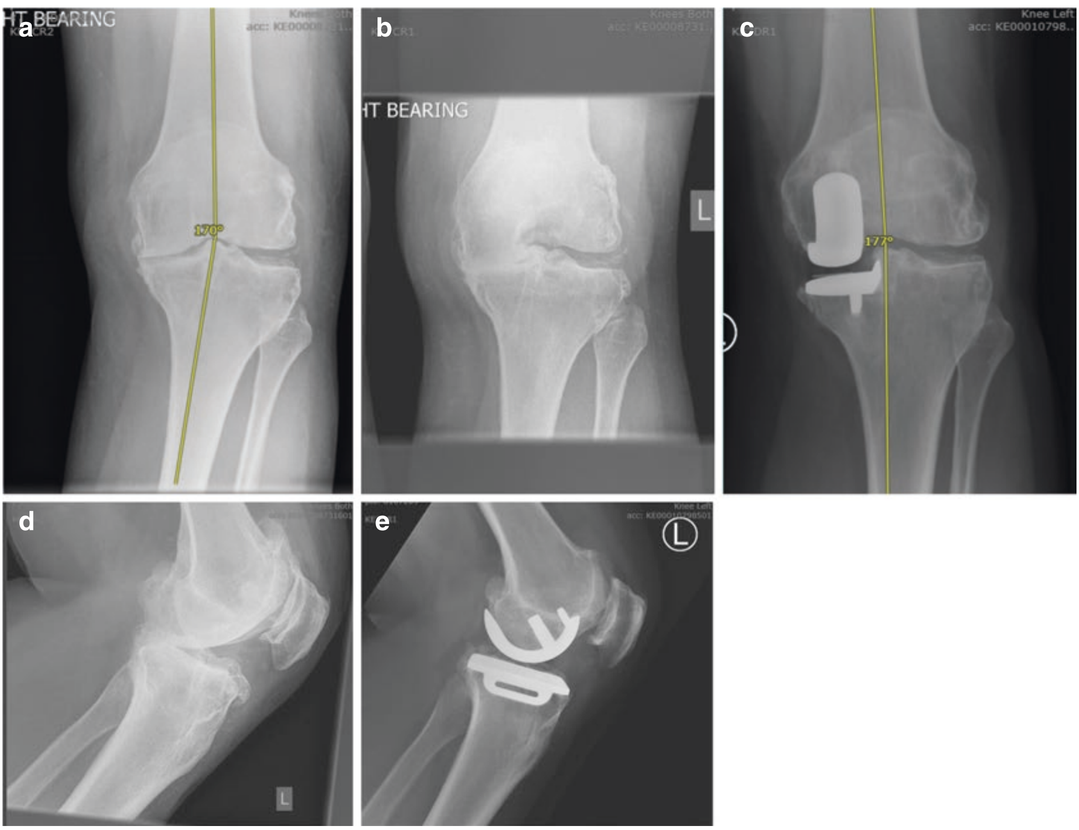

Fig. 13.4 (**a**–**e**) Medial arthrosis 30 years after ACL rupture (**a**) Standing AP, (**b**) Rosenberg, and (**c**) 3 years postop standing AP showing correction of the varus. (**d**) preoperative lateral showing marked anterior translation of the tibia on the femur (**e**) 3 years postop showing the restoration of tibiofemoral relations

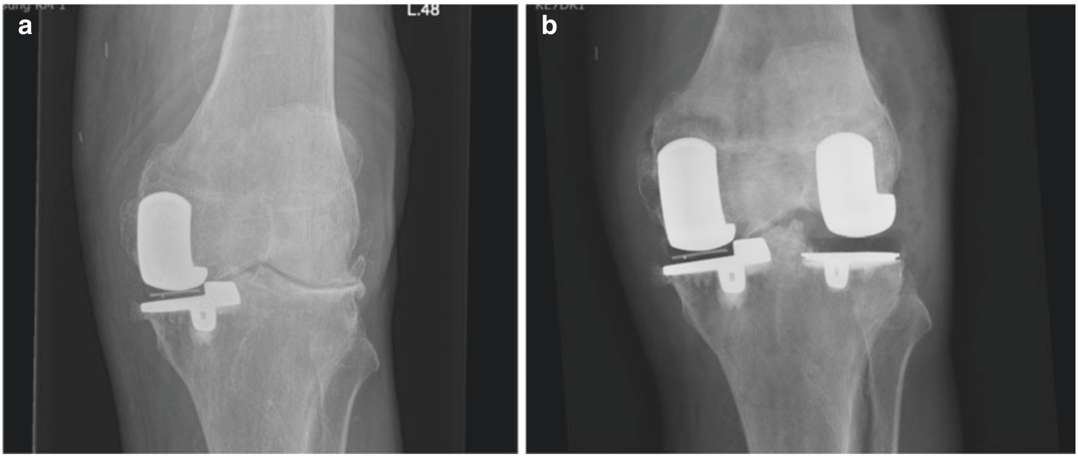

Fig. 13.5 (**a**, **b**) Patient 19 years after medial UKA with lateral arthrosis. (**a**) preop, showing well-fixed medial UKA and lateral arthrosis. Note the longstanding stress shielding below the well-fixed tibial component. (**b**) Postop, showing that the lateral UKA has restored the patient's natural physiologic varus

sagittal alignment is to ensure that the component is centred over the midst of the tibial component. In the varus knee, the femoral component may need to be lateralised on the condyle, as there is a tendency for the tibia to sublux laterally that is incompletely corrected by restoring the joint line height (Fig. 13.5a, b). Final attention to this element has to be paid intra-operatively, once the joint height is restored. In the valgus knee, the same tendency occurs, so the femoral component must be placed as laterally as possible without embarrassing the popliteus tendon.

The last element of surgical planning is device specific. Depending on the design characteristics of the interface, varus slope of the tibial component must be matched with the coronal plane and axial plane rotation of the femoral component. A spherical femoral component, on an entirely congruent meniscal bearing, will not need any adjustment from neutral, while a cam-type femoral component may need to be rotated by a few degrees to ensure linear rather than point contact.

Three-dimensional (3D) planning based upon either magnetic resonance imaging (MRI) or computed tomography (CT) facilitates the planning process. The great attraction of 3D planning, which appears to increase the complexity of the procedure, is that it allows almost all variables to be documented preoperatively (Fig. 13.3d, e), reducing the intra-operative procedure to a checklist, confirming the preoperative measurements in an expected sequence. The best example of this is the tibial bone resection or 'biscuit' which can be 3D printed and sterilised. The exact shape and size of the bone resection can then be compared with the plan, confirming that the resection is adequate in all dimensions. If 3D planning is undertaken, serious consideration should be given to the use of patient-specific instrumentation (PSI) [22].

More recent research looked at the kinematic alignment of the medial UKA [23]. No significant difference in the component fit was found between kinematic and standard alignment. However, the femoral component orientation was 4° (1° varus −7° valgus) more in valgus and the tibial component in 2.9° (8° of varus −0°) more in varus.

13.5 Technical Tips and Tricks

Prior to starting UKA surgery, it is worth rehearsing the choreography of the instruments with the scrub team. When well drilled in the sequence of events, the procedure should be a simple one. An extra few minutes may be needed for extensive osteophyte removal, cautious tibial recutting, and of course for cementing. When planning an operating list, with the whole setup and takedown, no more than 1 h should be allocated per UKA, with 4 typically being straightforward on a half-day list.

13.5.1 Medial UKA

The incision is made over the medial border of the patella, vertically down to just above the level of the tubercle. It can be easily extended proximally without any clinical significance or delay in recovery [24]. A mid-vastus split of a few centimetres, at the superior pole of the patella will give access if necessary, without compromising the speed of recovery.

Following the approach clearance of osteophytes in the notch, and from around the tibial insertion of the ACL, will help to make the knee fully extend. Full flexion may not be possible until posterior osteophytes are removed, but flexion to 100° should now be easy, with gentle flexion beyond gravity alone. The extent of medial material loss is appreciated best with the knee in 30° of flexion—with retractors in situ, there is no tension in the soft tissues, and the surgeon can confirm the amount of bone and cartilage loss due to OA. It is an important principle to be as much bone preserving as possible.

The tibial resection is usually undertaken first (tibia first technique), but a femur first option also works well (femur first technique).

If undertaking a tibia first technique, each degree of freedom such as varus/valgus, extension/flexion and internal/external rotation should be addressed serially.

1. Varus slope of tibia

   Varus slope needs to be preoperatively checked and replicated intra-operatively. For the varus knee, a varus slope of 3–5° is normal. Even in the valgus knee, a varus slope of 1–3° is normal. A neutral slope, perpendicular to the long axis of the tibia, is not normal, particularly on the medial side (Fig. 13.1) and will expose the patient to unnecessary risk of tibial subsidence, by cutting into bone in the middle of the tibia that is markedly less stiff than the rest of the bone interface.
2. Posterior tibial slope

   This is device and patient specific. The surgeon's aim is to restore the native joint line, unless the slope is being reduced to compensate for some cruciate insufficiency or increased to compensate for hyperextension.
3. Axial rotation

   A precise definition of the front of the knee is hard. The flexion axis of the knee is fairly reliable and should be used for the first cut. For round on flat designs, tibial rotation is not critical, while for meniscal bearing knees, more attention is needed, to ensure that the bearing is not constrained by the central wall.
4. Depth of resection

   Depth of resection should be minimal, based upon the amount of bone damage, and the minimum device thickness. The minimal thickness of the metal back tibial component is 8 mm in general, but depends on the implant.
5. Medial translation

   The sagittal cut should be close to the tibial spine. This may not be possible without some osteophyte trimming of the condyle, and retraction of both fat pad and patella. Some extension of the knee may help at this stage.

The tibial jig is pinned in place after these 5 degrees of freedom are considered. If in any doubt make a more superficial cut first. This will be in very hard bone, so irrigation may be needed, but a second and even third cut is not a problem, if the result is a very conservative bone cut in hard subchondral bone. The alternative of a deep cut in softer bone may be a cause of early failure by tibial subsidence or fracture.

The tibial bony fragment is then checked for depth and shape. Based upon its shape, adjustment may be needed. Commonly, the axial rotation may be adjusted, and a more lateral sagittal cut performed in order to avoid component overhang.

The femur is then addressed with the tibial trial prosthesis in place. The knee will by now have restriction-free range of motion between full extension and 100° of flexion. This is needed for femoral preparation. The femoral jigs are placed upon the knee, to ensure that adequate bone is removed in flexion. In medial OA, the posterior chondral surface of the femoral condyle is preserved, so it can be used as a datum point for ensuring that the flexion axis is restored.

The alignment of the flexion gap is chosen, based upon the preoperative analysis and plan including the device choice. A slight rotation of the cutting block may be needed, if a fixed bearing device is used. The extension gap is then assessed and compared with the expected gap on the plan. In medial OA, it is always greater than the flexion gap, owing to material loss, while following surgery, the opposite will be the case: the flexion gap will be 1 mm greater than the extension gap, as it is in nature. Once again, subtle rotation and translation of the cutting block may be needed if a fixed bearing device is used, while for a mobile bearing, a neutral alignment is sufficient.

Side Summary
Extension gap is always greater than the flexion gap in medial OA. The opposite is aimed after UKA. The flexion gap should be 1 mm greater than the extension gap.

Common errors include positioning the femoral block too medially if pushed outwards by a large patella in a large man, and failing to flex the knee sufficiently when cutting the flexion gap. While no harm arises if the flexion gap is cut in more than 90°, a flexion gap cut in less than a right angle will cause problems balancing the extension gap.

Fine-tuning of the balance between flexion and extension gaps can be achieved in several ways. Ideally, in full extension, the entire knee is snug. The ACL is under tension, and both the medial and lateral menisci are tense, with their coronary ligaments under a little tension. In this position of full extension, the whole knee shares the load. By rocking the knee into valgus and varus, some laxity is felt, even in full extension. It is usually much less than 1 mm. In balancing a medial UKA, full extension should result in the bearing being snug, and checks made for bony impingement in the notch—osteophytes on both tibial and femoral sides may cause this (Fig. 13.3a, b). In flexion, there should be no block caused by the device. Preoperative analysis and planning will have revealed the presence of posterior osteophytes which may need to be removed from the femoral condyle to enable full, impingement-free flexion. Loose bodies, or just a bulky calcified medial meniscal remnant, may need to be removed from the posterior capsular recess after final bony preparation, to minimise restriction in flexion.

13.5.2 Lateral UKA

The surgical approach to the lateral compartment is broadly similar to the medial, but differs in a few but important aspects. The incision begins at the top of the lateral edge of the patella with the knee at 90° of flexion, extending distally midway between Gerdy's tubercle and the tibial tubercle to 20 mm distal to the joint line. The deep dissection starts distally, opening the deep fascia on the lateral border of the patella tendon, which is clearly seen and felt. This linear dissection extends proximally to a point 5 mm clear of the inferolateral edge of the patella. At this level, there is a condensation of distal fascia that needs to be released, and then reattached in the repair. From this point proximally, the deep fascia is incised, leaving a 3–5 mm cuff of normal quadriceps expansion on the patella side to ensure easy closure. This incision is carried on proximally in the line of the tendon, into the bottom of vastus lateralis, splitting tendon and muscle. This time, it is deepened into the joint cavity through the capsule down to the inferolateral edge. At this point, the deep fascia is retracted laterally, allowing sharp dissection to dissect between Hoffa's fat pad and synovium laterally, effectively incising onto the articular margin of the femoral condyle, and then radially through the meniscal remnant onto tibial plateau.

A Kocher clamp conveniently grasps the meniscal fragment, lifting it up to allow full excision from beneath, at the junction with the ACL footprint. This deep anterior dissection continues distally freeing up the fat pad to allow the patella to be subluxed medially. A Hohmann retractor inserted from below, just medial to the lateral femoral condyle, contains the fat pad as it is retracted laterally [25]. In 45° of extension, the patella should sublux easily, allowing a careful inspection of the patellofemoral joint and the medial femoral condyle. Osteophytes are removed carefully at this time, from around the trochlea, including the medial side of it if necessary, as well as from around the patella, and notch, ensuring that there is no bony block to full extension.

The knee is then flexed and placed in a figure-of-4 position. The posterior meniscal remnant can be excised safely at this stage, taking great care to preserve the popliteal tendon. The tibial surface can be seen well in this position, and the tibial cutting block then attached. As with the medial side, tibial resection needs to be sufficient to restore the joint line with the minimal thickness of tibial component, to ensure that the strongest subchondral bone is preserved. The bone cut is made at the right orientation for the individual patient, usually in 1° or 2° of varus. Never cut the tibial slop in valgus. The tibial 'biscuit' is then removed and inspected. On the lateral side, the common error is to leave the sagittal cut too lateral. This might be due to the insertion of the patella tendon and the fat pad. One can get around this by placing the leg in a figure-of-4 position, with the foot on the operating table, and knee in the air, extending the knee to around 45°. This takes the tension off the extensor mechanism, allowing the surgeon to sublux the patella medially [25].

> **Side Summary**
> Never cut the tibial slope in valgus.

After ensuring that sufficient depth of bone has been resected across the whole lateral compartment, and that the sagittal cut is not externally rotated, femoral preparation is undertaken. This can be either in figure of 4 or in neutral. The patella is usually obstructing the femoral alignment guide, so it needs to be subluxed substantially, with the aid of either an intramedullary rod or a Hohmann retractor inserted into a drill hole just superolateral to the notch. Alignment of the femoral component is very similar to medial alignment, only differing in so far as the component should be lateral on the condyle, not central.

As with medial UKA, when undertaking lateral UKA it is essential that optimal bone is resected from the flexion facet of the femur. This is where the wear scar is greatest, while the distal extension facet may still have full thickness cartilage (supported by radiographic findings of a normal standing AP, but loss of chondral surfaces in the Lyon-Schuss view). Hence, care must be taken to reduce the extension height sufficiently to ensure full extension without tension. When the knee is rocked into varus in flexion, there should be at least 2 mm more gap than in extension, but in addition, at least 1 mm of opening should be possible in full extension, with no conflict between the edges of the components either in deep flexion or extension. With some ranges of devices, a long-standing valgus knee may be wider than the range, so the sagittal cut may be more lateral, enabling the tibial component to be placed under the femur.

> **Side Summary**
> There should be 1 mm of opening in extension after UKA.

13.5.3 Closure

After a final impingement check, the definitive devices are either impacted or cemented in place.

The fat pad is resutured to the synovial reflection, whether medially or laterally, ensuring that there is no entrapment in deep flexion and full extension. With less well-evolved devices, it may be necessary to reduce the size of the fat pad to accommodate the large anterior flange of the tibial component.

The deep fascia is then closed with heavy absorbable sutures, with routine closure of the fat and skin with a barbed absorbable suture, and glue.

13.5.4 Postoperative Regimen

Standardised postoperative care is of utmost importance. The following key points should be considered:

1. Leave the dressing closed. Do not change it, unless absolutely necessary.
2. Mobilise as pain permits.
3. There is no need for extensive physiotherapy in the first few weeks. If there is a full range of motion on the table, the same can be confidently expected postoperatively.
4. The knee is at risk of overdoing it in the first month. While weight-bearing is accepted, protection is a good idea, and avoiding overload is essential. So, at least one walking aid for the first 3 weeks, and two for bilateral cases.
5. Thromboembolic prophylaxis. This has to be customised for every patient. For those with low risks, which include the majority of UKA patients, a single aspirin every day for a month is sufficient.

13.6 Compartmental Arthroplasty

For those patients in whom the perceived risks of total knee arthroplasty outweigh the benefits, a compartmental approach to OA might be an option. Most commonly, adding a second UKA onto a first one is an appropriate and timely intervention.

Adding the lateral UKA onto a medial UKA is not a technical problem. Use a slightly more lateral skin incision than you otherwise would, but perform the procedure exactly as you would a regular lateral UKA. The only additional feature is that care should be undertaken to ensure that the patient's original alignment should be restored. As the knee was constitutionally varus, it should be restored to varus by the lateral UKA in someone who wishes to avoid a bigger operation (Fig. 13.5).

Adding a medial UKA onto a lateral UKA is also not a problem. A keen tennis player may get many good years out of a lateral UKA, and experience medial OA ten years later. Should the lateral UKA have been overcorrected, or the medial meniscus already injured, then this may come sooner. The medial UKA is added, simply by performing a standard medial UKA, without any compromise to the primary technique.

Adding a PFJ onto either a medial or lateral UKA: once again, this should be treated as a regular primary PFJ arthroplasty. No compromise to your primary technique is needed and approach the patella from whichever side is your preference. In general, valgus knees are best approached laterally, and PFJ can be easily achieved through a lateral patellofemoral approach, extended into the vastus lateralis, preserving the rectus tendon.

The indication for primary bi-UKA is precise. The typical patient will have lateral arthrosis, either from overuse such as skiing or from a plateau fracture. The medial side also has OA in extension. However, the cruciates are normal, and the patellofemoral compartment is also normal. To go straight to a total knee arthroplasty in a patient who still wants to play sport is unattractive. On examination, there is clear arthrosis medially on extension, and laterally in flexion. In these patients, correction of just one side will tend to precipitate OA on the other side, so a bi-UKA is worth considering. Technically, the procedure is exactly as one would expect – simply perform the primary procedure on both sides. Use a midline incision, without a tourniquet, and then use a fat-pad sparing approach first on the more affected side, and then on the less affected. The fat pad is seen to bleed normally on incising the second side, confirming that sufficient collateral flow exists. The final technical point is once again to restore the knee to the pre-morbid alignment. In patients who have been valgus for some time following trauma, but who are naturally varus, this correction may seem excessive. Consent the patient for subsequent fine-tuning of the bearing height and use a device that allows simple bearing exchange.

Primary Uni-PFJ: This procedure should be reserved for a small group of patients. Most people with tibiofemoral OA are best served by the small procedure of a medial or lateral UKA, without any patellofemoral procedure. For the small group of patients who have primary PFJ OA and more recent medial or lateral OA, this is a good option. Once again, the key indications are a knee that is fundamentally kinematically sound, with cruciates that seem satisfactory, and a patient who wants to avoid the large and irreversible procedure of TKA. The approach for UKA-PFJ is dictated by the tibiofemoral disease. Use the medial or lateral approach, perform the UKA as a routine and then add the PFJ while the trial components are in situ. Only in very small people is there any risk of conflict between the femoral and trochlea component. This is avoidable entirely by ensuring that the lateral femoral component is positioned peripherally on the lateral femoral condyle, when undertaking a lateral UKA-PFJ, and ensuring that the trochlea component is positioned sufficiently laterally when performing a medial UKA-PFJ. The choice of PFJ device is left to the surgeon, however a patella button that has a median ridge is of some attraction, as it provides a little more stability for the patellofemoral articulation in both full flexion and full extension. The active range of motion of a UKA-PFJ is substantially greater than that of a TKA, as both cruciates are intact, so there is a much greater range of motion for minor instability to be encountered.

Side Summary

In some cases compartmental reconstruction can be considered either in one stage or if needed when progression in OA occurs in other compartment. However, this should only be considered when all the implants are positioned correctly.

13.7 Postoperative Care

Following conservative arthroplasty of any sort, the postoperative course is not magical: the bone of the tibia in particular has to heal, and by leaving the varus knee in slight varus, the load across this interface can be critical. Weight-bearing should be gradual and limited by pain. Because the cruciates are intact, joint kinematics are preserved, so the risk of requiring a manipulation under anaesthetic for inadequate range of motion is very small indeed, and no pressure is needed to encourage early range of motion. Physiotherapists will naturally encourage faster rehabilitation, but this is not advisable. The use of a walking aid for the first 3–4 weeks is mandatory.

Take Home Message

- The LDFA and the MPTA differ between varus and valgus knees. While in varus deformity the LDFA is predominantly affected, the valgus deformity shows alteration on the tibial side.
- Isolated osteoarthritis in either medial or lateral femorotibial compartment is the ideal indication for UKA.
- Varus and posterior tibial slope, axial rotation, depth of resection and medial translation are essential for correct tibial component placement. Conservative resection at the tibial site should be performed in lateral UKA. The extension gap should show 1 mm opening in full extension.
- The flexion gap should be 1–2 mm greater than the extension gap.

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14 Principles of Total Knee Arthroplasty

David J. Weir, Roland Becker, and David J. Deehan

Keynotes

1. Modern generation knee implants are composed of a metal femoral and tibial cobalt chrome stainless steel alloy with an interposed high-density low-molecular weight polyethylene conforming spacer.
2. Fixation to bone is through press fit with cement (Polymethylmethacrylate), without cement (uncemented), or hybrid variants with the uncemented metal surface having a coating (porous or hydroxyapatite) which promotes bone ingrowth.
3. The articulating polyethylene spacer may be fixed or mobile bearing.

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14.1 Introduction

Total knee arthroplasty (TKA) has now become an established treatment for end-stage knee osteoarthritis (OA). The primary objective is to alleviate pain with secondary goals of improved function and correction of deformity. The modern era of TKA was heralded by John Insall [1]. The principal indication remains progressive rest pain but restitution of alignment in the valgus knee will also restore function and prevent progressive deformity. Key contraindications include recent or current joint sepsis, a neuropathic joint and caution should be exercised with a non-compliant patient.

Side Summary
Goals of TKA: Alleviate pain, improvement of function, correction of deformity.

14.2 Patient Selection

TKA is not without risk and requires intense rehabilitation and a motivated patient. Mismatch of expectation to anticipated outcome is a principal reason for poor outcome. The decision to proceed to surgery should be taken over several consultations with the opportunity for the

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patient to discuss concerns and be educated by a variety of allied professionals, that is, musculoskeletal physiotherapist, occupational therapist, arthroplasty nurse specialist, ward sister. All patients should attend preassessment, education classes, and be given both online and paper information resources. Preoperative knee scores should be recorded and best practice mandates informed consent about inclusion into both local and national registry prospective collection.

Side Summary
Mismatch of expectation and anticipated outcome is one reason for poor outcome.

14.3 Choice of Implant

The surgeon is presented with a range of implant choices, but certain key principles apply. Knee resurfacing may be partial or total. There are a range of modes of fixation of the devices to the host bone which broadly fit into either cemented or uncemented. There are differing levels of constraint of the device. Finally, the interface may be fixed or mobile bearing. Cement remains the mainstay of fixation of the metal component to bone. The combination of under resection and press fit implants to contoured precut host bone facilitates the role of cement as a grout which reduces interface stress and optimises load transfer. Uncemented knee replacements still represent a small number of cases in UK practice but offer the potential for quicker recovery and reduced blood loss at the time of revision (National Joint Registry 13th Report accessed (March 27, 2017) through http://www.njrcentre.org.uk/njrcentre/Portals/0/Documents/England/Reports/13th%20Annual%20Report/07950%20NJR%20Annual%20Report%202016%20ONLINE%20REPORT.pdf). Previous mention of “cement disease” is historical and no longer valid in contemporary practice. Varying levels of inherent construct constraint exist. The majority of primary TKA will be with the use of a cruciate (posterior cruciate ligament, PCL) retaining implant which facilitates the performance of a retained PCL and optimises femoral rollback (Fig. 14.1). Increasing levels of constraint are

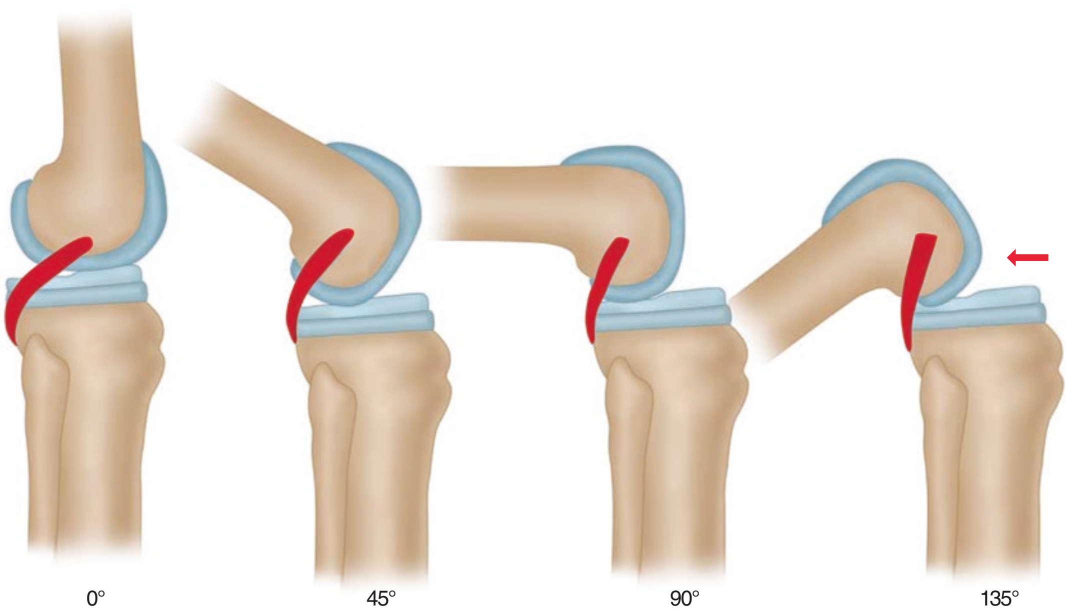

Fig. 14.1 Femorotibial contact during knee flexion

met with the use of a central polyethylene peg from posterior stabilised (PS) to a semiconstrained device through a continuum of increasing constraint (Fig. 14.2). In the presence of the deficiency of the medial collateral ligament, the surgeon should consider the use of a constrained hinge device. However, certain authors argue that increasing constraint may be associated with a reduced lifespan of the device. Mobile-bearing technology offers the potential for reduced shear force transmission and enhanced congruency with reduced polyethylene wear. Clinical results are equivocal but many argue that with increased constraint, mobile technology may reduce load and promote the survivorship of the device.

14.4 Polyethylene

All polyethylene material should be sterilised in a vacuum and sealed so as to reduce risk of early brittle failure from free radical induced cracking. Such failure classically occurs at 7–10 years after implantation. Newer technologies such as highly cross-linked polyethylene such as X3 or XLPE seem only to have a low effect of survival [2]. The highly cross-linked polyethylene reduces wear but increases the number of residual free radicals. It is argued that vitamin E impregnation of the polyethylene can further stabilise the highly cross-linked polyethylene promoting reduction of wear [3]. The central tenet of choice

Fig. 14.2 Level of constraint in TKA

of insert is to ensure correct seating of the metal base plate if a fixed device is used and to match the poly size to the femoral component.

14.5 Informed Consent and Preoperative Patient Education

The consent process is not one single event but should include clinic discussion of the operative and non-operative options, pre-arranged patient education classes which allow for information about in-patient stay and rehabilitation. Such scheduled classes are often led by a specialist nurse practitioner. Provision of information through websites, booklets, and witnessed discussion of risks and benefits of proposed surgery is now mandatory. Consent must involve a discussion of all available operative and non-operative treatment options, recorded discussion of the surgery, length of stay, expected outcome, and timeframes for such. Reference should be made to published outcome (both local and national) data. It is obligated upon the clinician to outline and record the discussion of possible complications such as pain, scar sensitivity, loss of motion, slow recovery, time off work, thrombosis, pulmonary embolism, nerve and vessel damage, and possible long-term sequelae from these. With a valgus knee deformity, specific discussion should focus on the risk of common peroneal nerve injury leading to foot drop. This may be permanent. The patient should also be cautioned that the natural history is one of progression of disease / deformity and of instability from incompetence of the medial ligament.

14.6 Preoperative Physiotherapy

Physiotherapy ideally begins in the preoperative phase and this allows the patient to be prepared both physically and mentally for the intensive rehabilitation that is to follow the surgery. The social circumstances of the patients must be established in order to identify barriers to discharge and recovery thereby affording an early opportunity to refer the patient to other healthcare professionals such as occupational therapy and social services if required. Advice and education are important [4]. These should aim to provide the patient with a better overview of knee arthroplasty and the postoperative course, including emphasis of the importance of patient involvement in the preparation for surgery and aftercare. It is also important to teach the patient exercises that will be done postoperatively, including the walking on crutches. This gives the therapist a chance to build up a rapport with the patient and gain the trust of the patient. The role of such work remains contentious [5]. Using a prehabilitation program, the knee score and function score of KSS were found to be improved prior to surgery, but no significant difference was found 12 months after surgery [6].

Side Summary
Physiotherapy prior to surgery may improve post operative reported knee function but is resource limited and is related to duration of and type of arthritic pathology prior to surgery.

14.7 Day of Surgery Preoperative Review

On the day of surgery, a thorough case note review with the patient should be performed. The limb should be marked and the nature of surgery recorded without encroaching upon the anticipated surgical site for risk of permanent tattooing. The patient should be given ample opportunity to ask any questions or consider deferment of surgery. This is an opportunity for reassurance. Pre- or peroperative antibiotics should be prescribed and a final check of history of allergy and documentation of such in a prominent written and online patient-specific area must be done by the senior surgeon. All necessary x-rays and investigations should be to hand.

14.8 The Operating Theatre Environment

This should facilitate safe, clean efficient surgery with minimal stress to the patient or operating personnel. It is a team approach and a formal WHO checklist and "hug" in advance of surgery should be performed (Fig. 14.3).

All TKA should be performed in a clean air environment with vertical laminar flow and judicious use of antibiotics given at least 30 min prior to induction of anaesthesia. A thorough skin wash with chlorhexidine should be carried out prior to isolation draping in the anaesthetic room. A high thigh tourniquet, if used, should be applied and isolated and sealed avoiding pooling of fluid or fluid ingress under the drapes. Repeat wash of the whole isolated limb with gowned staff in theatre should be performed using betadine and then chlorhexidine. At all times, there should be a restriction on the number of personnel in theatre, no unnecessary traffic, and no individual should enter the laminar flow area without being fully gowned up. All radiographic information of the joint should be displayed in easy view of the operating surgeon. Operating personnel should use water repellent gowns and consider the use of space suits (please see also Chap. 20).

Side Summary
Surgical safety check is very important. A team time out should be just before skin incision and all relevant information about the patient and surgical procedure should be repeated. Confirmation should be given by the anaesthetist and scrub nurse.

Surgical Safety Checklist

World Health Organization | Patient Safety — A World Alliance for Safer Health Care

Before induction of anaesthesia → **Before skin incision** → **Before patient leaves operating room**

Before induction of anaesthesia
(with at least nurse and anaesthetist)

Has the patient confirmed his/her identity, site, procedure, and consent?
☐ Yes

Is the site marked?
☐ Yes
☐ Not applicable

Is the anaesthesia machine and medication check complete?
☐ Yes

Is the pulse oximeter on the patient and functioning?
☐ Yes

Does the patient have a:

Known allergy?
☐ No
☐ Yes

Difficult airway or aspiration risk?
☐ No
☐ Yes, and equipment/assistance available

Risk of >500ml blood loss (7ml/kg in children)?
☐ No
☐ Yes, and two IVs/central access and fluids planned

Before skin incision
(with nurse, anaesthetist and surgeon)

☐ **Confirm all team members have introduced themselves by name and role.**

☐ **Confirm the patient's name, procedure, and where the incision will be made.**

Has antibiotic prophylaxis been given within the last 60 minutes?
☐ Yes
☐ Not applicable

Anticipated Critical Events

To Surgeon:
☐ What are the critical or non-routine steps?
☐ How long will the case take?
☐ What is the anticipated blood loss?

To Anaesthetist:
☐ Are there any patient-specific concerns?

To Nursing Team:
☐ Has sterility (including indicator results) been confirmed?
☐ Are there equipment issues or any concerns?

Is essential imaging displayed?
☐ Yes
☐ Not applicable

Before patient leaves operating room
(with nurse, anaesthetist and surgeon)

Nurse Verbally Confirms:
☐ The name of the procedure
☐ Completion of instrument, sponge and needle counts
☐ Specimen labelling (read specimen labels aloud, including patient name)
☐ Whether there are any equipment problems to be addressed

To Surgeon, Anaesthetist and Nurse:
☐ What are the key concerns for recovery and management of this patient?

This checklist is not intended to be comprehensive. Additions and modifications to fit local practice are encouraged. Revised 1 / 2009 © WHO, 2009

Fig. 14.3 WHO checklist available in different languages: https://apps.who.int/iris/bitstream/handle/10665/44186/9789241598590_eng_Checklist.pdf;jsessionid

14.9 Anaesthesia

Facilitation of safe surgery requires for early and close involvement of the anaesthetic team in the patient journey. This commences at time of preassessment through formal review of medical records, updated clinical examination, ordering of appropriate investigations all with a view to determining fitness for surgery. Ideally, the same anaesthetic team will oversee the preassessment and anaesthetic education as will perform such on day of surgery. During preassessment, the patient should be offered the opportunity to discuss such and be involved in the decision-making process around type of anaesthetic and fully understand the nature of controlled recovery. At surgery, effective anaesthesia may be achieved through general anaesthetic and/or a combination of spinal or regional nerve blockade. Combinations of such are now favoured. Spinal infiltration is reserved for selected bilateral knee replacement. The emphasis is on selective blockade of sensory nerve transmission whilst permitting early motor recovery and supervised physiotherapy, mobilisation, and safe discharge. Local infiltration anaesthesia (LIA) has become popular. LIA seems to be as efficient as spinal anaesthesia for perioperative pain management [7] (more details in Chap. 21).

14.10 Theatre Setup and Draping

Arrangement of instruments facilitates safe, efficient surgery. The instruments trays must be arranged such that the basic set is readily available to surgeon and he/she can swiftly pick up and replace basic instruments him/herself. The trolleys should always stay under the clean air canopy. The limb should rest unsupported with a side support and foot bolster at a lazy right angle. An unscrubbed assistant elevates the leg by holding the foot. A scrubbed member of the surgical team will paint the leg with alcohol-based povidine followed by chlorhexidine. The skin wash should include the foot and an occlusive stockinette rolled onto the limb and preparation completed by using isolation draping with impervious adhesive transparent skin antibacterial skin adhesive (see also Chap. 20).

14.11 Arthrotomy and Exposure

A midline incision made centred over the patella moving medially distally so as to avoid lying directly on the tibial tuberosity (Fig. 14.4). A curved parapatellar incision is then made onto the joint protecting the patellar tendon and elevating the deep component of the MCL at the tibial subarticular level (Fig. 14.5). Minimal medial release is performed. The patella is everted laterally. The fat pad should be partially excised so as to permit mobilisation of the patella and access (Fig. 14.6b). A medial meniscectomy is performed on the medial side. The ACL is transected in its mid portion. The tibia is then anteriorly dislocated by help of an angled retractor placed lateral to the PCL.

Fig. 14.4 Median skin incision for TKA. In case of a very prominent tibial tubercle, the incision should be placed slightly medial or lateral in order to avoid later discomfort

14.12 Tibial Alignment and Resection

An external alignment guide is applied parallel to the weight-bearing axis of tibia in frontal and sagittal planes (1). The block is pinned to the tibia maintaining a 3° front to back slope and the tibia is resected protecting the posterior and circumferential structures (Figs. 14.7 and 14.8). However, the tibial slope will be influenced by the type of implant (CR or PS design) and the specific design given by the manufacturer.

Fig. 14.5 Medial standard (Pay-) approach to the knee joint

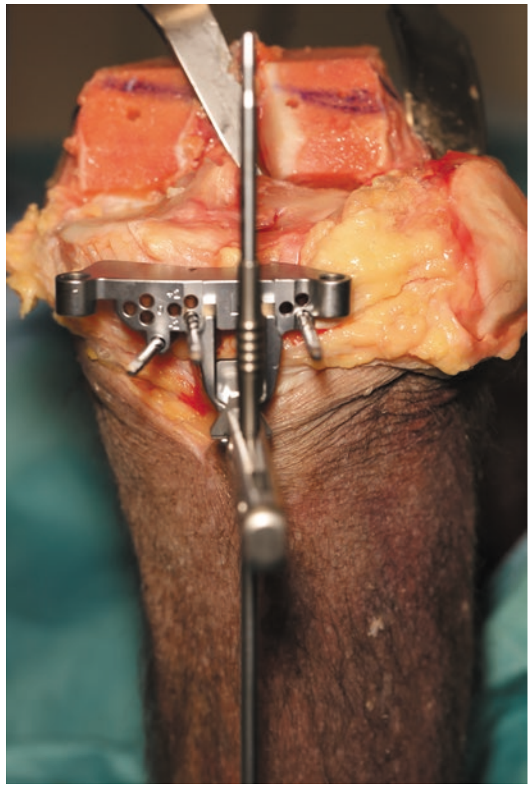

Fig. 14.7 Positioning of the tibial cutting guide using the extramedullary alignment technique

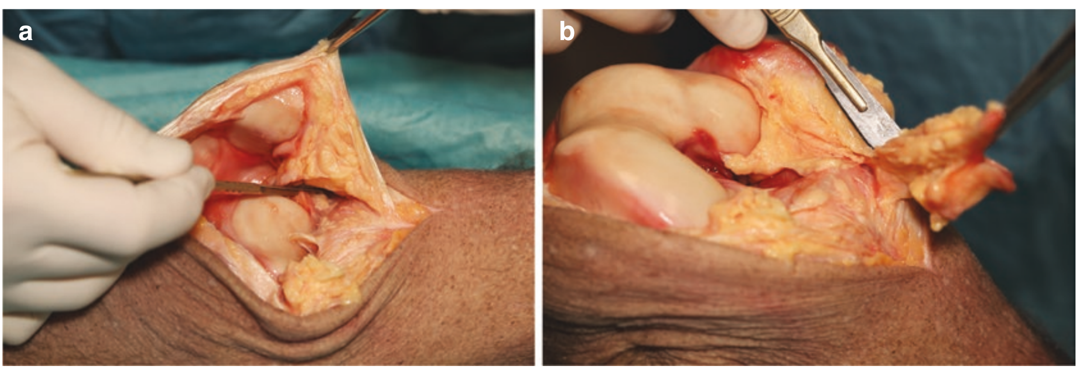

Fig. 14.6 (**a**, **b**) Preparation (**a**) and partial resection of the Hoffa's fat pad (**b**)

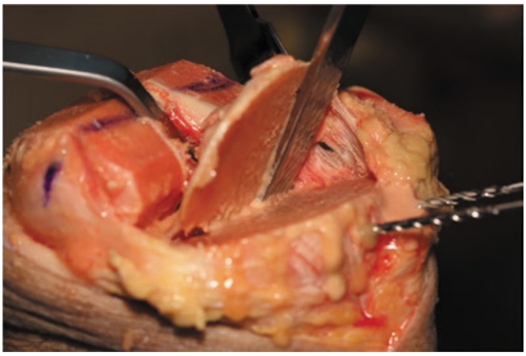

Fig. 14.8 Subchondral resection of the tibial plateau

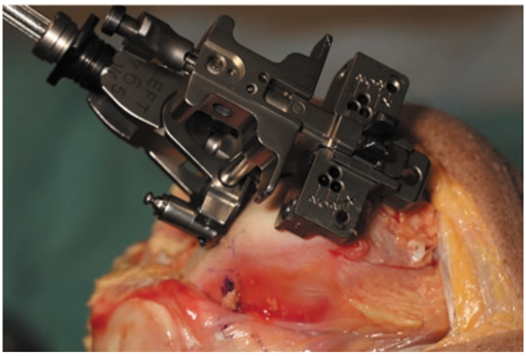

Fig. 14.9 Placement of the distal femoral cutting block using an intramedullary alignment rod

14.13 Distal Femoral Preparation

The femoral canal is opened with a 7-mm drill anterior to the origin of PCL. A 5° distal alignment is made and 8 mm of distal femur is resected (Fig. 14.9). The epicondylar and trochlear sulcus axis is used to optimise femoral cutting block rotation and ultimately component placement (Fig. 14.10).

14.14 Overview of Final Femoral Preparation

The AP size of the distal femur is determined (Fig. 14.11). A four in one cutting block is then positioned on the distal femur (Fig. 14.12A,B). The final cuts are then made. A trial femur is then inserted and then removed after confirming the accuracy of the cuts (Fig. 14.13).

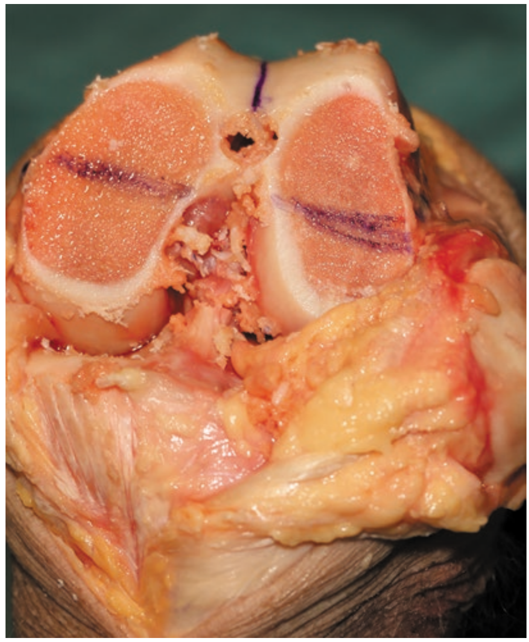

Fig. 14.10 The distal resection has been performed at the femur, and the surgical transepicondylar line and Whitsides line were drawn. These are the landmarks for correct femoral component placement in the axial plane

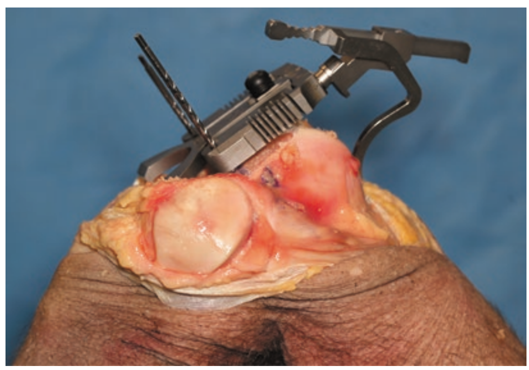

Fig. 14.11 Size of the femoral component is determined using an anterior referenced AP-sizing system

14.15 Soft Tissue Balancing

Soft tissue balancing minimises symptoms of stiffness, instability and optimise performance of the prosthetic joint. The artificial knee should allow for full movement whilst having inherent stability for mediolateral stress, varus/valgus laxity and anteroposterior movement. The extra

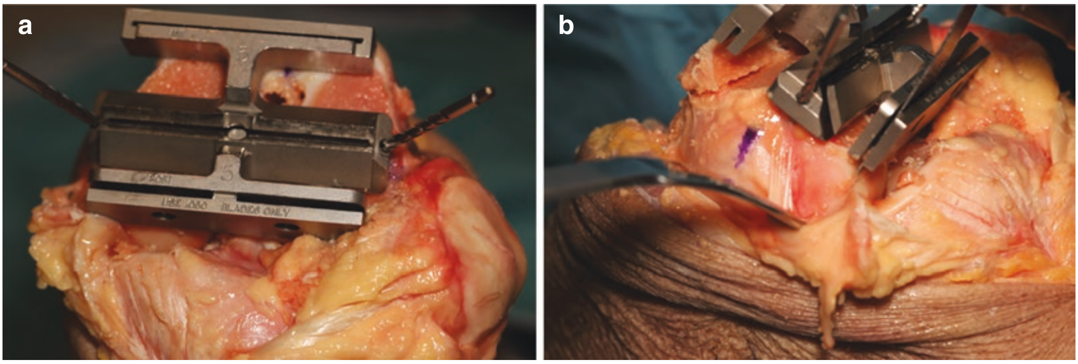

Fig. 14.12 (**a**, **b**): AP view (**a**) and lateral view (**b**) of the knee. The four in one cutting block is fixed on the femur using two pins

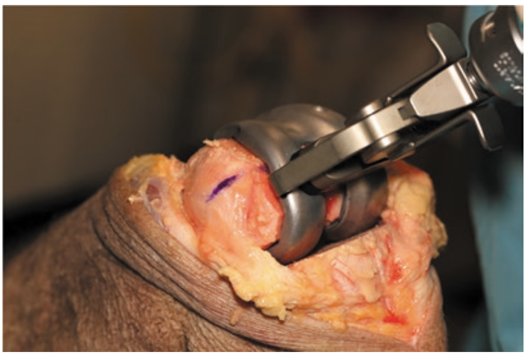

Fig. 14.13 The femoral trial component is placed on the femur

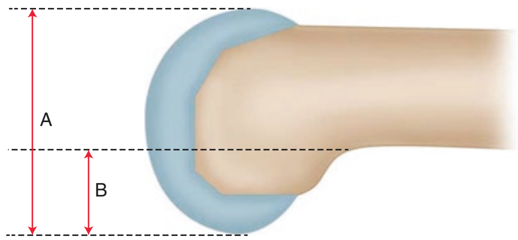

Fig. 14.14 The preservation of the posterior offset is important for good knee function after TKA

dimension is matching the flexion/extension gap which minimises distraction/compression instability in the longitudinal axis [8]. Patellar movement is reliant on correct femoral component rotation and balanced medial and lateral patellofemoral ligament integrity. The absence or dysfunction of the medial collateral ligament mandates use of a hinged device. Semiconstrained knee replacements often require intramedullary fixation through stems (cemented or uncemented), sleeves, or cones thereby dissipated host sharing and minimising stress risers and prolonged the lifespan of the construct. Optimal TKA performance is reliant on restoration of correct alignment, balancing the inherent soft tissue envelope with the inbuilt constraint of the prosthetic device. As a minimum, spacer blocks or a tensioning device (Derby balancer) should be used during surgery. Patellar tracking should be confirmed through the use of the no thumbs technique (Video 14.1). The posterior offset should be restored to achieve optimal flexion and near extension functional control (Fig. 14.14). Newer remote load sensing technology offers the opportunity to objectively determine load transferred across the tibiofemoral compartments and ultimately balance the knee.

Side Summary
Restore the anterior and posterior offset of the femoral component.

14.16 Final Implantation

All cut surfaces must be thoroughly washed and dried. If to be cemented, then the implant must be impacted onto the prepared tibial and femoral host bone prior when the cement is semisolid in form. There are a few aspects to consider during the cementing in order to achieve strong implant fixation. Early cementing after 2–5 min is better than late cementing [9]. Increase in cement penetration of almost 1 mm was seen when the cement was applied to both the bone and component [10]. The keel should be cemented as well [9]. Contamination of the metal/cement interface with fat reduces fixation strength by over 90%. Jet lavage is recommended in order to remove the fat from the bone. Significant increase in cement penetration was found when pulsed jet lavage was used in comparison to syringe lavage [11]. All extraneous cement must be removed. Final trialling of polyethylene insert must be made and the definitive insert seated fully. It must be confirmed and documented that there is full passive stable motion of the joint with safe easy patellar tracking.

Side Summary
Use pulsed jet lavage for cleaning the bone and removal of the fat. Cement should be applied to both bone and component.

14.17 Haemostasis

There is no substitute for peroperative control of bleeding and confirmed cautery of bleeding vessels prior to closure. This argues for release of the tourniquet prior to closure. Supplementary haemostasis may be achieved through the mechanical soft tissue distension action of local anaesthetic infiltration. Systemic agents such as tranexamic acid (TXA) may have an additional role. TXA significantly reduces blood loss regardless of topically or iv application [12]. Oral administration is as effective in terms of haemoglobin drop as iv delivery according to nine randomised controlled trials [13].

14.18 Prior to Closure

Tourniquet should ideally be released and haemostasis secured. However, a comparison of tourniquet release prior and after wound closure showed no difference in haemoglobin drop, blood product infusion, transfusion rate, thrombotic events and major complications according to a recent meta-analysis including 1010 patients [14].

There is a strong and increasingly validated argument for infiltration of local anaesthetic around the capsule to facilitate early mobilisation. Many studies use a cocktail of local anaesthetic and occasional steroid. Closure of the surgical site should be performed in layers with the knee in flexion (Fig. 14.10). This position will make sure sufficient patella mobility after wound closure. Furthermore, the knee flexion reduces blood loss. The 90° of flexion position might be kept after surgery in order to reduce additional blood loss [15].

Side Summary
Close the knee in 60–90° of flexion. It may prevent overtightening of the capsule if the repair is performed exclusively in knee extension.

14.19 Dressings

A sterile non -adherent dressing is applied to the wound. Sterile softband is loosely applied around the foot and moved proximally to cover entire leg to upper thigh upper mid thigh. Prior to transfer, it is important to confirm a warm distal limb with normal capillary return.

14.20 Immediate Medical Supervision

Early measures should include the observation of the peripheral circulation, review of the cardiopulmonary system, administration of intravenous fluids, and careful observation of fluid balance. The postoperative haemoglobin level should be documented. Dressings should be reduced and with early physiotherapy supervision early mobilisation commenced. All patients should receive a short course of antibiotics intravenously cognisant of any documented history of allergy.

14.21 Enhanced Recovery

Recovery commences upon skin closure but is planned in the preoperative phase. Close continued collaboration of the anaesthetic team, recovery staff employed and the physiotherapy team should ensure the optimisation of return of motor function, minimisation of pain and swelling and rapid commencement of active movement with a view to safe, comfortable discharge. The use of adjunctive agents such as reinfusion, tranexamic acid, and greater understanding of the biology of the stress response to surgery work towards optimal discharge. Such care is a team approach and may involve regional nerve blockade, combination of oral and parenteral analgesia, but is reliant upon continued, close discussion and audit of outcomes. The final decision for discharge should not be standardised but must be personalised and involve the patient, immediate family, occupational health professional, physiotherapist and take cognisance of the care available out with the surgical host site. Early recognition of complications minimises such and requires access 24/7 to a health professional after discharge [16].

14.22 After Care

Routine review involves assessment by a physiotherapist or surgeon. Documentation through knee scoring systems, for example, OKS or KOOS as part of institutional, regional, or national audit is central to optimisation of care [17].

14.23 Postoperative Physiotherapy

After surgery, local cooling of the skin through cautious use of ice packs or cryo-cuffs is often employed to minimise post-operative swelling and pain. Ice application causes an immediate vasoconstriction in the superficial tissues, which reduces capillary filtration pressures, thereby reducing bleeding and oedema production. A recent review of the literature has shown that cryotherapy following TKA may reduce postoperative pain [18]. The impact on reducing swelling or blood loss remains unclear. Active inhibition techniques are used where shortened muscle is restricting range of movement. The patient is required to perform a maximal isometric contraction of the tight muscle against resistance before it is lengthened. The maximal contraction of the muscle inhibits tension in the muscle so that it can be more easily lengthened passively, a process known as autogenic inhibition. In combination with dynamic resistance, the patient can be asked to dynamically contract the muscle opposite to the tight muscle (Hamstring vs. Quadriceps contraction). This causes a reciprocal inhibition of the tight muscle via the monosynaptic stretch reflex which allows the tight muscle to be lengthened passively.

14.24 Minimising Risk of Complications

Complications after surgery should be anticipated and thereby ideally prevented or treated early to minimise morbidity. They can be arbitrarily divided into local and systemic and further categorised by likely time of presentation. The attached table summarises the principal concerns for the surgeon performing TKA.

Complication	Timing	Available Preventative Measures
Bleeding	Early	Optimal surgical technique, Release tourniquet before capsule closure, Tranexamic acid
Calf thrombosis/ pulmonary embolism	Early	Mechanical and chemical prophylaxis, early mobilisation, stratification of risk performed preoperatively, at worst for high risk consider IVC filter
Peroperative fat embolism	Peroperative	Cautious reaming and thorough irrigation of canals, gentle pressurisation of cement in elderly at risk group
Nerve damage	Peroperative	Safe surgical technique, avoid hyperextension of knee and flex knee during surgery to avoid traction neurapraxia particularly in the valgus or pre-existent significant fixed flexion case
Arterial/vascular injury	Peroperative	Protection of posterior structures with a retractor and cautious use of the tibial cutting device
Pain	From onset or delayed	Rarely idiopathic and often from either low-grade infection or a capture patellofemoral articulation
Instability	Primary or secondary	Ensure balanced flexion/extension gap and appropriate tensioning through full arc of the collateral structures
Stiffness	Often from onset	Confirm easy full passive extension without tibial lift off at end of procedure, easy flexion of construct passively and no touch technique affirmation of normal patellar tracking
Wound infection	Delayed early presentation with days of surgery	Thorough lavage, pre-operative antibiotics, laminar flow theatre, space suits
Secondary infection	Hematogenous spread—Delayed	As above but advice to patient about good dental hygiene and early assessment for caries or symptoms of remote infection, for example, urinary or respiratory tract infection
Loosening	Late	Correct implantation, avoidance of edge loading, balanced knee with restoration of kinematic alignment
Periprosthetic fracture	Often late	Optimisation of bone health, minimisation of stress risers such as femoral anterior cortical notching
Patellar or popliteal tendon injury	Peroperative	Safe expert surgery with gentle soft tissue handling and protection of susceptible tissues by correct retraction peroperatively

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UKA Component Design: What Do We Need to Know?

15

Lukas B. Moser and Michael T. Hirschmann

Keynotes

The historical development of unicompartmental knee arthroplasty (UKA) has led to different implant designs. Differences affect the mobility of the inlay (fixed-bearing vs. mobile-bearing), the material of the tibial component (all-polyethylene vs. metal backed), and the implantation technique with or without cement. Contemporary off-the-shelf implant designs do not consider the anatomical differences between the medial and lateral compartment of the knee. Recently, patient-specific treatment with customized prosthesis and patient-specific instrumentation have been introduced. Long-term results investigating the clinical outcome of this patient-specific approach do not exist yet.

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15.1 Introduction

Unicompartmental knee arthroplasty (UKA) is an effective treatment of isolated medial or lateral compartment osteoarthritis (OA). Whereas high tibial osteotomy (HTO) was the gold standard procedure for unicompartmental OA in the 1990s, UKA has become very popular in recent years. National joint registries show a trend with increased usage of UKA, covering 10% of all arthroplasties worldwide. Approximately 90% of all UKAs are performed for the medial compartment and only 10% for the lateral compartment.

Although technological advances on implant design and optimizing patient selection have led to remarkable improvements on clinical outcome, revision rates of UKA are still significant higher than in total knee arthroplasty (TKA).

However, before focusing on the UKA implant design, we have to understand its historical development of the unicondylar knee prosthesis.

The concept of hemiarthroplasty started before the development of condylar knee designs. Campbell et al. reported in 1940 their preliminary results on interposition of vitallium plates in the medial compartment of arthritic knees. The aim was to prevent bone-to-bone attrition and provide pain relief. Interestingly, not before two decades after this report, in the late 1950s, the

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first hemiarthroplasty devices were developed. Almost at the same time, McKeever and MacIntosh introduced a unicompartmental device consisting of a metallic tibial plateau. However, there was only a disk inserted in the diseased compartment without any bony resections. Later on, McKeever added a keel to maintain fixation of the hemiarthroplasty device.

Since then, the idea of replacing both parts (distal femur and proximal tibia) became popular. In the late 1960s, Gunston et al. introduced a polycentric knee prosthesis that resurfaced the medial compartment of the femur and tibia.

Modern, contemporary UKA started in the early 1970s by introducing the fixed-bearing UKA. The following unicompartmental knee designs were developed in this time span: St.Georg Sled, Manchester, Liverpool, Marmor Modular, and Insall. In the late 1970s, Goodfellow and O'Connor designed the first mobile-bearing unicompartmental replacement. In 1984, Marmor et al. presented their first series on lateral UKAs.

Despite these technical improvements, the survivorship rates were contrary to the expectations. Malposition of the UKA, insert of less than 8 mm in thickness, ongoing pain, insufficient realignment of the lower limb, and development of patellofemoral OA led to disappointing results. As a consequence, the interest for UKA decreased.

Originally, UKA was indicated in patients with isolated medial knee pain, isolated medial knee joint surface destruction, and failure of the conservative therapy. Kozin and Scott questioned whether the poor results might at least partly be due to a deficient implant design. In 1989, they report strong inclusion criteria in order to improve the outcome of UKA. Indications affect the age (>60 years) and weight (<82 kg) of the patients and the degree of deformity correction during surgery (<15°) and ROM (Total ROM >90° and extension loss <5°). Contraindications are high activity and systematic inflammatory disease. Consequently, applying these criteria, better results were found in literature and the revival of UKA was determined. However, in the recent years, several authors endeavored to soften the strict exclusion criteria on age, weight, and ROM. Nevertheless, patient selection appears to be critical for the patient's outcome.

> **Side Summary**
>
> There were strict indications in the past, such as age of >60 years, no overweight, ROM of >90°, and extension loss of <5°

Longevity of prosthesis is mainly determined by three different factors that are linked to each other: the patient, the doctor, and the implant. The individual anatomy of the patient and his compliance is certainly the most unpredictable factor. The individual anatomy can be anticipated with meticulous planning or advancements in patient-specific treatments (customized prosthesis). A meticulous planning can reduce the probability of surgery-related failures (e.g., implant malposition). Due to the aforementioned technical advancements over the past century, the prosthetic component seems to be the most reliable and predictable factor in patient's outcome.

The following chapter therefore aims to present the most important facts on contemporary UKA designs.

15.2 Biomechanical Considerations

In contrast to total knee arthroplasty (TKA), UKA is solely an anatomic design. The aim of UKA is to preserve the natural knee kinematic by only replacing the missing bearing surface. This is done by restoring the joint line accurately in all planes while preserving the soft tissue ligaments. By matching the position of the contralateral meniscus, the knee becomes normally loaded. The smooth knee motion is enabled by the intact contralateral native component and the surrounding soft tissue in order to prevent a "kinematic mismatch."

Basically there are two different designs of UKA that are named after the mobility of the polyethylene insert: fixed-bearing and mobile-bearing designs.

15.3 Fixed-Bearing Design

Historically, the first available UKA was the fixed-bearing design.

In the fixed-bearing design, the polyethylene is fixed on the tibial baseplate. The poly is flat in order to not offer any guidance for motion. However, as the femoral component is curved, there is a small contact area between the femoral component and the inlay. All motion occurs between the femoral component and the fixed poly surface. The resulting high-load transmission puts a lot of pressure on the poly (especially in flexion) and can accelerate wear and component loosening.

Side Summary
Fixed-bearing design shows higher peak loading in comparison to mobile bearing design.

15.4 Mobile-Bearing Design

This problem of high-load transmission is addressed with the mobile-bearing design introduced by Goodfellow and O'Connor. The curved tibial inlay matches with the curve of the femoral component over the entire ROM. The increased contact area reduces contact pressure and poly wear. In order to not influence the native knee kinematics, the insert can move freely on the tibial plateau. Therefore, the mobile-bearing design enables decreased contact pressure by maintaining knee kinematics.

However, the fixed-bearing design requires intact ligaments in extension and flexion in order to maintain stability and prevent impingement of the insert. Dislocation of the inlay is more often seen in lateral UKA compared to medial UKA. The reason for this shortcoming is that the lateral compartment is more lax in flexion than the medial compartment. In order to address this problem, lateral mobile-bearing tibial components have been developed. A spherically convex and domed tibial plateau and a biconcave bearing with entrapments anteriorly and posteriorly shall prevent the inlay to dislocate. However, most surgeons favor a fixed-bearing design in the lateral compartment.

Side Summary
Mobile bearing increase congruency but also wear is higher due to more wear surface. However, the particles are smaller than in fixed bearing design and easier to phagocyte. There is a certain risk of insert dislocation.

15.5 Cemented Versus Uncemented

Cemented designs were regarded as the standard technique over the past decades, as survivorship was inferior in the cementless designs. However, the most important complications of cement are aseptic loosening, errors in cementation, and formation of fibrocartilage at the bone–cement interface. Technical advancements (hydroxyapatite coating) have led to increased usage of the cementless designs. The press-fit fixation enables improved fixation compared to older cementless designs at the expense of increased risk periprosthetic fracture. Additionally, several benefits, as a shorter surgical time and the avoidance of cementation errors have been highlighted recently. However, long-term follow-up data are still missing to prove overall advantage of the cementless technique.

Side Summary
Cemented fixation is still the gold standard in UKA. More recent studies using uncemented fixation show more promising results than previous ones.

15.6 All Polyethylene Versus Metal Backed

Two different designs are available for the tibial component in fixed-bearing implant designs. The all-polyethylene solely consists of polyethylene and is also named as "inlay." The metal backed design, also called "onlay," consists of a metal base plate (Fig. 15.1). Both designs show comparable clinical outcomes. Due to cost-effectiveness, a trend toward all-polyethylene tibial components has been observed. However, with regard to survivorship, contradictory data exit. Recent studies have demonstrated an increased risk of failure for the all-polyethylene design. All-polyethylene components lead to increased proximal tibial strain, whereas metal-backed components decrease strain on the tibial plateau. However, until now, there are no definite recommendations which component should be used (Fig. 15.2).

Side Summary
There is no difference in survival rate and outcome between all polyethylene and metal backed tibial component.

15.7 Customized Unicompartmental Knee Arthroplasty

Contemporary off-the-shelf (OTS) implant designs have different shortcomings as they do not consider the patients individual anatomy. The medial and lateral condyles of the femur are different in shape and orientation. The J-curve of both posterior condyles is similar. However, the anterior radius of the lateral condyles is larger compared to the medial condyle. On the tibial side, the lateral tibia plateau is rounder than the medial. These ana-

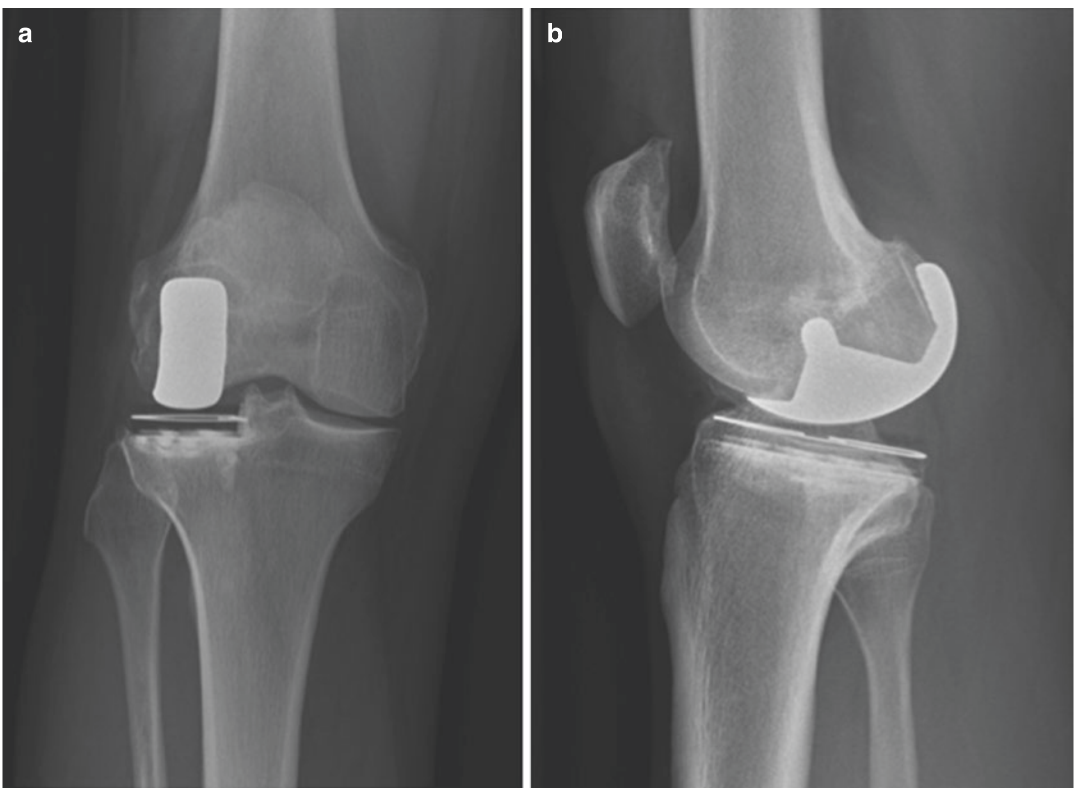

Fig. 15.1 (**a**, **b**) AP and lateral view of a lateral UKA and all-polyethylene tibial component

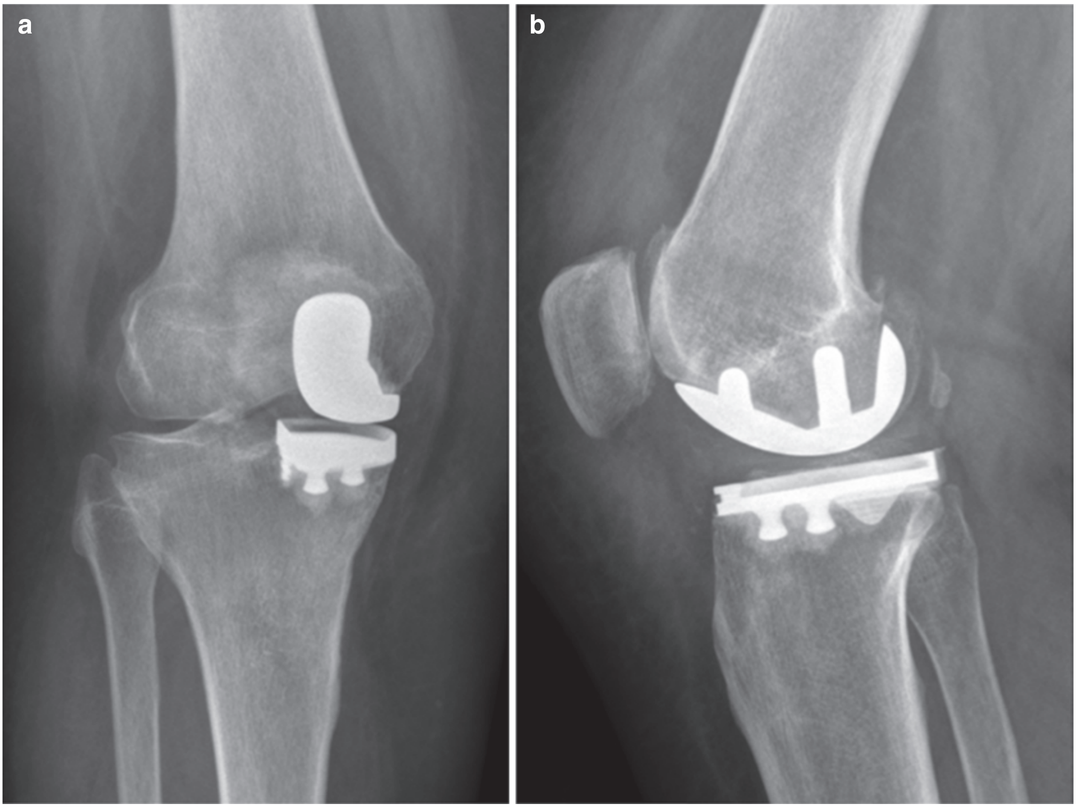

Fig. 15.2 (**a**, **b**) AP and lateral view of a medial UKA and metal backed tibial component

tomic differences raise the question whether the same prosthesis should be used for both condyles. The use of symmetric implants for asymmetric surfaces appears fairly trivial.

However, with regard to survivorship of medial versus lateral UKA, List et al. did not found any significant difference in 5, 10, or 15 years after implantation. The survivorship of medial UKA at 5, 10, and 15 years was 93.9%, 91.7%, and 88.9%, respectively. The survivorship of lateral UKA at 5, 10, and 15 years was 93.2%, 91.4%, and 89.4%, respectively. Furthermore, they investigated the difference of registry-based studies and cohort-based studies and found lower survivorship in registry-based studies. One reason for this might be that registries also include low-volume centers. It is known that the risk for revision surgery increases when center and surgeon volume decreases. However, lateral UKA is performed 10 times less then medial UKA. This fact obviously does not lead to a higher revision rate in lateral UKA. Clearly, further investigations are necessary to investigate differences in survivorship properly.

Multiple studies have shown that the geometry of the distal femur and proximal tibia differs with regard to gender and between different ethnicities. However, off-the-shelf implants are only available in a limited number of different sizes. Possible disadvantages might be incomplete bone coverage and nonanatomic match of the femoral and tibial surfaces.

These shortcomings can be addressed by customized implants that consider the patient-specific anatomy. The customized implants are planned on 3D-reconstructed CT scans including slices of the hip, knee, and ankle. However, long-term results investigating the clinical outcome of this patient-specific approach do not exist yet. The future will show if this patient-specific approach leads to better results.

16 TKA Component Design: What Do Engineers Need to Know?

Daniel Delfosse, Stefan Saladin,
and Roland Becker

Keynotes

1. Brief history is given about the development of total knee arthroplasty.
2. Different features in terms of component design of the femoral and tibial components have to be considered such as:
   Femoral component: - Single versus multiple radius femoral design
   – Fixed- versus mobile-bearing design.
   – Cruciate-retaining (CR) versus posterior-stabilized (PS) design versus bicruciate-retaining design.
   – Trochlea groove orientation.
   – Symmetrical versus asymmetrical tibial component.
3. Chrome cobalt is the most commonly used alloy for TKA.
4. Important aspects of instrument development for TKA are discussed.
5. The design and manufacturing of a medical device must be based on a thorough risk analysis.
6. Medical device regulation (MDR) sets high standards of quality and safety for medical devices in order to meet common safety concerns.

16.1 Introduction

The first endoprosthesis was implanted by Themistocles Gluck, the Head of the Department of Surgery at the Kaiser and Kaiserin Friedrich Children's Hospital in Wedding-Berlin, Germany, in 1890. He had designed a hinge prosthesis made of ivory. The components were fixed with cement, made of colophony, pumice, and plaster of Paris (Fig. 16.1). Gluck highlighted the nineteenth century as a period with three major scientific challenges: first, anesthesia using chloroform; second, Esmarche Constriction of the limbs; and aseptic treatment [1]. No further development during the following 60 years was seen until Walldius introduced a hinged prosthesis replacing the joint surface of both tibia and femur [2]. Numerous other designs were developed, but these implants did not mimic the complex knee kinematics. Modifications of hinged prosthesis were reported by Young and a group of French designers who had developed the

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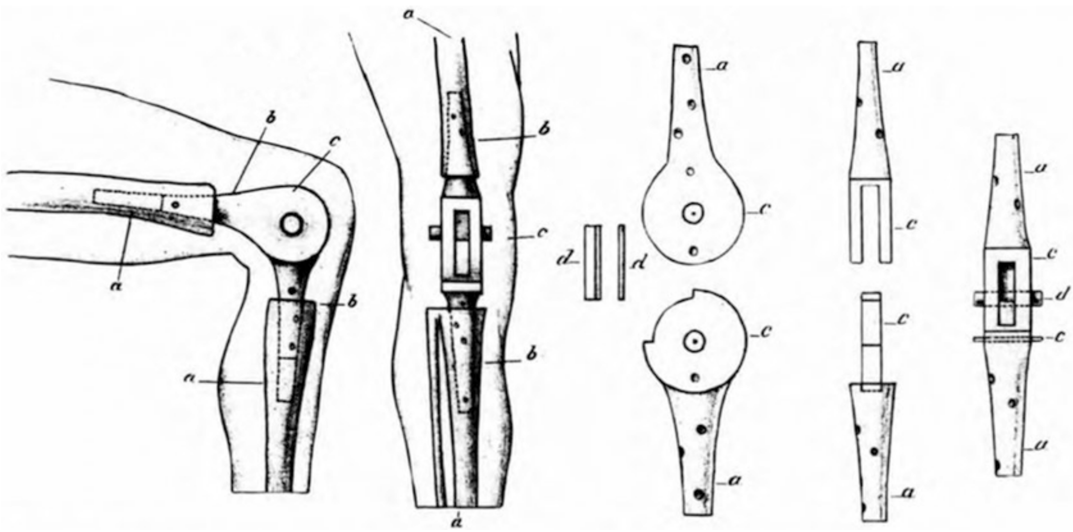

Fig. 16.1 First knee arthroplasty invented by Themistocles Gluck in 1890

Guepar prosthesis [3, 4]. Many other fixed hinged prostheses were introduced, all of them neglecting the patellofemoral compartment and the natural kinematics of the knee.

Between 1966 and 1968, Michael Freeman and Svanson introduced first the cemented condylar total knee at the Imperial College of London. At the same time, condylar knee design was introduced by Frank Guston, a Canadian surgeon who worked with Sir John Charnley [5]. Three types of condylar prosthesis were developed in the 1970s, the Duocondylar prosthesis by Insall and Ranawat et al. at the Hospital for Special Surgery [6], Conventry et al. [7], and Townley [8]. These implants had no anterior femoral flange for the articulation with the patella. While Freeman followed the philosophy of a functional design for total knee prosthesis, Yamamoto and Kodama followed an anatomical concept [9].

In 1972, Insall developed a resurfacing femoral implant with anterior patella shield. This was the beginning of the modern total knee arthroplasty area, replacing all three compartments of the knee. The components were cemented for fixation. The polyethylene liner was fixed to the tibial component [10]. Good and excellent results were reported in 91.5% of 461 knees after a follow-up time between 1 and 5 years.

Interestingly, the major design features of total knee arthroplasty have not changed much since that time.

16.2 Implant Design

There are numerous philosophies in total knee arthroplasty considering the design of the components and the fixation to bone in a cemented, uncemented, or hybrid fashion. The femoral condyles are designed following the concept of single radius or multiple radius such as the J- or G-curve. Furthermore, fixed- or mobile-bearing designs, and cruciate-retaining (CR) or posterior-stabilized (PS) designs have to be distinguished. Both symmetrical and asymmetrical tibial trays are used. Increased attention was paid more recently to the orientation and shape of the trochlea groove.

A recent survey of the European Knee Associates of ESSKA showed that in 2016, 56% of them used PS, 25% CR, 14% both, and 6% ultracongruent TKA implants.

16.2.1 Single Versus Multiple Femoral Radius Design

There are two major concepts considering the shape of the femoral component. The single radius design follows a more functional concept by having constant collateral ligament tension throughout a large part of the range of knee motion. The Triathlon® or Scorpio® system by

Stryker and the balanSys® system by Mathys are examples for single radius implant designs [11]. While the single radius of the Mathys system ranges from −20° to 90° of knee flexion (Fig. 16.2), the Stryker system ranges from 10° to 100° of knee flexion, using a single flexion extension axis of the knee as reference. A single radius has the advantage to create a nearly identical contact area between femur and tibial insert over a large range of knee motion from full extension to 90° of flexion (Fig. 16.3).

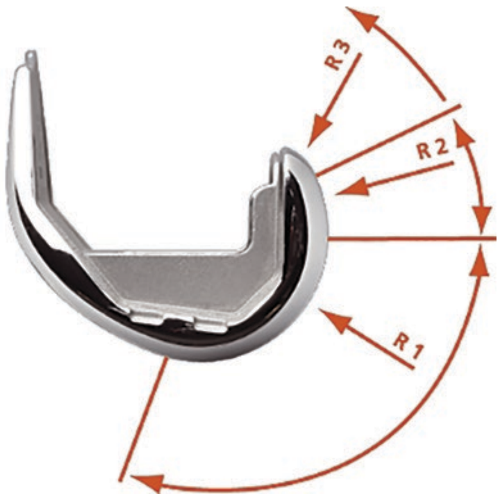

Fig. 16.2 Single radius design (R1 from −20° to 90° flexion) of the balanSys knee

Side Summary
There is nearly an identical contact area between the femur and tibial throughout the range of motion in a single radius design of the femoral component

Biomechanical studies on human specimens showed lower quadriceps extension force during knee extension in a single radius design when comparing with a multiple radius one [12]. In vivo analysis of the knee kinematic of the Triathlon® showed that the femoral rollback was 4 ± 3.2 mm on the medial side and 9.8 ± 2.7 mm on the lateral

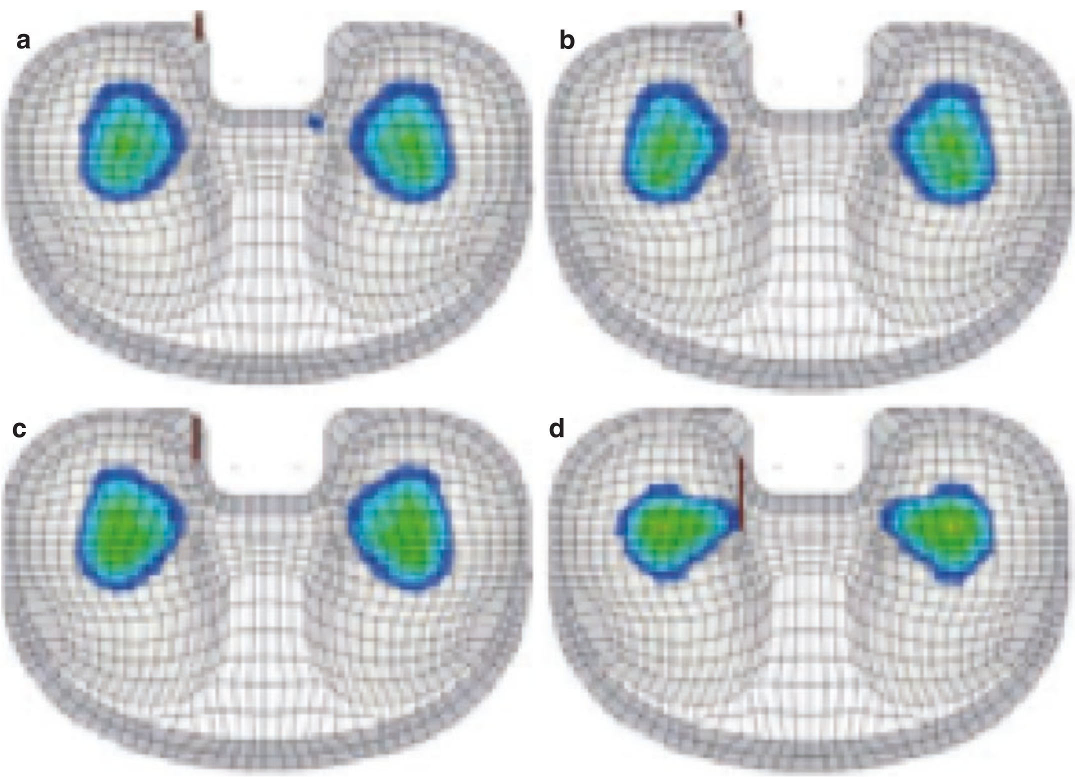

Fig. 16.3 Contact area of the balanSys fixed bearing knee from extension (**a**), 30°(**b**), 60° (**c**) and 90° (**d**) of flexion

side during a mean range of motion (ROM) of up to 120° [13]. Interestingly, it has been shown that the center of the axis representing femoral motion did not change from 0° to 70° of knee flexion. However, the above mentioned data depend from the design of the implant and there are significant differences between the systems.

The single radius design was compared with a medial pivoting design [14]. Again, no difference in clinical outcome based on KSS and OKS was found. There was also no statistical difference in walking speed, stride length and stance phase, peak stride, and push off force between the two systems.

Side Summary
Lower quadriceps force is required in a single radius design during flexion when compared with multiple radius design

The multiradius design (also known as J-curve or G-curve) is the second commonly used design for TKA. The radius of the femoral component increases with flexion in a multiple radius design in contrast to the single radius design. The J-curve design (e.g., PFC Sigma® by Depuy Synthes, NexGen® by Zimmer Biomet) uses two different radii, one between 0° and 30° and the second one between 30° and maximum flexion. In the G-curve design in contrast, the femoral radius changes more gradually, incorporating at least five different radii (Attune® by DePuy Synthes, Fig. 16.4). Significant more femoral rollback was found with the G-curve design in comparison to the J-curve design [15].

Side Summary
Increase in radius of the femoral condyles in a multiple radius designed implant

The long-term clinical outcome after single and multiple radius TKA without patella resurfacing showed no difference in clinical outcome based on HSS, KSS, WOMAC, SF-12, and range of motion [16]. A meta-analysis of the literature has also shown no difference in clinical outcome and range of motion between the single and multiple radius TKA [17]. However, complaints about anterior knee pain were reported more often in the multiple radius (17.5%) group than in the single radius group (10.4%). Gait analysis of single radius and multiple radius PS TKA was compared with healthy controls [18]. While the single radius design did not differ from controls, the multiple radius design showed decreased power absorption and alteration in muscle firing during the stand phase.

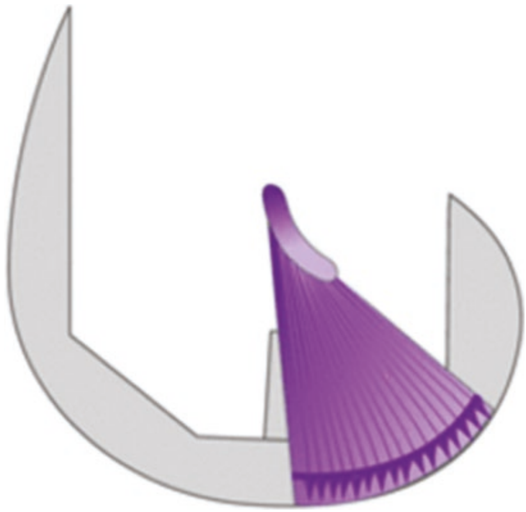

Fig. 16.4 Multi-radius design (G-curve) of the Attune knee

Side Summary
No difference in clinical outcome between single and multiple radius design. Anterior knee pain seems to be more frequent in multiple than single radius design

Considering stability, the single radius design was found to be more stable in 30° of knee flexion in comparison to a multiple radius design [19]. No difference was seen in 0°, 60°, and 90° of knee flexion. Differences in muscle function and kinematics were also reported when comparing the two implant designs [20]. During the sit-to-stand-up activity, the trunk flexion angle was 10° lower, the trunk flexion velocity $7° s^{-1}$ lower, and the extension velocity in hip and knee significantly higher in the single radius group than the multiple radius group.

Side Summary
Superior midflexion stability in a single radius design in comparison to the multiple radius design.

16.2.2 Fixed Versus Mobile Bearing Design

A Cochrane review of all studies up to February 2014 (19 studies with 1641 participants) showed no difference in clinical or functional outcome between fixed- and mobile-bearing TKA according to the Knee Society Score and HSS score [21]. There was also no difference in SF-12, revision surgery, mortality, and reoperation rate. All these findings are based on studies with moderate and low quality of evidence. A level-1 study also did not find any clinical difference between the two designs after 2 years of follow-up [22]. The comparison of the posterior-stabilized design and the mobile-bearing ultracongruent design showed no clinical difference after a minimum of 10 years of follow-up [23]. Revision surgery was required in 7.5% mainly due to aseptic loosening in 2% and infection in 1.8%.

Side Summary
No difference in clinical outcome between fixed- and mobile-bearing TKA

Looking at knee kinematics, different patterns were reported after fixed- and mobile-bearing TKA during stair ascent and descent [24]. The recruitment of the quadriceps muscle occurs at an increased knee flexion moment in the mobile-bearing group during stair ascent. During stair descent, the knee extension moment is less and the hamstring and gastrocnemius activity are extended.

However, despite the significant differences in knee kinematics between the different implant designs, the clinical impact on knee function, pain, or aseptic component loosening remains largely unknown.

16.2.3 Cruciate-Retaining, Posterior-Stabilized, and Bicruciate-Retaining *Design*

The most commonly used implant is the CR and PS design. In Europe, the cruciate retaining implants is more frequently used, in the United States, the posterior-stabilized design is more common. The protagonists for CR implants favor the preservation of the posterior cruciate ligament, because it can prevent posterior translation but is also a secondary restraint to resist extreme varus, valgus, and external rotation moments [25]. In addition, there is also more bone preserved.

According to kinematic studies, the PS design seems to show more natural knee kinematics because the center of femorotibial rotation remains in the medial compartment in contrast to other designs. 86% of the mobile bearing and 63% of the cruciate-retaining knees had a lateral center of rotation while 75% of posterior-stabilized knees had a medial center of rotation that corresponds better to natural knees [26]. Slightly more flexion can be expected when the PS design is used in comparison with the fixed-bearing design [26, 27]; however, the difference seems to be less than 10°.

On the other hand, the resection of the PCL leads to the complete loss of the cruciate ligaments with PS knees. Anteroposterior translation exceeds more than 20 mm in 30°, 60°, and 90° of knee flexion [28]. A small but significant increase in internal and external rotation and varus valgus angulation occurs. Proprioception may be impacted as well after resection of the PCL [29].

A meta-analysis of the literature compared the CR and PS design [30]. No difference in Knee Society Score and Hospital for Special Surgery Score was found, but the PS design was superior in terms of KSS function score and the Western Ontario and McMaster Universities Score. There was no difference in lower limb alignment and the frequency of mild or severe complications. Another meta-analysis including 4884 TKAs with a mean follow-up of 3.9 years showed an overall estimated effect in range of motion of 2.2° in favor for PS. Again, the WOMAC and function score of the KSS was in favor for the PS design [31]. Other factors such as anterior knee pain, instability, or revision rate did not show difference.

Based on the Australian registry, the cumulative revision rate after 13 years was 5% for the CR design and 6% for the PS design [32]. There was a 45% higher risk for revision in the PS design.

Side Summary
The revision rate after CR design and PS design in 5% and 6%, respectively

Besides surgeon preference, there might be specific indications for CR or PS knees. The PS design is recommended in knees with insufficient PCL, posterolateral instability, and significant deformity in the coronal plane [33, 34]. However, the surgeon should be aware of the conceptional and technical differences between the CR and PS designs. In general, PS TKA is considered to be easier to perform, but it cuts away more bone and soft tissues. In case of flexion contracture of more than 20°, steep posterior tibial slope or small femoral component sizes a PS design should be considered [35].

It has been shown that design conformity affects the performance reliability [36]. Less conform design shows higher kinematic variability and is more influenced by AP force and internal external torque. Contact reliability did not differ between the component designs.

In order to improve further knee kinematics in TKA, more attention was paid for preserving the anterior and posterior cruciate ligament. The so-called bicruciate-preserving TKA was first introduced by Gunston [5]. Computer simulation models have shown that the restoration of the natural knee geometry and both of the cruciate ligaments will improve knee kinematics [37]. There are similar findings in a cadaveric study [38]. Lower joint awareness and more stability in high flexion activities have been reported from the clinical point of view after bicruciate-preserving TKA [39, 40]. However, clinical studies have shown higher revision rate after bicruciate-preserving TKA [41]. Potential reason for revision seems to be impingement of the anterior cruciate ligament and aseptic loosening of the tibial component.

Side Summary
Lower joint awareness and higher stability in flexion activities have been found after bicruciate-preserving TKA in comparison to other designs

There are systematic differences when comparing TKA kinematics with healthy knees. First, the anteroposterior translation distance is less after TKA [42]. This is not surprising because most of the implants have a dished insert that limits AP translation. Second, maximum knee flexion is limited to 120° in average which may be related to knee kinematics and joint gaps [43]. Third, gap differences have shown direct correlation with external femoral rotation during squatting and lateral anteroposterior femorotibial translation. At last, patient-specific factors show significant impact on joint performance as well.

16.2.4 Orientation of the Trochlea Groove

The orientation of the trochlea groove differs between the natural knee and a total knee arthroplasty by as much as 6° [44]. The patella tracking is best described as being bilinear with the distal half orientated 0.2° ± 2.8° laterally and the proximal half oriented 4.2° ± 3.2° medially according to a three-dimensional measuring system of 100 human femora [45]. Patella maltracking can cause instability and often pain due to reduced patella mobility. Low mediolateral mobility immediately after surgery will cause inferior knee function and prolonged rehabilitation.

The evaluation of 58 CT scans prior to surgery showed significant variation of groove orientation in both the frontal and axial planes [46]. It is difficult to correctly predict individual trochlea anatomy. Another study analyzed the geometry of the native trochlea [47]. The anterior trochlea line was on average 4.3° ± 3.3° internally rotated to the surgical transepicondylar axis and 2.1° ± 3.0° internally rotated to the posterior condylar line. It was also found that the anterior trochlea line was more externally orientated in varus knees and more internally rotated in valgus knees.

Side Summary
It is very difficult to predict individual patella groove orientation. Femoral components do not restore the anatomical trochlea orientation of the single patient.

16.2.5 Symmetrical or Asymmetrical Tibial Trays

While in older TKA designs symmetrical tibial trays were used, the more recent development shows an increasing number of asymmetrical tibial trays which match the natural anatomy more closely. It is more difficult to achieve optimal coverage with a symmetrical design [48]. With a symmetrical design, there is an increased risk of lateral overhang due to the smaller dimension of the lateral tibial plateau in comparison to the medial plateau. To compensate for the anatomy, with a symmetrical tibial component, there is a higher tendency of placing the component in more internal rotation, which will affect patella tracking and lower limb alignment in flexion.

A clinical study showed that posterolateral tibial overhang of 3.6 ± 2 mm significantly increased posterolateral pain [49]. And, an increase of internal tibial component rotation by more than 10° represents an increased risk of lower function and more pain [50].

16.3 Implant Development—From the Idea to Clinical Application

16.3.1 Morphology Data

As described in the previous chapter, todays' designs are based on the morphology of the human knee but are not necessarily a very close match. Most TKAs impose the sacrifice of both cruciate ligaments (using a PS design) or at least the anterior cruciate ligament (using a CR design). Therefore, TKA relies on mechanical stability by implant design rather than on cruciate ligaments acting as reins.

The mean morphology of the bone structure of a human knee joint is readily available. However, to design a well-functioning knee implant, that also works in abnormal patient morphology or is forgiving re. surgeon errors in bone cuts, the morphological data cannot be used directly for the implant design but need to be adapted accordingly.

The pathway for the development of an anatomical tibia component is well described [51]. It comprises the following steps:

1. Acquisition of a sufficiently large cohort of 3D morphologic data using fine-slice computed tomography.
2. Calculation of an average master shape with a mathematical process called "bone-morphing".
3. Assessment of the rotational alignment tolerance for the final implant shape.
4. Design of a final shape that is optimized for the selected manufacturing process.
5. Selection of the implant size subdivision.

Step 3 willingly changes the morphology of the implant from the mean anatomical shape to an artificial shape that is, however, more forging for surgeon error.

16.3.2 Materials

The selection of materials that are approved for long-term human implants is quite limited. Materials commonly used for TKA components are listed in Table 16.1.

The components are intended for cemented or uncemented fixation. Cemented designs are fixed into the human bone with PMMA cement. The interface between implant and cement has to be specifically designed for a solid and long-lasting connection. As PMMA and the implant materials do not create a chemical bond but rely more on a form fit, the implant surfaces are generally roughened or contain features such as dove-tail grooves.

Uncemented designs rely on osseointegration of the bone onto the implant surface. These are thus optimized for bone on- or in-growth, using a variety of means to create a rough and porous surface that attracts the bone cells. In general, the surfaces are coated with titanium (as plasma spray or beads) and/or calcium phosphate such as brushite or hydroxyapatite.

Table 16.1 Materials commonly used in TKA

Component	State-of-the-art materials for TKA	Special materials used in TKA
Femur	CoCr-alloy cast (ISO 5832-4)	ZTA ceramic (zirconia-toughened alumina, ISO 6474-2) Ceramized metal («Oxinium»)
Tibial insert	UHMWPE (ISO 5834-2, ASTM F648) HXLPE (ASTM F2565)	AO-HXLPE (ASTM F2695)
Tibial baseplate	Cast CoCr-alloy (ISO 5832-4) Wrought CoCr-alloy (ISO 5832-12) Ti-6Al-4 V alloy (ISO 5832-3)	UHMWPE in all-poly tibia design
Patella	UHMWPE (ISO 5834-2, ASTM F648)	HXLPE (ASTM F2565)

16.3.3 Collaboration

A close collaboration between surgeons, material scientists, and design engineers is indispensable for the development of a novel TKA. Without surgeons, neither the implant nor the instrumentation would satisfy the need for accuracy, reliability, and ease-of-use in the operating theatre. Without the material scientists, the optimization of osseointegration and wear resistance would not have been possible. And without the design engineers, no implant would ever have been designed, validated, and optimized for manufacturing.

16.4 Development Method

A thorough preclinical testing required by law to fulfil the essential requirements, prerequisite to apply for CE-marking or FDA approval. A common procedure uses the waterfall model from the FDA Design Control Guidance (Fig. 16.5) to visualize the interactions of the design control elements during the development process.

Verification means confirming by examination and provision of objective evidence that specified requirements have been fulfilled, that is, design verification shall confirm that the design output meets the design input requirements. In short, design verification answers the question if the product was developed correctly.

In contrast, validation means confirming by examination and provision of objective evidence that the requirements for a specific intended use can be consistently fulfilled. Design validation

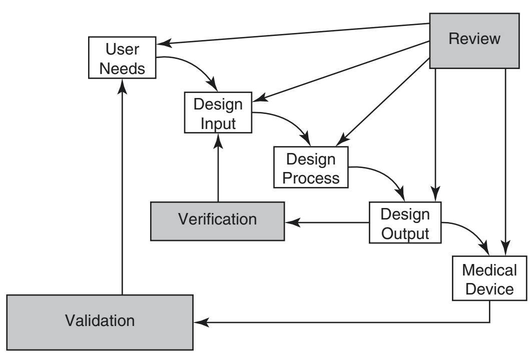

Fig. 16.5 Design control procedure

shall ensure that the device conforms to the defined user needs and intended use. In short, design validation answers the question if the right product was developed.

The specified design must be tested by appropriate methods selected by the design engineer and fulfil acceptance criteria defined in specifications. Some requirements can be easily verified based on documents such as technical drawings or material specifications (e.g., length, diameter, shape, markings on product, material composition). Functional and interface requirements may be verified by specific laboratory testing (e.g., application of a force or torque, adjustment of a length or an angle, assembly of two or more parts). For requirements that are common for certain groups of medical devices such as total knee arthroplasty, standardized test methods are defined in international standards (e.g., dynamic testing, wear testing, transport validation, biocompatibility testing, and shelf-life).

Mathys' list of applied standards for the development, material selection, testing, packaging, sterilization, and clinical introduction of a TKA incorporates around 150 international standards. The most relevant ones for development and testing are listed in Table 16.2.

The tests carried out are evaluated from both technical and clinical perspectives and the results documented. Together with other documentary evidence, they form the contents of the instruments' technical documentation. This represents an important part of the development of any medical product.

Specialists in the regulatory department then ultimately check that the products have been manufactured, verified, and have documentation in full compliance with the applicable standards and regulations. Only then the medical device is

Table 16.2 List of applicable international standards for TKA implant development relevant to design (D), risk assessment (R), and testing (T)

Standard	Name	Used for
ISO 7207-1 & 2	Implants for surgery—Components for partial and knee joint prostheses	D, R, T
ISO 10993-1 to 18	Biological evaluation of medical devices	R, T
ISO 13485	Medical devices—Quality management systems—Requirements for regulatory purposes	D, R, T
ISO 14243-1 & 2	Implants for surgery—Wear of total knee joint prostheses	T
ISO 14283	Implants for surgery—Fundamental principles	D, R, T
ISO 14630	Non-active surgical implants—General requirements	D, R, T
ISO 14879-1	Implants for surgery—Total knee joint prostheses—Determination of endurance properties of knee tibia trays	T
ISO 14971	Medical devices—Application of risk management to medical devices	R
ISO 16142	Medical devices—Guidance on the selections of standards in support of recognized essential principles of safety and performance of medical devices.	D, R, T
ISO 17853	Wear of implant materials—Polymer and metal wear particles—Isolation, characterization, and quantification	T
ISO 21536	Non-active surgical implants—Specific requirements for knee joint replacement implants	D, R, T
IEC 62366	Medical devices—Application of usability engineering to medical devices	D, R, T
ASTM F 1223	Standard Test Method for Determination of Total Knee Replacement Constraint	T
ASTM F 1800	Standard Test Method for Cyclic Fatigue Testing of Metal Tibial Tray Components of Total Knee Joint Replacement	T
ASTM F 2052	Standard Test Method for Measurement of Magnetically Induced Displacement Force on Medical Devices in the Magnetic Resonance Environment	T
ASTM F 2083	Standard specification for Total knee prosthesis	D, R, T
ASTM F 2182	Standard test method for measurement of radio frequency induced heating on or near passive implants during magnetic resonance imaging	T
ASTM F 2724	Standard Test Method for Evaluating Mobile Bearing Knee Dislocation	T
ASTM F 2777	Standard Test Method for Evaluating Knee Bearing (Tibial Insert) Endurance and Deformation Under High Flexion	T

given its «birth certificate», the CE mark, and can be used for the first surgical procedure in a clinical center—for the patient's benefit.

16.5 Risk Management

The design and manufacturing of a medical device must be based on a thorough risk analysis and the assessment of the benefit-risk ratio for each individual risk. Therefore, testing cannot rely on international standards only but must be based on the outcome of the risk analysis using worst-case scenarios.

All risks should be mitigated as much as possible, first by design, then by testing. In cases where a residual risk remains that cannot be overcome by design, a clear communication to the users and the patients is warranted. According to the ISO 14971 standard, all medical devices have to be made such that the inherent risks are as low as possible. This can be done by three methods:

1. Inherent safety by design.
   - Use specific connectors that cannot be connected to the wrong component.
   - Remove features that can be mistakenly selected.
   - Improve the readability of controls, labels, and displays.
2. Protective measures in the medical device itself or in the manufacturing.
   - Incorporate safety mechanisms such as physical safety guards, shielded elements, or software blocks.
   - Include warning screens or alerts to advise the user of essential conditions that should exist prior to proceeding with device use.
   - Use device technologies that require less maintenance.
3. Information for safety.
   - Provide written information, such as warning or caution statements in the Instructions for Use (IFU) that highlight the use-related hazard.
   - Train users to avoid the use error.

16.6 Instrumentation—What Are the Most Important Aspects?

The instrument precision and function, as well as their problem-free reprocessing, must be completely reliable over the course of many surgical procedures. Before a modern surgical instrument can be used on a patient, it must first undergo numerous developmental stages and checks.

The process should always begin with the question: What does the user want? As a result, the technical concepts for the later instruments are optimized right from the outset in collaboration with clinicians and theatre personnel to ensure their compatibility and practically in the workplace. This initially takes place rapidly and interactively, using instruments generated on 3D printers and on artificial bone in a laboratory setting.

Over the course of the development of the instruments, aspects such as dimensional stability, optimization of manufacturability, and inherent product safety are refined. This latter aspect means anticipating potential risks associated with their use and constructively implementing risk reduction measures such as design improvements.

Once all dimensional and geometric specifications are met in production, each individual function of the instrument is verified under simulated practical conditions. Fatigue and wear tests are carried out and the instruments are artificially soiled and their ability to be cleaned and sterilized is scrutinized. The biocompatibility of all materials and production processes used are confirmed.

Finally, practical user tests under simulated surgical conditions validate the design concepts with regard to usability. For this purpose, the instruments must be used by clinicians, operating theatre personnel, and processing personnel who were not involved in the development process, based on the product information provided. If the instruments can be used intuitively and confidently in line with their intended purpose, then their suitability for use is confirmed.

16.7 New Medical Device Regulation in Europe

In May 2017, the Medical Device Regulation ("MDR," EU 2017/745) was introduced to ensure the smooth functioning of the market as regards medical devices, taking as a base a high level of protection of health for patients and users. On May 2021, it shall enter into force for all medical devices used in the European Community and provide the basis for CE-marking. The MDR sets high standards of quality and safety for medical devices in order to meet common safety concerns. When placing their devices on the market or putting them into service, manufacturers shall ensure that they have been designed and manufactured in accordance with the requirements of this regulation.

The 123 Articles and 17 Annexes of the MDR make for useful reading for all people involved in the development, registration, and placing on the market of medical devices in the European Community. It is essential that all design engineers know at least parts of the MDR thoroughly (e.g., Annex I, II, VI) as it affects their daily work.

Because of its extensive need for technical documentation, it is often said that "the development of medical devices entails 10% brain work for engineering and 90% for documentation." Unfortunately, this is probably not very far from the truth.

Side Summary
MDR sets high standards of quality and safety for medical devices in order to meet common safety concerns.

Take Home Message

- A good understanding of the human knee joint is as important as knowledge about materials and manufacturing technologies to develop a safe and effective TKA. Therefore, a close collaboration between surgeons, material scientists, and design engineers is paramount for the successful development.
- Thorough preclinical testing is required by law to show that the new implant system will achieve the desired safety and performance. The technical documentation is the base for the approval by the notified body, leading to a CE-mark or FDA approval.
- The clinical introduction must be accompanied by clinical trials and a stringent post-market surveillance.

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17 Patellofemoral Arthroplasty: Onlay Versus Inlay Prostheses

Andreas B. Imhoff and Jonas Pogorzelski

Keynotes

- Generally, patellofemoral arthroplasty is considered a reasonable treatment option in patients suffering from isolated patellofemoral osteoarthritis.
- There exists no gold standard whether to use the inlay or onlay design.
- Patient selection is the key to success.
- Contemporary patellofemoral inlay arthroplasty demonstrates high patient satisfaction with significant improvements in knee function and pain relief at mid-term follow-up while avoiding progression of tibiofemoral arthritis.
- In patients with significant trochlea dysplasia or with (minor) rotational malalignment, an onlay prosthesis might be beneficial as its design addresses those factors better than an inlay design.

17.1 Introduction

The treatment of isolated patellofemoral osteoarthritis (PFOA) still remains challenging and various treatment strategies have proposed over recent decades [1–3]. When non-operative therapies have been exhausted, patellofemoral arthroplasty (PA) can be considered for patients suffering from severe isolated PFOA.

Following the release of the first prototype of patella arthroplasty in 1955 [4], the design and materials have significantly evolved over time. In general, an onlay or inlay technique can be used for the implantation of a patellofemoral prosthesis. Inlay design trochlear components (Fig. 17.1) are implanted flush with the surrounding cartilage after creation of a bone bed within the native trochlea. Moreover, modern second-generation inlay prostheses include a trochlear flange that narrows distally to ensure sufficient patella tracking without causing lateral hypercompression of the patella. Onlay design trochlear components (Fig. 17.2) completely replace the anterior compartment by using the same anterior cut, as is performed in total knee arthroplasty.

Early inlay designs, which are considered first-generation implants, are generally associated with higher failure rates compared to second-generation onlay designs. Therefore, onlay design trochlear components were considered the gold standard for several years. However, with the introduction of a second-generation inlay

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Fig. 17.1 Second-generation inlay patellofemoral prosthesis (Kahuna Prosthesis, Arthrosurface, Franklin, MA, USA)

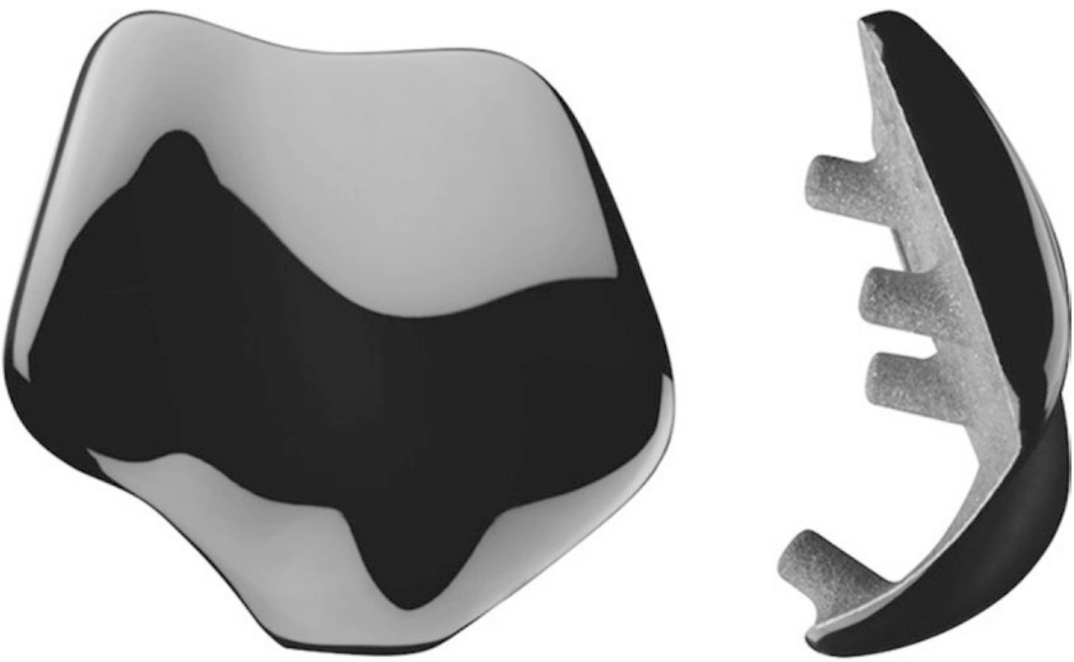

Fig. 17.2 Second-generation onlay patellofemoral prosthesis (PFJ Prosthesis, Smith & Nephew, Andover, MA, USA)

design, a promising alternative implant has become available.

This chapter aims to provide an overview of the indications and contraindications for patellofemoral arthroplasty, a comparison of onlay and inlay techniques, and finally some recommendations for clinical practice.

17.2 Indication

Patellofemoral Arthroplasty is indicated in patients suffering from isolated disabling PFOA with minimum grade III-IV of the Kellgren–Lawrence classification or chondral defects grade III-IV of the Outerbridge classification and refractory to conservative treatment and/or failed prior surgery. Based on established treatment algorithms, isolated patellofemoral arthroplasty is generally performed in patients without active patellofemoral instability. Moreover, severe patellofemoral malalignment as indicated by: a tibial tuberosity trochlear groove distance of more than 20 mm or less than 8 mm and a Caton-Deschamps Index of more than 1.2 or less than 0.8; or a lateral patellar tilt of more than 5° should be treated in addition to the implantation of a patellofemoral prosthesis. The same applies for severe tibiofemoral malalignment defined as mechanical valgus or varus of more than 5°, femoral anteversion of more than 20° or tibial torsion of more than 40°.

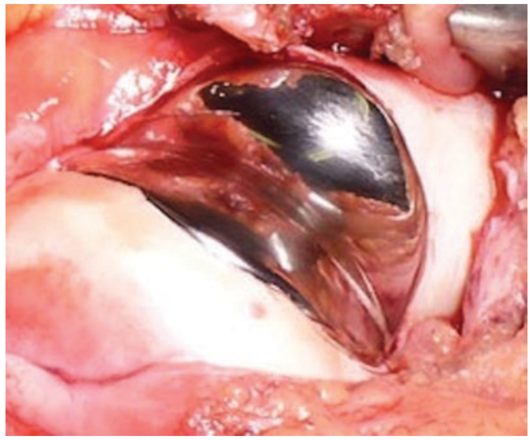

Fig. 17.3 Second-generation inlay patellofemoral prosthesis (WAVE Prosthesis, Arthrosurface, Franklin, MA, USA) implanted flush with the surrounding cartilage after creation of a bone bed within the native trochlea

17.3 Contraindication

Contraindications for patellofemoral arthroplasty are symptomatic tibiofemoral osteoarthritis (OA) with pain during activities of daily living, inflammatory arthropathy, chondrocalcinosis, chronic regional pain syndrome, active infection, and fixed loss of knee range of motion.

17.4 Inlay Prosthesis—Implant Design and Surgical Technique

The implant design of current inlay prostheses typically incorporates a cobalt chrome trochlear component that is connected to a titanium bone anchoring fixation stud via a taper interlock with an additional all-polyethylene patella component. Typically, inlay prostheses include a trochlear flange that narrows distally to ensure sufficient patella tracking without causing lateral hypercompression of the patella. Almost every system comes with multiple implant sizes with varying offsets which facilitates a patient-specific geometry match. All inlay prostheses are implanted flush with the surrounding cartilage after creation of a bone bed within the native trochlea, thereby avoiding significant bone loss (Fig. 17.3). Compared to an onlay system, the more anatomic approach of the inlay design closely reproduces the complex kinematics of the patellofemoral joint. Thus, this precludes soft tissue irritation due to overstuffing of the patellofemoral joint—a known risk factor for the development and progression of osteoarthritis due to secretion of pro-inflammatory cytokines.

> **Side Summary**
> The inlays design of patellofemoral arthroplasty shows a more anatomic approach when compared with the onlay design

For the implantation [2], a lateral minimally invasive surgical approach without eversion of the patella is typically used to protect the medial soft tissue structures. A further advantage of the lateral approach is that the often laterally overhanging osteophytes of the patella can be easily resected without compromising the view on the trochlea. With the knee in full extension, an offset drill guide is used to localize the centre for the

Fig. 17.4 An offset drill guide is used to establish a working axis normal to the central trochlear articular surface and to confirm trochlear defect coverage

Fig. 17.5 The implant bed is reamed with the aid of a guide block

reamer correctly, which lies in general in the centre of the trochlear articular surface and to confirm trochlear defect coverage (Fig. 17.4). Once the superior and inferior drill guide feet are aligned with the trochlear orientation, a guide pin is advanced into the bone. To determine the proper implant geometry, the superior/inferior and the medial/lateral offsets are measured using specific instrumentation. The implant bed is subsequently reamed three dimensionally with the aid of a guide block (Fig. 17.5). The screw fixation stud is then advanced into the bone and the trochlear component is aligned with the appropriate offsets on the implant holder and placed into the taper of the fixation stud. The trochlear component is finally seated using an impactor (Fig. 17.6).

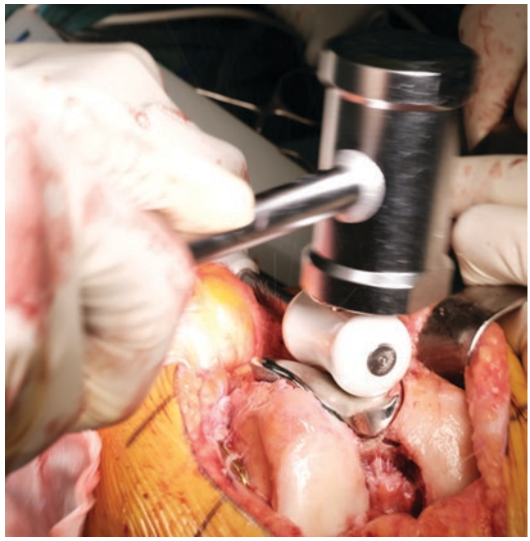

Fig. 17.6 The trochlear component is seated using an impactor

Debridement of patellar osteophytes, circumpatellar denervation, and resurfacing of the patella is performed subsequently. To replace the patellar surface, a drill guide is inserted with the aid of an alignment guide. The medial/lateral and superior/inferior offsets are measured and an implant bed is reamed. The patellar component is then aligned on the implant holder and cemented into the bone bed (Fig. 17.7). Postoperative radiographs in three planes are done routinely to check implant positioning (Fig. 17.8).

17.5 Onlay Prosthesis—Implant Design and Surgical Technique

Current onlay implant designs provide close to anatomical patellofemoral kinematics, such as an asymmetric trochlear groove, which is deepened and lateralized and is implanted with fixation pegs, which allow for changes in multiple implant sizes. When using an onlay design prosthesis, rotation of the trochlear component is determined by the surgeon, and internal rotation of the distal

Fig. 17.7 To replace the patellar surface an implant bed is reamed (left). The patellar component is then aligned on the implant holder and cemented into the bone bed (right)

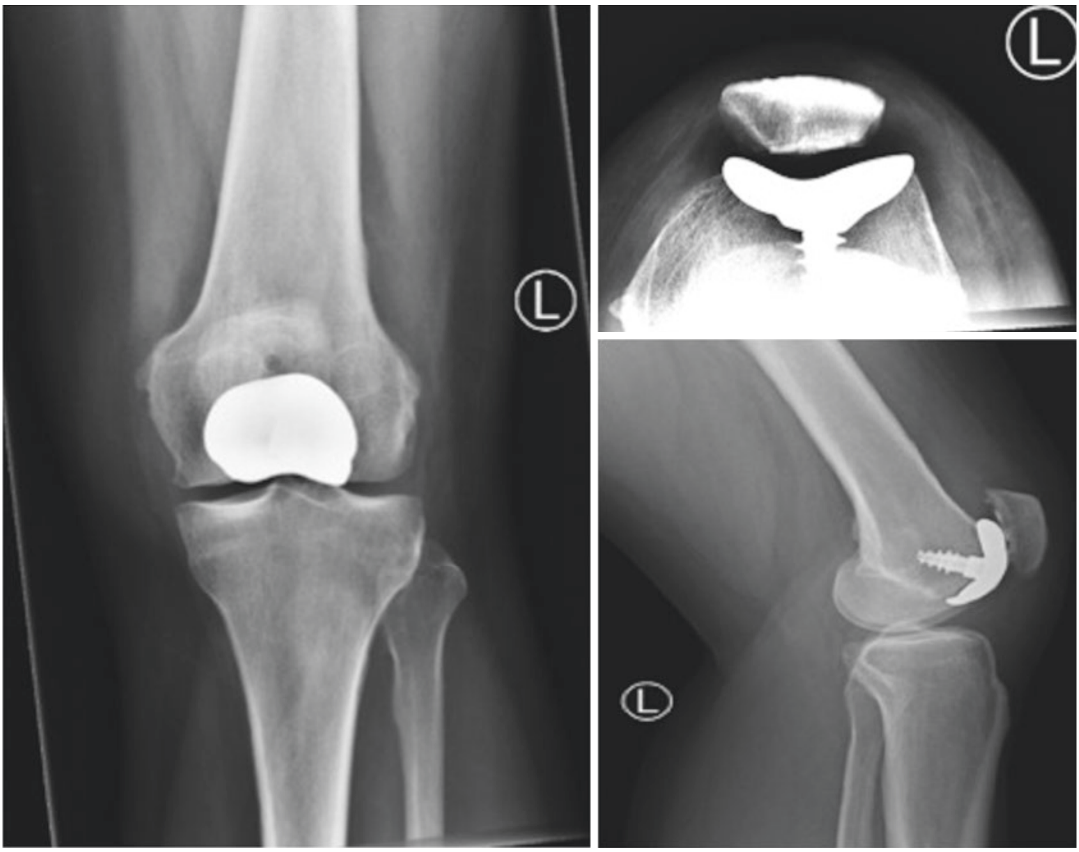

Fig. 17.8 Postoperative radiographs of the inlay implant in three planes are done routinely to check on implant positioning

femur can be corrected to some degree by placing the femoral component in external rotation. An onlay design component might therefore be beneficial in patients with minor rotational malalignment to avoid femoral osteotomy. In addition, an onlay design component might be considered also in patients with high-grade trochlear dysplasia, as positioning of an inlay prosthesis can be difficult in such cases, especially for inexperienced surgeons.

Side Summary
Onlay design might be considered in patients with patellofemoral dysplasia

Comparable to the surgical approach of an inlay prosthesis, a lateral standardized minimally invasive surgical approach without eversion of the patellar is used [5]. In contrast to an inlay prosthesis, a bony resection of the anterior portion of the trochlea is necessary and is done by using the same anterior cut as used in total knee arthroplasty using the manufacturer's intramedullary guiding instrument (Fig. 17.9). Next, the trochlea is deepened by guided reaming. Special care is taken to ensure a proper fit of the implant without femoral notching or over-stuffing. After satisfying patellar alignment, which is tested with a trial implant, the final implant is inserted and fixed with bone cement (Fig. 17.10). Finally, the undersurface of the patella is inspected and routinely replaced. Postoperative radiographs in three planes are done routinely to check implant positioning (Fig. 17.11).

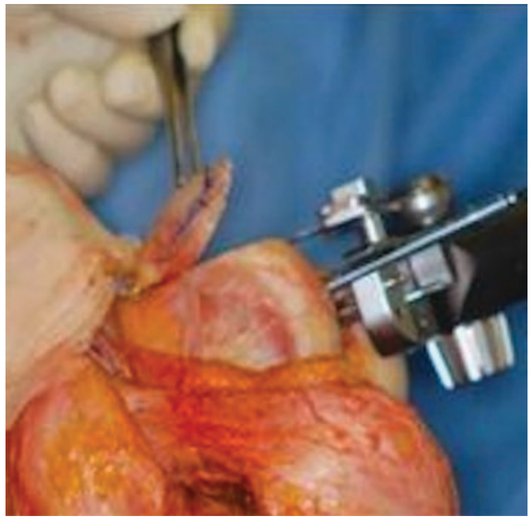

Fig. 17.9 After accessing the joint, the bony resection of the anterior portion of the trochlea by using the same anterior cut as used in total knee arthroplasty is performed using the manufacturer's intramedullary guiding instrument

Side Summary
More bony resection is required when the onlay design is used.

17.6 Postsurgical Rehabilitation

All patients are discharged when able to perform knee flexion to a minimum of 90 degrees and can climb stairs safely on crutches. Furthermore, all patients are instructed to do partial weight bearing with 20 kg for 2 weeks until complete healing of the soft tissue. Early rehabilitation includes

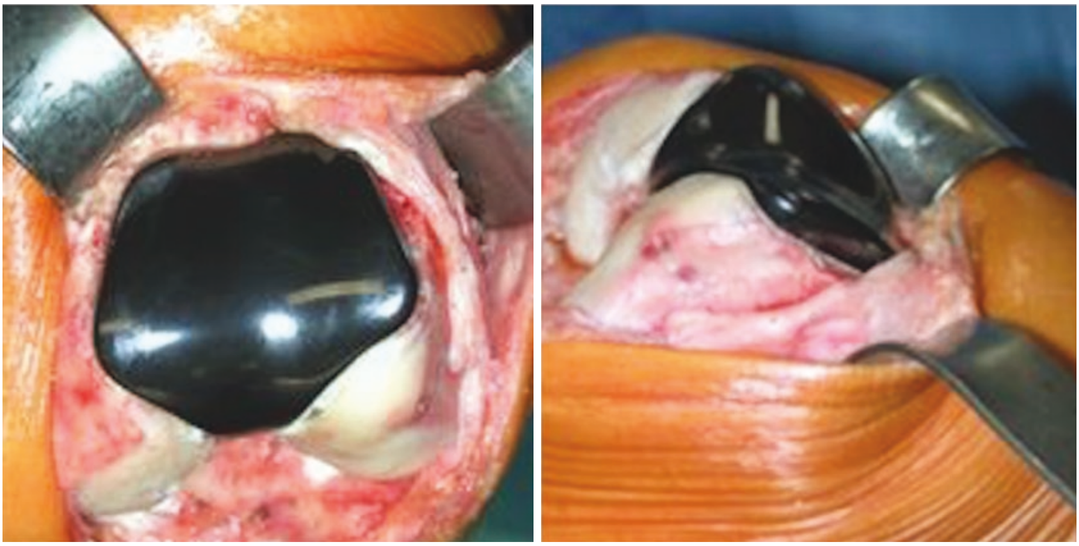

Fig. 17.10 After satisfying patellar alignment, which was tested with a trial implant, the final implant is inserted and fixed with bone cement. Left: antero-posterior view. Right: medio-lateral view

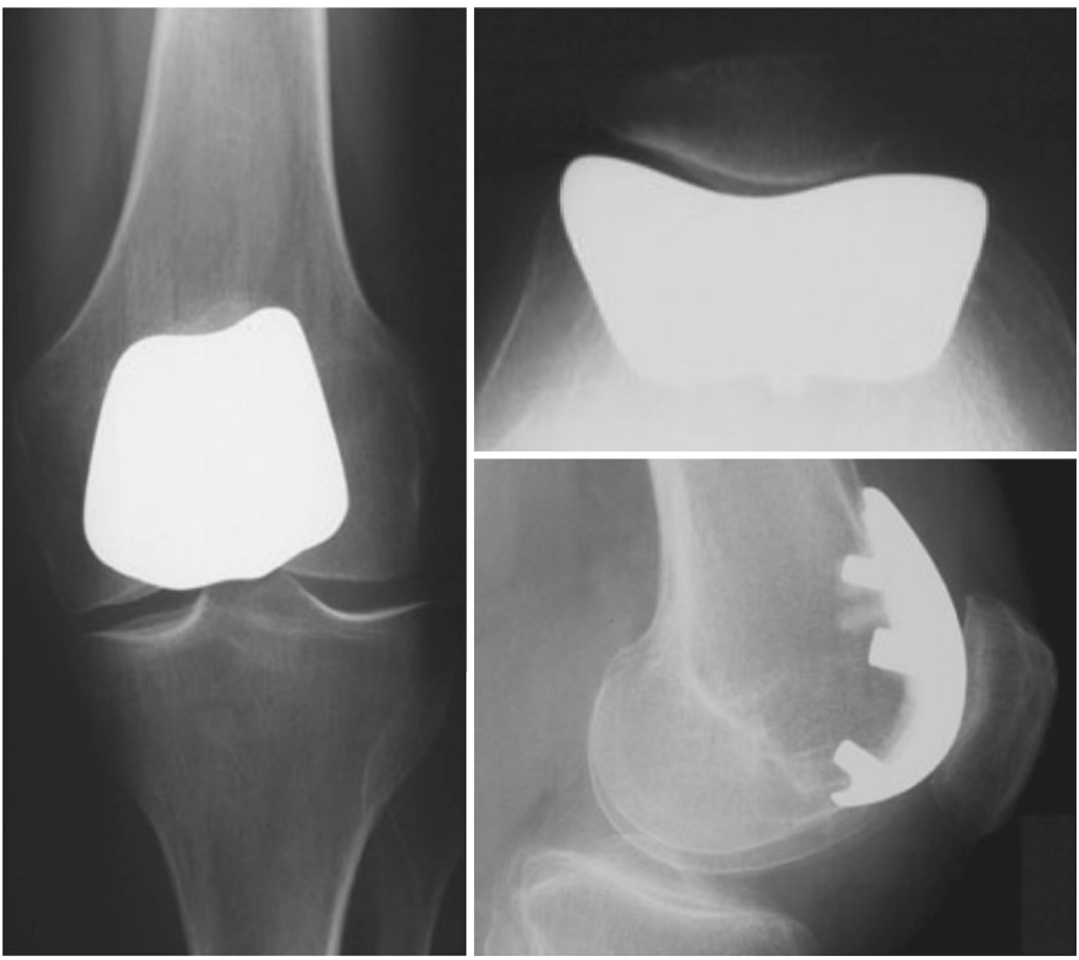

Fig. 17.11 Postoperative radiographs of the onlay implant in three planes are done routinely to check implant positioning

decongestant therapy and the use of unlimited pain-adapted continuous passive motion for the first 2 weeks. Patients are then allowed to increase weight bearing in a step-wise fashion until full weight bearing is achieved approximately 6 weeks after surgery. Full active range of motion is typically allowed 2 weeks after surgery.

17.7 Clinical Outcome

At present, there is no gold standard for the treatment of severe isolated PFOA. Although there is consensus that patellofemoral arthroplasty is a valid therapeutic option, the most suitable type of implant remains an ongoing matter of debate. To our knowledge, there is only one clinical study, which has compared the inlay and onlay design [1]. Out group showed that in a matched pair analyses of inlay and onlay trochlear designs for patellofemoral arthroplasty, no difference in clinical outcome was observed. However, less progression of tibiofemoral osteoarthritis was seen with inlay designs at a minimum follow-up of 2 years. One patient out of 15 of each group failed and underwent conversion to a total knee arthroplasty. The authors concluded that both techniques are suitable for the treatment of isolated PFOA, however, due to the lower progression rate of tibiofemoral osteoarthritis, a second-generation inlay design may be beneficial when considering long-term results and survival rates. This hypothesis is supported by another publication from our group in 2018 examining the outcomes of an inlay prosthesis after a minimum of 5 years [2].

Side Summary
No difference in clinical outcome between inlay and onlay design after 2 years

The total Western Ontario and McMaster (WOMAC) score and the visual analogue scale (VAS) pain improved significantly at the 2- and 5-years follow-up with no significant difference between the two time points. A total of six patients (17.1%) failed leaving a survival rate of 83% after 5 years. The main cause for postoperative failure was persistent knee pain, however, no significant pre-operative risk factor in patient characteristics could be identified. Overall, no significant progression of tibiofemoral arthritis or changes in patellar height were observed in patients who did not fail, until final follow-up. Similar results to ours were published by Zicaro et al. [6], who evaluated the outcome of 19 knees in 15 patients after a mean follow-up of 35 months following patellofemoral inlay arthroplasty. Significant improvements were observed across all outcome measures, and no progression of tibiofemoral osteoarthritis was observed. Two knees were converted to total knee arthroplasty because of persistent pain. However, results from isolated patellofemoral inlay arthroplasty are heterogenous throughout the literature. For example, Laursen [7] reported results of the same implant on 18 patients followed prospectively for 1 year; of those, 11 were followed for 2 years. Although significant improvements were observed for clinical and functional outcomes using the American Knee Society Subjective Score (AKSS) with an improvement in AKSS of more than 20 points in 91% of the patients, significant progression of OA in the medial tibiofemoral compartment caused a total of five implants (28%) to fail within 6 years. The high revision rate reported by Laursen [7] does not reconcile with our experience and may be explained not only by alternative indications and treatment, but also highlights the necessity for careful pre-operative patient selection.

This is exemplified by a recently published study by Beckmann et al. [8]. Out of a retrospective cohort of 20 patients who underwent inlay patellofemoral arthroplasty, 11 patients with an elevated Insall–Salvati index and an increased patellofemoral congruence angle showed an initial satisfactory result, but showed disabling pain and thus were converted to an onlay patellofemoral arthroplasty after a median time of 25 months (range 8–28 months). The authors concluded that patients with a patella alta as well as a craniolateral types of arthritis should be treated with an onlay patellofemoral arthroplasty as this type of implant covers the proximal part of the patellar tracking much better than an inlay system.

While the greater expansion proximally onto the distal femur is certainly an advantage of the onlay technique, it is certainly not without limitations. The onlay technique theoretically predisposes for an overstuffing of the patellofemoral joint, which is a well-known risk factor for the development and progression of osteoarthritis due to secretion of pro-inflammatory cytokines. Although a causal relationship has not been explicitly proven, multiple studies report a rapid progression of tibiofemoral osteoarthritis following the implantation of an onlay patellofemoral prostheses. Beitzel et al. [5] reported outcomes of 14 patients who underwent implantation of an onlay patellofemoral prostheses due to primary isolated patellofemoral osteoarthritis with no history or clinical signs of patellofemoral instability. At 24 months follow-up, significant increase in osteoarthritis compared to the pre-operative status within the medial and in the lateral tibiofemoral joint could be detected. Interestingly, the control group of this study consisted of eight patients who underwent the same surgery, however, suffering from secondary osteoarthritis due to patellofemoral instability, was not associated with a significant increase of tibiofemoral osteoarthritis at final follow-up. One possible explanation for this finding could be that patients with primary osteoarthritis may be more prone to develop degenerative changes of the tibiofemoral joint as part of the joint's osteoarthritic reaction.

Overall, further research is necessary to define risk factors for failure after patellofemoral arthroplasty, independent of technique adopted. However, it became obvious over the last decade that even with the improvements in technology and design, careful patient selection is the key to success.

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18 Surgical 2D Planning of Total Knee Arthroplasty

H. Meyer, K.-D. Heller, and Roland Becker

Keynotes

1. 2-D planning requires a series of radiographs necessary to identify not only correct limb alignment but also correct tibial and femoral component sizing and placement in both the frontal and sagittal plane.
2. The full leg weight-bearing radiography only provides the true lower limb alignment and is crucial for correct component placement in the coronal plane.
3. Different software is available for digital planning which is more precise than conventional planning using templates.
4. The amount of bone resection can be estimated during the planning and measured during surgery.

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18.1 Introduction

Planning prior to total knee arthroplasty (TKA) is essential and most commonly performed on conventional 2-dimensional (2D) radiographies. Different views are required to allow planning in both frontal and sagittal plane. In contrast to 3D-planing, the transverse plane is missing in 2D planning.

Pre-operative planning helps to identify the correct alignment of the lower limb, the correct implant sizing and the positioning of the implants in both the frontal and sagittal plane. Knowing the size of the implant prior to surgery increases the awareness of the surgeon during the procedure and will help to avoid complications. Bone morphology, alignment and deformities need to be analysed in order to choose the right implant for the patient.

The planning is based on standardized antero-posterior and lateral views. Planning software is provided by different companies and examples are as follows:

1. MediCAD (mediCAD Hectec GmbH. Altdorf Nähe Landshut, Germay)—https://www.hectec.de/content/index.php/us/
2. Trauma CAD (Brainlab, Westchester IL, USA)—https://www.traumacad.com/de.html#tcmobile

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3. Materialise Ortho view (Materialise, Leuven, Belgium)—https://www.materialise.com/en/medical/materialise-orthoview
4. EOS imaging (EOS imaging SA, Paris)—https://www.eos-imaging.de/de

Side Summary
Digital planning and the documentation of the planning prior to knee arthroplasty surgery has become obligatory in many countries.

18.2 Radiographies

Four different conventional radiographies are recommended for pre-operative planning. Stress radiographies in the sagittal or frontal plane are added when necessary in order to receive information about mediolateral or anteroposterior knee stability. The following set of radiographies are recommended for correct planning:

1. Anteroposterior view.
2. Lateral view.
3. Full weight-bearing long leg radiography, including the hip and ankle joints (Fig. 18.1).
4. Merchants view or axial weight-bearing view (Baldini's view).
5. Axial view of the distal femur (Kanekasu view).

The **anteroposterior** and **lateral view** is required for correct implant sizing and positioning of the components. The full weight-bearing long leg radiography provides information about the alignment of the lower limb and the condition of the hip and ankle joints. A coxa valga or a previous total hip replacement may influence the offset of the hip, which affects the lower limb alignment. Malunions after fracture may also show a significant impact on the lower limb alignment. Extra-articular and intra-articular deformities should be identified and may have a significant impact on the entire surgical procedure.

It is important to position the patients correctly when radiographies are taken in order to allow the true assessment of lower limb alignment and of bony landmarks. Various studies have investigated the influence of knee flexion and lower limb rotation on femorotibial alignment in the coronal plane [1, 2]. Radiographies of the lower limb taken in external rotation may pretend a varus malalignment and in internal rotation a valgus malalignment. A slight flexed position of the knee may pretend a varus alignment of the lower limb [3]. The true anteroposterior view of the lower limb can be estimated by several anatomical landmarks such as the position of the minor trochanter, the patella, tibial tuberosity, fibular head, the shape of the femoral notch and of the ankle joint (Fig. 18.1) [4].

Fig. 18.1 Full weight-bearing long leg radiography

Fig. 18.2 Rosenberg's view

More specific radiographic views provide additional information. The **Rosenberg's view** or 45°/10° weight-bearing view will allow better assessment of joint space of the medial and lateral compartment (Fig. 18.2) [5]. For example, the weight-bearing view, taken in full extension may show some joint space narrowing on the medial femorotibial compartment for instance while the Rosenberg's view presents already a complete collapse of the joint space (Figs. 18.1 and 18.2). The Rosenberg's view should be used primarily for evaluation of the medial and lateral joint space when plane radiographies are used.

Side Summary
Rosenberg's view is the most sensitive radiography of assessing femoro-tibial joint space narrowing correctly

The **Baldini's weight-bearing view** provides information about the femoropatellar tracking [6]. The patient is positioned in a semi-squatting position, having the tibia in 15° and the femur in 35° to the floor when the patients is lying supine (Fig. 18.3). The radiography can be taken also when the patient is in the upright position. Studies have shown that the Baldini's view allows a more functional assessment of patella tracking because the joint is under loading. Patients may present a slight lateral tracking of the patella under unloading condition. The same patella might be correctly aligned under loading conditions.

The **Kanekasu view** provides information about the posterior condylar line and clinical epicondylar axis [7]. For Kanekasu view the patient is in a sitting position, having knee and hip in 90° of flexion. The x ray beam is directed to the patella at a 10° upwards angle. The x ray tube is positioned posterior to the patient and the distance to the film cassette was set at 100 cm (Fig. 18.4a, b). The view helps to receive information about correct femoral component rotation in the transverse plane. The view can be used when CT-scan is unavailable.

Varus- and valgus stress radiographies provide information about collateral ligament function and the joint space (Fig. 18.4a, b). The Telos®-instrument is commonly used in order to apply defined stress on the either the medial or lateral side of the knee.

Side Summary
Use stress radiographies in case of ligament instability.

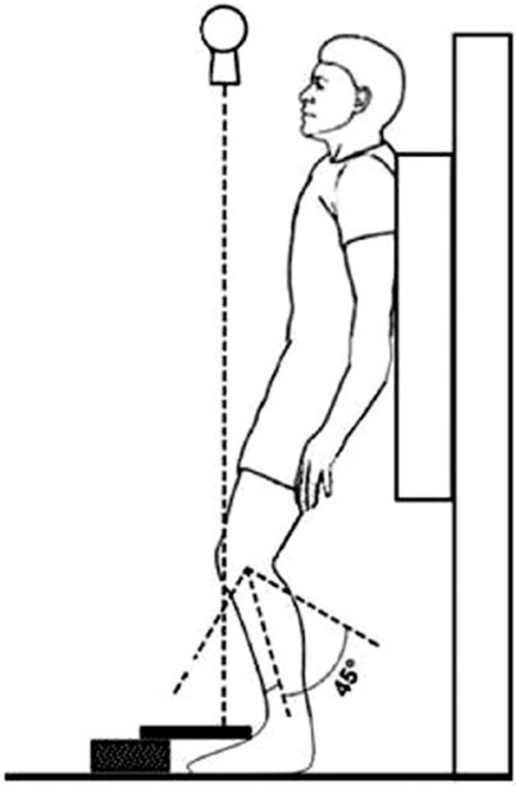

Fig. 18.3 Baldini's weight-bearing view. The distal femur and proximal tibial joint line is marked. The two vertical lines mark the medial and lateral border of the tibia

18.3 Digital Planning

The mechanical axis serves as a reference during the planning. The joint line is perpendicular to the mechanical axis (Mikulicz line) based on the mechanical alignment of the prosthesis.

The following planning will be performed using the MediCAD®-software provided by Hectec® for the BalanSys® total knee system (Mathys® Bettlach, Switzerland). Planning can be performed using an automatically algorithm or a manually one. A metal scaling sphere of 25 mm in diameter is placed as close as possible to the knee in order to guarantee the exact magnification of the object on the film (Fig. 18.5). The size of the scaling sphere has to be entered into the planning software (Fig. 18.6). Ranjitkar et al. [8] showed that proper scaling is very important for digital planning. The lack of reliable results was caused by the erroneous positioning of the scaling sphere [9]. The magnification factor also posed a problem during planning with templates: Bayne et al. [10] showed that radiographies taken with a fixed magnification factor of 115% were actual taken with a factor of 97%, representing a deviation of 20%.

18.3.1 Automatic Planning

The algorithm for the automatic planning is given by the software and defined landmarks have to be captured. The planing is shown for a mechanically aligned TKA.

1. The centre of the hip, knee and ankle is identified in order to determine the femoral and tibial axis (Fig. 18.7a–c).
2. The femoral and tibial joint line is marked (Fig. 18.8).
3. According to the centre of the intramedullary canal of both the femur and tibia, the anatomical alignment can be calculated including all relevant measurements according to Paley [11] (Figs. 18.9–18.11).
4. The mechanical axis of the femur (centre of the hip to the centre of the knee) and tibia (centre of the knee to the centre of the ankle) is taken to analyse the mechanical alignment for the lower limb, which should be ideally 0° (Fig. 18.12).
5. The femoral and tibial part of the radiography is moved into the calculated drawing (Fig. 18.13).
6. The femoral and tibial size of the components is measured by using the lateral view (Fig. 18.14). The anteroposterior sizing of the femoral component is crucial for the flexion gap and the patellofemoral compartment. Inappropriate sizing may cause an increase or decrease in the posterior condylar offset. However, planning of the tibial slope is difficult using the side projections, as there is a concave slope (medial tibial plateau) and a convex slope (lateral tibial slope) [11]. The

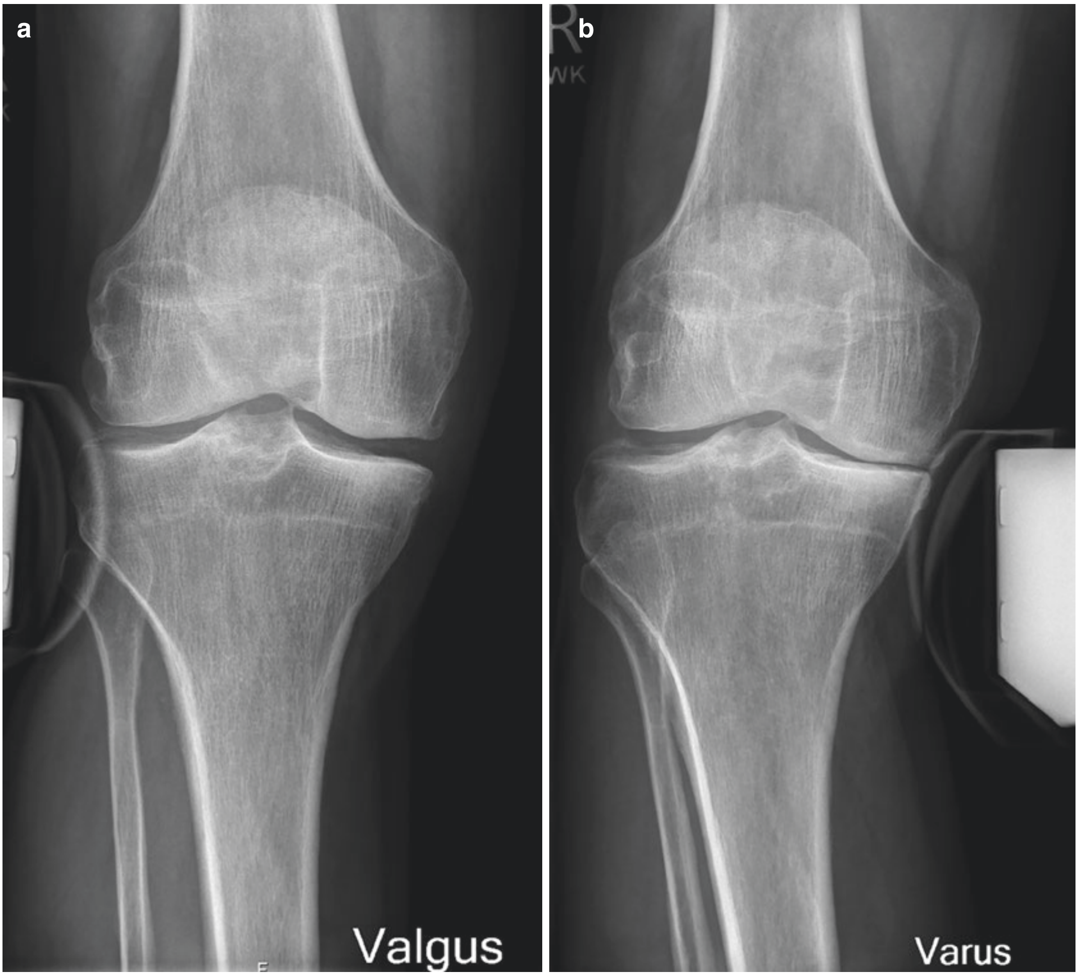

Fig. 18.4 (**a**) Axial CT scan of the right knee showing the surgical transepicondylar axis (sTEA) and the posterior condylar line (PCL). The Kanekasu view of the same knee is shown in (**b**)

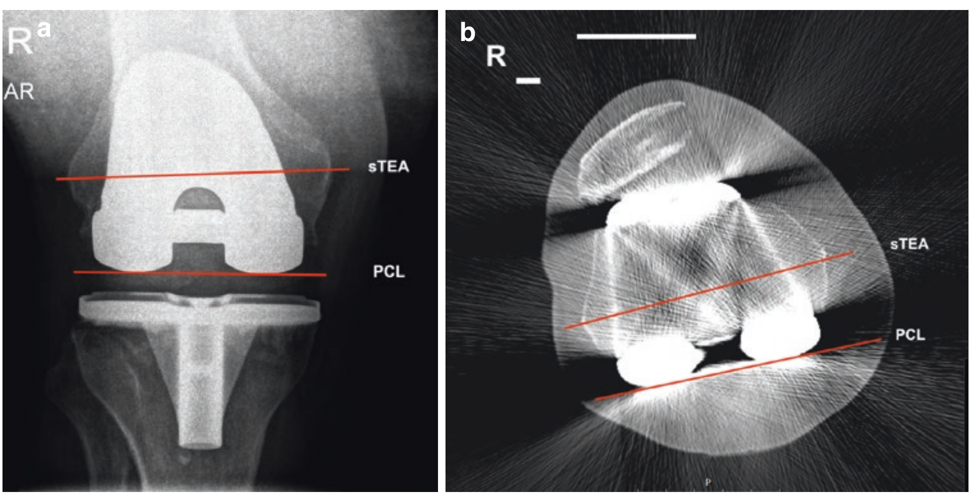

Fig. 18.5 (**a**) Valgusstress radiography (**b**) Varusstress radiography

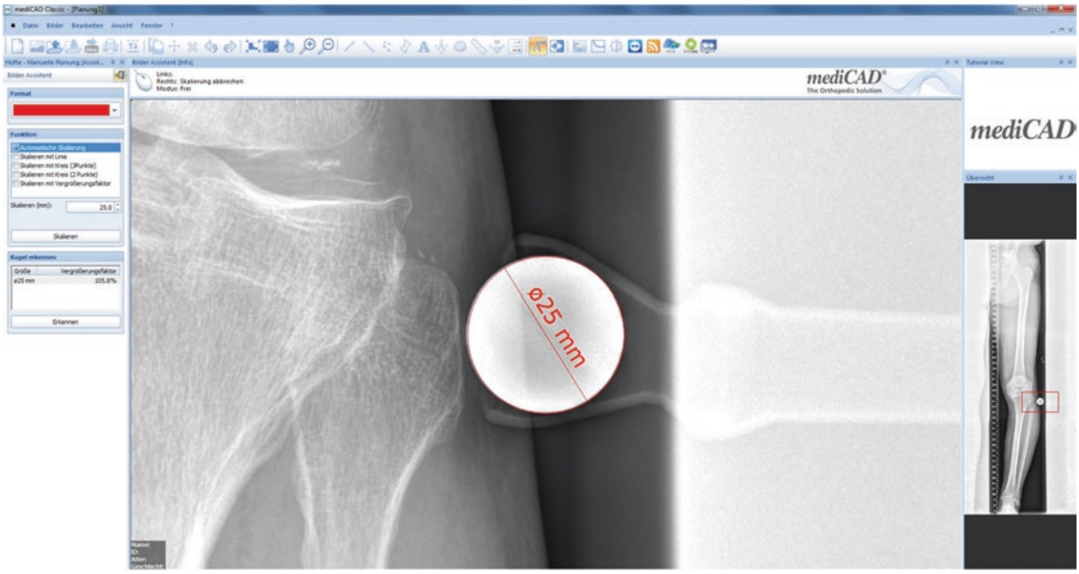

Fig. 18.6 The magnification sphere is placed closed to the knee joint. The ball serves for adjustment of the magnification (Four lines are drawn in order to identify the anatomical axis of the femur)

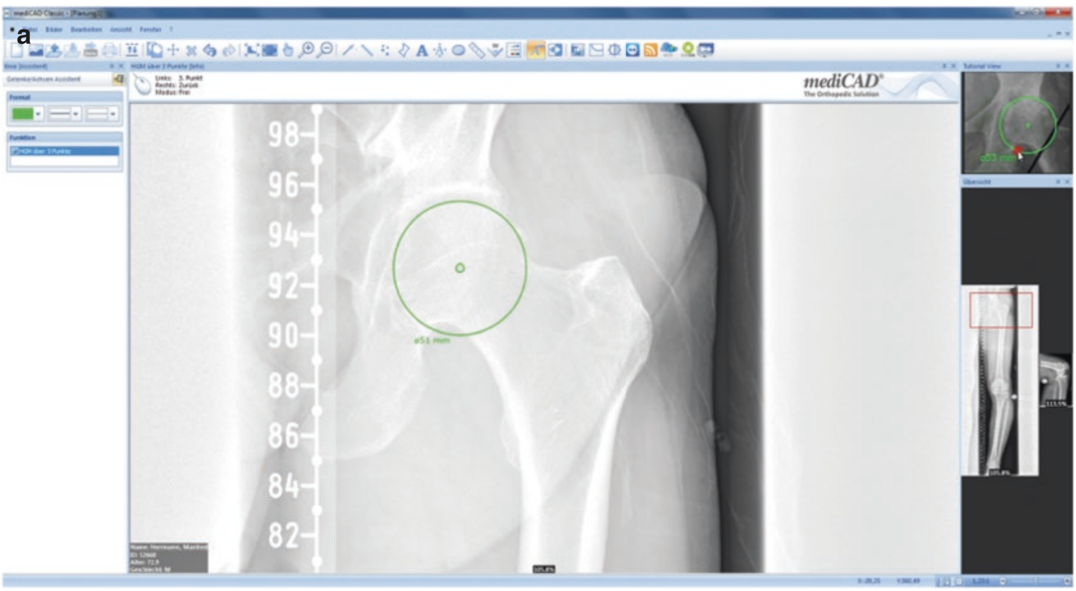

Fig. 18.7 (**a**) Identification of the hip centre (**b**) The distal femur and proximal tibial joint line is marked. The two vertical lines mark the medial and lateral border of the tibia (**c**) Measurement of the diameter of the tibia and determination of the centre. The menu on the left side guides the surgeon through the planing. Each step has to be confirmed prior the next step

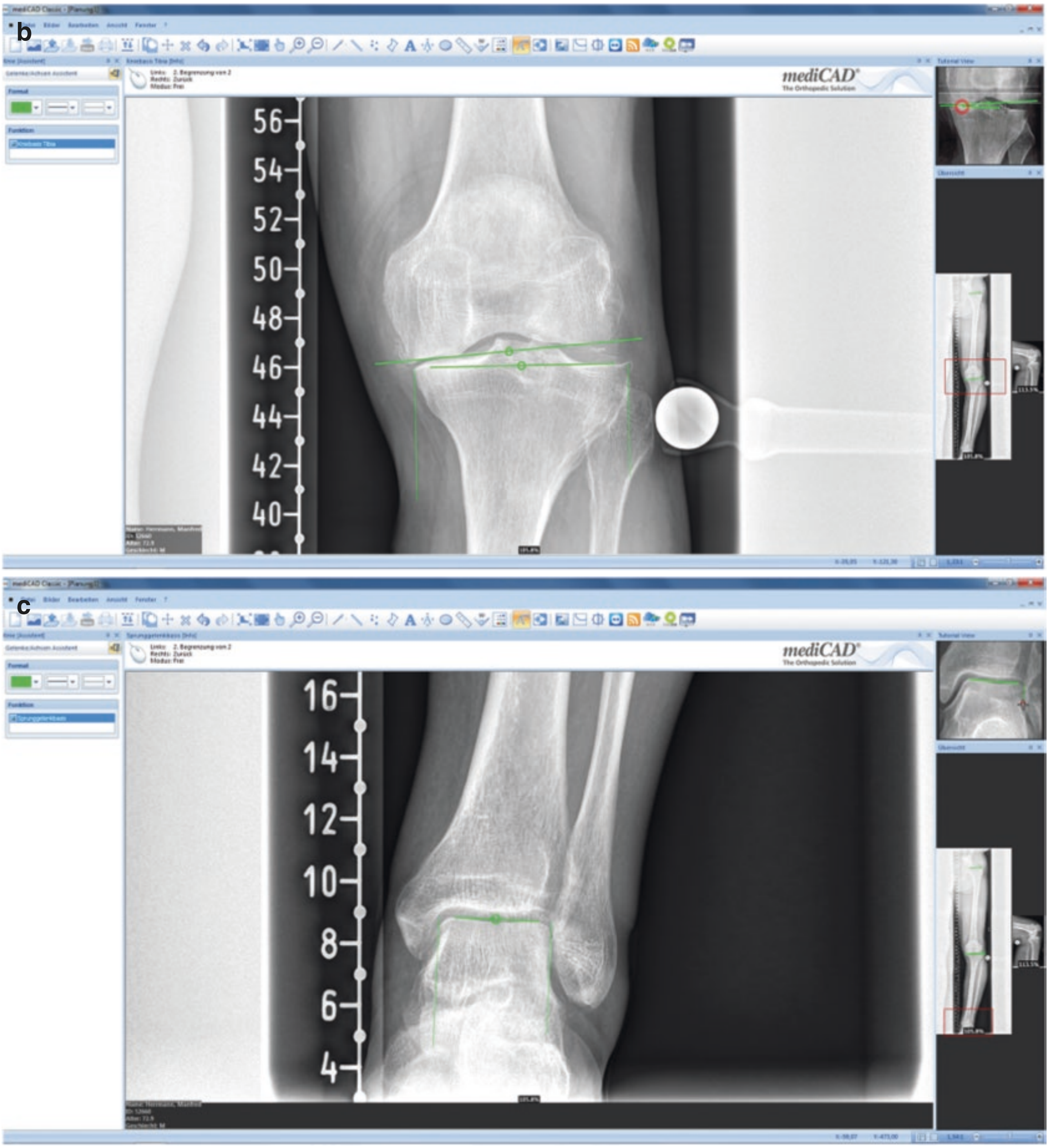

Fig. 18.7 (continued)

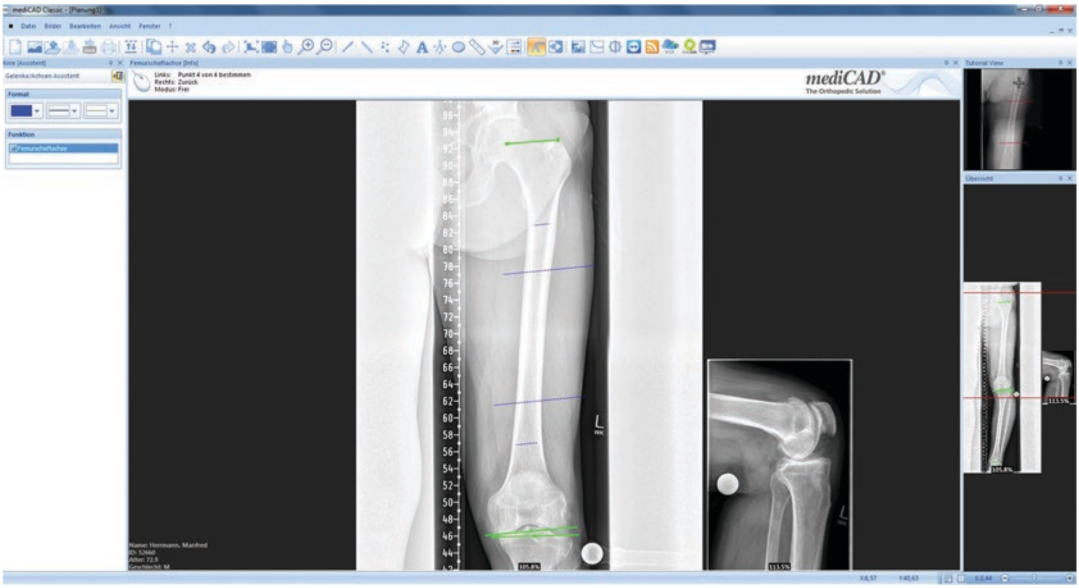

Fig. 18.8 Femoral and tibial jointline

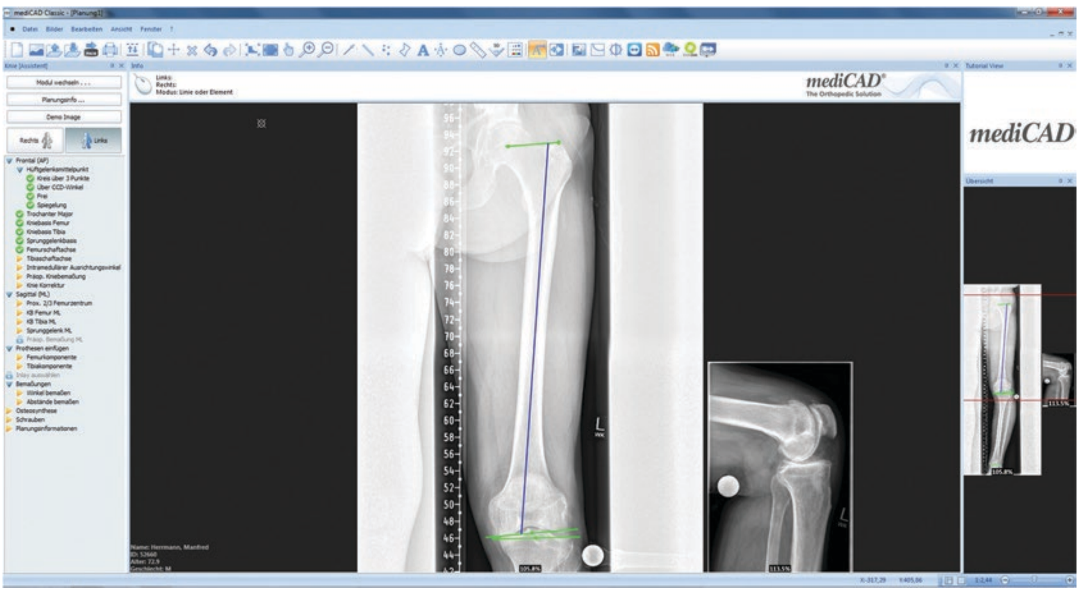

Fig. 18.9 The anatomical axis of the femur is calculated

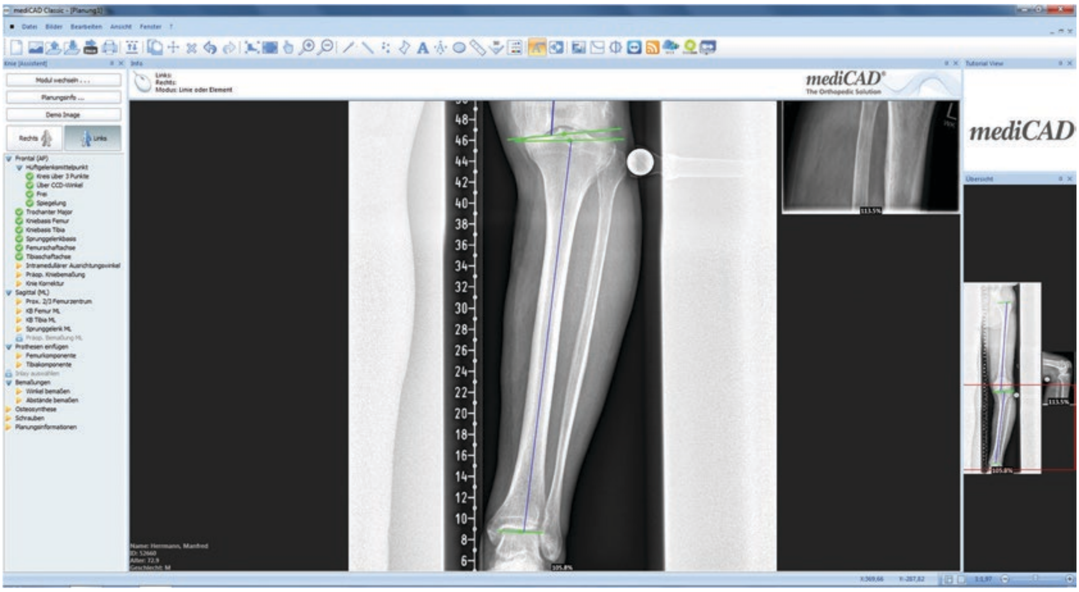

Fig. 18.10 The anatomical axis of the tibia is calculated

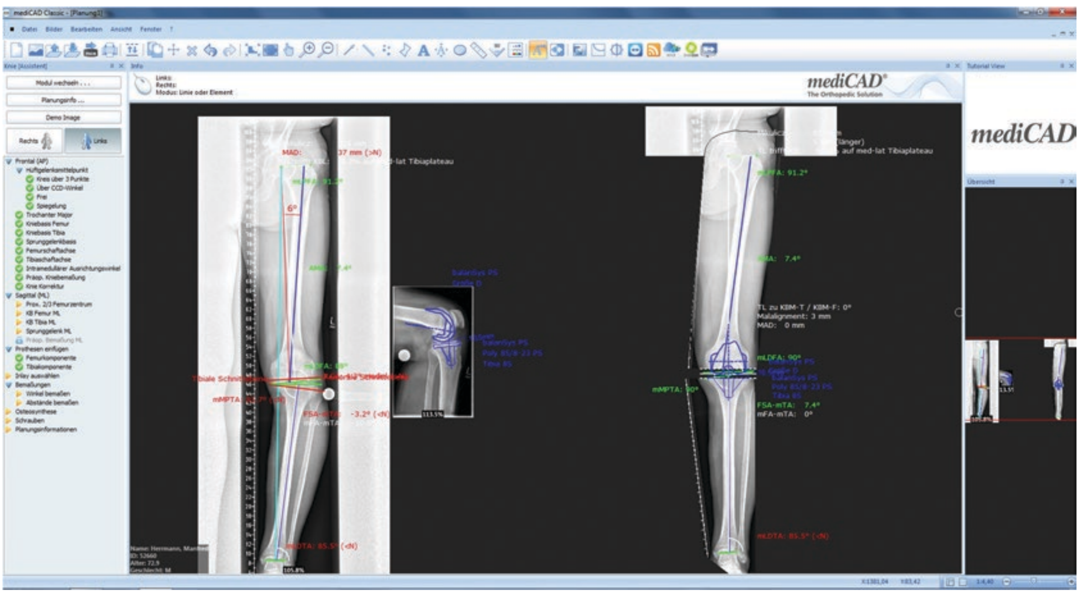

Fig. 18.11 (left side) There is an average angle of 6° between the anatomical and mechanical axis of the femur. (right side) Alignment correction and component placement in the frontal plane. Planning was made for 0° of mechanical alignment. The joint line is 90° to the calculated mechanical axis

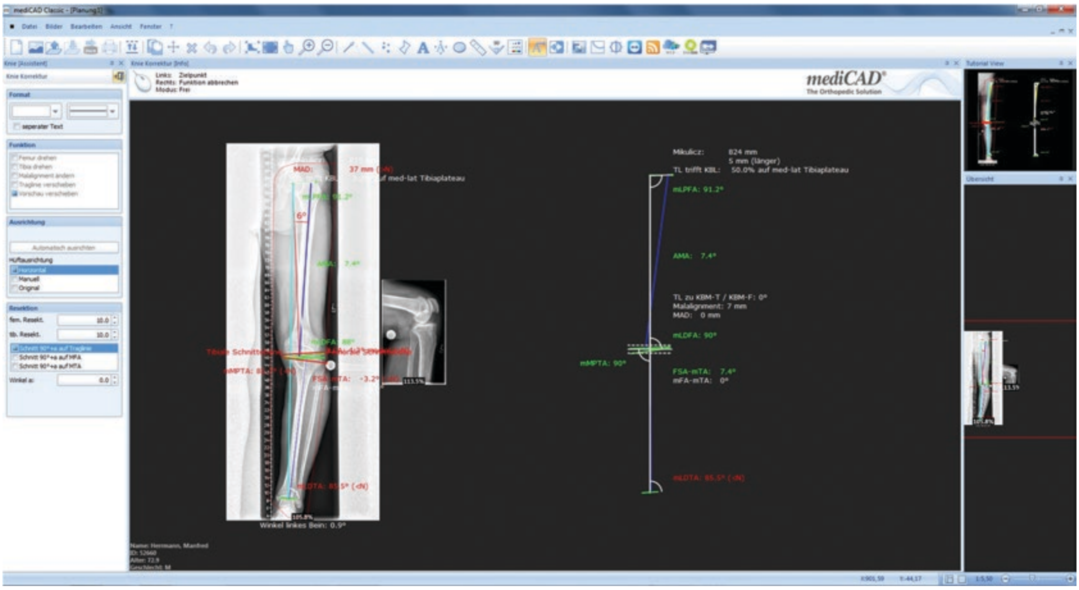

Fig. 18.12 Presurgical planning for mechanical alignment of the lower limb. Correction of the varus deformity according to Paley (left side). Corrected planning for mechanical alignment in 0° and perpendicular joint line (right side)

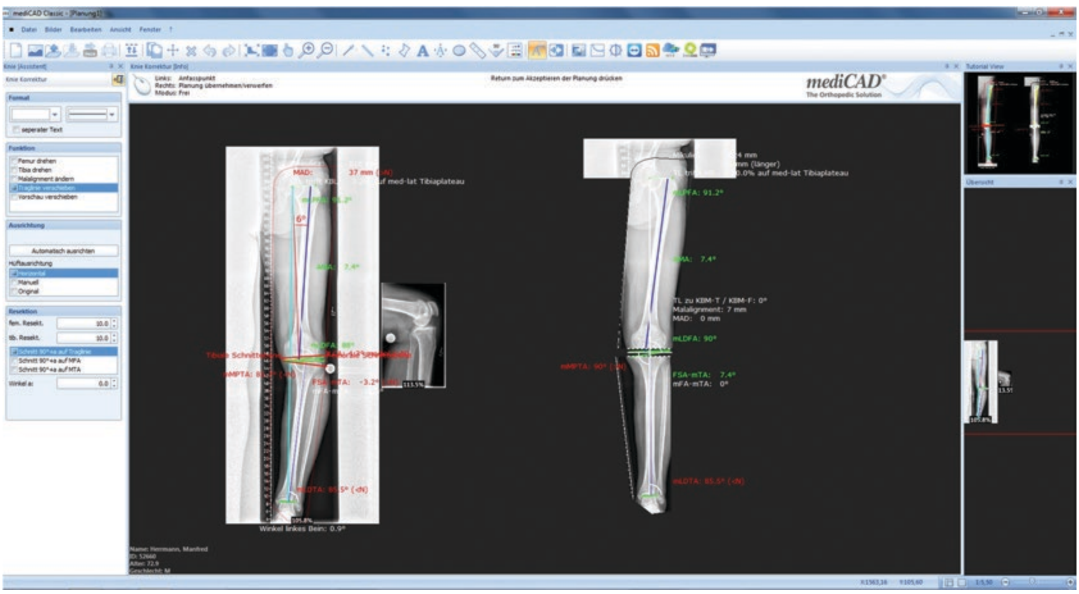

Fig. 18.13 Lower limb alignment prior and after correction according to the planning

medial tibial plateau might be used, however, in severe osteoarthritis (OA) with bone loss, one needs to choose the lateral compartment, which is more difficult due to the convexity of the lateral tibial plateau.

7. The size of the femoral and tibial component is measured in the anteroposterior view. The amount of tibial and femoral resection in both the medial and lateral compartment can be calculated precisely (Fig. 18.15).

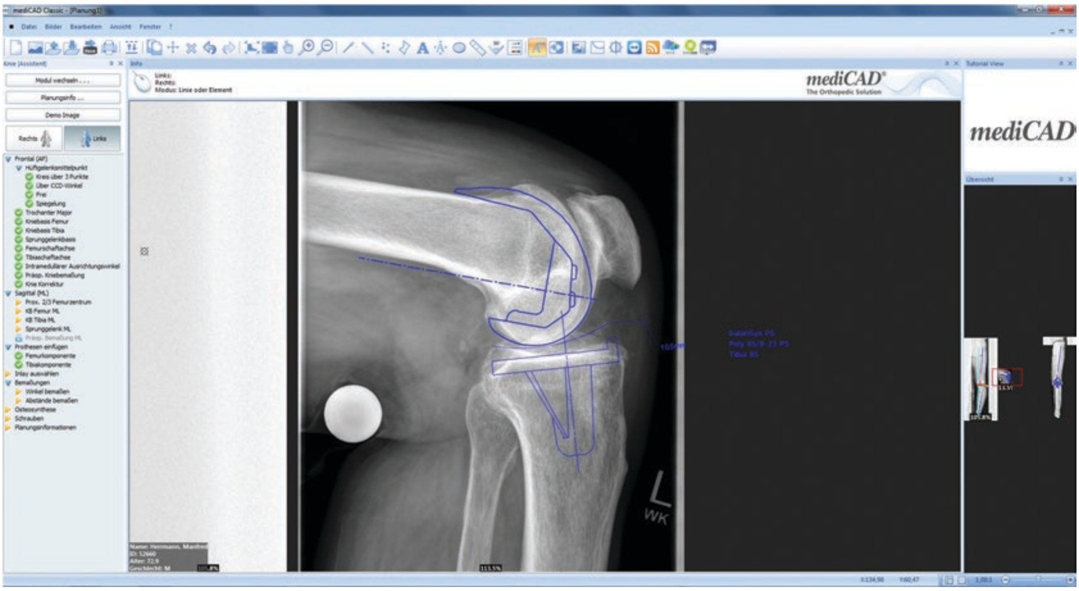

Fig. 18.14 The femoral and tibial component is inserted in the planning view taking the posterior condylar offset and the anterior femoral cortex on the femoral side and the anterior and posterior cortex of the tibia into consideration. The anteroposterior dimension is smaller on the lateral tibial plateau in regard to the medial one

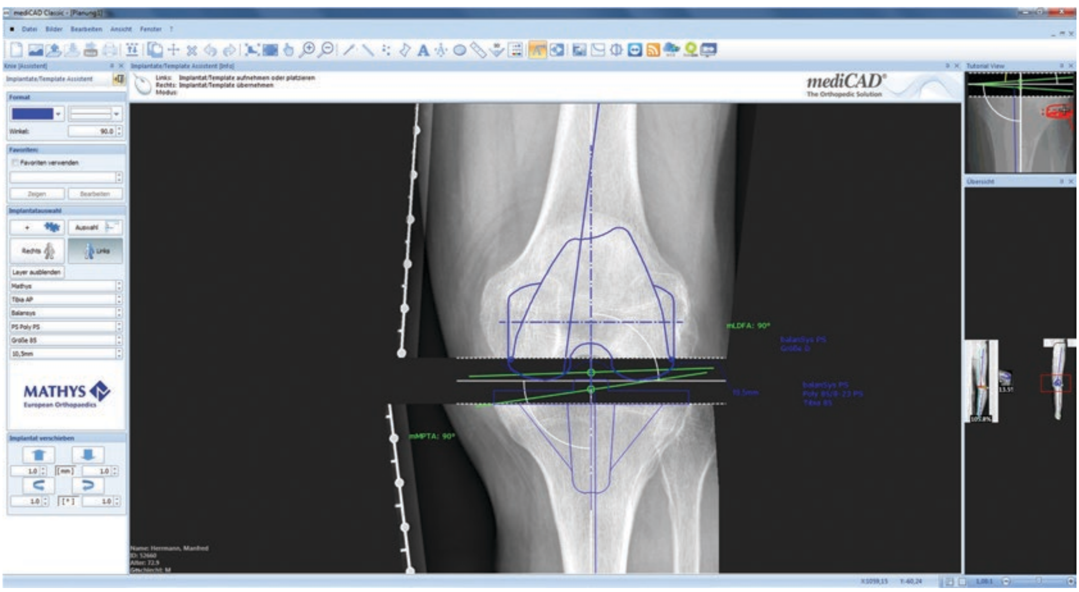

Fig. 18.15 The resected bone of the extension gap is removed and the components planed in the anteroposterior view are inserted. Especially the position of the tibial component needs to be checked for mediolateral overhang

18.3.2 Manual Planning

The planning starts either on the femoral or tibial site.

1. The femoral and tibial joint line is marked. No bone loss or instability is presumed in case the two lines running parallel (Fig. 18.16).
2. The tibial component is positioned on the tibia. The medial and lateral cortical bone serves as reference. Overhang should be avoided because it might have an impact on clinical outcome. There is a risk of inferior clinical outcome in patients presenting a mediolateral overhang of the components (Fig. 18.17) [12, 13].
3. The femoral component is planed in the frontal plane (Fig. 18.18).
4. The tibial component is planned on the lateral view. The posterior slope is very important for good function of the knee. In posterior stabilized (PS)-design the posterior slope should not exceed 5° in order to prevent a “clunk syndrome” (Fig. 18.19) [14]. Setting the slopes will depend on the implant selected: some authors recommend reduction of the slope in order to avoid post-cam impingement when posterior-stabilized implant is used [15].
5. The strong lateral view is often missing due to the lack of superimposition of the medial and lateral femoral condyle and correct sizing becomes difficult (Figs. 18.20 and 18.21). Talk to the radiologist and explain why these radiographies are so essential!

18.4 Accuracy of Planning

Accuracy in planning includes femorotibial alignment, the determination of the joint line and the sizing of the femoral and tibial component. The thickness of the resected bone on the medial and lateral side of the femoral and the tibial plateau can be calculated during the planning and allows comparison to the actual resected bone. Thus, a control of each step during of bony resection during the surgery is possible.

Before digital planning was introduced, templating was available for radiographic films. The

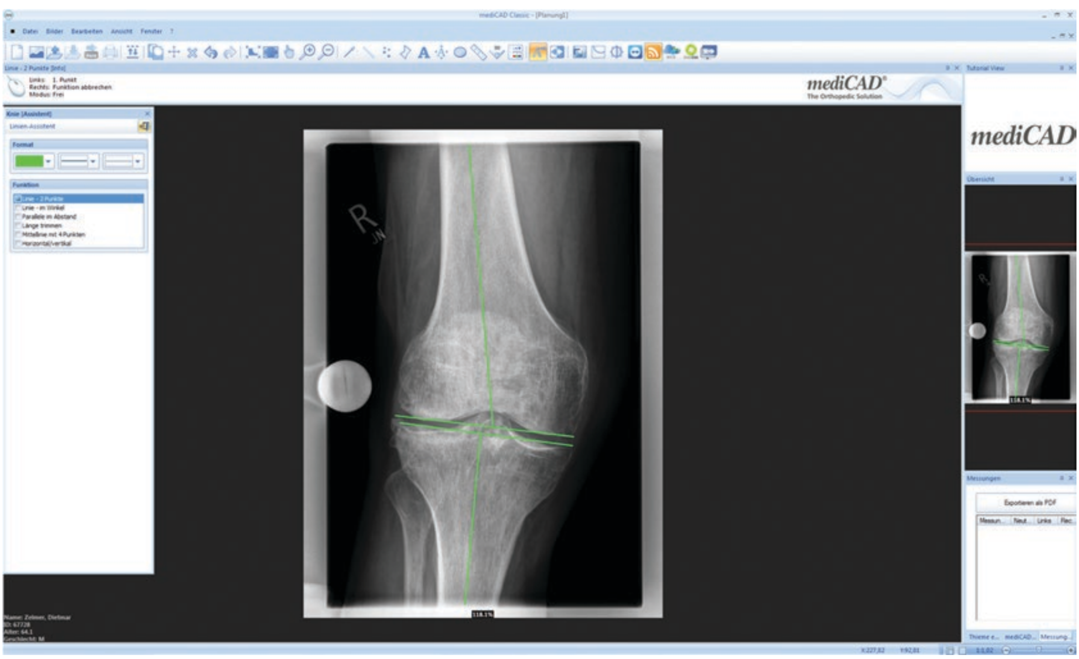

Fig. 18.16 Manual planning starts with marking the anatomical axis of both femur and tibia and the distal femoral and proximal tibial joint line

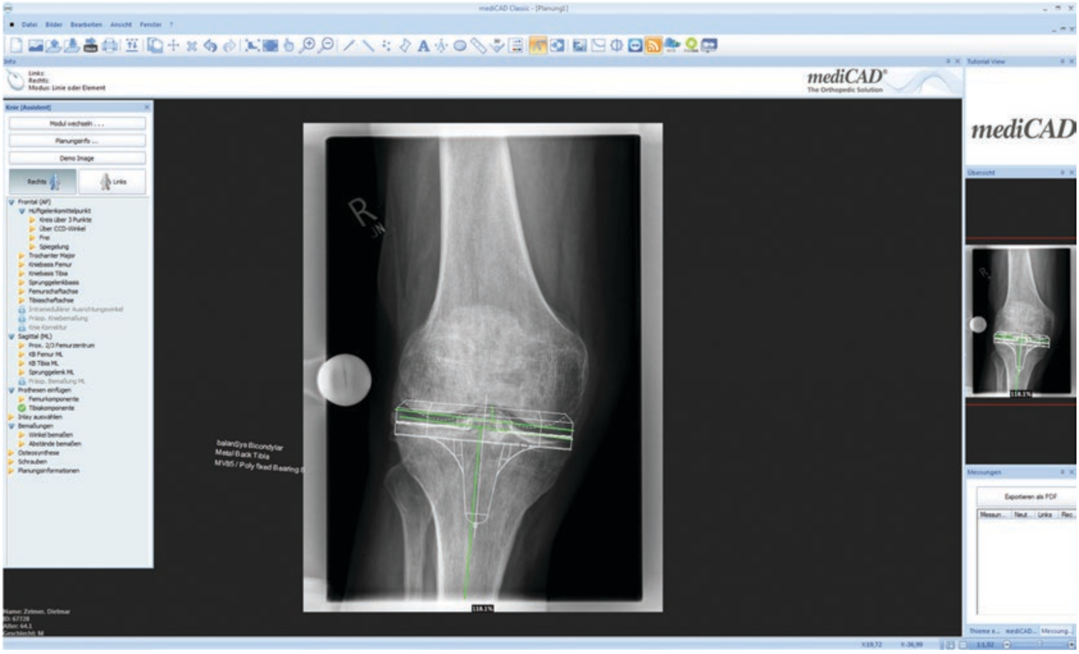

Fig. 18.17 Mediolateral sizing of the tibial component

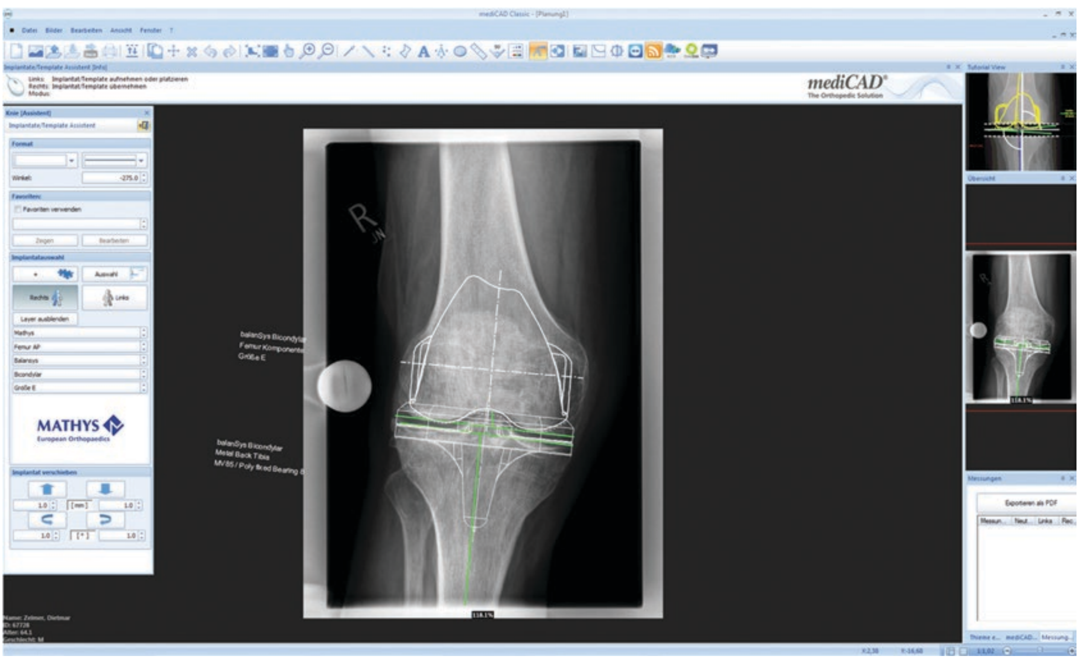

Fig. 18.18 Mediolateral sizing of the femoral component

Fig. 18.19 Anteroposterior sizing of the tibial component on the lateral view

Fig. 18.20 Lateral sizing of the femoral component. The lateral view is not correct, due to the lack of overlapping of the medial and lateral condyle. AP sizing is shown for size E, which is rather to large

Fig. 18.21 Estimated sizing with the femoral component D is shown. However, correct sizing is almost impossible

accuracy was limited to 44–53% only [16–18]. Using digital templating, some studies did not report significant improvement. Correct sizing was found in 48% on the femoral site and of 55% on the tibial site. The overall accuracy in these studies was 57%. However, others reported significant improvement in accuracy when digital planning was performed in comparison to analogue planning [19]. The accuracy improved to 90% when one error in size was tolerated [20]. Del Gaizo et al. reported about an exact sizing in 82.5% for the femoral component and in 79.5% for the tibial component [21]. When one size of deviation is accepted, the results improved on both the femoral and tibial site to 97% and 92.5%, respectively. These results were reported from others too [22].

Different philosophies in term of alignment are followed nowadays, however, there is a general agreement that alignment should not be fixed between 5° and 7° [23]. Patient's anatomy should be respected.

Take Home Message

- Correct planning of implant sizing and positioning should be mandatory for each case. In some countries such as Germany the planning is compulsory and has to be documented in patient file.
- Due to the planning, the amount of resection can be measured with a Vernier calliper after each step, which is in some cases helpful. For example, it helps to preserve the joint line.
- Planning can be performed using an automatic or manual algorithm. Unexperienced surgeon should rather use the automatic planning because the planning software will do the planning only when all information is given.
- Detailed planning will increase surgeon's awareness during the procedure. It helps to prevent complications.

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3D Planning of Total Knee Arthroplasty: Why and How?

19

Silvan Hess and Michael T. Hirschmann

Keynotes

1. Preoperative planning is key: it helps to identify possible alignment variations such extra- or intraarticular deformities and to define the optimal orientation and position of the TKA components.
2. Preoperative planning should be performed using 3D reconstructed CT data since it offers numerous benefits and enable us to overcome several limitations of conventional radiographs.
3. An optimized CT protocol allows to reduce the radiation burden for the patient.
4. The most important step in 3D planning is the establishment of a frame of reference. Anatomic landmarks are used to define this frame.

19.1 Introduction

Planning of a total knee arthroplasty (TKA) is mandatory for each individual patient. An optimal planning will help the surgeon to identify possible intraoperative problems and minimize the risks and complications of TKA.

During the planning process, the surgeon simulates the bone cuts and sizing and thereby identifies possible alignment variations such extra- or intraarticular deformities. In addition, possible logistical problems such as the need for larger or smaller sized TKA components are identified. Another goal is to define the optimal orientation and position for the TKA components as well as the desired limb alignment after surgery. Both orientation and position of the TKA components as well as limb alignment are crucial for a good postoperative outcome [1–3]. Clearly, a meticulous preoperative planning is the key to a happy patient. With state-of-the-art planning, the surgery is already performed in the surgeon's head before the actual operating room (OR) day.

To date, the planning is still predominantly performed using conventional radiographs. However, radiographs are only giving two-dimensional (2D) information. As projection imaging method, radiographs show a considerable number of limitations. One major limitation, when using radiographs, is the inability to sensitively detect and correct for an inaccurate position of the patient as well as rotation and flexion

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of the leg. This is a huge issue since most patients with severe osteoarthritis often show an extension deficit. Extraarticular deformities such as femoral bowing is another area in which radiographs have their limitations [4].

Only the few, who use patient-specific instrumentation (PSI), use computed tomography (CT) or magnetic resonance imaging (MRI) images. Three-dimensional (3D) reconstructed CT images offer numerous benefits and enable us to overcome several limitations of conventional radiographs. One major advantage is the possibility to adjust the two different frames of reference, which are the individual patient anatomy and the scanner axis. Thus, it is possible to correct for rotation and flexion of the leg as well as for rotational deformities and an incorrect position of the patient in the scanner. The two figures (Figs. 19.1 and 19.2) below illustrate the limitations of conventional radiographs and how the use of 3D reconstructed CT images is a richer source of information.

Furthermore, several studies questioned the reliability and accuracy of measurements based on radiographs and significantly better results were shown when 3D reconstructed images [3] were used.

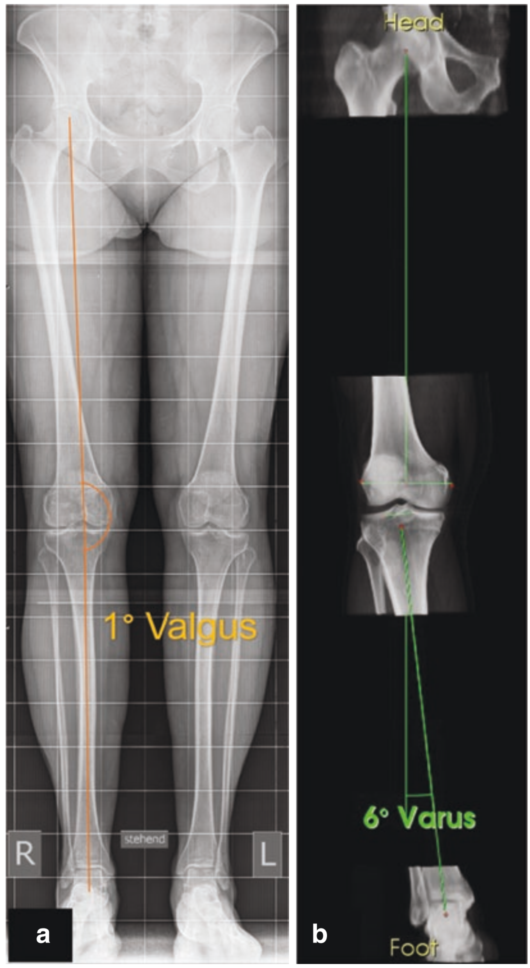

Fig. 19.1 The influence of flexion and extension on a patient's lower limb alignment. The radiograph on the left side (**a**) shows the patient in standing position, the measured limb alignment is a valgus 1°. However, the 3D reconstructed model of the patient (**b**) shows a valgus alignment of 7°. This difference may be caused by an external rotation of the limb on the radiograph

Side Summary

Preoperative planning is the key for a correct position and orientation of the TKA and thus essential for a good clinical outcome [2, 5]. It should be performed with reconstructed 3D images to achieve a higher accuracy and a more detailed and real preoperative plan.

19.2 How to Plan a TKA in 3D

19.2.1 Data Acquisition

For several reasons, the optimal source of data for 3D reconstruction and thus for 3D planning are CT scans. The most important ones are outlined in the following:

Firstly, a CT provides high-quality information on bone/tissue boundaries and high-resolution metal implant surface information.

Secondly, it is widely available and has rather low costs. MRI on the other hand is less frequently used as it has several disadvantages such as higher costs and is much more time consuming.

The biggest disadvantage of CT is the radiation burden to the patient due to ionizing radiation. However, the radiation dose of a CT can be minimized by using an optimized CT protocol.

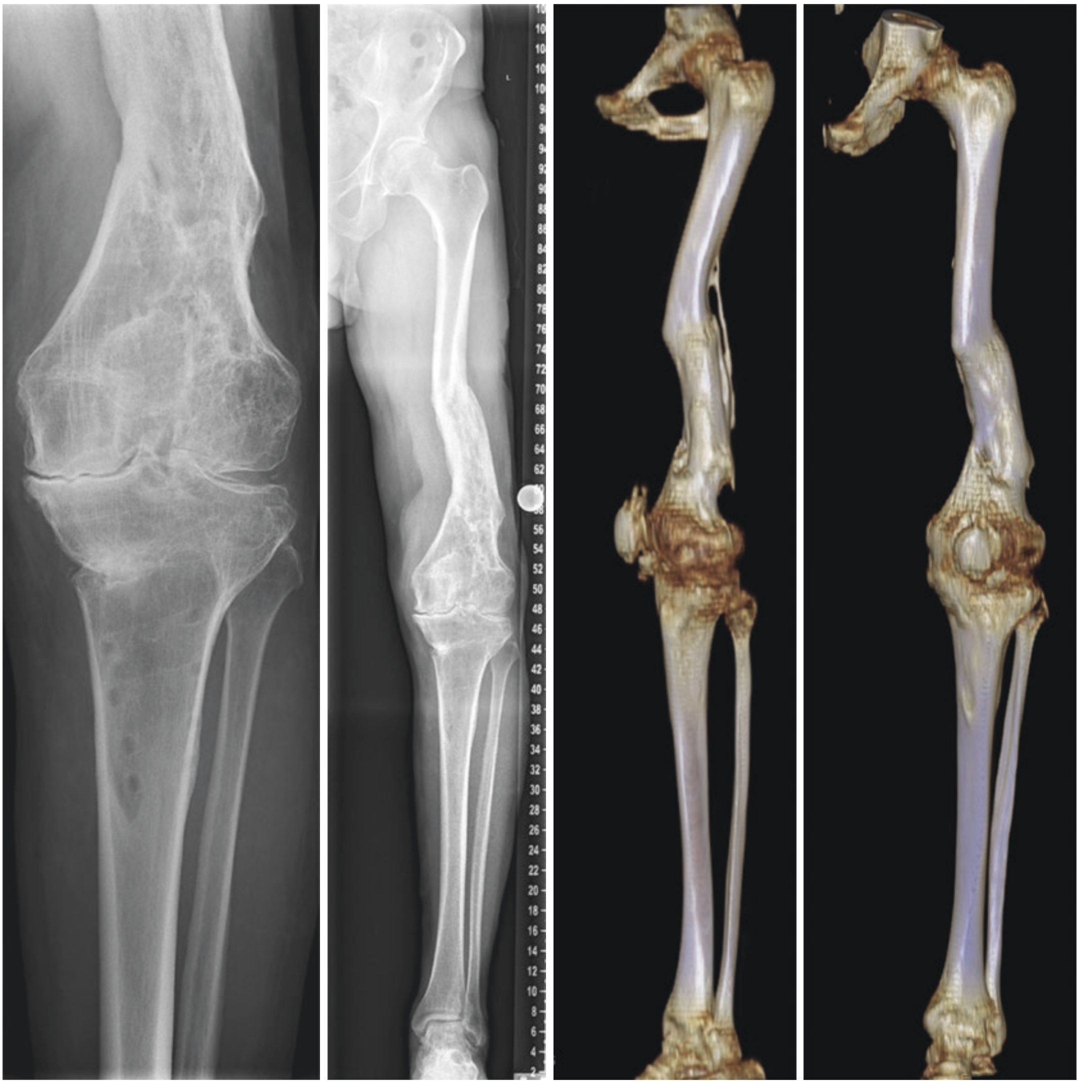

Fig. 19.2 The influence of femoral bowing on the measurements in radiographs versus 3D reconstructed CT images. The radiographs on the left side show a patient with a severe deformity of the femur. However, it is not clearly visible how and in which direction the femur is bent/deformed. The 3D reconstructed images on the right give a much better understanding of the anatomy

Thereby, the dose for a CT can be reduced to the dose of one single standing leg radiograph [6].

The figure below (Fig. 19.3) illustrates the scanning process for the modified imperial knee CT protocol [6]. To minimize radiation the slice thickness is reduced for hip and ankle (3 mm slice thickness). Only the knee joint is scanned with 0.7 mm slices.

Side Summary
Preoperative planning should be performed using 3D reconstructed CT data. An optimized CT protocol allows to reduce the radiation burden for the patient.

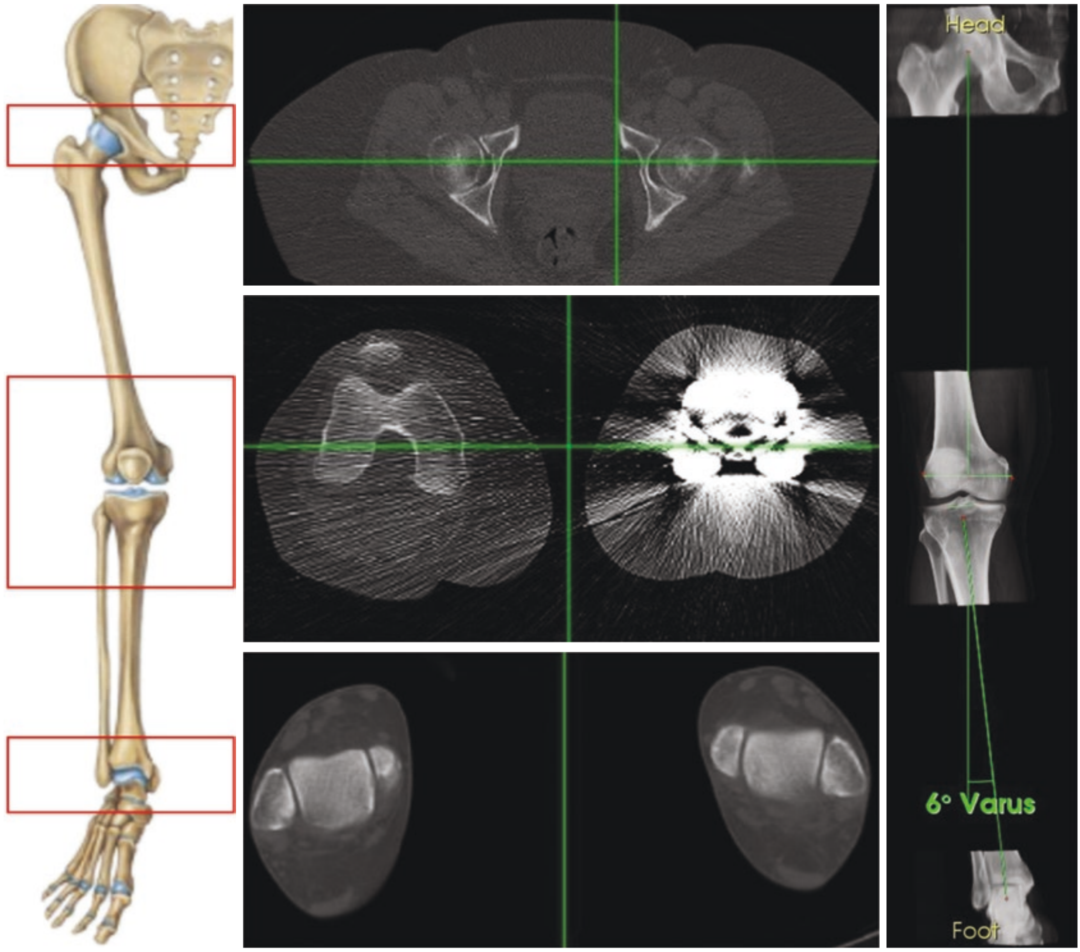

Fig. 19.3 The modified imperial knee CT protocol: reduced slice thickness (3 mm) for hip and ankle, regular slice thickness for knee (7 mm)

19.2.2 Frame of References

The most important step in 3D planning is the establishment of repeatable and reliable frames of reference.

This frame of reference enables us to

– Align the patient's anatomy with the scanner axis—as mentioned above.
– Relate the obtained information during 3D to the measurement in the OR—the same landmarks available during surgery are used for the frame of reference of the 3D images.

The frame of reference is usually based on anatomic landmarks and there is an ongoing discussion on which landmarks to use. However, the landmarks used in this tutorial are a trade-off between landmarks which are usable during surgery, visible before and after surgery and landmarks representing the biomechanical properties of the patient.

All frames of reference have orthogonal axis (x, y, z) and thus all calculations involving x, y and z are assumed to be normalized. Most CT scanners use the same axis as default.

- $+x$ is to the left of the patient
- $+y$ is to the back of the patient (posterior)
- $+z$ is to the head of the patient (cranial).

The xz plan represent an anterior-posterior (AP) view.

The *xy* plan equals an axial CT slice.

The yz plan equals a sagittal CT slice.

Additionally, the "+ medial" is a vector pointing to the middle of the body along the *x*-axis. Thus +medial is equal to +*x* on the right leg and -*x* on the left leg.

Side Summary
The first and one of the most important steps in 3D planning is the establishment of a frame of reference. Anatomic landmarks are used to define this frame.

19.2.3 Tutorial

19.2.3.1 Step 1: Femoral Frame of Reference

The femoral frame of reference can be defined as following (Figs. 19.4–19.7):

- ***x*-axis:** Rotation axis of the knee defined as transepicondylar line, which is the connection between the most lateral point of the lateral epicondyle and the most medial point of the medial epicondyle in the frontal plane,
- **Origin**: Center of the knee defined as the midpoint of the transepicondylar line.
- ***z*-axis:** Points from the center of the hip (center of the femoral head) to the center of knee in the frontal plane. It is equivalent to the femoral mechanical axis (FMA),
- ***y*-axis:** Defined by x-axis and z-axis (normalized cross product).

Several anatomic landmarks need to be selected to establish this frame of reference for the femur:

(a) Center of the femoral head.
(b) Most medial point of the medial epicondyle.
(c) Most lateral point of the lateral epicondyle.

The program then calculates the frame of reference for the femur based on these landmarks (Figs. 19.8–19.11).

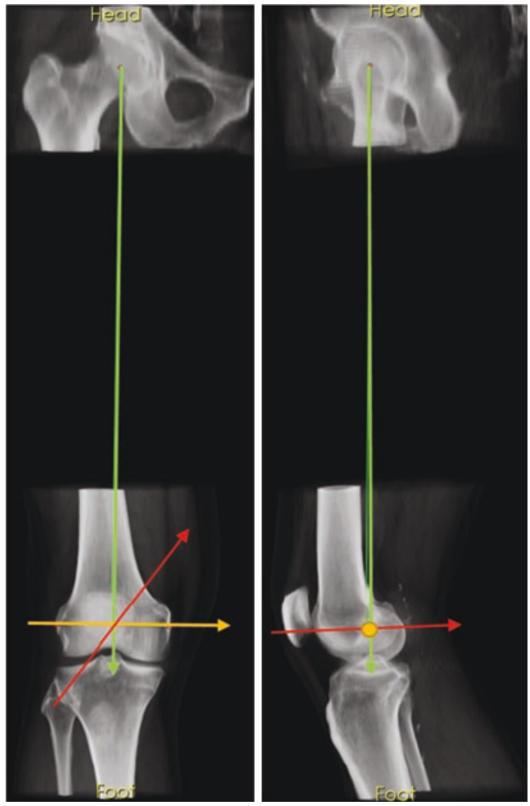

Fig. 19.4 3D reconstructed CT images of a patient's knee and hip in frontal (left) and sagittal (right) plan. The frame of reference of the femur as defined in the text is illustrated: *x*-axis (yellow), *z*-axis (green) and *y*-axis (red)

19.2.3.2 Step 2: Femoral Condyles

The next step is the definition of the two femoral condyles. Therefore, the following landmarks need to be selected:

(a) Most posterior point of the medial condyle.
(b) Most posterior point of the lateral femoral condyle.
(c) A sphere is placed on the medial condyle. It is placed in a way that its lower border follows the curve of the condyle boarder (in the frontal and sagittal plane).
(d) A sphere is placed on lateral condyle. It is placed in a way that its lower border follows the curve of the condyle boarder (in the frontal and sagittal plane).

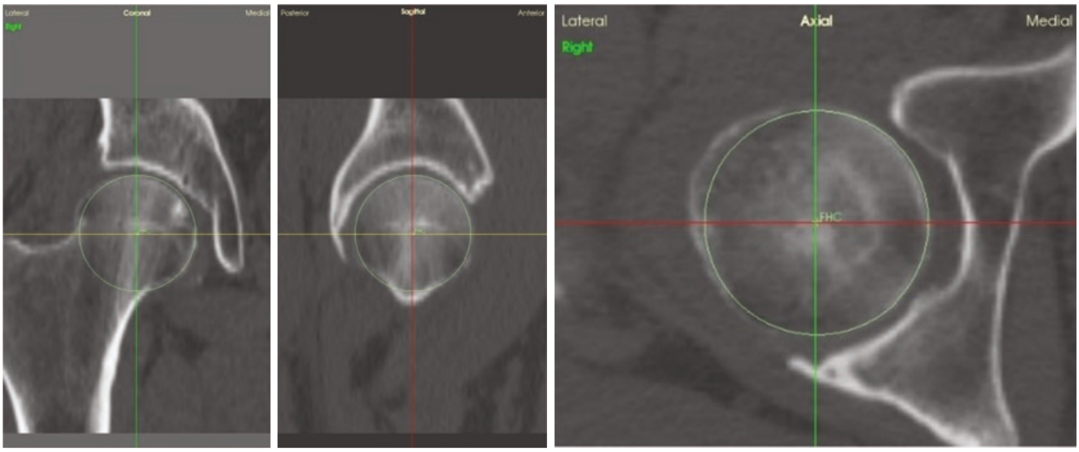

Fig. 19.5 CT slices of a patient's hip and the center of the femoral head selected

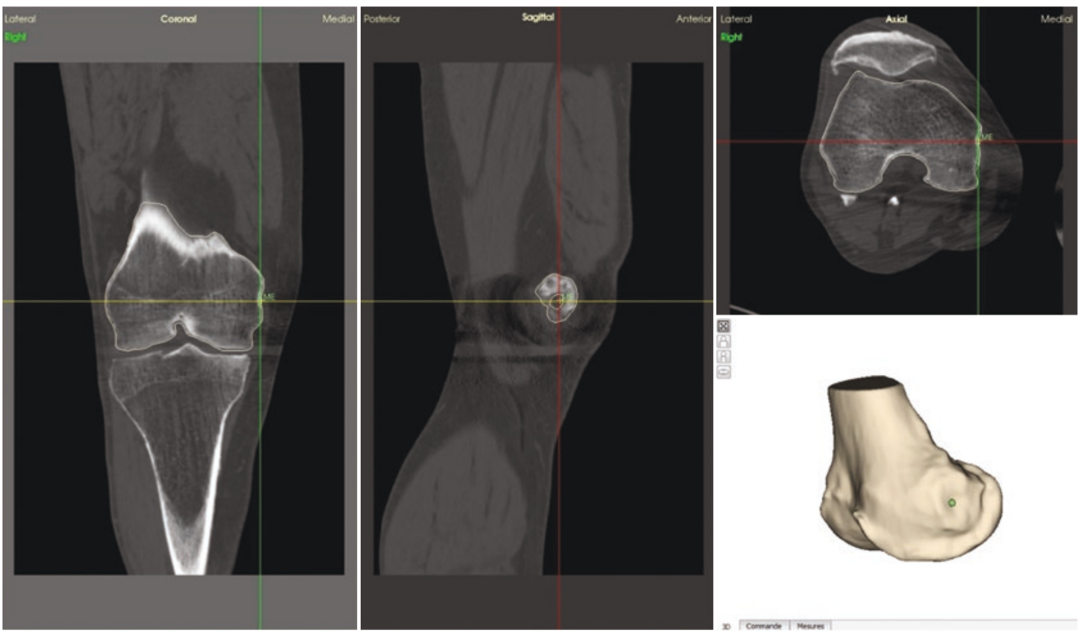

Fig. 19.6 CT slices of a patient's knee and the most medial point of the medial femoral epicondyle selected

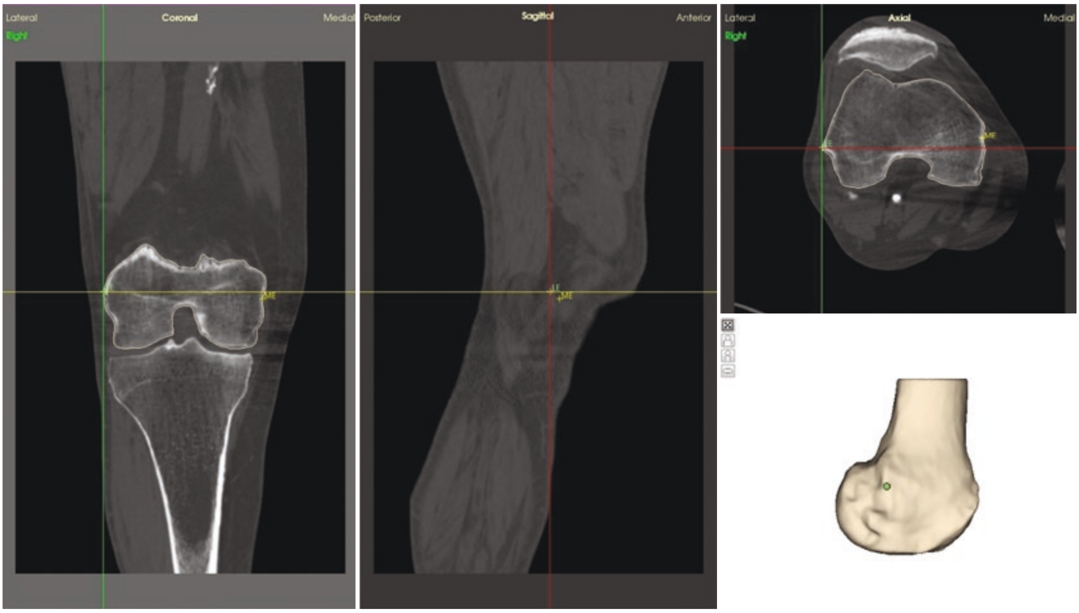

Fig. 19.7 CT slices of a patient's knee and the most lateral point of the lateral femoral epicondyle selected

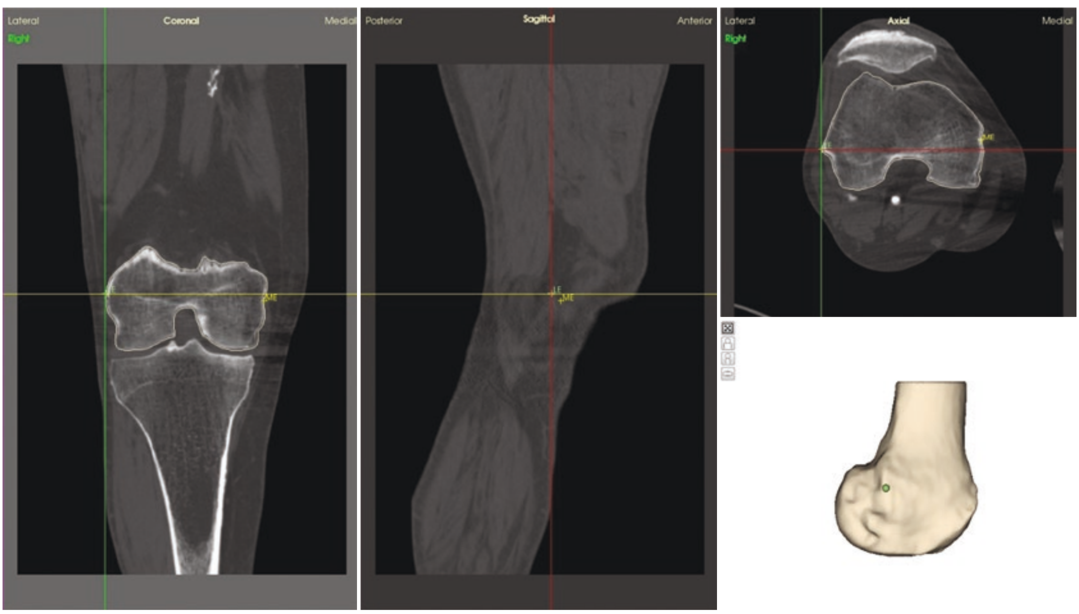

Fig. 19.8 CT slices of a patient's knee and the most posterior point of the medial femoral condyle selected

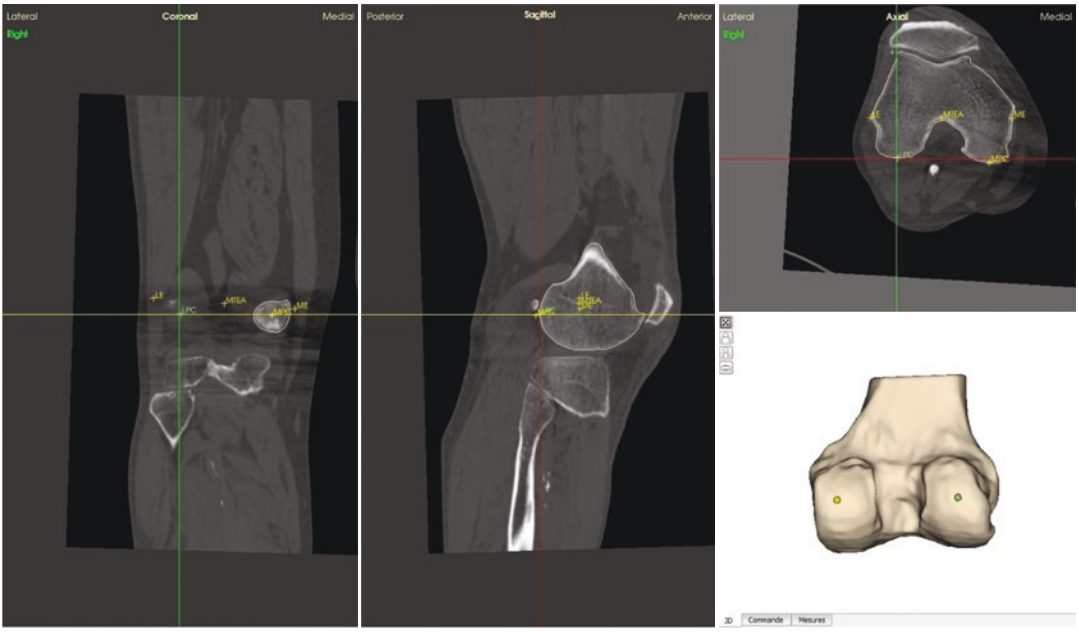

Fig. 19.9 CT slices of a patient's knee and the most posterior point of the lateral femoral condyle selected

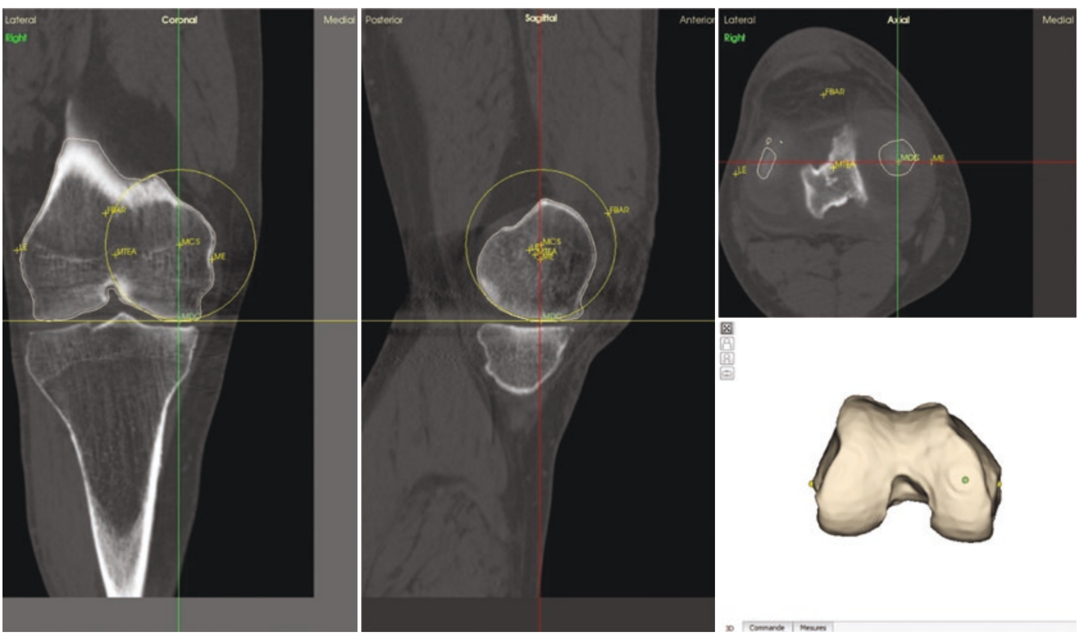

Fig. 19.10 CT slices of a patient's knee and a sphere is placed over the medial condyle of the femur

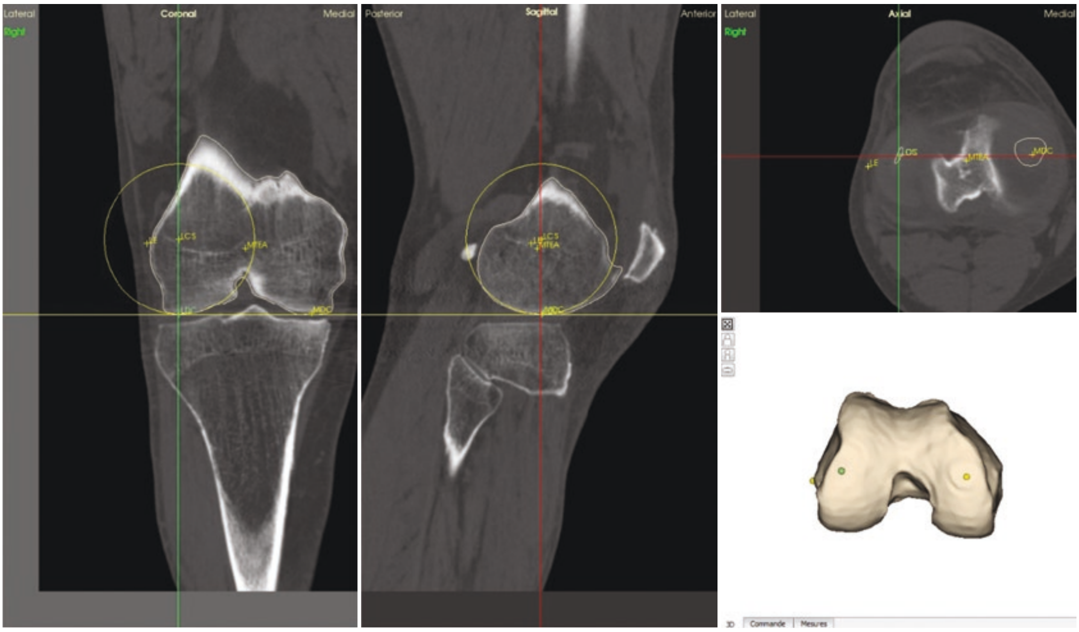

Fig. 19.11 CT slices of a patient's knee and a sphere is placed over the lateral femoral condyle

19.2.3.3 Step 3: Tibial Frame of Reference

Several frames of reference for the tibia have been described. In this example, the frame of reference for the tibia is defined as following (Figs. 19.12–19.16):

– Origin: Center of the proximal tibia.
– +*x* axis: Points from the center of talocrural joint to the proximal tibia center. This represents the mechanical axis of the tibia [(tibial mechanical axis (TMA)]
– +*y* axis: Normalized cross product of +*z* axis and the vector point form the rightmost posterior condyle point to the leftmost posterior condyle point.
– +*z* axis: Defined by +*z* and +*y* (normalized cross product).

Several anatomic landmarks need to be selected to establish this frame of reference for the tibia (Figs. 19.17 and 19.18):

(a) Center of the ankle joint.
(b) The position of the proximal tibia center depend on the assessed knee. When assess-

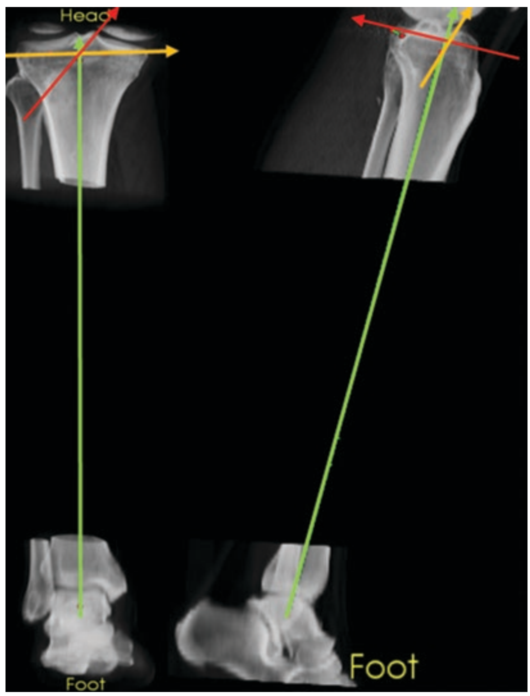

Fig. 19.12 3D reconstructed CT images of a patient's knee and ankle joint. The frame of reference as defined in the text is shown in anterior-posterior (*x*-axis in green, *z*-axis in yellow, *y*-axis in red) and medial-lateral (*x*-axis in green, *z*-axis in yellow, *y*-axis in red) view

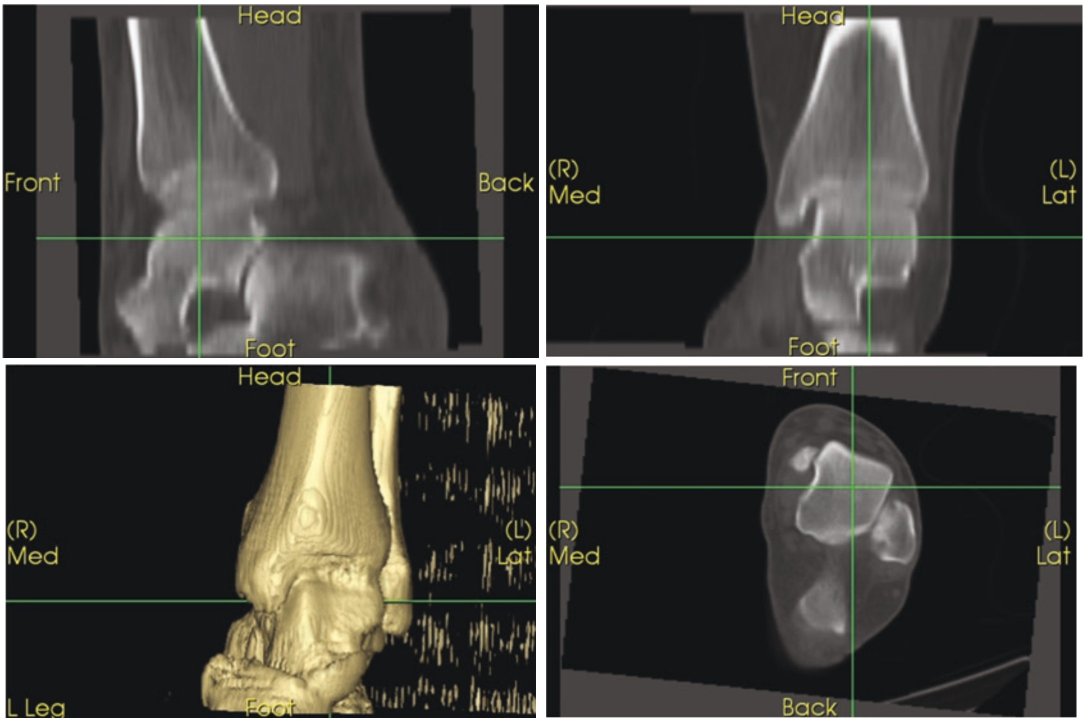

Fig. 19.13 CT slices of a patient's ankle and its center selected

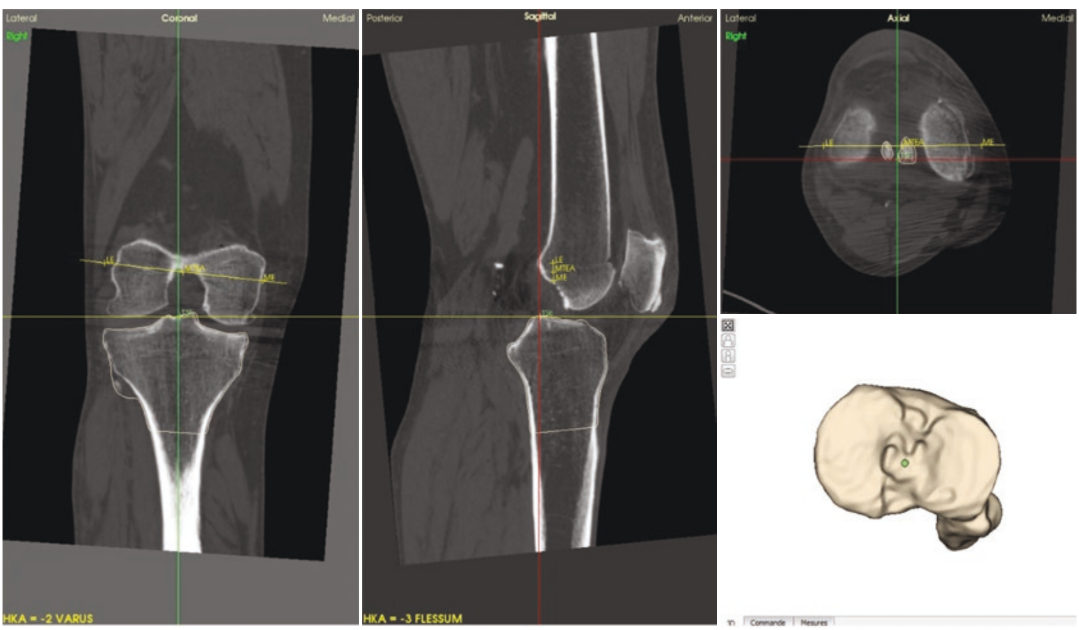

Fig. 19.14 CT slices of a patient's knee and the proximal tibia center selected

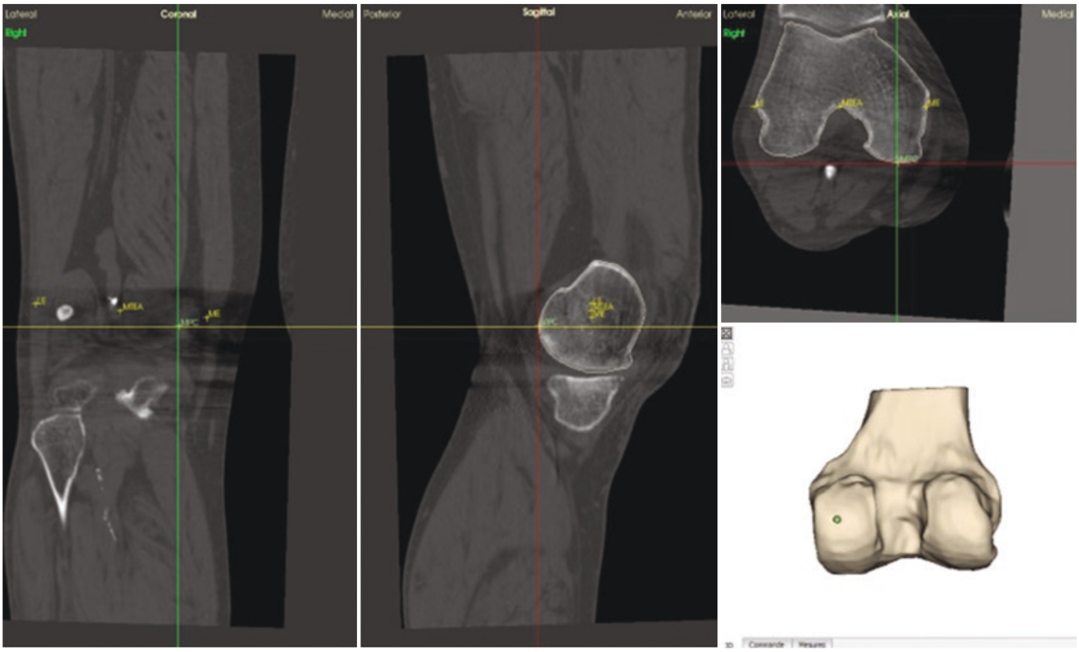

Fig. 19.15 CT slices of a patient's knee and the medial posterior condyle of the tibia selected

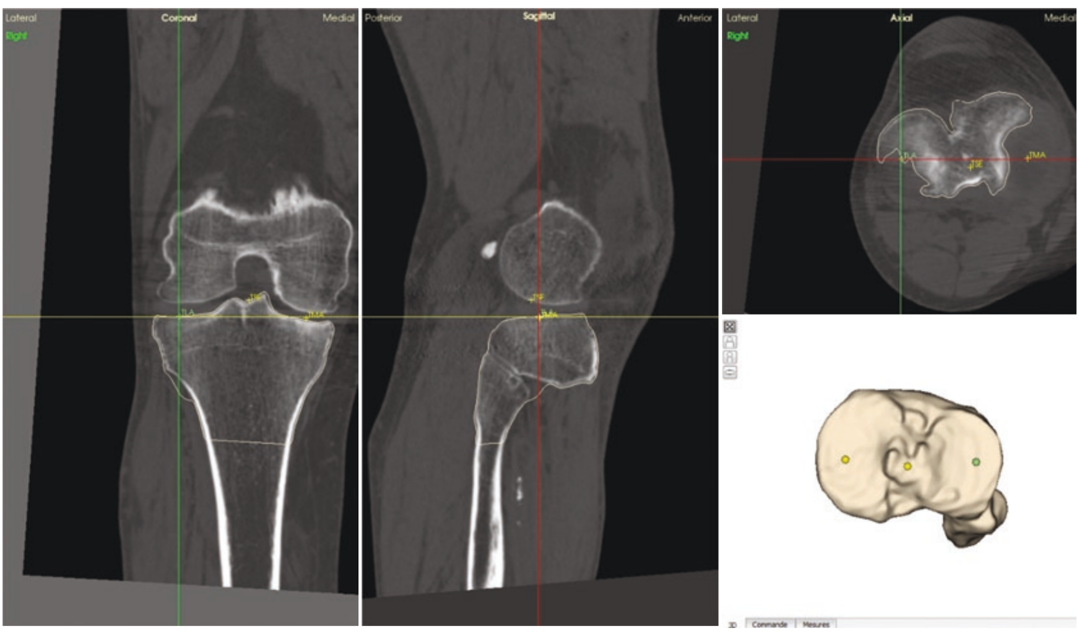

Fig. 19.16 CT slices of a patient's knee and the lateral posterior condyle of the tibia selected

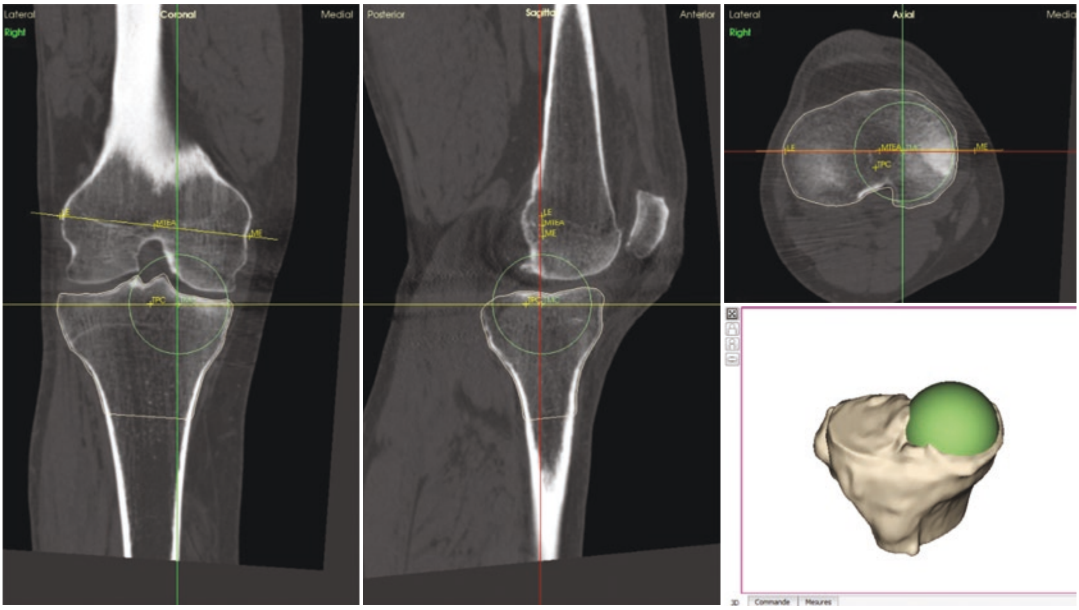

Fig. 19.17 CT slices of a patient's knee and a sphere placed on the medial tibial condyle

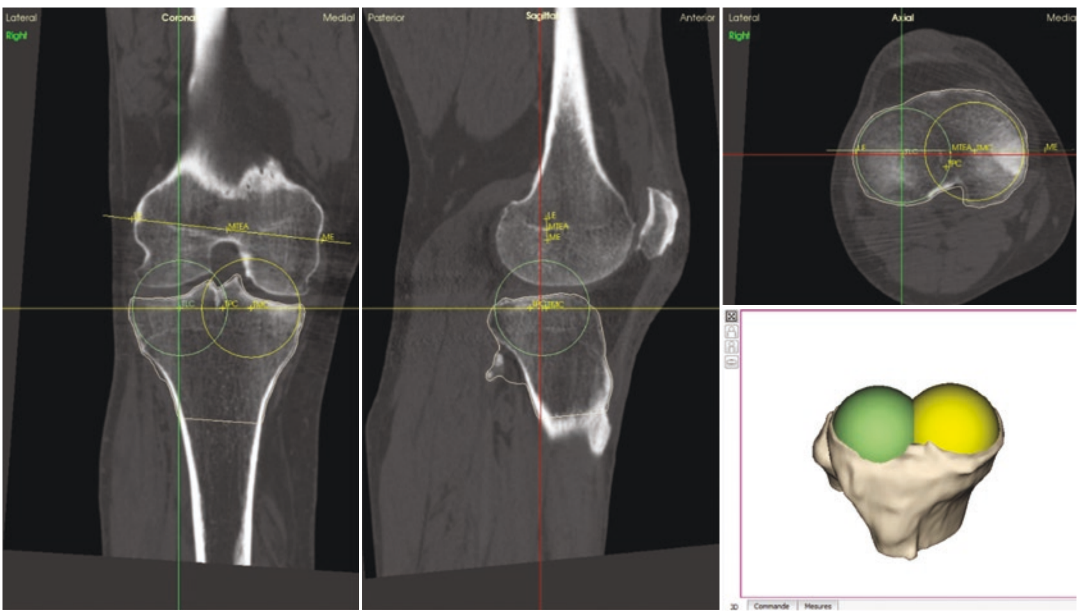

Fig. 19.18 CT slices of a patient's knee and a sphere placed on the lateral tibial condyle

ing a native knee, a point at center of the interspine sulcus should be used. When assessing a knee with an implant, use a point at center of the tibial plateau distal to the implant.

(c) Medial posterior condyle of the tibia is defined as.
   I. The most posterior point with respect to the tibial mechanical axis on the medial condyle on a native knee.

II. The most the posterior point on the bone, whose margins are sufficiently identifiable through the metal artifacts, when an implant is present.

(d) Lateral posterior condyle of the tibia is defined as.
   I. The most posterior point with respect to the tibial mechanical axis on the lateral condyle on a native knee.
   II. The most the posterior point on the bone, whose margins are sufficiently identifiable through the metal artifacts, when an implant is present.

19.2.3.4 Step 4: Tibial Condyles

Based on this frame, we now can define the tibial condyles. Therefore, the following landmarks need to be selected:

(a) A sphere is placed on the medial tibia plateau. Its border should follow the curve of the medial tibia plateau in the coronal plane.
(b) A sphere is placed on the lateral tibia plateau. Its board should follow the curve of the lateral tibia plateau in the coronal plane.

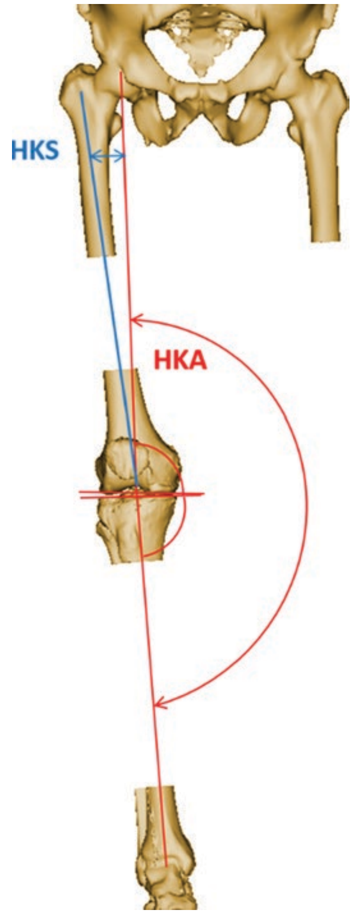

Fig. 19.19 3D Reconstruction of a patient's lower limb. The Hip−Knee−Ankle angle (HKA) in red and the Hip−Knee−Shaft angle (HKS) in blue are shown

19.3 What to Do with the Information Obtained in 3D Planning?

Based on the selected landmarks described in the tutorial, the planning software can calculate the following important axes and angles (Fig. 19.19).

19.3.1 Coronal Lower Limb Alignment

Figure 19.20 shows the hip-knee-ankle angle (HKA, Norm +/−180°) and the hip−knee−shaft angle (HKS, Norm ±6°) of a patient with a Varus deformity of 12°.

These two angles are important for the coronal alignment of the protheses components. The distal femoral cut is placed perpendicular to the HKA. However, only the HKS can be accessed during surgery (with the use of an intramedullary rod). Since we know the deviation between HKA and HKS form our preoperative planning, the HKA and thus position of the cut can be calculated based on the intraoperative measured HKS.

19.3.2 Joint Line Angulation

Joint line angulation can be assessed as well. This is important for the placement of the femoral as well as the tibial bone cut. Joint line angulation in the frontal plane is described by the

– **Femoral mechanical angle (FMA)** = The angle between femoral mechanical axis (FMA) and distal femoral condyle line (line

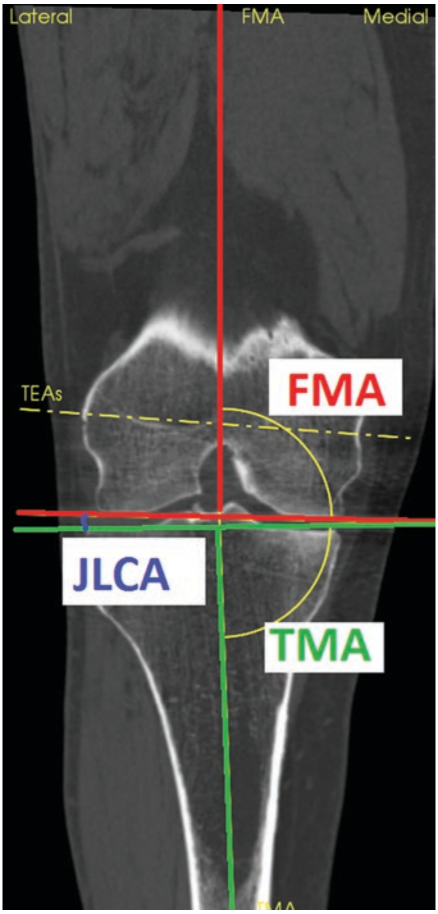

Fig. 19.20 3D reconstruction of knee in the anterior-posterior view. Femoral mechanical angle (FMA, red) as well as tibial mechanical angle (TMA, green) and joint line congruence angle (JLCA, blue) are shown

connecting the most distal point of the femoral condyles) in the frontal plane measured medially*.

– **Tibial mechanical angle**** = Angle between tibial mechanical axis and the tibial plateau line (a line parallel to the tibia plateau) in the frontal plane measured medially.
– **Joint line congruence angle (JLCA)** = Angle formed between the tibial plateau line and distal femoral condyle line.

*Referred to as mechanical Lateral Distal Femoral Angle (mLDFA) if measured laterally.

**Also referred to as mechanical medial proximal tibia angle (MPTA).

19.3.3 Femoral Rotation

The rotation of the femur can only be assessed on 3D/2D CT images (coronal view). However, 3D reconstructed images are again more accurate than conventional 2D CT images because not all landmarks are visible in one slice in 2D CT images. Rotation of the femur is often described by the **mechanical posterior femoral angle** (= posterior condylar angle, **Alpha-post**). The angle is formed by the trans-condylar line (line connecting both epicondyles) and the posterior condylar line (line connection the most posterior points of both condyles) (Fig. 19.21).

19.4 How 3D Planning Influences Knee Surgery? – The Knee Phenotype Concept

Lower limb alignment and joint line angulation are two important factors when planning and performing a TKA. However, they are difficult to measure correctly when using conventional radiographs (2D). In 3D planning they are easily accessible, and the figure (Fig. 19.22) below shows how important it is to measure. Every patient below has the same knee alignment, HKA = 180° (neutral alignment). But the values describing the knee phenotypes are different for every patient and thus need an appropriate and personalized surgical planning response.

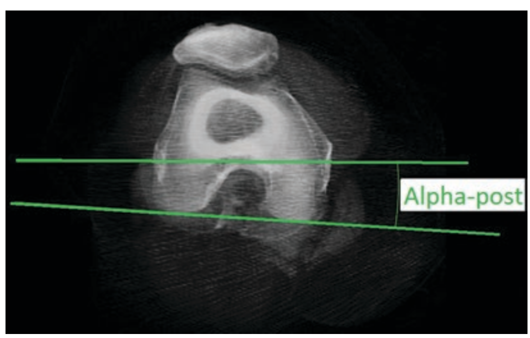

Fig. 19.21 3D reconstruction of a femur in caudal-cranial view. The mechanical posterior femoral angle (= posterior condylar angle, α-POST) is shown

Fig. 19.22 3D reconstructions of the lower limbs of three patients and below anterior-posterior and cranial-caudal views of the patient's femur. Every patient has HKA of 180° (neutral alignment). But the values describing the knee phenotypes are different for every patient and thus need an appropriate and personalized surgical planning response

Take Home Message

Preoperative planning is the key for a correct position and orientation of the TKA and thus essential for a good clinical outcome. It should be performed with reconstructed 3D images to achieve a higher accuracy and a more detailed and real preoperative plan.

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20 Optimal Setup of the Operating Room

Roland Becker and Mahmut Enes Kayaalp

Keynotes

- Operating rooms (OR) should provide a sterile environment to reduce surgical site infection (SSI).
- There are different options to reduce the risk of potential infection; however, some are yet to be proven efficient. The usage of air suites or laminar airflow ventilation systems remain controversial.
- The behaviour in the OR is of significant importance. The team time out is an important element of presurgical preparations. All relevant aspects should be checked by the surgeon and confirmed by the anaesthesiologist and the OR nurse before the skin incision is performed.
- Door opening and the number of people in the OR have an impact on SSI. Door opening should be avoided as much as possible.
- There are different options of positioning the surgeon, assistant and scrub nurse at the OR table. It depends on the surgeon's preference but needs to be well adapted by the entire staff.
- The setup in the OR should be standardized as much as possible in order to prevent unexpected and undesirable events.

20.1 Introduction

Risk factors for surgical site infections can be divided into the following categories: (1) patient-related factors, such as age, presence of diabetes mellitus, other comorbidities and obesity, (2) characteristics of the relevant surgical procedure including surgical wound classification, operating time, required surgical skills, prophylactic antibiotic therapy and hypothermia control and (3) operating environment. The following chapter will focus on operating room (OR) ventilation and settings during the surgical procedure.

20.2 Operating Room Requirements

Operating rooms are designed to provide **microbiologic clean air** as surgical environment in order to avoid surgical site infections (SSI). An

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operating unit is divided into different isolated areas such as the operating room itself, the transfer zone and the recovery area.

Hygiene classes of operating rooms are based on the colony forming units (CFU) per m^3 of air [1]:

Class 1	A and B	<10 CFU/m^3
Class 2		<200 CFU/m^3
Class 3		<500 CFU/m^3

The classification of air quality in the operating room is defined by DIN 1946–4 in Germany, which specifies the norms for clean air technique requirements in public health-care settings [1].

Operating rooms of class 1A have ventilation systems of unidirectional flow for attaining a protection area where surgery takes place. Operating rooms of class 1B have a ventilation system of mixed or turbulent displacement flows. For instance, this system is required in cardiac procedures [2].

The index for microbial air (IMA) contamination quantifies the microbial flow directly related to the contamination of the surfaces [3]. The index is based on the count of microbial fallout onto open Petri dishes over a period of 1 h. The Petri dishes are placed 1 m from the floor and at least 1 m from walls or any obstacle. The maximal acceptable level of IMA is less than 5 for class 1A and less than 25 for class 1B rooms. The IMA values of >2 are significantly less frequent in unidirectional airflow ventilation (58.9%) when compared with mixed airflow ventilation (87.6%) based on data from 1228 elective total knee and hip replacements [4]. The study also reported a positive correlation between number of door openings and microbial air contamination. Door opening during surgery is one of the major problems during arthroplasty surgery. It has been reported that up to a mean of 0.84 door openings per minute occurs during the pre-incision period of total joint replacement surgeries [5].

According to the maximally accepted level of IMA, the environments at risk are calculated [1].

Environment at risk	Characteristics	Maximum accepted level of IMA
Very high	Ultra clean room: Operating room for joint replacement	5
High	Clean room: Conventional operating theatre	25
Medium	Hospital wards	50
Low	Facilities	75

Joint replacement surgery has to be performed in operating rooms of class 1A. In order to achieve the highest hygiene standard in the OR, the following requirements have to be fulfilled:

– Vertical displacement flow (Laminar air flow).
– Minimum size of the ULF® (acronym for filter circulation technology) diffuser 9.0 m^2.
– Terminal, manufacturer-inspected, high-efficiency particular air (HEPA) filter H13.
– Surrounding airflow aprons down to the height of the doors (approx. 2.1 m between airflow apron and floor).
– Supply air volume flow >8000 m^3/h.
– Outdoor air supply 800–1200 m^3/h.

Specific setups in the OR is essential in order to avoid unnecessary air turbulences during the surgical procedure.

Side Summary
Joint replacement surgery requires an operating room of class A1

The vertical, low turbulence displacements of less than 5% is deemed to be appropriate. However, there is still a lack of strong evidence that laminar air flow will reduce the rate of periprosthetic joint infection [6].

The aspect of thermal comfort necessitates a defined temperature and humidity in the OR. Metabolic rate ranges from 0.8 MET for a patient lying on the OR table to 1.2 MET for anyone working while sitting up, to 2.4 MET for an orthopedic surgeon performing a major operation.

MET is the unit for measuring metabolically mediated heat emission from persons, prEN 1752. The temperature in the OR should be 18–24 °C at any time and the humidity should not exceed 50%.

Frequency of door opening, number of staff, and staff behaviour are all significantly associated with SSI. Switching staff during surgery, hectic movements, loud noise, and presence of visitors increase the risk [7]. Number of people in the operating room show another significant impact on microbial air contamination [4].

Side Summary
The temperature in the OR should be between 18 and 24° and the humidity should not exceed 50%

It has been shown that door opening may cause loss of positive pressure in the room and air flow reserve in the operating room [8]. The reasons for door opening was analysed in an article and revealed the following causes with relevant frequencies [9].

Expert consultation	30 (8%
Instrument needs	128 (31%)
Lunch/coffee breaks	75 (19%)
Social visit	12 (3%)
Scrubbed team member	108 (27%)
No detectable reasons	49 (12%)

Side Summary
Door opening during surgery correlates with increase in microbial air contamination

The use of air suites in total hip and knee arthroplasty is still debatable. According to the study by Vijaysegaran et al., air suites do not reduce the risk of infection [10]. They cause an increase in particle and microbiological emission rates when compared with standard surgical gowns. A review article also did not show a reduction in contamination or deep infection during arthroplasty [11].

Side Summary
Air suits do not decrease the risk of infection in total knee arthroplasty

A review of the literature has concluded that laminar air flow ventilation will not reduce the SSI in arthroplasty surgeries [12]. Furthermore, a different cost-effectiveness modelling study of strategies to reduce the risk of infection concluded that systematic antibiotics, antibiotic-loaded cement and conventional ventilation led to the largest annual cost savings and the greatest gains in quality-adjusted life-years. Whereas it was also concluded that laminar air flow and exhaust suits only increased the costs and caused worse health outcomes [13].

20.3 Setup of the Operating Room during Knee Arthroplasty

Most of the operating rooms are equipped with laminar air flow, which necessitates a central placement of the OR table (Fig. 20.1).

The surgeon stands at the side of the operated knee (Fig. 20.2). This means that the surgical instruments should be used with both hands depending on the side of the operated knee. For a right-handed surgeon, it seems easier to operate the patients' right knee, because the usage of the saw, hammer and other instruments is predominantly performed with the right hand. Better knee extension and function as reflected by Korean Shoulder Scale (KSS), and pain score has been reported for right knees compared to left knees in right-handed surgeons [14]. Surgeons need to be aware that when operating predominantly with the non-dominant hand, the surgical results might be inferior due to the risk of performing a less traumatic and accurate surgical procedure. Alternatively, some surgeons prefer to stand always on the same site of the knee during surgery. In that case the position of the surgeon

Fig. 20.1 Operating room with laminar air flow ventilation. The patient is positioned at centre of the room

Fig. 20.2 Positioning of the surgical team and the instruments round the patients during the procedure

is between patient's legs instead of standing on the contralateral side of the patient during surgery (Fig. 20.3). This allows use of the dominant hand predominantly for instrumentation during surgery.

Either one or two assistants will help the surgeon during the surgical procedure, which also depends on the presence of technical equipment. A hydraulic leg holder for instance allows free movement of the lower limb between full knee extension and 120 degrees of flexion without any manual help. Further detailed information about patients positioning on the operating table is given in Chap. 19.

If only one assistant is available during the surgery, he might stand on the same site with the surgeon or on the opposite site (Figs. 20.4 and 20.5). Standing of the same site with the surgeon allows the scrub nurse to stand with all the equipment on the opposite site. This setting is also more convenient in case of a computer-assisted surgery; where the tracking of the marker wouldn't be disturbed. Having the assistant on the opposite side on the other hand would provide the surgeon more space. In that case both the assistant and the scrub nurse are placed on the opposite side of the OR table.

Fig. 20.3 The surgeon may stand always at the same side of the patient. In case the surgeon is right-handed, he will stand on the right side of the patients even when operating the left knee

Fig. 20.4 The surgical assistant stands at the same time of the surgeon leaving the space for the scrub nurse on the opposite side. The position is also used when computer-assisted surgery is performed, leaving free access to the patient's knee for the navigation system

The position of the scrub nurse in relation to the surgeon is of significant importance. The surgeon should not be forced to move around the operating table or change his position to receive the instruments during the surgery. Moreover, instruments should be handed over to the surgeon without an eye contact. This allows the surgeon to stay focused with the eyes on the operating field and decreases the risk of distraction of the surgeon during the operation (Fig. 20.6).

The optimal workflow in the operating room is essential for minimizing the risk of any complications during the surgery. The patients should be anaesthetized before the surgical instruments and additional equipment for knee arthroplasty is placed on the instrumentation table. If everything

Fig. 20.5 The assistant and the scrub nurse are positioned on the opposite site of the patients. This gives the surgeon more space to move

Fig. 20.6 The instruments should be passed to the surgeon and back to the scrub nurse without eye contact. The scrub nurse should solely the instrument table, knowing the exact place of each instrument

is prepared, the relevant extremity is disinfected three times and sterilely draped.

Additional instruments such as suction and diathermy are placed on the table and connected to the devices.

When everything is prepared in the operating room "team timeout" has to be performed [15]. Surgical safety checklists are used worldwide to reduce errors, increase patient's safety and improve professional communication [16].

Side Summary
Team timeout is essential and reduces the risk of complication during surgery. At that moment, everybody will get focused to the surgical procedure

The following information of the surgeon has to be shared with the entire team in the operating room including:

- Name of the patient.
- Diagnosis.
- What joint and the side of the limb will be operated on.
- The size of the expected implants should be mentioned.
- The scrub nurse has to confirm that all instruments and implants are available for the surgery.
- The anaesthesiologist provides information about comorbidities, relevant medical problems such as allergies, presence of a pacemaker or a defibrillator.
- The application of i.v. antibiotics by the anaesthesiologist prior to surgery needs to be confirmed.

Despite all efforts, a high rate of communication failure in the operating room has been reported previously [17]. Failure types were classified into four different entities. The entity "occasion" was used where timing was poor, "content" where information was missing or inaccurate, "purpose" where issues were not resolved and "audience" where key individuals were excluded. Of a total of 421 communication events 129 were identified as a communication failure.

The following frequencies of types of failures were noticed:

- Failure type "occasion" in 45.7%.
- Failure type "content" in 35.7%.
- Failure type "purpose" in 24%.
- Failure type "audience" in 20.9%.

Significant improvement in communication in the OR was shown when dedicated training sessions were performed such as instructions, interactive participation, role-play, training films and clinical vignettes were used [18]. Moreover, the use of a safety checklist improves both perceived and observed teamwork and the communication in the OR [15].

Take Home Message

- Total knee arthroplasty should be performed in an OR of class A1. Laminar air flow, however, was shown not to reduce the risk of SSI. The number of door openings and the number of people in the OR increase the risk of SSI. All instruments including the implants should be in the OR before surgery starts. There are different options how the surgeon, the assistant and the nurse are positioned around the OR table. A very high degree of standardization has a positive impact on the entire workflow and reduces the risk of complications.
- The number of door opening should be reduced as much as possible. In some hospitals, the OR door is never opened during the surgery and before the dressing is applied to the wound.
- Communication is very important in the OR between all individuals; surgeon, assistant, scrub nurse and anaesthesiologist.

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Pain Management in Total Knee Arthroplasty

21

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Keynotes

1. Prehabilitation regimens show promising results with gains in muscle strength after TKA.
2. The use of oral analgesics continues to be important in pain management, but they are more commonly used as adjuncts rather than sole agents.
3. Traditional peripheral nerve blockade provided good pain relief but was associated with poor mobility.
4. Periarticular injections were effective in alleviating pain after TKA, providing superior pain relief to PCA and epidurals in the postoperative period.
5. CPM devices, although not so efficient in pain relief, are advantageous in reducing the proportion of patients undergoing manipulation under anesthesia at 6 weeks following TKA.
6. Cooling therapies have demonstrated promising results with regard to pain and can be used adjunctively in the postoperative period.
7. NMES and TENS may help with postoperative pain and have the potential advantages of having a negligible side-effect profile.

21.1 Introduction

Total knee arthroplasty (TKA) is associated with considerable postoperative pain that may impair mobility, reduce the ability to participate in rehabilitation, lead to chronic pain, and consequently reduce patient satisfaction [1].

Perioperative pain management of TKA remains challenging for physicians and anesthesiologists. Reducing postoperative pain is an essential component of patient satisfaction, functional outcomes, and hospital length of stay. Traditional general anesthesia, patient-controlled analgesia, opioids, and epidural anesthetics provide good pain relief but can be associated with side effects and serious complications, including postoperative nausea and vomiting (PONV), hypotension, urinary retention, respiratory depression, delirium, and an increased infection rate [2, 3]. Consequently, newer pain control modalities applying multimodal pain management regimens have been used to reduce the use of opioids while providing adequate pain relief. However, nowadays, there is still conflicting evidence about which modalities provide superior pain relief.

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The aim of this chapter is to review recent literature and summarize current anesthetic and analgesic options for TKA, thus assisting to better optimize patient outcomes.

21.2 Preoperative Management

21.2.1 Preoperative Physiotherapy

There is strong evidence that prehabilitation, physical therapy as a preparatory measure prior to TKA, potentially improves outcomes. Brown et al. showed that prehabilitation exercises of unweighted leg joint movements allowed for sustained exercise expectations, greater strength gains, and higher mean Physical Functioning scores [4]. In his study, Swank et al. assessing prehabilitation versus standard care demonstrated significantly greater peak extension torques in the operated leg in the prehabilitation group [5]. In addition, Walls et al. showed that quadriceps muscle area decreased significantly less in the prehabilitation group compared to the control group (4%/12%) at 12 weeks post-TKA [6].

Side Summary
Prehabilitation might lead to better early function after TKA.

21.2.2 Anesthesia

The types of anesthesia and analgesia administered perioperatively may affect the rates of surgical site infection, urinary retention, ileus, nausea and vomiting, and the ability to safely participate in early postoperative rehabilitation [2, 3, 7–11]. Nowadays, more and more studies refer to the term “multimodal analgesia.” Its aim is to address several aspects of pain and provide superior postoperative pain control through the simultaneous modulation of several pathways while minimizing the excessive administration and adverse effects of opioid dugs.

21.2.2.1 Preemptive Analgesia

Preemptive analgesia administered hours or days before surgery has the goal to prevent peripheral and central nervous system sensitization secondary to the surgical incision and surgical tissue manipulation and thus improving the patient’s postoperative pain [12]. Specific drugs, such as cyclooxygenase-2 (COX-2) inhibitors, gabapentin, and acetaminophen, are used for this purpose. COX-2 inhibitors, at a dose of 400 mg/daily, prevent prostaglandin’s production with a reduced risk for gastric ulcers and platelet dysfunction, compared to conventional NSAIDs. Lin et al. concluded that the perioperative use of COX-2 inhibitors resulted in lower pain scores (visual analogue scale—VAS), greater range of motion, less opioid consumption, and a reduction in opioid-related adverse effects at 3 days postoperatively [13].

Side Summary
Preemptive analgesia starts before TKA and aims to prevent peripheral and central nervous system sensitization due to surgery.

21.2.2.2 General Versus Spinal Anesthesia

General anesthesia is associated with reduced perioperative tissue oxygen level as well as postoperative nausea, vomiting, and delirium, which are avoided by use of peripheral anesthesia [2, 14]. On the other hand, administration of neuraxial anesthesia requires technical skills and is associated with common adverse effects such as postoperative hypotension and urinary retention. Moreover, the technique shows a failure rate of approximately 4%, necessitating conversion to general anesthesia [15]. Complications rate of spinal and epidural anesthesia, although reported to be extremely low (0.03%), may be devastating including spinal and epidural hematomas, abscess formation, cauda equina syndrome, and meningitis [16]. However, in his comparative study, Memtsoudis et al. reported higher risks of pulmonary compromise, pneumonia, acute renal failure, and overall 30-day mortality with general anesthesia [2]. Similarly, in the study of Pugely et al. patients receiving neuraxial anesthesia had significantly lower rates of surgical site infection, transfusions, overall complications, and length of stay [3].

Side Summary
The most commonly used methods of anesthesia are spinal and general anesthesia.

21.2.2.3 Peripheral Nerve Blocks

Peripheral nerve blocks following major knee surgery reduce local pain transmission and postoperative inflammatory response by blocking nerves supplying the lower limb [17, 18].

A number of meta-analyses have been conducted on related topics in recent years focusing on specific types of peripheral nerve block, such as the femoral nerve, sciatic nerve, and continuous peripheral nerve block [11, 19–21]. Peripheral nerve blocks offer a number of advantages for postoperative analgesia following major knee surgery. They result in better analgesic control, fewer opioid-related side effects, earlier improvements in knee flexion, and less pain during rehabilitation [22, 23]. Additionally, they avoid motor blockade to the nonoperated leg, thereby encouraging early ambulation and relieving psychological stress to some degree. In the study of Xu et al. published in the Cochrane Database of Systematic Reviews, the authors support that peripheral nerve blocks, as adjunctive techniques to systemic analgesia for TKA, resulted in a lower pain intensity scores at rest (from 0 to 72 h) and with activity (in the 24–72 h interval) postoperatively. However, no significant differences in the mean visual analogue scale (VAS) for pain on movement were noted over the time period of 0–23 h postoperatively [24].

21.2.2.4 Peripheral Nerve Blocks Versus Intrathecal Morphine

Femoral nerve blocks (FNBs) provide good pain control with fewer adverse effects when compared with systemic opioid use. However, patients must be exposed to an additional procedure. On the other hand, intrathecal morphine (ITM) is a simple procedure providing satisfactory analgesia, but it is associated with side effects, such as nausea, vomiting, and respiratory depression [25, 26]. Li et al. showed no significant differences between intrathecal morphine and femoral nerve block in the VAS scores and morphine consumption at 6, 12, and 24 h following TKA [27].

Continuous FNB has been extensively criticized for the length of time of the procedure, high risk of infection, and high failure rate, which limited its clinical application [28]. Although ITM has been associated with high rate of nausea and vomiting, dose-finding studies have demonstrated that 200 mg is the optimal dose to obtain the best balance between the efficiency of pain control and the minimization of side effects [29]. For elderly patients, a dose of 100 mg morphine has been shown to be more suitable, following joint replacement [30].

Side Summary
Femoral nerve blocks (FNBs) provide good pain control with few adverse effects. However, patients must be exposed to an additional procedure.

21.2.3 Tourniquet Time

Intentional ischemia for a period of 30–120 min represents a custom procedure during TKA to produce a bloodless surgical field and reduce intraoperative blood loss [31, 32]. Prolonged tourniquet application may result in local tissue ischemia leading to ischemia/reperfusion (I/R) injury and consequent endothelial activation [33, 34]. Although the role of endothelial cell activation, innate immunity, and activation of the plasma cascade systems in I/R injury in the context of tourniquet use in orthopedic surgery has not been investigated in detail, in clinical practice, prolonged local ischemia time during TKA has been linked to I/R injury [35].

There are limited data on the influence of a reduced tourniquet time strategy on outcome after TKA. Dreyer et al. reported reductions in anabolic signaling and upregulation of the catabolic FOXO and UPR pathways [36–38]. The authors concluded TKA with tourniquet induces expression of the molecular components of muscle atrophy [39].

Rathod et al. in a comparative study concerning tourniquet time (incision to arthrotomy closure/cementation) reported no significant differences in visual analogue scale pain scores, narcotic consumption, ability to straight leg raise during hospital stay, range of motion (ROM) at discharge, as well as isometric quadriceps strength, ROM, Short Form 36 scores, Knee Society scores at 6 weeks, 3 months, and 1 year follow-up [40]. Similarly, Tarwala et al., using periarticular cocktail injections, reported no differences in pain scores between the two groups [41]. On the other hand, Barwell et al., in a study of 44 patients, reported higher pain scores in the late tourniquet release group as compared with early tourniquet release [42]. Rama et al., in a meta-analysis of studies comparing early release (before wound closure to secure hemostasis) with late release (after wound closure) of tourniquet, reported increased intraoperative and calculated blood loss (on the basis of hemoglobin difference) in the early release group but a higher incidence of local complications in late release group [43].

21.3 Postoperative Management

21.3.1 Oral Analgesics

Oral analgesics have a distinguished role in perioperative pain management in patients undergoing TKA. Tramadol, oxycodone, and morphine sulfate have been shown to provide effective control of moderate to severe postoperative pain. However, they are associated with serious side effects that can interfere with postoperative recovery and rehabilitation [44, 45]. Alternatively, anti-inflammatory drugs (NSAIDs), exerting their action through cyclooxygenases (COX) inhibition and inflammatory process suppression, have been widely applied. However, because of their nonspecific action on prostaglandins, these drugs have been associated with serious side effects including gastric erosions and ulcers, impaired bone healing, as well as inhibition of bone ingrowth on implant surfaces during cementless procedures [46–49].

In addition to NSAIDS, calcium channel ligands, such as gabapentin and pregabalin, may aid in the treatment of both neuropathic and postsurgical pain [50]. Clarke et al. assessing the effect of perioperative gabapentin showed a significant reduction in morphine consumption in the first 24 h postoperatively in the gabapentin group, while no significant differences in assessment of physical function or pain scores were noted between the study groups. However, it was reported that the effects of gabapentin may take longer to be effective and therefore should rather be used for chronic pain associated with surgery [51].

> **Side Summary**
> Oral analgesics still have an important role in postoperative pain control. They are more commonly used as adjuncts rather than sole agents.

21.3.2 Joint Infiltration Analgesia

Local infiltration of analgesic agents (LIA) into soft tissues following TKA is believed to provide effective pain control while facilitating accelerated rehabilitation. The technique initially described by Andersen et al. mandates infiltration of all instrumented tissues as well as thorough intra-articular infusion [52]. Following the initial report, a wide range of local agents have been used, including steroids, nonsteroidal anti-inflammatory drugs, morphine, and magnesium-sulfate [53–55].

Gibbs et al., in their review assessing the results of 29 randomized trials on local infiltration following TKA, stated that the most effective technique involved the systemic infiltration of all exposed tissues, including the posterior capsule with a mixture of high-dose ropivacaine with adrenaline and ketorolac [56]. Taking into account the results of the studies of Carli et al. and Toftdahl et al., the authors recommend that although the technique is safe and efficient, it should be used as an adjunct to, rather than substituting, a femoral nerve block [57, 58]. No definitive conclusion on the length of hospital stay could be drawn from this analysis. In the meta-analysis of Jimenez-Almonte, the authors reported no difference between local infiltration analgesia and peripheral nerve blocks in terms of cumulative opioid use and pain scores 24 h after surgery, although local infiltration analgesia had a greater probability of being ranked first in efficacy for patient outcomes [59].

Side Summary
Local infiltration of analgesic agents (LIA) into soft tissues following TKA is believed to provide effective pain control while facilitating accelerated rehabilitation. Numerous different protocols can be used.

21.3.3 Cryotherapy

Among the many available techniques to control acute postoperative complications following TKA, cryotherapy has been extensively applied, mainly due to the low costs and the low rate of side effects [60, 61]. While initial systems included gel packs and crushed ice in plastic bags, nowadays, third generation devices enable computerized control of continuous cold therapy [62]. The rationale of cold pack application is to downregulate the tissue metabolism and to induce vasoconstriction, decreasing the inflammatory response and edema. Moreover, the analgesic effect of cold is produced by slowing or eliminating the pain signal transmission, working at the spinal level to inhibit the stretch reflex, thus reducing muscle spasm [63, 64].

Although Bech et al. found no additional benefit of consistent cooling [63], Morsi et al. performing bilateral-staged TKA on 30 patients 6 weeks apart, with each knee receiving either a continuous cooling device or no cooling device, demonstrated a lower mean visual analogue pain score in the cold therapy knees when compared to the control knees on postoperative days 1–6 [65]. In another study by Levy and Marmar comparing cold compressive and normal dressings following TKA, the cold compression group required less morphine consumption per 48 hours. In addition, the cold compression group demonstrated better VAS scores on postoperative days 2 and 3 [66]. Similarly, Su et al. reported reduced narcotic use and greater satisfaction with overall pain control following cryotherapy [67].

Side Summary
Cryotherapy is an important adjunct for pain control in the direct postoperative phase after TKA.

21.3.4 Continuous Passive Motion

Continuous passive motion (CPM) refers to the use of a motorized device that is applied to a patient's lower extremity, and continuously moves the patient's knee through a predefined arc of motion [68]. This device is typically used during the immediate postoperative period, and it has been theorized that early passive range-of-motion (ROM) can prevent the formation of adhesions that cause joint stiffness, promote early mobilization, improve knee flexion ROM, and reduce edema thus contributing to the alleviation of postoperative pain [67, 69]. However, Herbold et al. reported that CPM use in postoperative rehabilitation does not appear to offer long-term benefits after unilateral TKA, regardless of initial ROM [70]. Similarly, Boese et al. conducting a randomized, comparative trial to determine the efficacy of CPM following TKA stated that CPM provided no benefit to patients recovering from TKA [71]. In the Cochrane's study of Chaudhry et al. although no significant differences were detected between the CPM and control groups, the device was shown to be advantageous in reducing the proportion of patients undergoing manipulation under anesthesia at 6 weeks follow-up [72].

Side Summary
Continuous passive motion (CPM) refers to the use of a motorized device that is applied to a patient's lower extremity, and continuously moves the patient's knee through a predefined arc of motion.

21.3.5 Neuromuscular Electrical Stimulation (NMES)

NMES aims to assist quadriceps strengthening in the immediate postoperative phase following TKA [73, 74]. Stevens-Lapsley et al. reported significantly better hamstring and quadriceps muscle strength, stair-climb test timed up and go test, 6-min walk test, and active range of motion (ROM) when compared to the control group. Additionally, a relative improvement in quadriceps muscle strength in the NMES and physical therapy group was observed when compared with the physical therapy alone group, at 1-year follow-up [75]. Similarly, Avramidis et al. reported superior walking speed, American Knee Society function score, and Oxford Knee Score, and walking speed for the NMES group at 6 weeks [76, 77]. However, Petterson et al. found no significant difference between patients receiving progressive resistance exercise and NMES to those with progressive resistance exercise alone [78]. Similar results were presented by Levine et al. between patients with NMES and unsupervised at-home ROM exercises to therapist-managed physical therapy following TKA [79].

21.3.6 Transcutaneous Electrical Nerve Stimulation (TENS)

TENS exerts its analgesic effect through activation of inhibitory centers, thus decreasing central nervous system sensitization [80–82]. Stabile and Mallory reported limited opioid consumption in the TENS group compared to the group receiving intramuscular hydromorphine alone [83]. Similarly, Rakel et al. showed that the addition of TENS during immediate postoperative physiotherapy resulted in significantly reduced movement pain and pain at gait-speed testing when compared with stand-of-care therapy [84]. On the other hand, Angulo and Colwell found no significant difference between patients receiving sensory subthreshold and sensory threshold TENS combined with CPM [84]. Similarly, Breit and Van der Wall [85] reported no differences in pain management between patients receiving patient-controlled analgesia (PCA) alone and patients receiving PCA and TENS [86].

Take Home Message
In this analysis, we have reviewed the use and efficacy of different modes of perioperative analgesia in TKA. Prehabilitation regimens show promising results with gains in muscle strength after TKA. The use of oral analgesics continues to be important in pain management, but they are more commonly used as adjuncts rather than sole agents. Traditional peripheral nerve blockade provided good pain relief but was associated with poor mobility. Periarticular injections were effective in alleviating pain after TKA, providing superior pain relief to PCA and epidurals in the postoperative period. CPM devices, although not so efficient in pain relief, are advantageous in reducing th.e proportion of patients undergoing manipulation under anesthesia at 6 weeks following TKA. Cooling therapies have demonstrated promising results with regard to pain and can be used adjunctively in the postoperative period. NMES and TENS may help with postoperative pain and have the potential advantages of having a negligible side-effect profile. Moreover, they can be safely applied at home which ultimately may be cost effective and convenient for the patient.

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22 Optimal Positioning of the Patient

Sebastian Kopf and Roland Becker

Keynotes

1. Patient positioning is important for successful surgery.
2. Look for critical areas in order to avoid pressure sores.
3. The operated leg requires free range of motion without restriction due to patient positioning.
4. Supports are required to keep the leg in different flexion positions.
5. Final check for correct position has to be performed by the surgeon.

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22.1 Introduction

Optimal patient positioning on the operating (OR) table means a safe position of the patient without causing any pressure sores. All joints should be ideally in a position close to neutral. The operating area has to be exposed without compromises. Limitations during surgery due to patient's position are not acceptable.

22.2 Positioning of the Patient on the Operating Table

The patient requires a stable position on the OR table during surgery and intraoperative manipulation such as flexion-extension of the knee. However, the operating knee needs to be freely accessible by the surgeon. Poor position of the patient may cause limited access to the patient's knee during surgery and will increase the risk for complications. Optimal position of the patient for each knee procedure should follow the standard operating procedures (SOPs). This is important to make everybody in the operating room aware of the correct patient position on the table. The surgeon should always perform a final check of the patient's position before disinfection and sterile draping starts.

Supports and paddings should be used to avoid pressure sore, which may occur when external pressure exceeds the normal capillary filling

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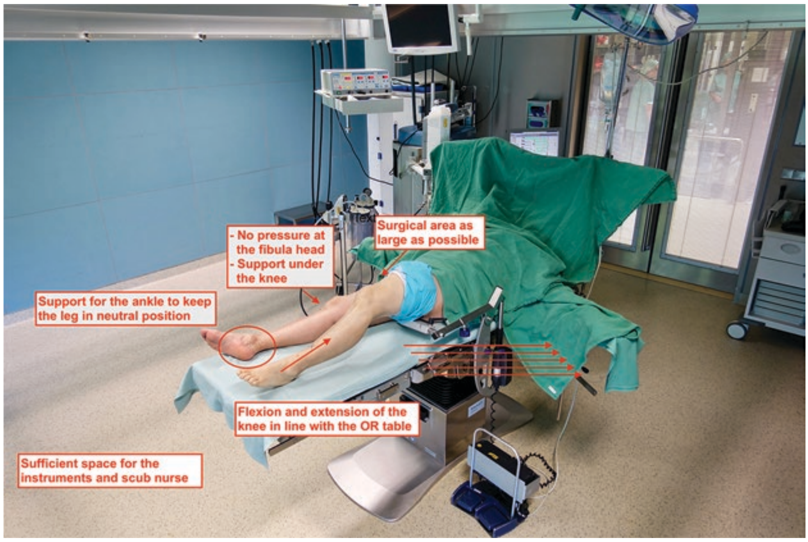

Fig. 22.1 The patient is positioned supine. Special attention is paid to bony prominence sites such as the calcaneus fibula head. The opposite leg should be positioned in neutral with a support under the knee

pressure of approximately 32 mmHg [1]. This is even more important for patients with diabetes mellitus, poor vascularization, elderly age, or low body mass index who have an increased risk for pressure ulcers. All bony prominences need to be well padded. Nerve injuries may occur due to pressure or abnormal joint position. Clearly, checking an optimal and safe patient position on the OR table is the surgeons' responsibility.

The following aspects should be checked (Fig. 22.1):

- Correct supine position of the patients close to the operating side of the OR table.
- Maximal flexion of the knee without restriction due to patient positioning.
- Adjustment of the supports in order for keeping the leg in different flexion position.
- The contralateral leg should be positioned in neutral or slight flexion using a support under the knee.

22.3 Positioning of the Surgeon in the OR

The surgeon also has to find the optimal position for himself during the surgical procedure. A comfortable position means that the surgeon stands or sits without feeling any pain or stiffness. It prevents early exhaustion or distraction of the surgeon during the operation. The table should be placed in a comfortable height, which may change during surgery. The knee might be positioned in extension or flexion, which causes a difference in distance to the surgeon and should be adjusted with the operating table.

There are different options for patient positioning on the operating table. Patient is positioned in a supine position for total and unicondylar knee arthroplasties (Fig. 22.1). The shoulder should not be abducted to more than 90° and the elbow should be flexed to less than 90°. The forearm should be positioned in neutral or slight supinated position. That position may help to avoid compression at the cubital tunnel by the retinaculum [2]: Ulnar nerve injuries are most common and comprise 28% of all nerve injuries during anesthesia [3].

A lateral support at the level of the thigh and a foot support will keep the knee in a flexed position with the help of an assistant (Fig. 22.2). The knee can easily be positioned in flexion or extension (Fig. 22.3). The location of the foot support is essential because it determines the degree of flexion in the knee joint. Total knee replacement is performed at 70°–90° of knee flexion. Increase in flexion will tighten the collateral ligaments and the extensor apparatus, and more force needs to

Fig. 22.2 The leg can be positioned using a support at the thigh and the foot. The support at the thigh will prevent external rotation of the hip. The foot support keeps the knee in adjusted position

Fig. 22.3 The leg can be moved easily between the extension and flexion position

be applied to the surrounding soft tissue. A silicon cushion may serve as a foot support (Fig. 22.4).

Another option is the usage of a hydraulic leg holder (Figs. 22.5 and 22.6). The leg holder allows free flexion and extension of the knee without manual help (Video 22.1). The tourniquet will help to position the thigh correctly in the leg holder. When surgery is performed without tourniquet compression, it has been discussed that compression of the veins may occur resulting in an increase in bleeding.

Alternatively, the leg can be positioned in the hanging position where the knee will be flexed at 90° as used for arthroscopy (Fig. 22.7). The position is used by some surgeons specifically when unicondylar knee arthroplasty (UKA) is performed. UKA is predominantly performed knee at 90° of flexion. Due to the hanging knee the joint is easily accessible and free movement of the knee is allowed during surgery too.

In case of using a tourniquet during surgery, the cuff should be fixed as proximal as possible on the thigh in order to allow free access to the knee (Fig. 22.5). When the tourniquet is placed distally close to the knee, the skin incision proximally to the knee might become limited and patella eversion becomes more difficult.

Fig. 22.4 A silicon cushion can be used as a foot support as well. The cushion can be easily adjusted during surgery. That will increase the flexibility in terms of degree of knee flexion

Figs. 22.5 and 22.6 The hydraulic leg holder will be used by the surgeon and saves the second assistant during surgery. The knee can be flexed to any position but is well fixed at the same time. No assistant is required to support the leg

Fig. 22.7 The knee is placed in a hanging position at 90° of flexion. It allows good access during unicondylar knee arthroplasty, where the knee is mainly at 90° of flexion

Take Home Message

- Patient's position on the operating table requires final check by the surgeon because it is the surgeon's responsibility.
- Sufficient padding of exposed bony areas should be performed.
- The contralateral leg should be kept in a neutral position.

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23 Pros and Cons of Using a Tourniquet

Bruno Violante, Maria Chiara Meloni, and Russalka W. Hoedemaeker

Keynotes

1. A tourniquet is a device that can be used to constrict and compress the limb for a period of time in order to control venous and arterial circulation. Pressure is applied circumferentially upon the skin and underlying tissues of the extremity, causing temporary occlusion of the vessels.
2. Pneumatic tourniquets have been widely used in total knee arthroplasty (TKA) to reduce intraoperative blood loss and to improve visibility of the surgical field, which allows the surgeon to work with greater precision and to save time.
3. The potential benefits of the use of a tourniquet always have to be weighted against its risk and possible complications.
4. The reported complications are mostly pressure-related but can also occur due to excessive tourniquet time. Typical minor complications are skin blistering, subcutaneous fat necrosis, increased wound hematoma leading to persistent wound drainage and subsequent increased infection risk, increased swelling, stiffness and limb pain.
5. Major complications are a nerve palsy mediated or modulated by compression neuropraxia, a vascular injury, muscle damage with delay of muscle-power recovery and deep vein thrombosis (DVT). More severe complications include pulmonary embolism (PE), acute pulmonary oedema or cardiac arrest.
6. DVT, pulmonary embolism (PE), acute pulmonary oedema and cardiac arrest are very rare but devastating consequences.
7. A "post tourniquet syndrome" due to prolonged ischaemia is characterized by a stiff, swollen limb and muscle weakness.
8. Prolonged tourniquet time is also known to impair postoperative functional recovery and negatively affect range of motion, clinical outcome and comfort for the patients.

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23.1 Introduction

A tourniquet is a device which can be used to constrict and compress the limb for a period of time in order to control venous and arterial circulation. Pressure is applied circumferentially upon the skin and underlying tissues of the extremity, causing temporary occlusion of the vessels.

For nearly a century pneumatic tourniquets have been widely used in total knee arthroplasty (TKA) to reduce intraoperative blood loss and to improve visibility of the surgical field, which allows the surgeon to work with greater precision [1–5].

Side Summary
A tourniquet is a mechanism that can be used to constrict and compress the limb for a period of time in order to control venous and arterial circulation. Pneumatic tourniquet is widely used in total knee arthroplasty in order to reduce intraoperative blood loss and improve visibility of the surgical field.

23.1.1 Historical Perspectives [6–8]

Archigesius Heliodose, who practised medicine during the Roman Empire, was the first to describe the use of a tight cloth band and narrow straps made of bronze during amputation (Fig. 23.1).

In 1718, a French surgeon, Jean Louis Petit, developed a screw tourniquet, which was a complex mechanical device with gear wheels and a handle on a threaded shaft for occluding blood flow in surgical sites. From this screw device the word tourniquet (from the French *tourner* – to turn) was derived (Fig. 23.2).

In 1873 Friedrich von Esmarch developed a rubber band that was wrapped around the extremity to exsanguinate the extremity and tied it at the proximal end so as to facilitate bloodless surgery in the distal extremity (Fig. 23.3).

In 1904 Harvey Cushing created a pneumatic tourniquet, because of his concern with the high incidence of nerve palsy. His modification and others after him have resulted in the modern Conn or Kidde pneumatic tourniquet (Fig. 23.4).

In the early 1980's modern, electronic tourniquet systems (also called computerized tourniquets or microprocessor-controlled tourniquets) were invented by James McEwen (Fig. 23.5).

Fig. 23.1 Tourniquet as used during the Roman Empire

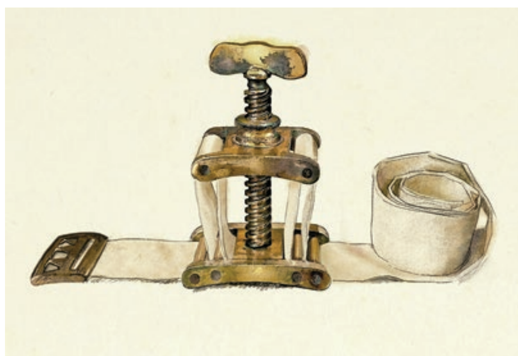

Fig. 23.2 Tourniquet "screw devise" developed by Jean Louis Petit

Fig. 23.3 Esmarch's rubber bands

Fig. 23.4 Pneumatic tourniquet

23.2 Characteristics of Tourniquets in TKA

The most commonly used tourniquet in TKA is a single bladder pneumatic tourniquet. Such a pneumatic tourniquet uses a gas-inflated cuff to constrict the blood flow, and the cuff pressure exerted on the limb can be controlled.

Modern pneumatic tourniquets have seven basic components (Fig. 23.6) [9]:

There are many different cuff designs available. The optimal fit and size of a tourniquet cuff should be individualized, taking into consideration the size and shape of the patient's limb and the specific demands of the operative procedure.

Fig. 23.5 Electronic pneumatic tourniquet system

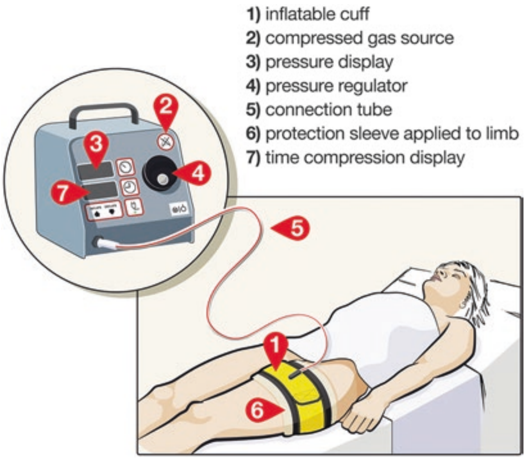

Fig. 23.6 The components of a modern pneumatic tourniquet

In order to reduce injuries to the skin and underlying soft tissue, it is recommended to use a limb protection sleeve, which is available in different shapes.

Another important issue is that the tourniquet limb occlusion pressure (LOP) needs to be determined. LOP is defined as the lowest pressure applied to a limb in order to occlude blood flow distal to the cuff. There is an inverse relationship between LOP and the ratio of the cuff width to the limb circumference. Thus, for a given limb circumference the narrower the cuff, the higher the pressure needs to be to occlude the blood flow [10].

23.3 Cuff Pressure and Duration

Generally, orthopaedic surgeons use fixed inflation pressures (e.g. 280–300 mmHg for the thigh) or a fixed pressure above systolic arterial pressure (e.g. 100–150 mmHg for the thigh). This concept, although widely used, does not take into account age, systolic blood pressure, atherosclerosis and limb circumference.

The lowest pressure applied to a limb in order to occlude blood flow distal to the cuff is defined as limb occlusion pressure (LOP). LOP depends on systolic blood pressure (SBP), limb circumference and shape (obesity and muscle trophism) and might vary from one to the other patient.

Side Summary
Safe tourniquet inflation time depends greatly on the patient's anatomy, age, physical status and the vascular supply to the extremity. There is a general agreement that for reasonably healthy adults, 90 min for TKA has been identified as a general guideline for inflation duration

An automated plethysmographic system is built into the tourniquet, and it measures limb occlusion pressure in about 30 seconds at the beginning of an operation. An additional safety margin of pressure is added to the measured limb occlusion pressure to account for physiologic variations. According to the developer McEwen, the safety margin to be added is 40 mmHg for limb occlusion pressures of <130 mmHg, 60 mmHg for those between 130 and 190 mmHg, and 80 mmHg for those of >190 mmHg [1–6].

In practice, safe tourniquet inflation time depends greatly on the patient's anatomy, age, physical status, and the vascular supply to the extremity. It is commonly agreed that for reasonably healthy adults, 90-min inflation time is considered as safe in TKA surgery [11].

Releasing the tourniquet for a period of time and then re-inflating, the so-called down-time technique, allows for removal of metabolic waste products from the limb and nourishment of the tissue with oxygenated blood. During this time, elevate the limb 60 degrees to encourage venous return and apply steady pressure to the incision with a sterile dressing. Tissue oxygenation periods should last at least 10–15 minutes the first time and 15–20 minutes subsequently. To proceed with the surgery, re-exsanguinate the limb before re-inflating the cuff. There is no consensus on safety limits in terms of the number of oxygenation intervals.

It is however clear that complications increase as tourniquet time increases and with increasing tourniquet pressure. Hence, it is important to keep the cuff pressure and the duration of tourniquet use to a minimum.

23.3.1 Cementation

The use of a tourniquet during cementation of prosthesis still is controversial in TKA. It is well known that blood and fat negatively affects binding of the cement to the prosthesis and or bone interface. The tourniquet during cementation in TKA ensures an increased cement penetration into the trabecular bone and consequently improved primary implant stability [12–14].

Side Summary
There is no consensus on the use of a tourniquet; analysis of literature does not establish a guideline. The use of tourniquet during cementation is commonly agreed on

In a recent meta-analysis it was stated that there are not enough high-quality randomized control trials to determine the potential benefits of tourniquet use in TKA. Potential benefits include reduced intraoperative blood loss, improved surgical field visualization and cement penetration [15]. In another systematic review and meta-analysis of RCTs by Alcelik et al., 19 studies were included. The authors highlighted that the main reason for using a tourniquet in TKA was to achieve better cementation, and in theory, this should result in longer implant survival. They concluded that there were no data on implant survival in any of the studies, so this hypothesis could not be tested. They found less need for blood transfusions in the tourniquet group, both a higher incidence of minor complications [16].

Pfitzner et al. investigated 90 patients divided in two groups with and without a tourniquet during cementation in TKA. They found a statistically significant difference in cement penetration in favour of the tourniquet group. An increased cement mantle thickness was also found to increase implant stability and survival [14]. In contrast, they found that the use of a tourniquet led to an increased total blood loss and increased postoperative pain.

In contrast, Vertullo et al. found that the use of a tourniquet during cementation did not lead to deeper tibial cement penetration in a single-blinded randomized trial. This was also confirmed by Ledin et al. who found no difference between the two groups in terms of component migration at 2 years [15–19].

The use of a tourniquet currently still appears to be more a matter of preference than evidence.

23.4 Possible Complications Related to the Use of a Tourniquet

The potential benefits and risks of using a tourniquet should be considered individually.

The reported complications are mostly pressure-related but can also occur due to excessive tourniquet time. Typical minor complications are skin blistering, subcutaneous fat necrosis, increased wound hematoma leading to persistent wound drainage and subsequent increased infection risk, increased swelling, stiffness and limb pain. Major complications are a nerve palsy mediated or modulated by compression neuropraxia, a vascular injury, muscle damage with delay of muscle-power recovery and deep vein thrombosis (DVT). More severe complications include pulmonary embolism (PE), acute pulmonary oedema or cardiac arrest [20]. DVT, pulmonary embolism (PE), acute pulmonary oedema and cardiac arrest are very rare, however, with devastating consequences.

A “post tourniquet syndrome” due to prolonged ischaemia is characterized by a stiff, swollen limb and muscle weakness.

Prolonged tourniquet time is also known to impair postoperative functional recovery and negatively affect range of motion, clinical outcome and comfort for the patients [21].

Side Summary
Typical complications related to the use of a tourniquet are an ischaemic reperfusion injury, muscle soreness or damage, nerve injuries and DVT.

23.4.1 Ischaemia Reperfusion Injury

Ischaemia reperfusion injury (IR) is a combined effect of ischaemia and subsequent reperfusion (Fig. 23.7). During ischaemia due to tourniquet use the cell metabolism is down-regulated in order to decrease oxygen demand and cell damage. The higher the oxygen deprivation the higher the cell stress. After release of tourniquet oxygen levels are refilled. This phase is called the reperfusion phase. Metabolic products accumulated during ischaemia are released and reactive oxygen species (ROS) are generated exceeding the capacity of endogenous antioxidants to neutralize them. This leads to a severe inflammatory response. During this inflammatory response fluid leaks from the cells into the extracellular matrix due to increased cell membrane permeability for cytoplasmic enzymes. Furthermore, reperfusion may also lead to secondary cell damage, a disturbance of intracellular homeostasis, lipid peroxidation, membrane disintegration and DNA damage, with the apoptosis and necrosis of endothelial, parenchymal and immune cells.

From the histological point of view, muscle damage is found from 30 to 60 min after tourniquet inflation with progressive hypoxia and acidosis (decreased pH-values, PO_2 and increased PCO_2, K+ and lactate) [22–25].

23.4.2 Muscle Damage

Skeletal muscle damage is well documented with tourniquet use. The skeletal muscle in limbs is very sensitive to ischaemic changes [26].

Ejaz et al. investigated in vivo metabolic changes in the skeletal muscle using microdialysis during TKA with and without tourniquet use. They found significant differences in all metabolites detected between the two groups. Compared to baseline, tourniquet-induced ischaemia resulted in decreased levels of glucose and pyruvate to 54% and 60%, respectively. In addition, accumulation of lactate to 116% and glycerol to 190% was observed. In the non-tourniquet group the metabolic changes were less pronounced and normalized within 60 minutes after TKA [23].

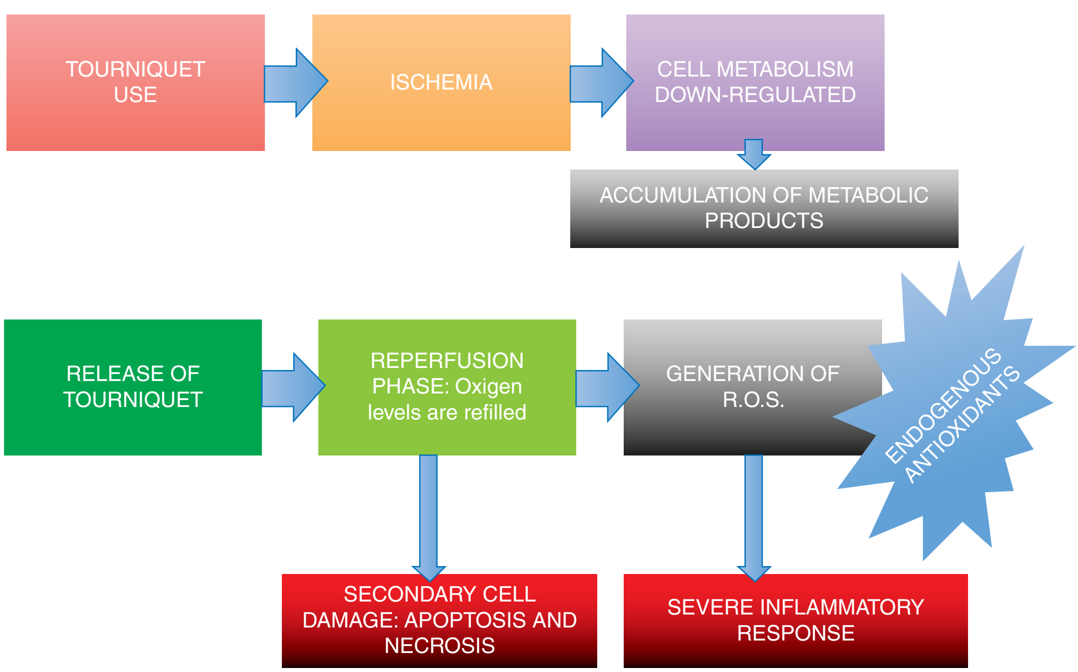

Fig. 23.7 Ischaemia reperfusion injury

Huda et al. found that tourniquet-induced skeletal muscle damage led to increased plasma levels of some cytokines, including IL-6 [24]. Serum creatine phosphokinase concentration is also elevated in response to muscle damage due to tourniquet use.

Dreyer et al., who measured quadriceps volume using MRI, found a 14% reduction of muscle volume in patients after TKA. It was speculated that muscle atrophy was not only due to the postoperatively reduced ambulation but also due to the metabolic response and inflammatory cascade [27].

In a level I study, Dennis et al. found that patients who underwent TKA using a tourniquet had reduced quadriceps strength during the first 3 months after TKA [28].

Furthermore, in very rare cases, rhabdomyolysis has been described as a complication of prolonged ischaemia time after tourniquet application. The clinical presentation of rhabdomyolysis is pyrexia, tachycardia, pain, tenderness and dark urine.

23.4.3 Nerve Injuries

Nerve injury related to tourniquet application ranges from paraesthesia to paralysis. The incidence is estimated to be 0.01–0.02% [4]. Nerve damage caused by tourniquet use has been documented in histologic, electromyography (EMG) and nerve conduction velocity (NCV) studies. A period of 120 minutes of tourniquet was associated with an increased risk of nerve injury in TKA [29]. Nerve injuries typically occur at the proximal and distal edges of the cuff where the shear stress is the greatest [30].

Peripheral neuropathies associated with the use of a pneumatic tourniquet are due to compression and ischaemia, which leads to slowing or cessation of both sensory and motor nerve conduction.

Compression plays a more important role in the first 2 to 3 h. From then irreversible structural changes may occur. Direct damage of the nerve is due to the compressive effect and is mainly localized directly under the cuff.

Ischaemia, however, although it affects the nerve as well, has a greater impact on the muscle. In the early stages it is usually limited to the occluded area, while after 4 h of tourniquet use, it also spreads distally [29].

According to McEwen "Tourniquet paralysis may result from either excessive or insufficient pressure, but the latter is considered more dangerous, resulting in passive congestion with possible irreversible functional loss. Patients with flaccid, loose skin (e.g., the elderly), or patients with large amounts of subcutaneous tissue on cone-shaped limbs are subject to nerve and tissue injury from a shearing force mechanically created by an improperly fitting cuff. Most often, shearing stress occurs at the proximal edge of the cuff. Risk of shearing-related injury may be reduced by selecting a contoured cuff (which fits the limb taper) and a matching limb protection sleeve" [31].

23.4.4 DVT and PE

Thromboembolism is one of the most common complications after TKA [32]. The reported incidence of DVT after TKA ranges from 40% to 84%, and PE from 0.5% to 1.8% [33].

The incidence of clinical thromboembolic events was higher in patients managed with a tourniquet than in those without [34]. The use of a tourniquet can cause venous stasis, compression of the vessels and endothelial damage, with increased activation of tissue factor and other clotting factors, secondary to distal limb ischaemia [35]. The severity of vascular compression may also be unpredictable due to arteriosclerosis secondary to calcification [36].

The critical point is the deflation of the tourniquet [37]. Studies with transesophageal echocardiography demonstrated shower-like echogenic materials circulating from the lower limbs to the right atrium, ventricle and pulmonary artery after release of the tourniquet. However, this sonographic phenomenon was rarely clinically relevant but might result in PE [38]. Postoperative mechanical and chemical DVT prophylaxis should be routinely performed by all TKA surgeons [39].

23.5 Practical Recommendations

Select a tourniquet cuff that best fits the shape and size of the limb of the patient. Use a correct sleeve to prevent damage to skin and underlying tissue. Minimize applied pressure to avoid pressure-related injuries. In order to minimize time-related ischaemic injuries, tourniquet time should be monitored and minimized.

Take Home Message

Pneumatic tourniquet is widely used in TKA. It helps to reduce intraoperative blood loss and improve visibility of the surgical field. However, there is no clear consensus if, when and how a tourniquet should be used in TKA. It is more a matter of preference than evidence.

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24 Pro and Cons of Tranexamic Acid (TXA) in Total Knee Arthroplasty

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Keynotes
1. The usage of tranexamic acid has become very popular in TKA surgery.
2. Significant reduction in blood loss is achieved when TXA is used.
3. There is no difference of effect in terms of TXA administration (I.V. injection versus topically).

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24.1 Background

Perioperative bleeding is considered to be a major complication in total knee arthroplasty (TKA). The average perioperative blood loss ranges from 800 ml to 1800 ml. Allogenic blood transfusions are required in 10–38% [1–3]. Excessive local haematoma may lead to increased pain and swelling. A consecutive delay in rehabilitation may have lasting negative effects on postoperative outcome. Additionally, allogenic transfusions (associated with a number of possible complications, for example anaphylactic reactions, graft-versus-host reactions, intravenous fluid overload and transmission of infectious disease) may be necessary in order to compensate for blood loss [4, 5].

Side Summary
Perioperative bleeding is considered to be a major complication in total knee arthroplasty (TKA). The average perioperative blood loss ranges from 800 ml to 1800 ml. Allogenic blood transfusions are required in 10–38%

Surgical trauma leads to an activation of the fibrinolytic cascade. The consecutive hyperfibrinolysis is considered to be a major cause for bleeding. While a pneumatic tourniquet may

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temporarily help to prevent intraoperative blood loss, its deflation towards the end of surgery, however, will force further fibrinolysis [6, 7].

In order to counter the adverse effect of hyperfibrinolysis, different antifibrinolytic agents (e.g. aprotinin, aminocaproic acid, TXA) have been employed. Among these, TXA has prevailed as the most efficient and safe option. Since its discovery in 1962 by Ukato Okamoto, it has gained foothold in a variety of clinical disciplines (e.g. gynaecology, dentistry, urology and orthopaedic surgery) [8] (Fig. 24.1).

24.2 Basic Pharmacokinetics

As a synthetic analogue of the amino acid, lysine TXA reversibly binds to lysine receptors on plasminogen (Fig. 24.1). Thus, it functions as a competitive inhibitor of plasminogen by blocking its proteolytic activity. At higher doses it has a noncompetitive inhibiting effect on plasmin. Its antifibrinolytic in vitro effect is roughly 8–10 times higher than its precursor drug ε-aminocaproic acid.

> **Side Summary**
> TXA is a synthetic analogue of the amino acid lysine and reversibly binds to lysine receptors on plasminogen. Thus, it functions as a competitive inhibitor of plasminogen by blocking its proteolytic activity. At higher doses it has a non-competitive inhibiting effect on plasmin

Maximum plasma concentrations are reached 2 h after oral, 30 min after intramuscular and 5–15 min after intravenous drug administration. Antifibrinolytic concentrations remain in the serum for 7–8 h after drug administration, in different tissues up to 17 h. The biological half-life in joint fluid is approximately 3 h. Elimination occurs

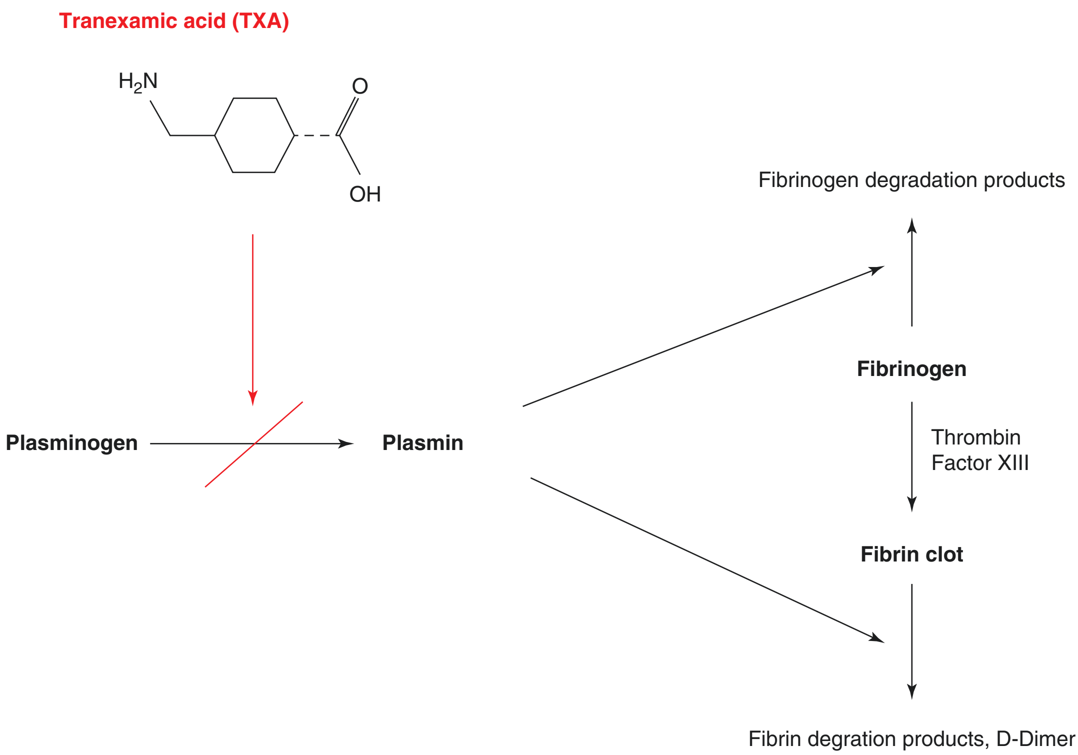

Fig. 24.1 Tranexamic acid (TXA) and its effect on the fibrinolytic pathway

through the renal pathway. The drug's renal clearance is equal to the overall plasma clearance. Twenty-four hours after drug administration, 90% of TXA is eliminated by urine excretion.

24.3 Modes of Administration

A plethora of intravenous, topical and oral administration techniques are available in clinical practice.

Side Summary
TXA can be administered intravenously, topically or orally.

24.3.1 Intravenous Administration

24.3.1.1 Bolus Regimens

A standard dose of 1 g (ranging from 500 mg to 3 g) is suggested by most authors. Other authors recommended a weight-adapted dosage of 10–20 mg per kg body weight. However, weight-adapted bolus administration could not be shown to be superior to a standardized 1 g bolus.

The recommended timing for drug administration varies widely in current literature. Most commonly, the first bolus is given preoperatively or intraoperatively (before inflation of the tourniquet if one is used). Isolated postoperative administration of TXA has shown to be inferior in terms of its efficacy on blood loss.

Single shot as well as double and triple bolus regimens with 6–8 h intervals has been proposed [9–11].

24.3.1.2 Continuous Regimens

Suggested protocols differ from author to author. Doses vary from 2 mg per kg body weight per hour over 20 h to 10 mg per kg body weight per hour over 3 h. The suggested protocols seem to be effective without one being able to claim superiority over the other.

24.3.2 Topical Administration

Intravenous drug administration was initially suspected to be associated with an increased risk of thromboembolic events in high-risk patients. For this reason, topical application methods were introduced. The objective was to effectively reduce blood loss while minimizing the drug's systemic side effects.

24.3.2.1 Intra-Articular Administration Regimens

TXA can be administered directly into the joint. Intra-articular injection after arthrotomy or wound closure is one option. Retrograde instillation via an intra-articular drain, with or without drain clamping, is another. Suggested dosages range from 250 mg to 3 g of TXA diluted in 75 ml to 250 ml of saline solution.

24.3.2.2 Topical Wash Regimens

The same solution can be used to lavage the operative site after implantation of the definitive components, usually before deflating the tourniquet. The topical wash is left in situ for a minimum of 2 min, so the drug can properly unfold its effect.

24.3.3 Oral Administration

Oral TXA use has already been widely used in other medical disciplines. Lately, this mode of administration has also found its way into orthopaedic surgery. Single and multiple dose regimens have been described as being successful in lowering blood loss, haemoglobin drop and transfusion rate. Dosages ranging from 500 mg to 1 g have been recommended up to a maximum of four times a day [12].

24.3.4 Combined Administration

Lately, a combined intravenous and topical/oral approach has been proposed in order to achieve further reduction of postoperative bleeding.

While current literature does not doubt the efficacy of TXA in reducing the risk of postoperative bleeding, there is no clear consensus on a superior administration regimen at this time [13]. Reports are conflicting because of inadequate sample sizes in relation to patient heterogeneity and diversity of treatment protocols.

24.4 Efficacy

A multitude of level-1 studies have confirmed the efficacy of TXA in the reduction of postoperative bleeding [14–22] (Table 24.1). The measured parameters usually include intraoperative blood loss, drain output, postoperative drop of haemoglobin levels and the need for allogenic transfusion.

Both intravenous, topical and oral administration methods have been proven to be effective. Systematic reviews do not support the superiority

Table 24.1 Overview of systematic reviews and meta-analyses of randomized controlled trials and prospective cohort studies on the efficacy of TXA in total knee arthroplasty

Author	Regimen	Results
Altria S et al. (2011)	iv, topical, oral	Mean reduction of blood loss: 591 ml (95%-CI 536–647 ml; $p < 0.001$) Reduction in transfusion risk rate: 2.56 (95%-CI 2.1–3.1; $p < 0.001$)
Alshryda S et al. (2014)	Topical	Reduction in transfusion risk rate: 4.51 (95% CI 3.1–6.7; $p < 0.001$)
Kim T et al. (2014)	iv, topical	Range of reduction in blood loss: 191–942 ml (14–64%) Range of drain output reduction: 65—785 ml (8–66%) Range of haemoglobin drop: 0.4–2.8 g/dl (12–70%) Conflicting results of iv and topical regimens, variability in transfusion rates
Panteli M et al. (2013)	Topical	Mean reduction in blood loss: 220 ml (95%-CI 160–279 ml; $p < 0.00001$) Haemoglobin drop: 0.94 g/dl (95%-CI 0.65–1.24 g/dl; $p < 0.00001$) Reduction in transfusion risk rate: 0.47 (95%-CI 0.26–0.84; $p = 0.01$)
Shemshaki H et al. (2015)	iv, topical	Mean reduction in blood loss (iv): 392.7 ml (95%-CI 257.3–528.1 ml; $p < 0.001$) Mean reduction in blood loss (topical): 282.4 ml (95%-CI 9.9–574.7 ml; $p < 0.001$) Reduction in transfusion risk rate (iv): 0.44 (95%-CI 0.33–0.59; $p < 0.001$) Reduction in transfusion risk rate (topical): 0.27 (95%-CI 0.16–0.45; $p < 0.001$) No differences between iv or topical administration (total blood loss $p = 0.50$; transfusion risk rate $p = 0.30$)
Wang H et al. (2014)	iv, topical	Mean reduction in total blood loss: 14.4 ml (95%-CI 63.3–92.0 ml) Haemoglobin drop: 0.43 g/dl (95%-CI 0.25–1.11 g/dl) Mean drain output reduction: 21.9 ml (95%-CI 85.0–128.8 ml) Reduction in transfusion risk rate 1.02 (95%-CI 0.7–1.9)
Wu Q et al. (2015)	iv, topical	Mean reduction of total blood loss (iv): 1.01 (95%-CI 0.60–1.43; $p = 0.00$) Mean reduction in total blood loss (topical): 0.86 (95%-CI 0.59–1.14; $p = 0.000$) No reduction in intraoperative blood loss Haemoglobin drop (iv): 0.85 g/dl (95%-CI 0.44–1.26 g/dl; $p = 0.000$) Haemoglobin drop (topical): 0.65 g/dl (95%-CI 0.35–0.96 g/dl; $p = 0.000$)
Yue C et al. (2015)	Topical	Mean reduction in blood loss: 280.65 ml (95%-CI 184.8–376.4; $p < 0.00001$) Mean reduction in drain output: 194.6 ml (95%-CI 73.3–315.9; $p < 0.002$) Reduction in transfusion risk rate: 0.26 (95%-CI 0.19–0.37; $p < 0.00001$) High concentration regimens (mean reduction in blood loss 335 ml, transfusion risk ratio 0.23) better than low concentration regimens (213.5 ml and 0.37 respectively)
Zhang L et al. (2012)	iv	Mean reduction in blood loss: 487 ml (95%-CI 344–629 ml) Reduction in transfusion risk rate: 0.4 ($p < 0.00001$)
Zhang L et al. (2017)	iv, oral	Comparable results for average haemoglobin drop ($p = 0.88$), total haemoglobin drop ($p = 0.57$), total blood loss ($p = 0.42$), transfusion rate ($p = 0.16$), complications ($p = 0.61$) and length of hospital stay (p = 1.00)

of one application form over another [23, 24]. Recent randomized trials suggest a combination of multi-dose, intravenous bolus regimens combined with a local infusion may be superior to a unimodal approach. Metadata, however, does not clearly support this hypothesis so far. High dose concentration regimens are more potent than their low dose counterparts.

24.5 Risk of Thromboembolic Disease

In theory, antifibrinolytics may lead to intravascular clot formation [25]. The complication of venous thromboembolic disease (VTE) remains a major issue in current literature and daily clinical practice.

The United States Food and Drug Administration (FDA) provides four explicit scenarios, in which the administration of TXA is contraindicated (Table 24.2). Surprisingly, a medical history of venous thromboembolic disease is not among them. Single events of arterial and venous thrombosis and thromboembolism under TXA therapy are documented. The FDA, however, only points to the possibility of an increased risk of VTE recurrence in high-risk patients. No explicit recommendation against the use of TXA in this patient collective is uttered. A number of other conditions requiring the physician's special attention are provided (Table 24.3).

A prothrombotic effect of TXA in healthy patients has been thoroughly refuted. Its use is safe, independent from its mode of administration. The risk of VTE is well compensated for by common postoperative chemoprophylaxis (e.g. aspirin, warfarin, low-molecular-weight heparin and factor Xa inhibitors) [26–30]. Some authors even discussed a potential antithrombotic effect secondary to the drug's anti-inflammatory properties [31–33].

The risk of VTE recurrence in high-risk patients after intravenous TXA administration still remains a subject of debate. Until recently, high-risk patients have specifically been excluded from randomized trials investigating drug safety. For this reason, level-1 evidence in this patient collective is currently not available. Recent retrospective studies, however, were unable to support the general notion of an increased incidence of VTE in high-risk patients [34, 35].

Table 24.2 Contraindications for the administration of TXA (Cyklokapron®) as provided by the United States Food and Drug Administration (FDA)

Condition	Rationale
Acquired defective colour vision	Sudden disruption of colour vision indicates drug toxicity
Previous subarachnoidal haemorrhage	Anecdotal reports of cerebral oedema and cerebral infarction
Active vascular clot	Disruption of perithrombotic coagulatory processes
Known hypersensitivity	

Table 24.3 Warnings about the use of TXA (Cyklokapron®) in patients with potentially relevant comorbidities as provided by the FDA

Condition	Rationale
Renal failure	Drug accumulation (dose adaptation required)
Upper urinary tract bleeding	Ureteral obstruction
Previous venous thromboembolic disease (VTE)	Potentially increased risk of clot recurrence
Factor IX complex or anti-inhibitor coagulant concentrate treatment	Increased risk of thromboembolic disease
Disseminated intravascular coagulopathy (DIC)	Further disruption of prothrombotic and fibrinolytic homoeostasis (strict supervision of experienced physician required)
Dizziness	Compromised ability to drive or control machinery

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Standard Approaches to the Knee

25

G. Mattiassich and J. Hochreiter

Keynotes

1. The planning of the procedure and the surgical approach to the knee are crucial for achieving satisfactory results after TKA.
2. In cases of a standard primary implant, the classical approach with midline incision and medial parapatellar arthrotomy is used.
3. Less-invasive approaches, such as midvastus or subvastus approaches, might have the potential to preserve quadriceps function but should be restricted to experienced surgeons and are not recommended as the standard approach in difficult cases or revisions.

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25.1 Introduction

Sufficient joint exposure is of utmost importance to perform soft tissue balancing and to obtain sufficient space to position the implants for total knee arthroplasty (TKA).

The following approaches modify the arthrotomy approach but not the skin incision, although certain situations such as the existence of previous skin incisions present different considerations. Alternatives to the standard approaches include modifications of the plane and amount of muscle dissection and possibly result in different degrees of visualization and post-surgical clinical function.

The most common approaches for TKA are the midline, medial and lateral parapatellar approaches. Further medial approaches, such as the midvastus or subvastus approach, are sometimes applied to perform minimally invasive muscle-preserving surgery.

25.2 Skin Incision

The skin of the knee region is rather vulnerable. Considering the skin incision, it is essential to avoid wound complications as the skin lies directly over the joint, patella and tibial tubercle. Incisions directly over the tibial tubercle might jeopardize the patellar tendon, especially in older

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Fig. 25.1 Pre-existing scar after marking a previous knee arthroplasty. The previous median standard approach will be reused

Fig. 25.2 Another example of a right knee after previous medial and lateral arthrotomies for TKA

patients with diminished microvascularity of the skin and subcutaneous tissue.

To reduce the risk of skin necrosis, pre-existing scars should be incorporated in the incision, or the incision should be made with a safety distance of at least 5 cm, even when there is a long interval between the operations (Figs. 25.1 and 25.2). Also an angle between scar and incision of more than 60° should be considered to avoid wound healing problems. In case of multiple previous incisions, the most lateral incision should be used to minimize damage to the lymphatic drainage of the skin and subcutaneous tissue over the knee. Prior well-healed arthroscopic portals and transverse skin incisions (such as those that are used for high tibial osteotomy or sometimes in cases of patella fracture stabilization) can be crossed at right angles without risks [1].

The incision should be made perpendicular to the surface of the skin to avoid devascularization and can be performed as a midline, medial or lateral parapatellar incision.

The most often used midline incision runs from 2 to 6 cm proximal the patella anteriorly towards approximately 2 cm distal and slightly medial to the tibial tubercle [2]. It is advised to perform the incision with the operated knee in a slightly flexed position. The length of the incision depends on the size and constitution of the patient and should allow a full exposure of the knee without forming skin flaps and without applying much tension onto the soft tissues. The incision is then extended deep into the extensor mechanism and the fascia. The subcutaneous tissues are divided according to the line on the skin to ensure haemostasis. Most of the cutaneous vessels arise from the medial genicular arteries. Electrocautery is used to coagulate any bleeding. Large varicose veins are tied with ligatures. Care should be taken to minimize both trauma to the soft tissue and not undermining of the skin.

The medial parapatellar incision, as an alternative, begins 6 cm proximal to the patella and is slightly curved from the patella base to the medial aspect of the knee (Fig. 25.3); the incision is then continued forward to the tibial tubercle to avoid hampering the circulation of the skin and to prevent skin necrosis. This technique does not exhibit a clinically relevant benefit [2]. A disadvantage of this incision may be the risk of transection of the infrapatellar branch of the saphenous nerve, resulting in numbness, which can limit kneeling ability and can sometimes lead to the formation of irritating or even painful neuroma [3]. The numbness usually resolves over time. Repair of the nerve is not necessary. However, the nerve end should be buried in fat to prevent a painful neuroma.

If a lateral release is necessary, undesired flap formation may be needed, leading to an increased risk of wound healing problems. The lateral parapatellar incision is performed as a mirror image of the medial parapatellar approach when performing a lateral capsule incision.

It is important to remember that the currently planned procedure may not be the final intervention, and the midline incision gives the surgeon every option without precluding further opera-

Fig. 25.3 A medial parapatellar incision was made to incorporate an existing scar in this case, and the incision was advanced to the joint capsule and extensor apparatus

tions; therefore, we recommend this incision. Cosmetically, however, a slightly curved incision is preferable and can therefore be argued for.

25.3 Arthrotomy

25.3.1 Midline Capsular Incision

With the patient's knee almost extended or flexed depending on the surgeons' preference, the midline capsular approach starts at the proximal aspect of the quadriceps tendon and runs over the medial quarter of the patella through the anterior capsule and fat pad distal to the patella, approximately 1 cm medial to the patella insertion. The joint is opened by sharply cutting through the joint capsule and the synovium.

The quadriceps expansion is sharply dissected from the medial aspect of the patella in a subperiosteal manner without directly dividing the insertion of the vastus medialis. Therefore, closure of the incision has inherent stability. This incision was originally described by Insall, with later modifications, and enables strong suture placement and secure closure at the end of the operation [4].

Theoretically, midline capsular arthrotomy minimizes disruption of the vastus medialis attachment to the patella, thereby ensuring a straight pull on the extensor mechanism.

25.3.2 Medial Parapatellar or Anteromedial Arthrotomy

This approach is also known as the classic approach, Payr approach or von Langenbeck approach and is possibly the most common method of attaining excellent exposure in TKA [5] (Fig. 25.4).

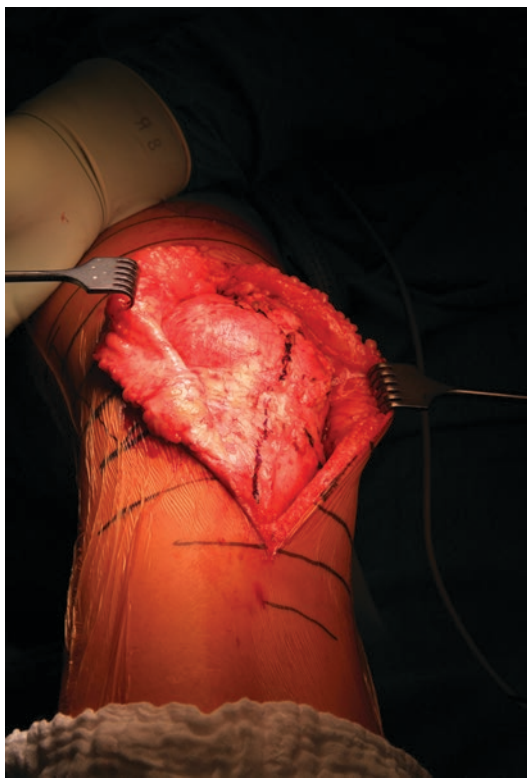

Fig. 25.4 The medial parapatellar approach will be performed. The planned arthrotomy is marked with a sterile pen and ends approximately 1 cm medial to the tibial tubercle

The arthrotomy should be 0.5 cm medial to the patella and is performed by leaving a cuff of tissue on the medial aspect of the patella rather than on the vastus medialis obliquus (VMO) muscle to prevent shortening of the ligament.

If the VMO is attenuated, it can be difficult to place sufficient sutures to close the capsule. A major disadvantage of this approach is that the insertion of the vastus medialis and the medial retinaculum into the patella is divided from the patella. Repair of the quadriceps muscle or the retinaculum can ideally restore a similar state, but the previous level of function will never be achieved.

25.3.3 Lateral Parapatellar Arthrotomy

In this approach, the arthrotomy is performed between the vastus lateralis and the rectus femoris muscle. Fixed valgus deformity presents a major challenge for TKA, especially in moderate or severe valgus cases. The literature suggests that use of the medial parapatellar approach for the correction of fixed valgus deformities leads to higher failure rates, particularly at the patellofemoral joint. In a prospective case-controlled study, Karachalios et al. found inferior clinical outcomes and increased patellar subluxation or dislocation in patients with preoperative fixed valgus deformities [6]. The lateral approach allows a direct approach to the deformities and optimal assessment for the correction of the soft tissue and bone deformities that are more challenging in the valgus knee.

The lateral parapatellar approach may also be beneficial if a preoperative lateral subluxation of the patella is obvious. Its major advantage may be that the VMO is unaffected. Nevertheless, displacing the patella medially in the flexed position can be difficult, and avulsion of the patella ligament from the tibial tubercle must be avoided.

25.4 Exposure of the Joint

To visualize the joint, the patella must be everted or retracted while the knee is flexed up to 90°. No difference in clinical outcome exists between these two techniques in terms of ligament balancing [7] (Fig. 25.5).

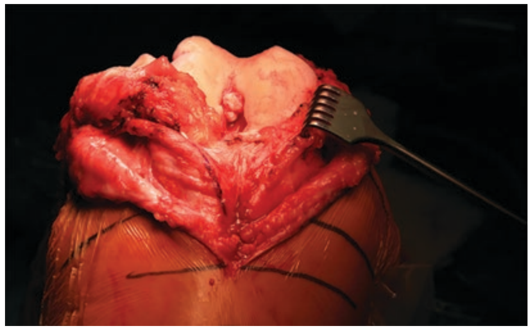

Fig. 25.5 Excellent exposure of the joint after the patella is everted and the knee is flexed in a 90° position

Removal of patellar osteophytes (especially on the lateral side) and release of the lateral retinaculum can facilitate the complete eversion of the patella, and its articular surface faces forward. If the eversion is hampered due to previous procedures such as high tibial osteotomy, in cases of revisions with scar formation, or simply in cases of patella infera, it is of paramount importance that the patella ligament is not avulsed.

In ankylosed knees, some authors recommend a second capsular incision on the proximal part of the quadriceps tendon angling 45° distally and laterally to the quadriceps tendon, vastus lateralis and upper portion of the iliotibial tract. This procedure was called quadricepsplasty by Coones and Adams and was modified by Scott in 1985 [8].

In fixed knees, we prefer the distal release by osteotomy of the tibial tubercle, although a possible risk exists of compromising the vascular supply of the extensor mechanism. During this procedure, one should remain aware that the central peg of the tibial component of the knee arthroplasty can make reattachment of the bone block with cannulated screws challenging. The tibial tubercle must be of sufficient bone quality and thickness, or the procedure must be performed as a tibial crest osteotomy to properly reattach the tibial tubercle and foster bony reintegration.

To expose the medial joint adequately, subperiosteal release of the medial capsule and the deep layer of the medial collateral ligament is

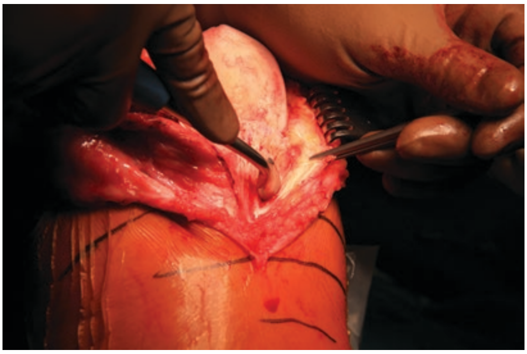

Fig. 25.6 The deep layer of the medial collateral ligament is released using a slightly curved rasp and can be extended as required for proper ligament balancing

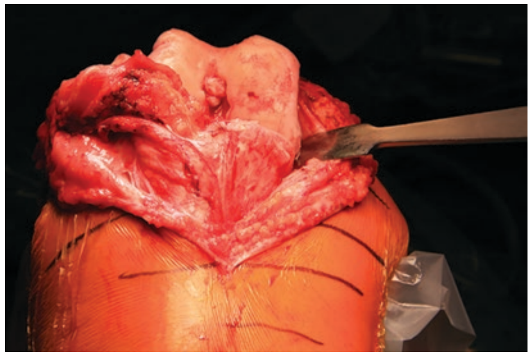

Fig. 25.7 Medial Hohmann retractors are introduced after release of the collateral ligament. Remnants of the anterior cruciate ligaments in the femoral notch can be seen

performed utilizing electrocautery or a slightly curved rasp (Fig. 25.6). The release is facilitated by externally rotating the leg and is forwarded until the midcoronal equator line or even the posteromedial rim of the tibial plateau. The amount of medial collateral ligament release can be adjusted as required for ligament balancing. Overlapping medial osteophytes must be removed with a nibbler prior to this procedure, as they might significantly increase tension on the medial collateral ligament.

The next step is to remove lateral parts of Hoffa's fat pad to obtain better access to the lateral compartment. The fat pad is retracted or excised as dictated by the need for exposure. Some surgeons radically remove fat pad tissue for better visualization, although others argue that proprioception may be impeded without the infrapatellar fat pad [9].

The anterior cruciate ligament is removed, and the notch, which is sometimes surrounded by osteophytes, is enlarged using straight or curved chisels. At this point, the knee is further flexed, which is easily performed using a standard or automatic leg holder. The lateral capsule can be released with an electrocauter.

After these steps, Hohmann retractors can easily be placed medially and laterally, and a blunt retractor is easily placed posteriorly (Fig. 25.7). By introducing a blunt retractor behind the tibial plateau and advancing it against the femoral condyle, the tibial plateau can be shifted forward, and the potential risk of dissecting the popliteal artery with the tibial osteotomy can be minimized.

25.5 Tissue-Sparing Arthrotomies

Tissue-sparing arthrotomies are based on the theoretical assumption that reducing the surgical incision and soft tissue damage will result in a better aesthetic and surgical outcome as well as in terms of pain and functional recovery. The following approaches are proposed to avoid violation of the extensor mechanism [10].

25.5.1 Subvastus Approach

The approach was introduced by Erkes in 1929 and was modified by Bechtol and Hofmann [11].

After blunt dissection with the finger or scissors, the vastus medialis is lifted. The deeper layer of the dissection can be safely extended by the finger. When the medial border of the vastus medialis is palpable, the finger is pointed against the medial femur under the muscle. The relatively thin capsule is visible, and the arthrotomy is then performed 10 cm proximally to the adductor tubercle, enabling an exposure comparable to standard incisions. Reduced blood loss and postoperative pain and faster recovery of quadriceps strength are possible advantages [12, 13]. Advocates of this approach claim that it is more anatomical than medial parapatellar arthrotomy. Complications include haematoma formation under the VMO and excessive stretching of the fibres of the VMO during displacement of the patella, rendering the approach unsuitable for obese or very muscular patients or for patients with stiff knees with excessive varus deformity. It is also not recommended for revision surgery. The approach is suitable for all types of arthroplasty except lateral unicompartmental arthroplasty.

25.5.2 Midvastus Approach

The midvastus approach was first described by Engh et al. in 1997 and differs from the standard parapatellar approach and the subvastus approach in that it involves opening an interval in the midsubstance of the vastus medialis muscle [14]. The stabilizing role of an undamaged extensor mechanism above the patella is preserved by the vastus medialis, which inserts into the quadriceps tendon. The VMO must be exposed, and the fascia and muscle fibres are cut in the vector direction of the muscle. The full thickness of the muscle is opened over a distance of 4–5 cm, ending at the superomedial corner of the patella. The point where the vastus medialis inserts into the superomedial border of the patella is a safe location for a muscle-splitting incision.

Most of the VMO is preserved, including the proportion attached to the patella. Sparing of the extensor mechanism with faster recovery of the quadriceps muscle strength and greater patellofemoral stability are the advantages of this approach [14]. A reduction of the need for lateral release has been evaluated in a prospective study; the researchers found a 3% prevalence of lateral release in the midvastus group versus a 50% prevalence in the standard group [15]. However, other studies have not reported this possible advantage [16].

A quadriceps or rectus cut can improve exposure. Obesity is not a contraindication to the midvastus approach, which also provides sufficient surgical exposure for varus and valgus knee deformities.

A major disadvantage is the potential denervation of the VMO, which has been evaluated using electromyography (EMG). Although EMG abnormalities were transient, this should be considered and can be important during patient rehabilitation under the premise of rapid recovery with early strengthening of the quadriceps function [17].

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26 Is There an Optimal TKA Component Position?

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Abbreviations

aMA	Adjusted Mechanical Alignment
CR	Cruciate Retaining
FAA	Femoral Anatomical Axis
TAA	Tibial Anatomical Axis
FMA	Femoral Mechanical Axis
HKA	Hip-Knee-Ankle angle
KA	Kinematical Alignment
PS	Posterior Stabilized
rKA	restricted Kinematical Alignment
sTEA	surgical Transepicondylar Axis
TKA	Total Knee Arthroplasty
TMA	Tibial Mechanical Axis
TTA	TransTibial Axis

Keynotes

1. Despite great advancements in the understanding of knee kinematics, the essential question about the optimal TKA alignment remains controversial.
2. The quest for the optimal TKA alignment is focusing on three aspects: the forces distribution around the knee joint, the functional outcomes, and the survival of the implants. Current literature suggests contradictory answers to each one of these questions.
3. The current alignment strategies can be broadly divided into systematic (classical mechanical and anatomical alignment), hybrid (restricted kinematic alignment, adjusted mechanical alignment), or patient specific (kinematic alignment) techniques.
4. The main target of the classical mechanical alignment strategy is to restore neutral weight bearing lower leg axis (HKA of 180°), while creating joint line which is perpendicular to this axis (FMA and TMA of 90°).
5. The adjusted mechanical alignment (aMA) aims to preserve a mild to moderate coronal deformity of ±3°. Only severe valgus or varus (HKA <177° or HKA >183°) are attenuated.

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6. The main target of the anatomical alignment is to anatomically recreate a joint line orientation of 2°–3° varus (in order to restore the mean native joint line orientation: FMA of 93° and TMA of 87°).
7. In kinematically aligned (KA) TKA the femoral and tibial components are positioned in order to restore the patient's three-dimensional pre-arthritic limb kinematics regardless of the definite coronal alignment.
8. The restricted kinematic alignment (rKA) restricts the indication for KA TKA by creating safe zones (HKA >177° or HKA <183°, FMA 90°–95°, TMA 85°–90°). If a knee is outside this envelope, bone adjustments are performed in order to have it in the aforementioned safe zones.
9. The role of individualized alignment methods is still under ongoing debate.
10. Current acceptable coronal mechanical alignment goals: femoral component of 0°–7° valgus, tibial component of 0°.
11. Current acceptable sagittal mechanical alignment goals: 0°–3° flexion of the femoral component; posterior tibial slope of 0°–3° for posterior stabilized TKA and 5–7° for cruciate retaining TKA.
12. Current acceptable rotational alignment goals: 0°–5° femoral component external rotation (relative to sTEA) and 0°–5° tibial component external rotation (relative to TTA).

26.1 Introduction

Alignment of total knee arthroplasty (TKA) is considered as one of the key factors for outcome but still is an unsolved issue of modern TKA. Despite great advancements in the understanding of knee kinematics and the emergence of new prosthetic designs, the essential question about the optimal TKA alignment remains controversial [1–4].

Answering the question whether there is an optimal alignment can be focused on three different levels. Firstly, is there a biomechanical rationale of forces distribution which can be demonstrated in cadaveric or laboratory studies. Secondly, what is the evidence regarding the functional outcomes and postoperative pain in the short-, mid-, and long-term. Thirdly, what is the evidence regarding survival of the implants, the time to failure, and the necessity for revision surgery. The paradox and complexity of modern TKA alignment might lead to a different or even contradictory answer to each one of these questions.

Basically, there are three different alignment strategies: the mechanical alignment, the anatomical alignment, and the kinematical alignment. Based on these approaches the goals of the tibial and femoral component position differ. The mechanical and anatomical alignments use a systematic approach by positioning the femoral and tibial component according the same standard, regardless of the individual native anatomy. In contrast, the kinematic alignment mimics the natural individual limb and joint line alignment.

The mechanical alignment is the most commonly used method and aims to restore a neutral HKA by creating joint lines that are perpendicular to their mechanical axis (FMA and TMA of 90°). An adaption of the conventional mechanical alignment is the adjusted mechanical alignment (aMA) technique. Only severe coronal deformities (HKA > 177 or HKA > 183) are attenuated. Mild to moderate deformities (HKA of 180° ± 3) are preserved by adjustments only on the position of the femoral component. However, the tibia is always mechanically aligned (TMA of 90°).

Restoring a neutral mechanical lower leg alignment (HKA of 180°) has been for long time the gold standard for TKA alignment and still is [5–8]. When neutral mechanical alignment is restored, the load is evenly distributed within the joint and hence considered as one of the most important factors for implant survival by most surgeons [3]. Recently, several reports found little or no correlation between postoperative mechanical malalignment and TKA survivorship or knee function [1, 9–12]. Consequently, it was speculated whether using the mechanical target in all knees may cause ligament unbalance explaining the considerable high rate of unhappy TKA [4, 13–15]. The discussion about modern TKA alignment strategies is a hot topic and not solved yet [2, 3, 5] (Fig. 26.1).

The main goal of the anatomical TKA alignment strategy is to anatomically recreate the native joint line orientation of the distal femur (FMA of 93°) and the proximal tibia (87°) [16].

The kinematic alignment (KA) aims to restore the native patient-specific pre-arthritic limb (HKA) and joint alignment (FMA and TMA). The bone cuts are performed to restore the pre-arthritic alignment regardless of the extreme values [17]. An adaption of the KA is the restricted kinematical alignment (rKA). The rKA restricts the indication for KA TKA by creating safe zones (HKA > 177° or HKA < 183°, FMA 90°–95°, TMA 85°–90°). If a knee is outside this envelope, bone adjustments are performed in order to bring them into the aforementioned safe zones.

Kinematic alignment is more patient-specific technique striving to restore the individual variable native pre-arthritic limb and joint line alignments [18]. In contrast to the mechanical and anatomical alignment, in kinematically aligned TKA the femoral and tibial components are positioned in order to restore to the patient's three-dimensional natural alignment [14, 18].

However, the role of those alignment methods is still under ongoing debate. Despite promising preliminary results of the patient-specific strategy, the mechanical alignment is still considered as the gold standard in TKA.3D-reconstructed CT scans including slices of the hip joint, the knee, and the ankle joint are considered as gold standard for evaluating the component position. Malposition can occur in the coronal (valgus, varus), sagittal (flexion, extension), and axial (external rotation, and internal rotation) plane. Only 3D imaging modalities are able to measure the component position appropriately in all planes.

This chapter aims to give an overview about optimal mechanical TKA position in coronal, sagittal, and rotational plane (Table 26.1).

Table 26.1 References for measuring the TKA position in the coronal, sagittal, and axial plane in 3D-reconstructed CT scans

Axis	References
Femur coronal alignment	Mechanical axis of the femur
Tibial coronal alignment	Mechanical axis of the tibia
Femur sagittal alignment	Mechanical axis of the femur
Posterior tibial slope	Mechanical axis of the tibia
Femur rotational alignment	sTEA
Tibial rotational alignment	TTA

sTEA Surgical transepicondylar axis, *TTA* Transtibial axis

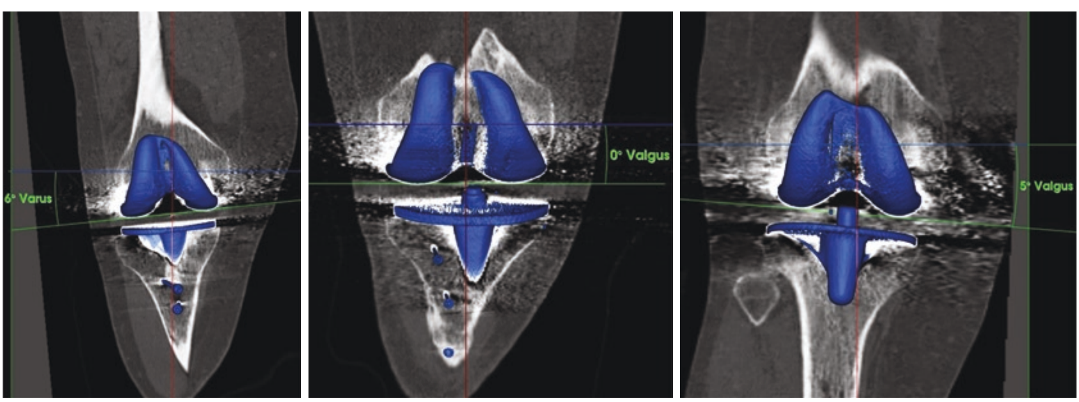

Fig. 26.1 Femoral component in 6° of varus (**a**), neutral position (**b**), and 5° of valgus (**c**)

The current evidence for mechanical alignment is reviewed and presented in detail.

26.2 What Is the Evidence?

26.2.1 Optimal Coronal TKA Alignment

The coronal position of the femur is measured as the angle between the mechanical axis of the femur and a tangent of the distal femoral prosthesis (≙FMA). The coronal position of the tibia is measured as the angle between the mechanical axis of the tibia and the tibial plateau (≙TMA). The acceptable goal for the femur is 0°–7° valgus and for the tibia 3° varus-3° valgus (Fig. 26.2).

Components outside this envelope can result in an implant femur, bone collapse, or increased wear of the polyethylene.

26.2.1.1 Coronal Alignment of Femoral Component

The cut of the distal femur is aimed to be performed perpendicular to the mechanical axis of the femur (FMA = 90°). However, in TKA only the anatomical axis of the femur is visible during surgery and therefor used as a reference intraoperatively. The hip-knee-shaft angle (HKS angle) between the anatomical and mechanical axes of the femur is measured preoperatively as an approximation. Intraoperatively, the same angle (HKS) is cut based on an intramedullary rod representing the anatomical axis of the femur.

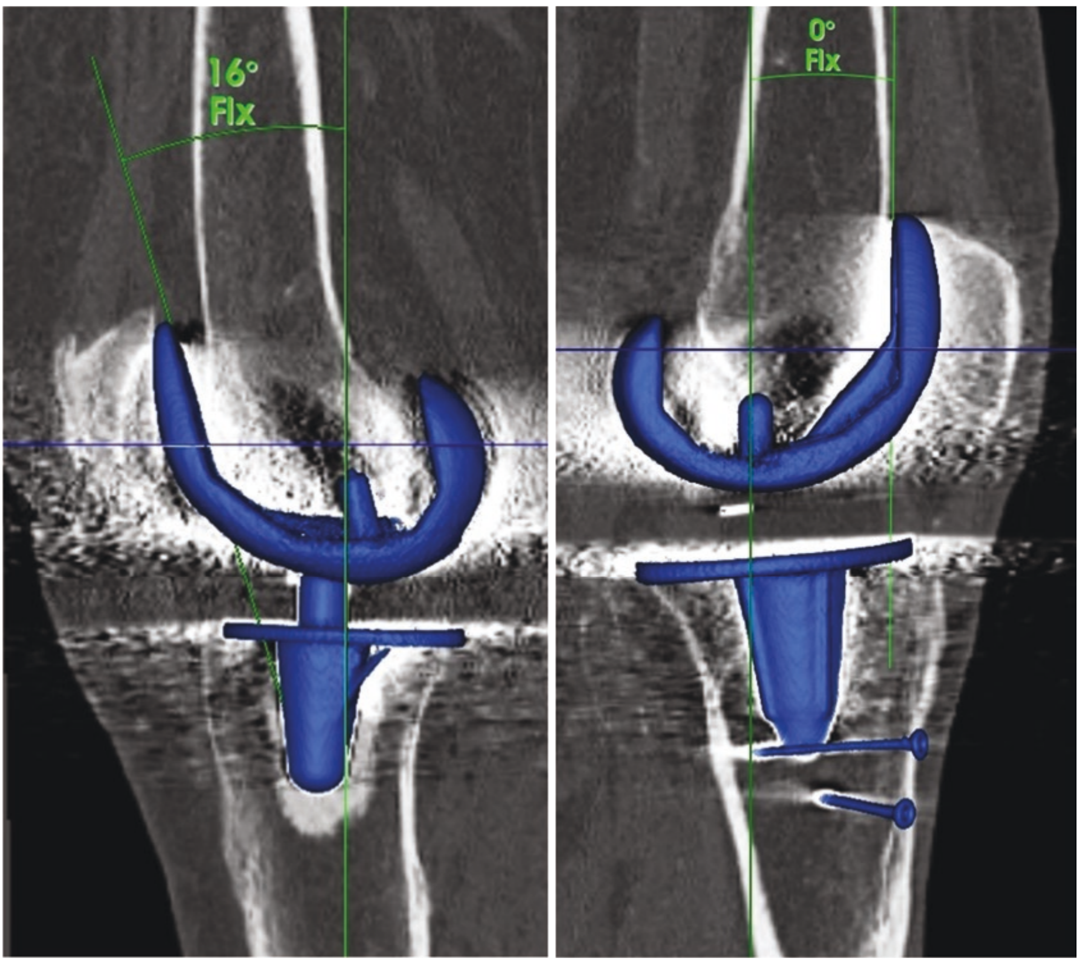

Fig. 26.2 Femoral component in severe flexion (16°) (**a**) and without malposition (**b**)

Several studies have evaluated the relationship between the survival of the knee arthroplasty and postoperative coronal alignment. Kim et al. [19] reviewed 3048 knees with a mean follow-up of 15.8 years and found that the failure rate was 0.7% in knees with neutrally aligned femurs compared to a 1.7% in femoral valgus alignment >8° and 5% in <2° valgus alignment. Likewise, Ritter et al. [20] reviewed 6070 TKA and showed that a femoral component alignment of >8° of valgus resulted in a 3.6% failure rate, five times higher than neutral femoral alignment (Fig. 26.3).

With regard to functional outcomes the current evidence is more variable and less clear. In a systematic review by Hadi et al. [21] six studies found no association between femoral coronal malalignment and inferior outcome measures compared to two studies which showed that coronal malalignment was associated with inferior outcome.

26.2.1.2 Coronal Alignment of Tibial Component

In mechanical alignment the proximal tibial cut should be perpendicular to the mechanical tibial axis (TMA = 90°). Although the anatomical and mechanical axes can be identical in some patients, they can differ widely in others. Therefor it is important to measure the mechanical axis of the tibia.

Historically, inferior results were reported for varus malaligned tibial components. Investigating 3152 TKAs Berend et al. [22] reported that varus tibial component alignment of more than 3° was associated with an increased failure rate due to medial bone collapse, component subsidence and tibial loosening.

Kim et al. [19] reported that the revision rate was 3.4% in TKA with tibial varus malalignment (tibial alignment of less than 90°) whereas no TKAs were revised in neutrally aligned tibial components.

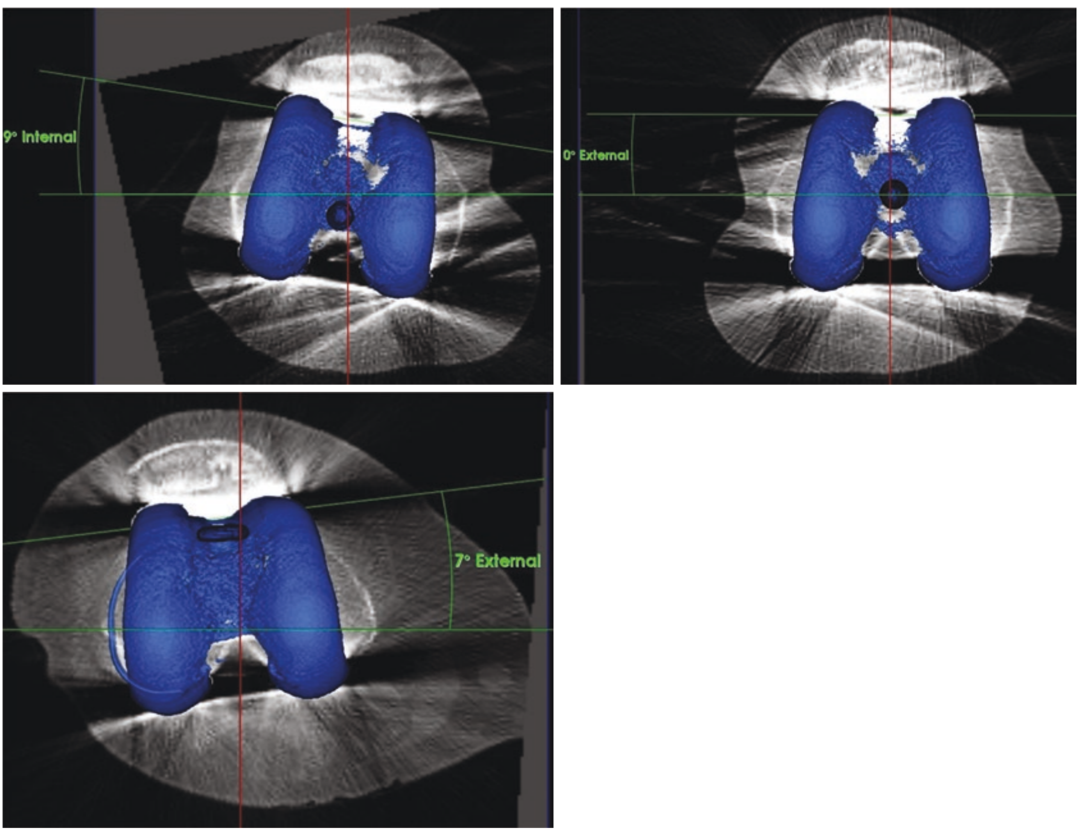

Fig. 26.3 Femoral component in internal rotation (9°) (**a**), neutral (**b**), and (**c**) external rotation (0°)

Similar results were found by Ritter et al. [20]. They reported that tibial alignment of less than 90° was associated with a 3.8% failure rate in comparison to 0.2% in neutrally aligned tibial components.

However, the current evidence with regard to functional outcome is less clear. Dossett et al. [14] compared kinematically aligned TKAs with mechanically aligned TKAs in an RCT of 82 patients. They found that the angle of the tibial component was a mean of 2.3° more varus than the mechanically aligned group and that at 6 months postoperatively, the mean WOMAC Index score was 16 points better, the mean Oxford Knee Score was seven points better, the mean combined Knee Society Score was 25 points better, and the mean range of flexion was 5.0° greater in the kinematically aligned group (Fig. 26.4).

In the systematic review already mentioned above by Hadi et al. [21] no association was found between tibial coronal malalignment and inferior outcome measures in eight studies compared to only one study which showed that malalignment was associated with inferior outcome.

26.2.2 Optimal Sagittal TKA Alignment

The sagittal position of the femur is measured as the angle between the mechanical axis of the femur and the tangent of the posterior aspect of the anterior femoral component. The sagittal position of the tibia (tibial slope) is measured as the angle between the tibial plateau and a line perpendicular to the mechanical axis of the tibia.

The most acceptable goal is to achieve a posterior slope of 0°–3° for posterior stabilized (PS) TKA and 5–7° for cruciate retaining (CR) TKA. This cut has a significant influence on force distribution of the tibial plateau, flexion stability, and postoperative flexion (Fig. 26.5).

Excessive hyperextension of the femoral component may lead to notching at the anterior femoral cortex, which might increase the risk of a supracondylar fracture. Excessive flexion of the femoral component might lead to patella baja and patellofemoral overloading as well as tightness in flexion.

A tibial slope outside the acceptable goals can lead to flexion gap tightness and instability. In posterior-stabilized (PS) femoral components it might lead to impingement of the femoral cam on the tibial post, resulting in increased wear and potential early loosening [23].

26.2.2.1 Sagittal Alignment of Femoral Component

Lustig et al. [24] found that posterior sagittal alignment of greater than 3.5° from the mechanical axis was shown to increase the relative risk of a mild flexion contracture by 2.9 times. Kim et al. [19] found that the failure rate was 0% in knees with neutral (0°–3°) sagittal alignment of the femoral component compared to 3.3% in femoral

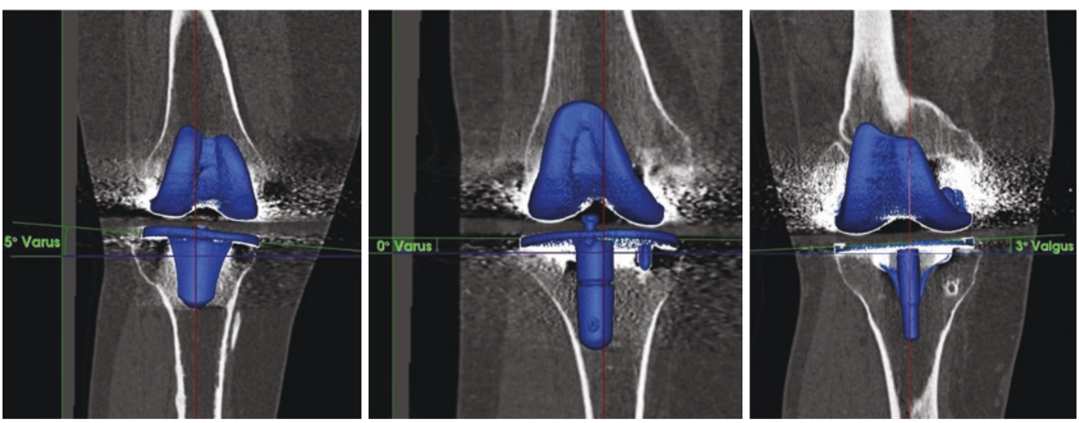

Fig. 26.4 Tibial component in 5° varus (**a**), neutral (**b**), and 3° valgus (**c**)

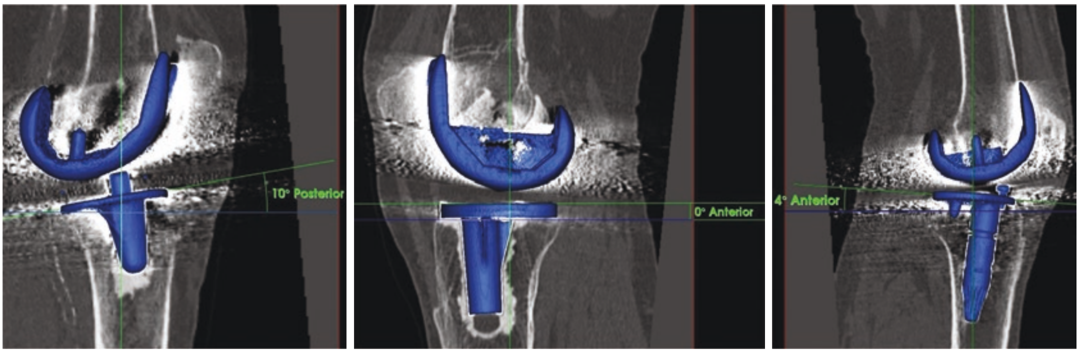

Fig. 26.5 Tibial component showing an increased posterior slope (10°) (**a**), in neutral position (**b**), and showing an increased anterior slope (4°) (**c**)

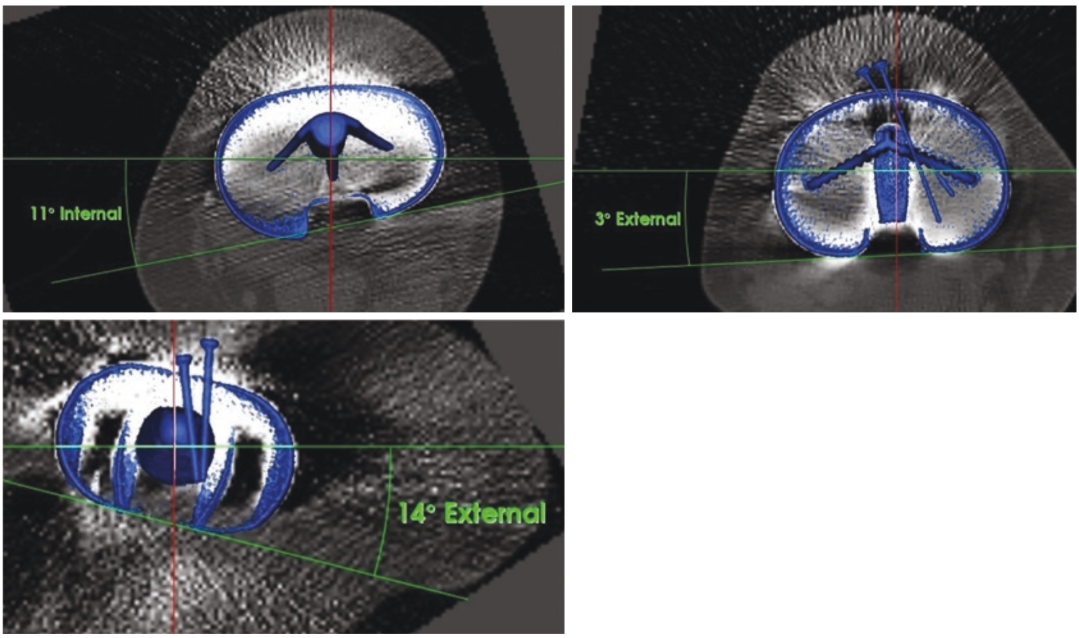

Fig. 26.6 Tibial component in internal rotation (11°) (**a**), within the acceptable goal (3° external rotation) (**b**), and in 14° external rotation (**c**)

sagittal alignment greater than 3° flexion and 0.9% in sagittal alignment greater than 1° extension. In a systematic review Hadi et al. [21] found no association between sagittal femoral malalignment and inferior outcome in all included studies (Fig. 26.6).

26.2.2.2 Sagittal Alignment of Tibial Component

Increasing the tibial slope in CR TKA improves maximal flexion before tibial insert impingement occurs against the femoral bone. In a cadaveric study by Bellemans et al. [25], an average of 1.7° flexion was gained for every degree extra of tibial slope between 0° and 7°. Despite the basic science studies and the intuitive presumption that decreased flexion would be the result of TKA with decreased posterior slope of the tibial component, most published clinical studies have failed to show an effect of tibial slope on maximal flexion [25]. Kansara et al. [26] found no significant differences between 0° or 5° posterior tibial slope with regard to postoperative flexion or improvement of Hospital for Special Surgery (HSS) score.

In contrast to CR-TKA, the flexion gap rarely becomes tight with a PS TKA. Ken et al. found that the influence of changing the tibial slope by 5° on the flexion gap was 2 mm with CR-TKA and 1 mm with PS-TKA [27].

With regard to implants' survival, Kim et al. found that the failure rate was 0.2% in knees with neutrally aligned tibial slope compared to a 4.5% in tibial slope of less than 0° or greater than 7° [19]. However, no association between sagittal tibial malalignment and inferior outcome was found in a systematic review by Hadi et al. [21].

26.2.3 Optimal Rotational TKA Alignment

The rotational axis (axial plane) of the femur is measured as the angle between the posterior condylar angle and the surgical transepicondylar axis (sTEA).

The rotational axis of the tibia is measured as the angle between the transtibial axis (TTA) and a line connecting the most posterior parts of the tibial component.

Optimal rotational alignment of femoral component makes a compromise for patellar tracking as well as flexion gap stability. In the average knee the posterior condylar axis is 3° internally rotated toward the transepicondylar axis. Therefore, one aims for 3° of external rotation of the femoral component with regard to the posterior condylar axis [28]. However, anatomy is very variable and hence rotations need to be adapted to the individual knee. Varus knees tend to have external rotation, whereas valgus knees have often more internally rotated femur.

Rotational malalignment of the femoral component might lead to instability due to an asymmetric, unbalanced flexion gap, and patellar maltracking. Although both internal and external malrotation are associated with inferior results, the overall goal is to avoid internal rotation which strongly correlates with pain and synovitis due to the lateral direction of the patellar tracking.

26.2.3.1 Rotational Alignment of Femoral Component

Although the technical optimal femoral component rotation reference has been debated for many years and few different methods for determining the proper femoral component rotation are still been used abundantly, there is general agreement that internal rotation should be avoided. Cadaveric studies have shown that optimal patella tracking is achieved when the femoral component is in a neutral position [29]. Regarding postoperative anterior knee pain, Bell [30] and Murakami [31] showed that an internally rotated femoral component (>0.3° or >0 internally rotated in relation to sTEA) was a significant factor in patellofemoral pain following TKA [30]. Evidence regarding the negative effect of excessive external rotation can be found in the cadaveric study by Miller et al. [32] as increasing tibiofemoral wear motion and worsening of patellar tracking were found with excessive femoral external rotation. Regarding the survival, Kim et al. found that the failure rate was 0% in knees with neutrally (2°–5°) external rotation of the femur compared to a 6.7% in femoral axial alignment less than 2° and 1.9% in excessive external rotation (>5°) [19]. Regarding patient reported outcomes, in the systematic review by Hadi et al. [21] only 50% of studies found an association between femoral rotational malalignment and worse PROMs.

26.2.3.2 Rotational Alignment of Tibial Component

In a similar fashion to the femoral component rotational alignment, there is a debate regarding the best reference intraoperative method of determining tibial component rotation. In particular the question is whether the alignment should be performed relatively to bony landmarks (e.g., the tibial tubercle (the junction of the medial and central thirds of the tubercle as an anatomical landmark)) or whether the tibial component is rotated into alignment following the femoral component during extension. Moreover, it was noted that using a combination of landmarks may improve both positioning and outcome [33]. Internal rotation of the tibial component by >9° (in relation to neutral TTA) was a major cause of pain and functional deficit following TKA in one study performed by Nicoll et al. [34]. In the same study, external rotational errors were not found to be associated with pain. Barrack et al. [35] found a significant effect of internal rotation of the tibial component (>6°) when comparing painful to well-functioning knee arthroplasties, and Bell et al. [30] found that greater than 5.8° of internal rotation (in relation to neutral TTA) was a substantial factor for pain following TKA, respectively. Regarding the survival, Kim et al. found that the failure rate was 0.04% in knees with 2°–5° external rotation of the tibia compared to a 6.5% in tibial external rotation alignment less than 2° and 1.4% in excessive external rotation (>5°) [19]. Regarding patient reported outcomes, in the systematic review by Hadi et al. [21] only 50% of studies found an association between femoral rotational malalignment and worse PROMs.

Take Home Message
TKA alignment is considered as one of the key factors for outcome and still an unsolved issue. The complexity is mainly based on the contradictory in the literature between the optimal alignment to ensure equally forces distribution around the joint. The optimal alignment that provides maximum prosthesis survival together with best functional and pain free results has not been defined yet. As the role of the more "individualized" (kinematic) alignment strategies is still on debate, despite promising preliminary results, mechanical lower leg alignment is still the gold standard and the optimal mechanical TKA position in coronal, sagittal, and rotational plane should be used as the reference for the routine TKA alignment (Table 26.2).

Table 26.2 Goals of TKA position in mechanically aligned TKA

Axis	Acceptable goal	Possible disadvantages of outliers
Femur coronal alignment	0°–7° valgus	Implant failure
Tibial coronal alignment	3° valgus to 3° varus	Medial bone collapse Increase wear Implant failure
Femur sagittal alignment	0°–3° flexion	Increase flexion contracture Supracondylar fracture Implant failure
Posterior tibial slope	0°–7° slope	Flexion gap tightness/contracture Instability Implant failure
Femur rotational alignment	3° internal rotation–6°external rotation	Increasing the Q angle, patellar subluxation Abnormally stress on the patellar implant Anterior knee pain Implant failure
Tibial rotational alignment	0°–7° external rotation	Patellar tracking complicationsAnterior knee pain Decrease ROM Implant failure

FAA Femoral anatomical axis, *TAA* tibial anatomical axis, *sTEA* surgical transepicondylar axis, *TTA* transtibial axis

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27 Neutral Mechanical Alignment: The Gold Standard

Daniel Kendoff, Federico Calabro, Amihai Rozentsveig, and Nemandra Amir Sandiford

Keynotes
1. Achievement of a neutral mechanical axis remains the 'gold standard' in total knee arthroplasty (TKA).
2. The current literature suggests that neutral mechanical alignment is associated with improved survivorship.
3. It is likely that optimal clinical results are multifactorial and potentially related to patient factors, surgery related factors, coronal, sagittal and rotational alignment and possibly implant-related factors.

27.1 Introduction

Restoration of neutral mechanical alignment is traditionally considered as an important factor with respect to the durability and function of a total knee arthroplasty (TKA) (Fig. 27.1) [1, 2]. When neutral mechanical alignment is restored, the weight-bearing axis of the lower limb passes from the centre of the hip through the centre of the knee and through the centre of the ankle [3]. In fact, this results in symmetric mediolateral load distribution and minimizes risk for implant wear and component loosening (Fig. 27.1). This concept was popularized by John Insall in the 1970s from the Hospital for Special Surgery in New York [4].

Several techniques have been described to obtain intraoperative restoration of mechanical alignment including intramedullary or extramedullary alignment rods, sophisticated computerized navigation methods and patient-specific instrumentation (PSI). These technological advances could potentially improve TKA component positioning; however, they also result in additional costs and inventory in the operating theatre. Furthermore, their use is associated with a considerable learning curve [5, 6].

Side Summary
- Restoration of neutral mechanical alignment is considered the gold standard in total knee arthroplasty.
- The postoperative alignment influences wear and durability of the TKA prosthesis.

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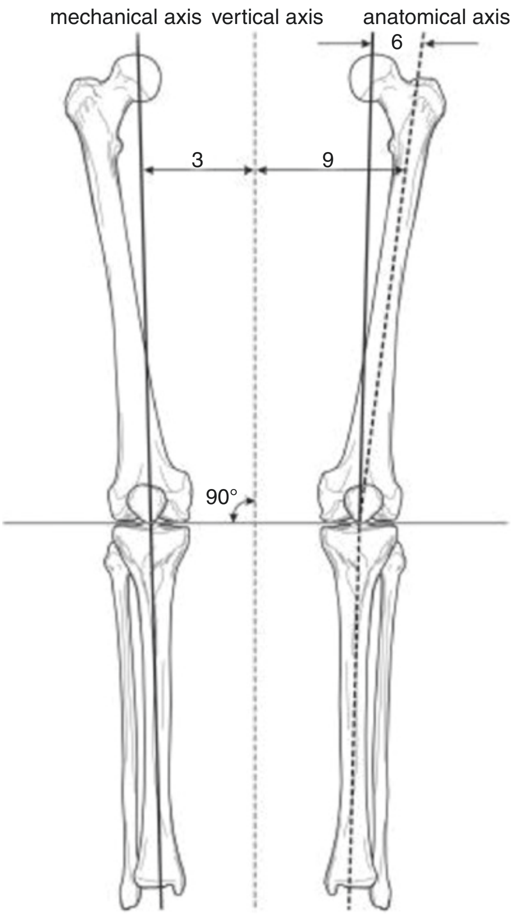

Fig. 27.1 Alignment of the distal femoral resection guide, while orientation is performed through an intramedullary guide

27.2 The Current Evidence for Restoration of Mechanical Alignment (Table 27.1)

The survival rate of TKA increases if lower limb alignment is restored within 3° of valgus or varus with regard to the mechanical axis [1, 16]. Malpositioning of a TKA can lead to early wear and loosening as well as suboptimal functional performance and reduced implant survivorship [17]. The evidence base for this value is not robust, however. It is likely that any deviation from neutral will reduce longevity by an amount which is proportional to the malalignment [18]. Jeffrey et al. demonstrated that restoring the mechanical axis of the lower extremity through the centre of the knee resulted in improved TKA survivorship [17]. More recently, the effects of malalignment of the tibial tray on bone and polyethylene have been examined. For instance, a patient-specific finite element analysis performed by Perillo-Marconeet et al. [19, 20], which adjusted for relative bone density, showed that varus and valgus angulation of the tibial tray resulted in increased loading of the medial and lateral tibial condyles, respectively. They found the presence of higher bone density in the medial tibial condyle and they concluded that there was a greater risk of tibial component overload in cases with valgus malpositioning of the tibial component due to increased loading of the relatively weaker lateral tibia. Collier et al. [15] reported a significantly greater loss of thickness of polyethylene in the medial compartment influenced mainly by the shelf age of the polyethylene, the age of the patient and when the limb was aligned in >5° of varus (in gamma-irradiated-in-air polyethylene, $P < 0.05$).

Hai-Xiao Liu et al. [21] reviewed over 12,000 knees and found a higher rate of failure and revision if the tibial component was placed in more than 3° of varus when compared to cases in which neutral alignment was obtained post operatively. However, they found a paucity of evidence correlating valgus alignment of the tibial component with survivorship of the TKA [22]. Wong et al. demonstrated that shear forces in the proximal tibiae of knees in which the tibial component was inserted in varus exceeded the fatigue threshold of bone by using finite element analysis techniques in fresh frozen cadaveric specimens. Their findings were the first to suggest the possibility of fatigue failure of the bone as an independent mode of failure of TKA [17, 23]. Liau et al. [15] found that polyethylene wear was minimal when a high conformity curve-on-curve knee design was used. They also found that the rotational line between the femoral and tibial components has the least effect on polyethylene wear, but varus/valgus malalignment led to

Table 27.1 The results of neutral mechanical alignment in TKA

	Year	Number of patients	Type of study	Outcome measures	Results	*P* value
Fang [7]	2009	6070	Retrospective	Failure/revision rate by alignment in degrees	The best survival was found for alignment between 2.4° and 7.2° valgus. 6.9 times higher risk of failure in varus outlier knees	<0.0001
Choong [8]	2009	115	PRCT	Mechanically aligned knees performed conventionally vs computer assisted	Superior KSS and SF-12 physical scores at 6 weeks, 3, 6 and 12 months after TKA	<0.046
Bonner [9]	2011	501	Retrospective	Aligned 0–3° Varus outliers >3°	Implant survival was not significantly higher in the aligned group	<0.47
Parratte [10]	2009	398	Retrospective	Aligned 0–3° Varus outliers >3°	A post-operative mechanical axis of 0° (SD 3°) did not improve the rate of survival 15 years post-operatively	
Longstaff [11]	2009	159	Retrospective	"Good" 0–2° "Bad" >2°	Improved KSS scores in the "good" group	<0.15
Ritter [12]	2011	6070	Retrospective	Overall tibiofemoral alignment and alignment of the tibial and the femoral component in the coronal plane	Failure was least Likely to occur if both the tibial and the femoral component were in a neutral orientation 90° and <8° of valgus, respectively	<0.0001
Lutzner [13]	2013	67	PRCT: CONV vs CAS	In terms of KSS score	No difference at 5 years in the alignment between the 2 techniques. No statistical difference in survivorship or function	0.048
Mahoney [14]	2016	1030	A 1:9 matched case-control analysis.	Aseptic loosening	Knees in more than 3° of varus had a significantly higher rate of loosening.	0.0035
Collier [15]	2007	81 UKA 89 TKA	Retrieval	Quantified polyethylene loss	A limb that was aligned in 5° more varus increase polyethylene loss by 0.11 to 0.14 mm/year	<0.05

TKA Total Knee Arthroplasty, *UKA* Unicompartmental Knee Arthroplasty, *PRCT* Prospective Randomized Controlled Trial, *KSS* Knee Society Score, *CONV* Conventional, *CAS* Computer Assisted Surgery

accelerated wear even with the best designed prostheses.

D'Lima et al. also noted condylar lift-off as a risk factor for increased stress [23].

The studies presented above are just some few out of many in the literature, suggesting that factors which contribute to survivorship are not limited to the coronal plane alignment of TKA but include bone quality, implant design, conformity and positioning [10, 23].

Side Summary

- Malposition is defined as more than 3° varus or valgus in one TKA component.
- Malpositioning of a TKA can lead to early wear and loosening as well as suboptimal functional performance.
- Malpositioning can lead to early failure.
- Other factors which influence polyethylene wear are shelf age, gamma irradiation in air and when the limb was aligned in >5° of varus.

27.3 Mechanical Alignment

The mechanical axis of the lower limb is a line drawn from the centre of the femoral head to the centre of the ankle joint and passes through the knee just medial to the tibial spine. The mechanical axis does not correspond to the vertical axis (a common cause of confusion), but generally makes an angle of 3° with the vertical axis; however, this can vary subtly depending on the height of an individual and the width of the pelvis [16].

Achievement of a mechanically aligned TKA relies on restoring the hip–knee–ankle angle of the limb to neutral or as close to a straight line as possible [24, 25]. This principle is based on studies that suggest limb and knee alignment is related to long-term survival and wear. The mechanical alignment is the most commonly used method to restore lower limb orientation in the coronal plane in TKA. It is a reproducible technique and requires little extra inventory in the operating theatre [3, 24].

An initial distal femoral cut is made which is perpendicular to the mechanical axis of the femur. The tibial resection must likewise be perpendicular to the mechanical axis of the tibia. Final intraoperative confirmation of overall tibial alignment is verified using a long rod through the centre of a handle on the trial tibial component. When this rod is aligned with the centre of the hip and the centre of the ankle, it should pass through the centre of the knee in the coronal plane, recreating the mechanical axis of the lower limb. The result is a knee that is aligned at 4°–5° valgus in general but may be varied according to patient's height and limb morphology. The purpose of this alignment is to create an even load distribution on the new joint line. Insall noted that if the knee joint aligned using the anatomical axes of the femur and tibia, the tibial component may be loaded asymmetrically with a fixation failure of the medial tibial plateau [26]. He also popularized femoral component positioning at 3° of external rotation in order to balance flexion and extension gaps.

Mechanical alignment is still considered the "gold standard" in TKA. Fang et al. [7] reviewed 6070 consecutive primary TKAs in 3992 patients performed between 1983 and 2006. They reported a 6.9 times increased risk of failure by medial tibial collapse in varus knees compared to those that were mechanically aligned ($P = 0.0001$). They further concluded that outliers in overall alignment have a higher rate of revision than well aligned knees. Choong et al. [8] performed a randomized controlled trial comparing the alignment, function and patient quality-of-life outcomes between patients undergoing conventional (CONV) and computer-assisted (CAS) knee arthroplasty. They found that patients with coronal alignment within 3° of neutral had superior International Knee Society and Short-Form 12 physical scores at 6 weeks, 3 months, 6 months and 12 months after surgery. Ritter et al. [12] concluded that attaining neutrality in all three planes is important in maximizing total knee implant survival. "Correction" of one component in order to compensate for another component malalignment is also associated with increased odds of failure.

Side Summary

- The mechanical axis of the lower limb is represented by a line passing from the centre of the femoral head to the centre of the ankle. This line should pass through the centre of the knee in the coronal plane.
- The mechanical axis generally makes an angle of 3° with the vertical plane.
- Positioning of the femoral component at 3° of external rotation results in balancing of the flexion and gap.

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The Anatomical Alignment Concept for Total Knee Arthroplasty

28

Silvan Hess, Hagen Hommel, and Michael T. Hirschmann

Keynotes

1. The mechanical total knee arthroplasty (TKA) alignment concept simplifies the biomechanics of the knee to maximise durability which inevitably impacts functionality and patient's satisfaction rate.
2. Hungerford and Krackow presented the anatomical TKA (AA) alignment concept with the goal to improve functionality by closer mimicking the native alignment.
3. In coronal plane the goal is still a neutral aligned limb, but the joint lines are orientated oblique to the mechanical axis to reflect the native joint line orientation.
4. The femur is cut in 3° valgus to the mechanical axis (FMA = 93°) and the tibia in 3° varus to the mechanical axis (TMA = 87°).
5. The goal for the sagittal alignment is neutral for the femur (perpendicular to the femoral mechanical axis) and depends on the used implant type for the tibia.
6. The goal for the rotational alignment is neutral and therefore the posterior femoral cut is placed parallel to the PCA.
7. A randomized controlled trial found no difference in clinical and radiological outcome measurements between the mechanical alignment concept and anatomical alignment concept.

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28.1 Basics for a Better Understanding

Historically, the goal for the lower limb alignment after total knee arthroplasty (TKA) was driven by the desire to maximize durability. Therefore, a mechanically neutral aligned lower limb (hip-knee-ankle angle (HKA) = 180° ± 3)

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with joint lines perpendicular to the mechanical axis was defined as the gold standard [1]. This decision was supported by basic science studies, which confirmed increased stress in the medial compartment and increased wear of polyethylene in knees with varus alignment or tibial varus position. This mechanical TKA alignment (MA) concept resulted in good-long term implant survivorship and a relatively high patient's satisfaction rate.

However, the MA concept simplifies the biomechanics of the knee to maximise durability which inevitably impacts functionality and patient's satisfaction rate. Thus, already in the 1980s, Hungerford and Krackow presented the anatomical TKA (AA) alignment concept with the goal to improve functionality by closer mimicking the native alignment [2]. The goal of the AA for the overall alignment is still neutral but the joint lines are orientated oblique to the mechanical axis to reflect the native joint line orientation (3° femoral valgus and 3° tibial varus). Two biomechanical studies found better load distribution on the tibial component, better patellar kinematics and reduced risk for lateral ligament stretching with this joint line obliquity [3, 4]. Despite these potential advantages, the widespread use of the concept was prevented by concerns regarding the risk of excessive (>3°) varus alignment of the limb and/or tibial implant positioning. Both have been associated with early loosening and failure. Today, these concerns have been overcome by precision tools for implant positioning (navigation system and robotic technology) as well as TKA implant incorporating a 3° joint line obliquity allowing a perpendicular tibial cut.

More recently, Howell and colleagues introduced the kinematic TKA alignment concept which aims even to closer resemble the native knee by trying to restore the pre-arthritic alignment of each individual patient [5]. Thereby any form of postoperative lower limb alignment and joint line orientation is accepted.

28.2 Coronal Alignment

The coronal alignment goal of the MA concept is a neutrally aligned lower limb (HKA = 180° ± 3) with joint lines perpendicular to the mechanical axis (femoral mechanical angle (FMA) = 90° ± 3, tibial mechanical angle (TMA) = 90° ± 3). Figure 28.1 shows the orientation of the cuts in the coronal plane with the knee in extension.

The coronal alignment goal of the AA concept is a neutrally aligned lower limb (HKA = 180° ± 3) with a joint line obliquity of 3°. Therefore, the femur is cut in 3° valgus to the mechanical axis (FMA = 93°) and the tibia in 3° varus to the mechanical axis (TMA = 87°). However, a tibial joint line obliquity of 3° can also be achieved by combing a neutral cut (TMA = 90°) with an 3° oblique prosthesis inly. Figure 28.2 shows the orientation of the cuts in the coronal plane in extension.

28.3 Sagittal Alignment

The sagittal alignment goal is the same for the MA and the AA concept. The femoral joint line is placed perpendicular to the femoral mechanical axis. The goal for the orientation of the tibial joint line depends on the used implant type: In posterior cruciate retaining TKA (CR) the aim is to restore the native posterior slope which is generally between 5° and 7°. In posterior cruciate substituting TKA (PS) the aim is a posterior slope of 0°–3° to compensate for the sacrificed posterior cruciate ligament.

28.4 Rotational Alignment

The rotational alignment goal is the same for the MA and AA concept. However, the cuts have to be orientated differently to prevent rotation dur-

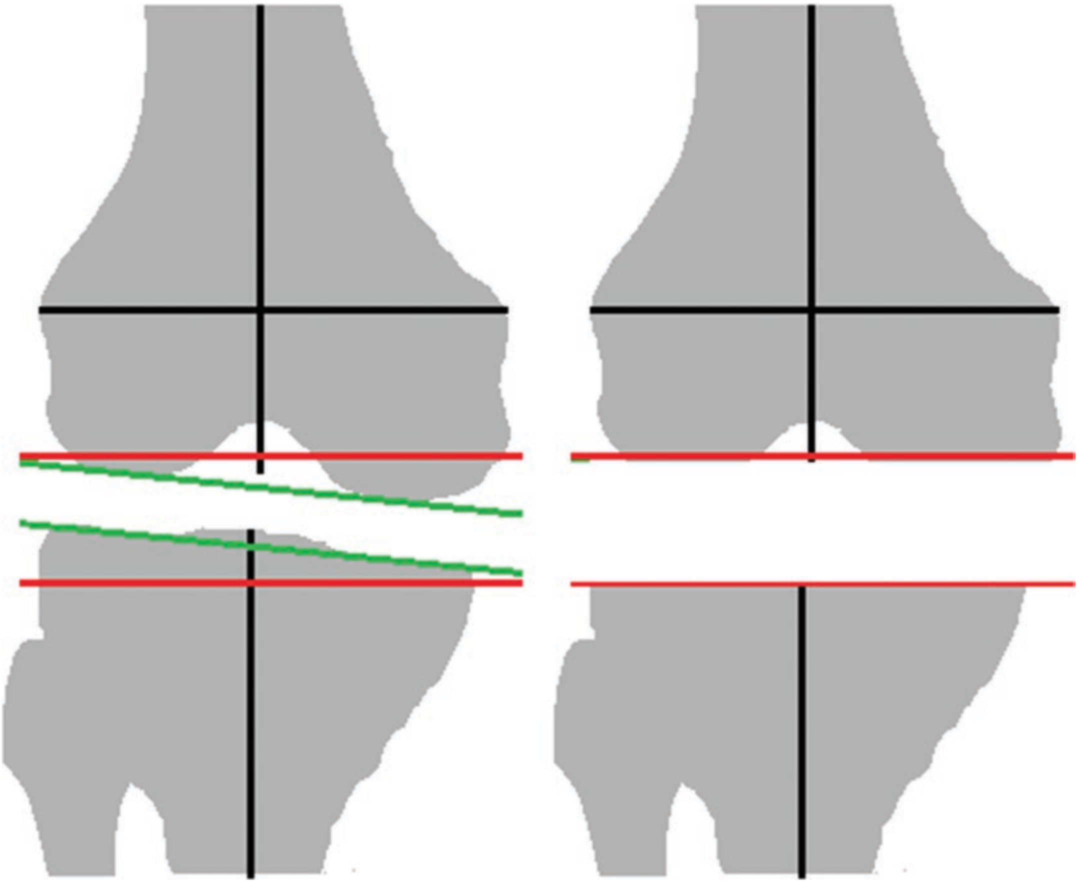

Fig. 28.1 Knee in extension. The mechanical axes in black, the joint lines in green and the cuts in red. The MA concept places the distal femoral cut and the tibial cut are perpendicular to the mechanical axis

ing flexion. The posterior condylar axis is in mean physiologically 3° internally rotated to the epicondylar axis (to match the 3° tibial varus). As the tibia is cut neutrally in the MA concept, the posterior femoral cut must be 3° external rotated to the posterior condyle axis (parallel to the epicondylar line or perpendicular to the Whiteside's line) to match the new tibial joint line (Fig. 28.3). In the AA concept, the tibial joint line is still in 3° varus and the posterior femoral cut therefore has to be placed parallel to the PCA (in 3° internally rotation to the epicondylar axis) (Fig. 28.4).

28.5 Clinical Outcome Anatomical Alignment Versus Mechanical Alignment

There is only one randomized controlled trial comparing the outcome of patients with an anatomical aligned TKA with the outcome of patients with a mechanical aligned TKA [6]. The clinical outcome measurements included varus and valgus laxities, ROM, HSS and WOMAC scores. Yim et al. followed the patients for a minimum of 2 years and found no significant differences in any of the clinical parameters. They

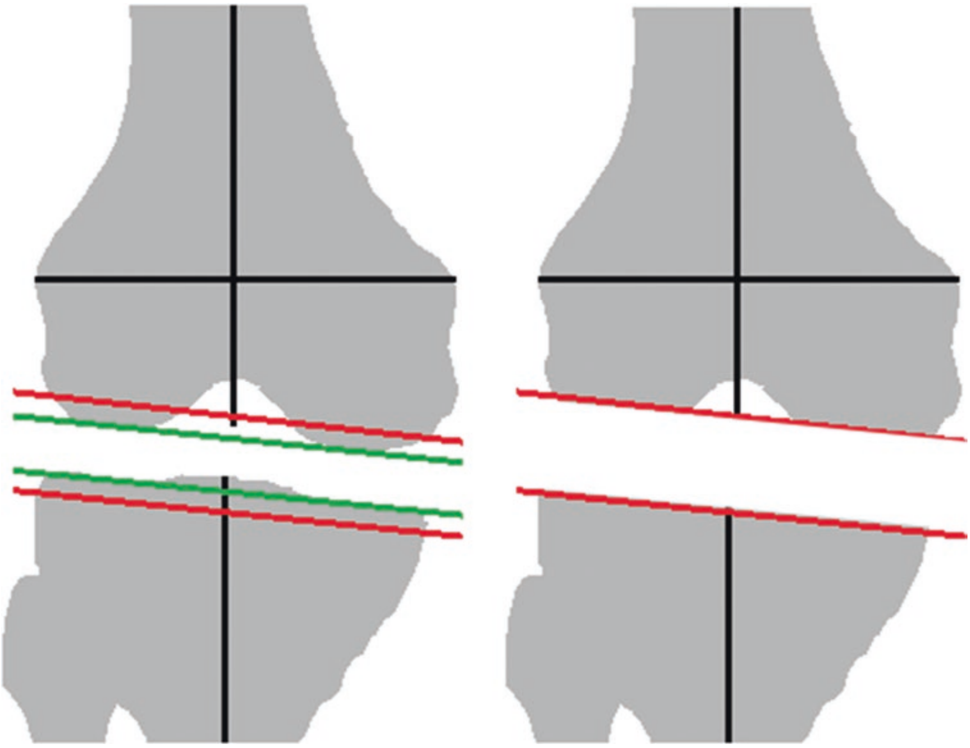

Fig. 28.2 Knee in extension. The mechanical axes in black, the joint lines in green and the cuts in red. The AA concept places the distal femoral cut and the tibial cut in 3° varus/valgus to the mechanical axis (parallel to the native joint line)

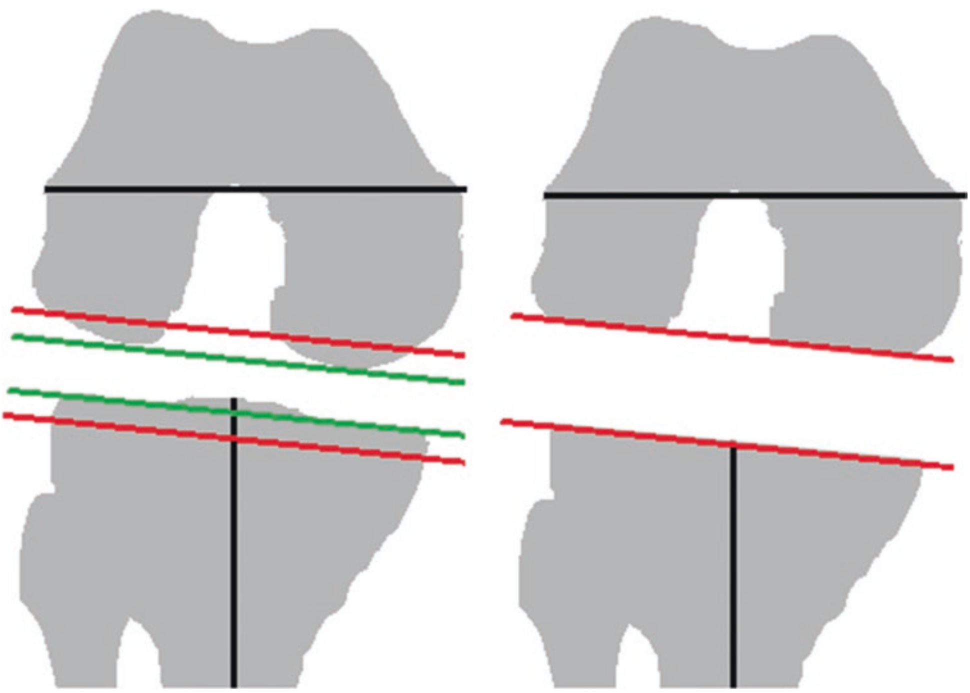

Fig. 28.3 Knee in flexion. The mechanical axes in black, the joint lines in green and the cuts in red. The MA concept places the posterior femoral cut parallel to transepicondylar axis

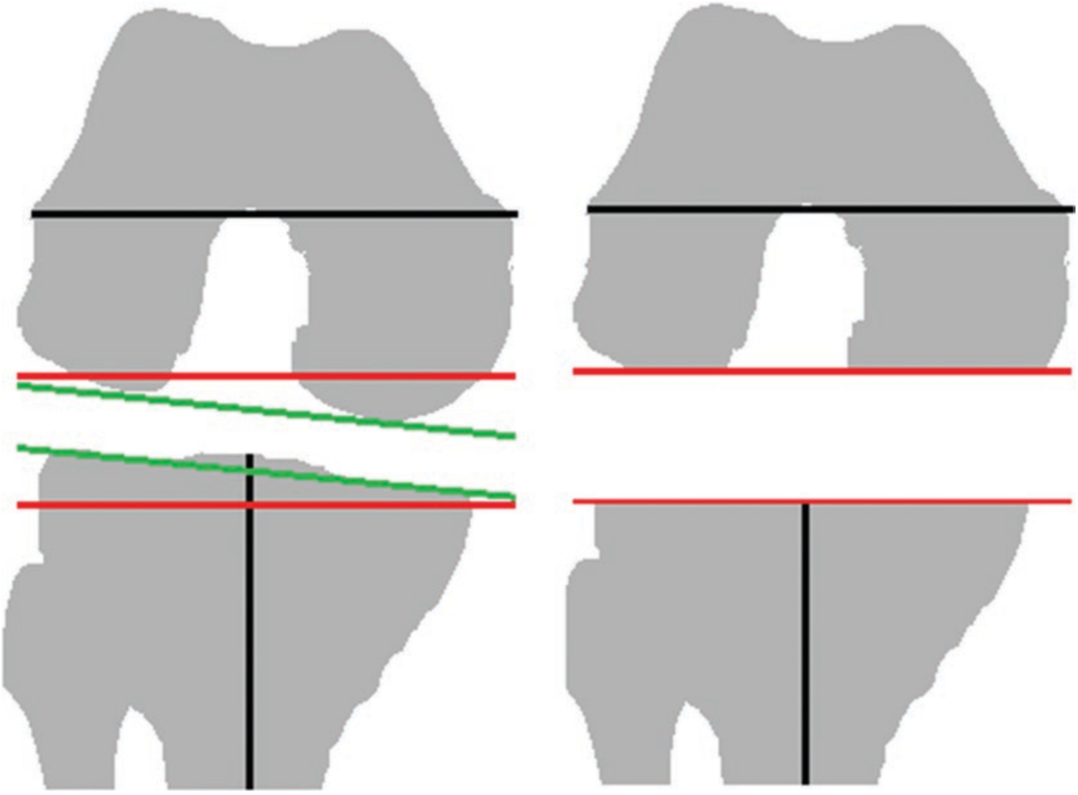

Fig. 28.4 Knee in flexion. The mechanical axes in black, the joint lines in green and the cuts in red. The AA concept places the posterior femoral cut parallel to posterior condylar line

additionally assessed radiological outcomes and did not find any differences either. Hence, they concluded that that the two alignment methods provide comparable clinical and radiological outcomes after primary TKA.

Take Home Message

The coronal alignment goal of the AA concept is a neutrally aligned lower limb (HKA = 180° ± 3) with a joint line obliquity of 3° to the mechanical axis (FMA 93°, TMA 87°). The goals for the sagittal and rotational alignment are the same for the MA and the AA concept. However, the posterior femoral cut must be placed differently in the two concepts to achieve a symmetrical gap in both. A randomized controlled trial found no difference in clinical and radiological outcome measurements between the MA concept and AA concept.

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29 Kinematic Alignment in Total Knee Arthroplasty

T. Callies, M. Ettinger, and H. Windhagen

Keynotes

1. The concept of kinematic alignment is to restore the constitutional anatomy and the physiological joint line orientation of the knee in TKA.
2. Three kinematic axis are defined in order to describe femorotibial and patellofemoral kinematics.
3. Kinematic alignment aims to reconstruct the pre-arthritic femoral surface with the femoral component in the first place, and thus co-aligns the prosthesis to said kinematic axes.
4. The tibia orientation follows the femur to produce a symmetric and stable extension gap.
5. The flexion gap typically reconstructs the physiological lateral laxity of the knee and remains trapezoidal.
6. In surgery, the key is to estimate cartilage wear and to compensate for it.
7. Several verifications checks are performed during surgery to have a safe and reproducible technique.
8. Kinematic alignment is a “no release” technique for TKA, restoring the physiological soft tissue orientation and tension.
9. Key is a meticulous resection of the osteophytes to restore natural ligament length.
10. The today’s evidence base shows patient reported outcome and complications that are at least as good as with mechanical alignment.

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29.1 Introduction

Traditionally, there is a consensus that the best compromise is to position both the tibial and femoral components perpendicular to the mechanical axis of each bone, aligning the overall limb to neutral [1]. This is in the belief that a mechanical alignment (MA) optimizes load distribution and thus minimizes implant failure. However, this neutral limb alignment is not physiological to most of the people with the average population having a mild constitutional varus and an oblique joint line [2, 3]. Correcting these deformities to neutral means to adapt the soft tis-

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sue envelop with the risk of instability and paradoxical kinematics, which is referred to be one major reason for revision surgery. Based on these limitations, more and more surgeons postulate the idea of a more natural knee alignment in TKA restoring the constitutional anatomy [4]. It is supposed that this will improve soft tissue balance, reduce the need for ligament releases, reproduce more natural kinematics, and enhance functional outcome.

This chapter discusses the concept of kinematic alignment (KA) as an alternative alignment. Theoretical aspects, surgical techniques, and today's clinical evidence are discussed.

29.2 Kinematic Alignment

Kinematic alignment (KA) means that the TKA implants are positioned according to the pre-arthritic anatomy of each individual patient and to co-align the prosthesis to the natural kinematic axes of the knee. Therewith an individual restoration of the three-dimensional anatomy appears possible with said advantages of improved stability throughout the whole ROM (especially physiological medial compartment isometry) with none, or less releases.

29.2.1 Biomechanical Rational for Kinematic Alignment

The biomechanical rationale for KA is based on classic models on the kinematics of the unloaded knee motion initially published by Hollister and coworkers [5] and later verified by others [6]. In this model three kinematic axes are defined governing the movement of the tibia and the patella with respect to the femur.

The first axis is the **primary flexion-and-extension axis** for the tibia. The axis runs through the distal femoral condyles. Based on the idea of a single radius axis between 10° and 110° degrees of flexion it is geometrically defined by the axis of a cylinder aligned to the articular surface of the distal and dorsal condyle (Fig. 29.1a).

The second axis runs perpendicular to the first axis and is for **internal and external rotation** of the tibia (Fig. 29.1b). Though, the actual position of the tibia rotation axis is dynamic throughout the movement cycle. This is necessary in order to

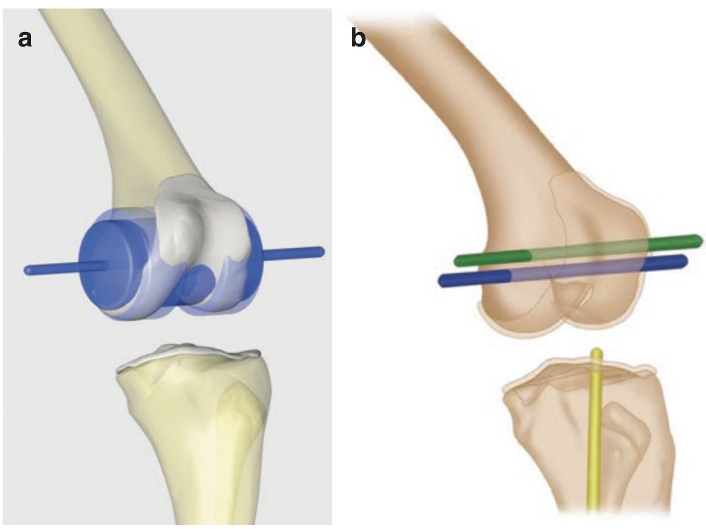

Fig. 29.1 (**a**) The primary kinematic axis of the knee about which the tibia flexes and extends is geometrically defined by the axis of a cylinder aligned to the articular surface of the distal and dorsal condyle. (**b**) Schematic representation of the three movement axes of the knee joint according to Hollister et al. Blue is the primary axis about which the tibia flexes and extends. Green is the flexion axis of the patella, and yellow represents the tibia rotation axis. All three axes have a defined orientation to each other

realize the femoral rollback and tibial pivoting. This theoretical model is in line with several biomechanical in vivo investigations showing that the position of this tibial rotation axis is depending on different motor tasks and loading conditions [7, 8].

The **third kinematic axis** describes the patellofemoral motion. The patella rotates around this axis (Fig. 29.1b). It has again a static position within the femur. In the ideal kinematic model of the knee with no patellofemoral or condyle dysplasia this axis is defined to be parallel to the primary femur axis and located anterior and proximal to it. As the knee is a force fit joint, meaning that there is always a contact between the tibia and the femur the knee motion is defined by the femoral surface anatomy and guided by the soft tissue. In particular, the rollback of the femur and the rotation kinematics are driven by the soft tissue envelop.

29.2.2 Concept of Kinematic Alignment

The concept of kinematic alignment is to restore the constitutional anatomy and the physiological joint line orientation in TKA. Based on the kinematic model, the key is to restore the articular surface of the joint with the prosthetic components and especially the distal and dorsal shapes of femur. Thereby, the flexion radius of the femoral prosthetic component is co-aligned to the physiological primary flexion-extension axis of the knee enabling the restoration of the isometric stability of the medial compartment. The trochlea radius is automatically co-aligned to the patella-rotation axis as it is parallel. Furthermore, orientating the tibia component with respect to the femur (parallel) also restores the perpendicular tibia rotation axis. As outlined, it is suggested that this will improve soft tissue function and balance, reduce the need for ligament releases, and reproduce a more natural kinematics of the joint following TKA.

Compared to the traditional thinking in TKA one new dimension of this concept is that the pre-arthritic joint surface of the individual patient is the reference and not the osteoarthritic situation that is present in surgery. Thus, the key in this concept is to estimate the wear, to calculate the pre-arthritic situation, and to restore it with the prosthetic components as close as possible.

Side Summary
Kinematic alignment (KA) means that the TKA implants are positioned according to the pre-arthritic anatomy of each individual patient and to co-align the prosthesis to the natural kinematic axes of the knee. Key is to restore the articular surface of the joint with the prosthetic components, especially the distal and dorsal shapes of femur. It is suggested that this will improve soft tissue function and balance, reduce the need for ligament releases, and reproduce a more natural kinematics of the joint following TKA.

29.3 Surgical Technique

29.3.1 Tibia First Vs. Femur First Technique for KA TKA

As already outlined, different surgical techniques were introduced to achieve a more individual alignment in TKA. This leads to a general discussion about tibia first or femur first concepts. The major advantage of a tibia first technique is that the varus-valgus orientation of the tibia component is clearly defined, which might play a role in the medicolegal discussion of a tibia vara (see below).

However, the **tibia first** technique also has major drawbacks with respect to the introduced concept of KA.

Firstly, typically the osteoarthritic wear is more likely to be on the tibial side representing bone abrasion in many cases. This makes a reliable reconstruction of the physiological joint line surface more difficult than on the femur. Additionally, the natural mediolateral asymmetry of the proximal tibia and the variability of the tibial cartilage thickness and menisci are aggravating that problem.

Secondly, one of the worst understood parameters in TKA in general, but especially in KA TKA, is the tibial slope and its influence on knee kinematics. In a tibia first concept this has to be set right away and later adaptations are not that easily possible, because the femur is build up on the tibia. Thirdly, every error made on the tibial cut is transferred to the femur. Thus, the surface of the femur is not reconstructed and the kinematic axes of the knee are not met. Fourthly, the flexion gap in the physiological knee is not symmetric but usually presenting a lateral laxity [9]. Thus, aligning the femoral rotation by the use of a flexion-gap-balancing technique means to externally rotate the femur to its natural alignment. Also, the extensor apparatus is of unpredictable influence to the flexion gap balancing [10].

Side Summary
A tibia first technique has major drawbacks with respect to the introduced concept of KA: Pre-arthritic joint line and the physiological slope are hard to estimate in worn knees. Later corrections or adaptions are not possible, as the femur is built up on the tibia cut. Errors result in malalignment of the components to the kinematic axes on the femur. Flexion gap is unreliable for balancing as it is trapezoidal.

Starting with the **femur first**, it is easier and more reliable to reproduce the natural joint surface and to meet the kinematic axis of the knee [11]. From here the tibia follows the femur orientation. Parameters like the tibial slope can be stepwise adapted to the joint stability and rollback.

The only two major drawbacks in this technique are: Firstly, the tibial joint line orientation is defined by the femur and thus can result outside the currently accepted range of a tibia vara in individual cases. And secondly, with the use of a standard prosthetic design adaptions to the individual anatomy are to be made even on the femur. These changes can potentially lead to a compensatory malorientation of the tibia. However, this problem can be foreseen in a preoperative planning and result in an exclusion of the patient as discussed more in detail below.

In summary, with the currently available surgical techniques the femur first concept seems to be favorable to follow true KA in TKA. Possibly, if minor corrections or compromises are to be made (see indication KA), a combined technique adapting the femur on a defined tibia cut is an interesting alternative.

Side Summary
The femur first concept seems to be favorable to follow true KA in TKA. It is easier and more reliable to reproduce the natural joint surface of the femur and thus to meet the kinematic axis of the knee. Parameters like the tibial slope can be stepwise adapted to the joint stability and rollback.

29.3.2 Manual Surgical Technique: Femur First

As outlined, the primary goal in KA TKA is to reproduce the physiological joint line surface of the distal and posterior femur in the first place. This means to follow a true measured resection technique so that exactly that amount of bone and cartilage is resected that is replaced by the implant thickness. The key issue is to take the wear that is present into account aiming for the pre-arthritic surface and to compensate for it during surgery. There are a lot in vitro and in vivo data available about the average cartilage thickness and typical wear patterns [11, 12]. In varus osteoarthritis wear is mostly located at the distal femur, whereas in valgus arthritis more in the posterior aspect. Additionally, the elasticity of the cartilage and meniscus by about 20–25% of the volume has to be taken into account as the prosthetic components do not reproduce that elasticity [13, 14]. Based on this data, 2 mm have been established as a good average estimation for complete cartilage wear. On the femoral side bony wear is rare, but could add another 1 mm to the algorithm. If in doubt, this can be visualized on preoperative MRI (cartilage + bone) or CT (bone wear only) scans.

During surgery the wear is compensated by the use of spacer blocks of 1–3 mm thickness adjusted to the distal or posterior reference of the instruments, respectively. The orientation of the distal cut is aligned to the physiological joint line orientation instead of the mechanical axis. The femoral rotation is aligned to the posterior condylar line at 0° external rotation. In the concept of true measured resection a strict posterior referencing for the component position and sizing is mandatory.

Thereby, already four of six degrees of freedom to position the femoral component are defined. The only two parameters left are about the mediolateral alignment of the component (which is of minor biomechanical impact), and the femoral flexion. The femoral flexion should be orientated with respect to the physiological flexion of the distal femur (distal one-fourth) as this influences patella tracking and sizing of the component [15]. To achieve that an intramedullary alignment with respect to the distal portion of the femur has been described as a reliable technique [16]. In the standard technique a 10 cm long intramedullary rod is inserted after the entrance point is identified in the anteroposterior and mediolateral direction. Usually it is positioned central over the notch, about 0.5–1 cm above. As only the femoral flexion is defined here, the mediolateral position or varus-valgus angulation is of minor interest.

The resected bone of every cut is measured using a caliper and if not appropriate adapted to the plan. When over-resection of the distal femur occurs as one example, 1 mm washers are used do compensate during the further cuts on the femur. The defect is later filled with cement. The saw blade thickness is also taken into account, so that the typically resection is about 7 mm with no wear present and 5 mm with complete cartilage abrasion (for a 8 mm component). The surgical protocol for the femur is shown in Fig. 29.2a–d.

Side Summary
In the surgical technique key is to estimate cartilage wear, approximated with 2 mm cartilage thickness, and to compensate for it. With a caliper the accurate measured resection of the distal and posterior femur is verified for each step.

The tibial cut follows the femur with the aim to produce a symmetrically balanced extension gap and an isometric balance on the medial compartment through the whole ROM. On the lateral side the physiological laxity in flexion is accepted accordingly. As the femoral surface is restored physiologically a mismatch of the flexion to the extension gap does not happen and the physiological isometry of the medial compartment can be reconstructed.

For alignment of the tibia the femoral trial component is used in the first place. After clearing all relevant osteophytes, it is placed onto the femur and the knee is brought to extension. Using spacer blocks, the wear on the tibial side and the ligament tension of the extension gap can be assessed. According to the extension gap the varus, valgus orientation of the tibia will be determined and the resection level can be set. With both cruciate ligaments still intact even the tibia rotation can be determined with respect to the femur (Fig. 29.3a,b). Furthermore, the natural femoral rollback on the medial side is visualized bringing the knee into flexion with the femoral trail in place (Fig. 29.4). This can be objectified with the caliper by measuring the tibio-femoral-offset. This rollback should be reconstructed with the prosthesis. If the later trial reduction shows a different offset and rollback, the slope could to be adapted (if excessive rollback occurs) or the prosthesis could to be changed to a posterior stabilized design (if paradoxical anterior contact point). Usually the native slope should be reduced in the first place to compensate for the loss of the anterior cruciate ligament.

Fig. 29.2 (**a**) The entry hole for intramedullary alignment rod to set the femoral flexion is central to the femoral canal. The alignment rod is introduced by approx. 10 cm. (**b**, **c**) The distal reference plate is aligned with respect to the physiological joint line orientation, so that both distal medial and lateral condyle have contact. If there is cartilage wear, it is compensated by the use of a spacer block (**c**).(**d**) Rotation alignment sizing is strict posterior referencing with 0° external rotation to posterior condylar line. Again, cartilage wear is compensated by the use of spacer blocks. (**e**) The correct resection of both distal and posterior cuts are verified with the help of a caliper. A 7 mm resection is correct for an 8 mm prosthetic component (1 mm gone due to saw blade thickness) and if no cartilage wear is present. Depending on the amount of cartilage less resecction is required

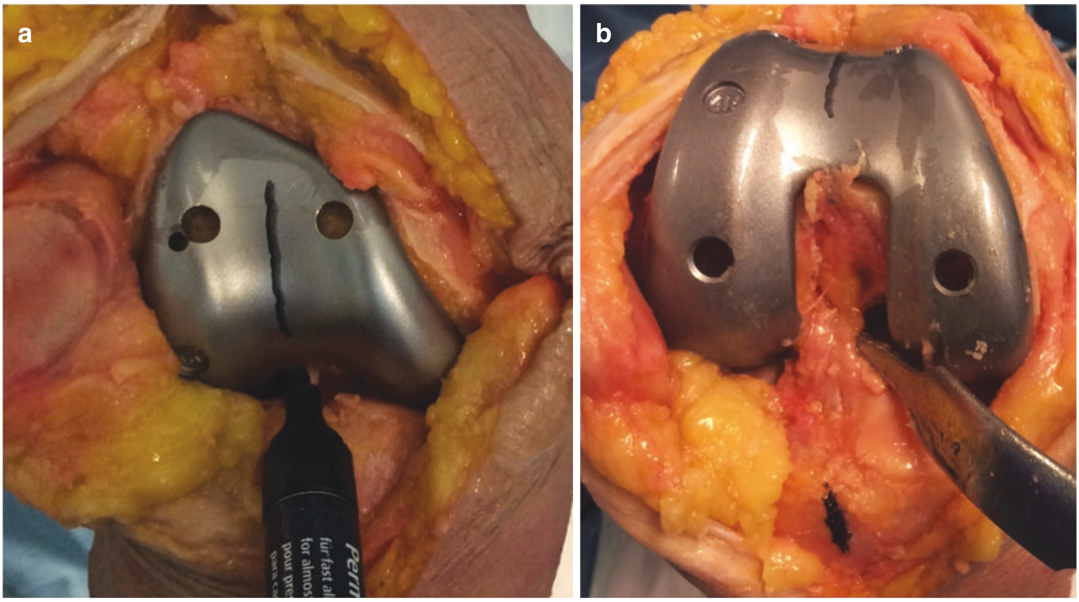

Fig. 29.3 (**a**, **b**) With the femoral trial component in place the knee is evaluated in terms of the joint stability, ROM, patella tracking, and the natural tibiofemoral rotation that is marked if patella tracking is appropriate (**a**). The most reliable technique is to maintain the anterior cruciate ligament for this step (**b**)

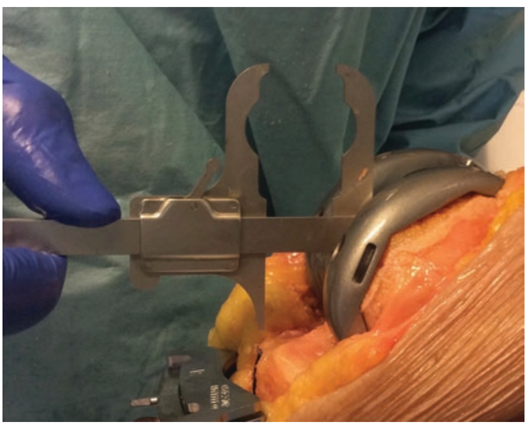

Fig. 29.4 With the femoral trial component in place the tibio-femoral-offset and medial rollback in flexion is evaluated that should be restored with the prosthesis

Based on these parameters evaluated with the femoral trail in place the tibial cut is aligned and conducted. The varus orientation can be visualized using an extramedullary alignment rod and a goniometer (Fig. 29.5). After that the joint balance and kinematics are evaluated by the use of balancers and trail components. If there is an imbalance present, the tibial cut is adapted accordingly. Distal femoral referencing plate is preferred set to a 2 mm resection level to recut the tibia. To adapt the alignment to more varus or valgus orientation, or to change the slope precisely, the angle wing is used to direct the correct plane (Fig. 29.6).

> **Side Summary**
> Tibia cut is orientated parallel to the distal femur, resulting in a perfect stable extension gap. To verify correct orientation key is to meticulously take of all osteophytes around the knee. To address any imbalances, tibia cut is adapted.

The described technique can be carried out with standard instruments for TKA.

Only a few basic conditions have to be fulfilled: (1) ability to set the femoral valgus angle independent to the intramedullary guide, (2) strict posterior referencing of the femur size and rotation, and (3) extramedullary alignment of the tibia to reassemble the varus and slope indepen-

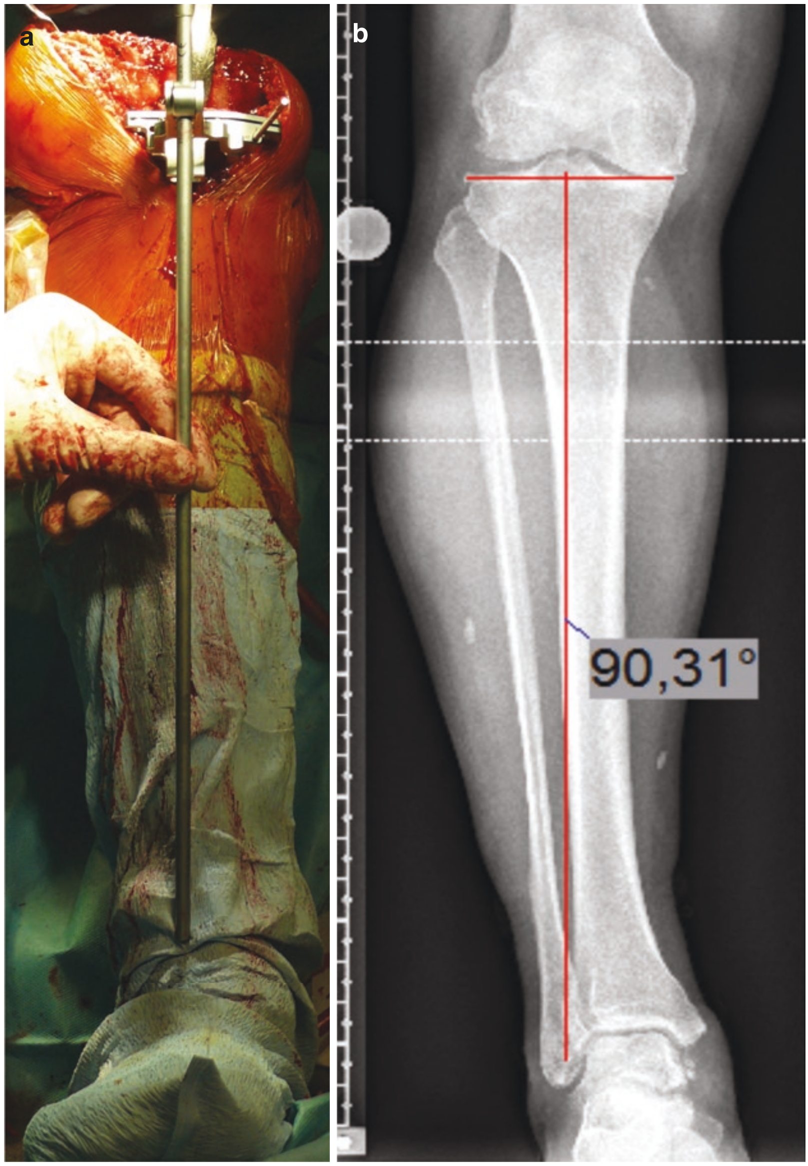

Fig. 29.5 (**a**, **b**) The extramedullary alignment rod is used to verify the tibial varus alignment (**a**). This can be compared to the preoperative planning (**b**)

dent from anatomical axis. Recently, individual companies released specially set up instruments for manual kinematic alignment. Also, first implants got CE marked and FDA approval for kinematic alignment without restrictions. The authors have developed a Femur-First-Extension-Gap-Balancer to simplify the tibia alignment parallel to the distal femur in described manual KA technique. This alternative technique is currently under further evaluation. A demo video is in the supplement of this book chapter.

29.3.3 Computer-Assisted Surgical Techniques.

As alternatives to the described manual technique several computer-assisted opportunities are to be discussed in brief.

First, there is the possibility to use patient-specific cutting guides (PSI) transporting the idea of KA into the operation theatre. As outlined below, this was the initial technique of KA TKA. The major advantage of that technique is,

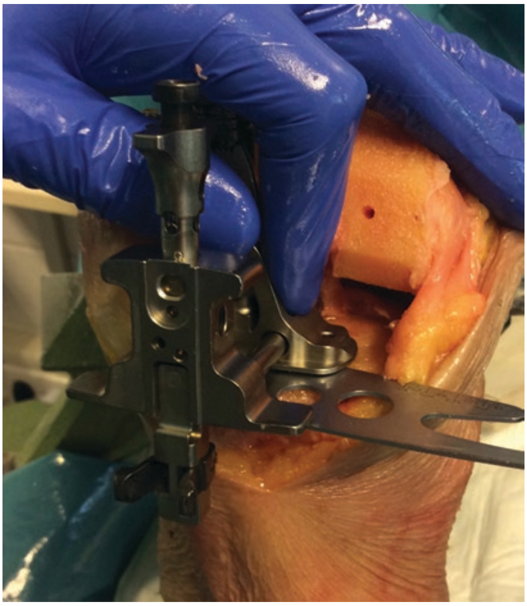

Fig. 29.6 Recuts on the tibia are directed by referencing to the present tibia cut and using the angle wing to guide the correction. In the shown example, the tibial slope is increased

that it relies on an image based, segmented three-dimensional (3D) model of the individual patient derived from MRI or CT scans. This enables to calculate the pre-arthritic situation of the knee by the use of software algorithm. Thus, a precise reconstruction of the individual anatomy and joint surface is possible by positioning the implant in this 3D model. More to this a lot of information can be obtained from the imaging and calculated prior to surgery. The resulting overall limb alignment can be displayed, the interaction between the actual joint geometry and the later prosthetic geometry can be visualized, and parameters like the optimal component flexion for example can be determined. However, the drawbacks of the technique are (1) that the process of segmentation, planning, and transferring into PSI is a new source of error that is not visible to the surgeon in every detail, (2) that the accuracy of PSI is controversially discussed in the literature [17, 18], and (3) that no soft tissue is included in the planning. This becomes a major limitation whenever compromises in the position of the prosthesis, for example, in terms of the slope, are to be made.

The second technology is computer navigation. In the concept of KA it can be perfectly used to reconstruct the femur in the first place [19]. Following the same principle than with the manual technique, again a true measured resection technique taking the wear into account is conducted. Thus, the navigation system is used to set the distal femur cut to 8 mm on the lateral and 6 mm on the medial side as an example and to do likewise with a total resection of 8 mm posteriorly. Depending on the features of the system the tibial cut is adjusted to the femur taking the soft tissue information into account or independently in an anatomical approach like with the PSI. Again, the soft tissue balance is evaluated and the tibia cut adjusted if necessary, analog to the manual technique. In comparison to the manual technique the major advantage of computer navigation supported KA is that the tibia and femur component orientation as well as the resulting overall limb alignment are displayed in real time and can be adapted if out of the accepted or desired range. Furthermore, modern navigation devices are capable of displaying the soft tissue balance over the entire range of motion that gives valuable information to position the tibia component correctly or to do minor adjustments, respectively. Up-to-date navigation technologies even allow to record the anatomy and the soft tissue balance at the beginning of the surgery and to virtually position the prosthesis with respect to the soft tissue balance before any bone cuts are made. However, possible drawbacks of these techniques are that most of the systems are imageless and based on only a number of average bone models. This is a potential source for errors, as individual parameters cannot be determined precisely such as the femoral flexion as one example or the trochlea anatomy and orientation.

Robotic-assisted surgery as a fairly new technology appears promising especially in the concept of KA [20, 21]. In contrast to traditional computer navigation, these systems are mainly image based and thus having the major advantage of a patient individual planning and prosthetic position based on the 3D anatomy of the knee (Fig. 29.7). In contrast to the PSI they have the feasibility to include the soft tissue stability and

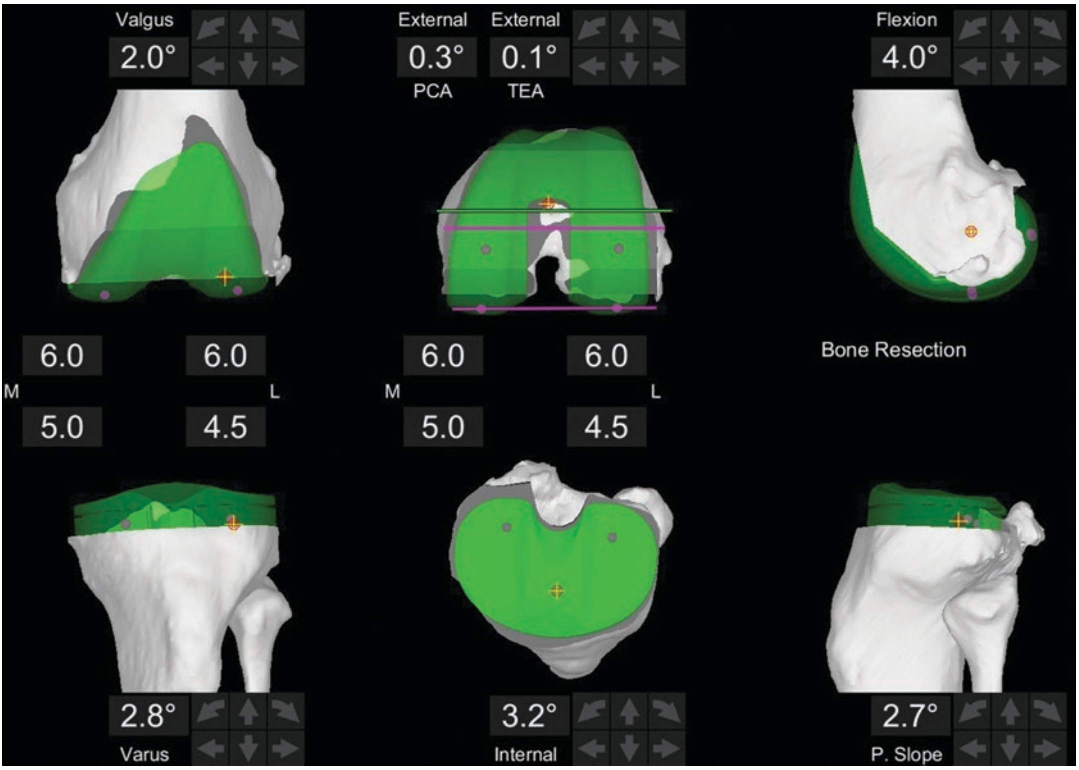

Fig. 29.7 Example of a preoperative planning for KA-TKA using a CT-based robotic-assisted technology. The femoral resections are set to 6 mm distal and posterior, and the tibia orientation is roughly orientated to the natural joint line and adapted based on the soft tissue information during surgery to achieve a symmetric and stable extension gap

tension at the beginning of the operation and thus the preoperative plan can be adapted to the individual situation of the patient to achieve best stability and kinematics with the prosthesis. This virtual planning allows to compensate for minor changes that are to be made with the prosthesis compared to the native knee before the bone cuts are conducted. And lastly, one major advantage of robotic-assisted techniques is that the precision in the execution of the preoperative planning is described to be superior to other computer assisted technologies [22, 23]. Especially when recuts are necessary this technology gives the opportunity to recut in 0.5 mm steps.

Side Summary

In the current need of reliable scientific data to benchmark the effect of KA vs. MA on the outcome, the use of computer assistance of some sort appears to make perfect sense to have an objective control of what is produced with the alternative alignment. This is true for (1) the prosthetic position itself and (2) the resulting soft tissue balance.

29.4 Clinical Evidence Base

The initial technique of KA TKA was based on patient-specific cutting guides (PSI) manufactured by a single company—the OtisMed Corporation [24, 25]. They developed a specific MRI-based algorithm to segment a patient individual 3D model of the arthritic knee and to calculate the pre-arthritic anatomy by the use of a proprietary software. Based on this computer model the prosthetic alignment was individually planned with the focus on restoring the physiological joint surface anatomy. PSI was the vehicle to transport the computer planning into the operating room. In January 2006 Stephen Howell MD, Sacramento, completed the first kinematic aligned TKA using that PSI guides. Subsequently, approximately 20,000 KA TKA using the OtisMed technology were implanted in the United States. In 2009, the FDA approval for the KA-PSI was withdrawn, mainly based on regulatory issues. From this time period only very limited scientific data is available describing an early clinical benefit compared to MA. The first studies were published by the developer group reporting a high function and patient satisfaction with KA TKA [25]. However, there were no control groups in these studies. Dossett and coworkers published a first inventor independent randomized controlled trial of 41 kinematically aligned versus 41 mechanically aligned patients [26, 27]. They showed significant improvement in several outcome scores, such as mean Oxford Knee Score (40 vs. 33 points, $p = 0.005$), WOMAC (15 vs. 26 points, $p = 0.005$), and combined KSS (160 vs. 137 points, $p = 0.005$) as well as a greater mean flexion (121° vs. 113°, $p = 0.002$) in the kinematically aligned group at 6 and 24 months postoperatively.

While Waterson et al. [28] and Young et al. [29] found no statistical difference in the outcome between KA and MA, Calliess et al. [18] reported a significant better outcome for WOMAC (13 vs. 26 points, $p = 0.001$) and KSS (190 vs. 178 points, $p = 0.02$) in favor of kinematic aligned TKA. In this study it was described that a very high amount of patients showed excellent outcome, whereas several patients showed a very poor outcome in the KA group that was not seen in the control group (Fig. 29.8). The further analysis suggested that those failed treatments were mainly caused by inaccuracies within the PSI technology. In the whole collective an average deviation from the initial KA plan by about 2.5° was observed and this had a significant effect on the clinical outcome. The differences between

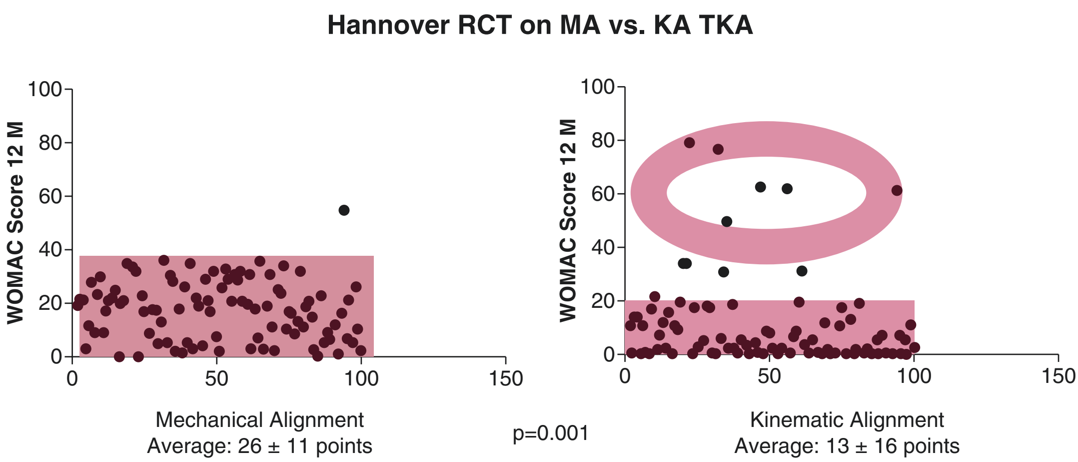

Fig. 29.8 Frequency distribution of WOMAC scores at 12 month postoperatively for MA vs. KA (Modified figure from Calliess et al. [18]). A high number of patients in the KA group show a WOMAC of 0 points (best outcome) whereas also some outliers are observed that are not present in the MA group (highlighted with circle)

the three studies could further be explained with (1) differences in the surgical technique of the control group and (2) differences in the indication for KA. Calliess et al. had restricted indication criteria for study inclusion, and no severe deformities resulting in an alignment more than 4° off the mechanical axis were enrolled. Young et al. on the other hand conducted soft tissue releases in the KA-group which is against the basic philosophy of KA.

Recently, several systematic reviews have attempted to combine published data comparing KA versus MA. There are three meta-analysis available reporting functional results in favor of KA [30–32]. However, these publications have included also non-comparative case series from the development center for PSI guides. In collaboration with Waterson et al. [28] and Young et al. [29] we have recently carried out an own meta-analysis of level 1 studies and were sharing raw data among the authors to analyze change scores and perform subgroup analysis [33]. As a result we found pain and functional improvements in KA TKA at least as good as in MA technique, but no strong evidence in favor of KA. Pooled data for function scores showed a trend toward a greater benefit in the KA group, but any advantage as measured by the scores used was small. Subgroup analysis suggests that differences in preoperative alignment did not alter outcomes with the KA technique, but we found evidence that the inaccuracy of the PSI technique may play a role regarding the clinical outcome of KA. As a bottom line, the available data on PSI KA TKA may not be universally valid as errors with the KA PSI technology might have negatively affected the outcome.

So, there is a growing interest in alternative approaches to achieve KA, especially in technologies with a higher procedural precision. Howell and coworkers recently developed generic manual instruments for KA TKA [34]. They reported good and excellent results for a case series of 101 consecutive patients treated with manually KA TKA, which were prospectively followed. However, again no control group was presented and it was not evaluated how accurate the kinematic axes were restored. Matsumoto et al. published a prospective trial on KA vs. MA TKA using a navigation system [19]. They reported a significant better postoperative flexion and functional activity scores in the kinematic than in the mechanical group ($p < 0.003$ and 0.03, respectively). However, the evidence on those alternative techniques is very limited at the moment.

Up to date, there is no data concerning the long-term survivorship of this technique. The longest follow-up period is again from the developer group. Howell et al. showed that at a mean of 6.3 years after KA TKA, varus alignment of the tibial component, knee, and limb did not adversely affect implant survival or function [35]. In an analysis on the 10-year survival of 220 TKA, Howell et al. reported a survivor rate of 97.5% for revision for any reason and 98.4% for aseptic failure [36]. Furthermore, Nedopil et al. indicate that tibial component failure after KA TKA was 0.3% and was caused by posterior subsidence or posterior edge wear and not varus subsidence [37].

Most recently, also a positive influence of kinematic alignment compared to mechanical on normal gait parameters was observed [38]. Whereas the KA group showed no significant knee kinematic differences compared to healthy knees in sagittal plane ROM, maximum flexion, abduction curves or tibial rotation, the MA group displayed several significant differences: for example, less sagittal motion (49° vs. 54°, $p = 0.02$) and increased adduction angle (2–7.5° vs. 2.8–3°, $p < 0.05$).

Side Summary

Based on the current evidence it can be stated that KA-TKA is at least as good as MA-TKA in terms of the functional outcome, with growing evidence indicating a clinical benefit. No study reported inferior results. However, long-term results are still missing.

29.5 Indications and Limitations

Since the primary goal of KA TKA is the restoration of the physiological alignment, soft tissue tension, and the interrelationship among the kinematic axes of the knee, this technique in our hands is only applicable for primary osteoarthritis. Posttraumatic deformities affecting the natural movement and load introduction of the knee are conflicting with the idea of KA and thus represent contraindications to us. Same applies to soft tissue injuries or inflammatory osteoarthritis affecting the primary ligament stability of the knee. Regarding the discrimination between physiologic deformities that can be reconstructed with KA TKA and pathologic situations that should be corrected there is an ongoing debate around the actual parameters. Yet, no clear consensus is achieved on possible borders of a feasible and safe alignment. Nor it is clear whether those pathologic deformities should be corrected to neutral or left in a constitutional deformity. In this section the current knowledge about inclusion or exclusion criteria for true KA is discussed.

29.5.1 Constitutional vs. Pathological Alignment and Biomechanical Aspects

In general, the overall varus or valgus alignment of the limb in the osteoarthritic condition does not represent an inclusion or exclusion criteria for KA TKA. In a meta-analysis of randomized controlled trials (RCT) with KA TKA, a subgroup analysis of the raw data showed no difference in clinical outcomes 1–2 years postop (OKS, WOMAC, KSS) between preoperative varus, valgus, and neutral alignment groups [33]. However, other studies indicate that patients with a postoperative valgus alignment were more likely to be unhappy being left in valgus (mainly for cosmetic reasons but functional deficits or pain) [39]. Whereas patients with a constitutional varus did not complain about their restored natural alignment. In our own RCT on KA TKA valgus patients sometimes showed a higher valgus deformation after surgery than preoperatively [18]. This effect can be attributed to (1) a potential medial laxity requiring a compensatory valgus tibia cut to stabilize the knee, (2) a dysplastic lateral femur condyle, or (3) due to thicker physiological lateral cartilage thickness on the tibia that was not taken into account correctly. When using a symmetric implant the lateral condyle hypoplasia can lead to an overstuffing of the lateral aspect, again requiring a valgus tibia cut to compensate. Thus, a true bony valgus deformity with a lateral dysplastic femur does represent an exclusion criterion for KA to us. Those radii differences can be estimated on AP radiographs, or more precisely determined on CT or MRI scans (Fig. 29.9a, b). Currently, we do accept a difference of 2 mm medial to lateral condyle radius.

Furthermore, especially valgus patients need a comprehensive clinical examination of their gait and the hip joint. An insufficiency of the abductor and/or external rotator muscles of the hip typically leads to a pathological valgus loading of the knee joint during motion. This can also be the actual cause of the valgus osteoarthritis. Again, we judge these patients not to be ideal for KA TKA leaving any valgus alignment. They have a high risk of secondary medial instability and should be corrected to neutral or even provided with a higher level of constrained.

The most critically discussed parameter in KA TKA is the varus position of the tibia component. Historically, it is stated that varus alignment of the tibia leads to early implant failure [40]. However, the scientific support for this convention is surprisingly weak. Most of the literature reporting on higher revision rates when the prosthesis is positioned more than 3° deviant to the mechanical axis date back to the 1990s evaluating implants from the 1970s or 1980s. Many papers can also be criticized regarding the methodology used (short leg radiograms) and the sample size. The more recent literature on modern implants showed conflicting results and imply that factors other than alignment might be more important for determining the survivorship [41, 42]. In the end,

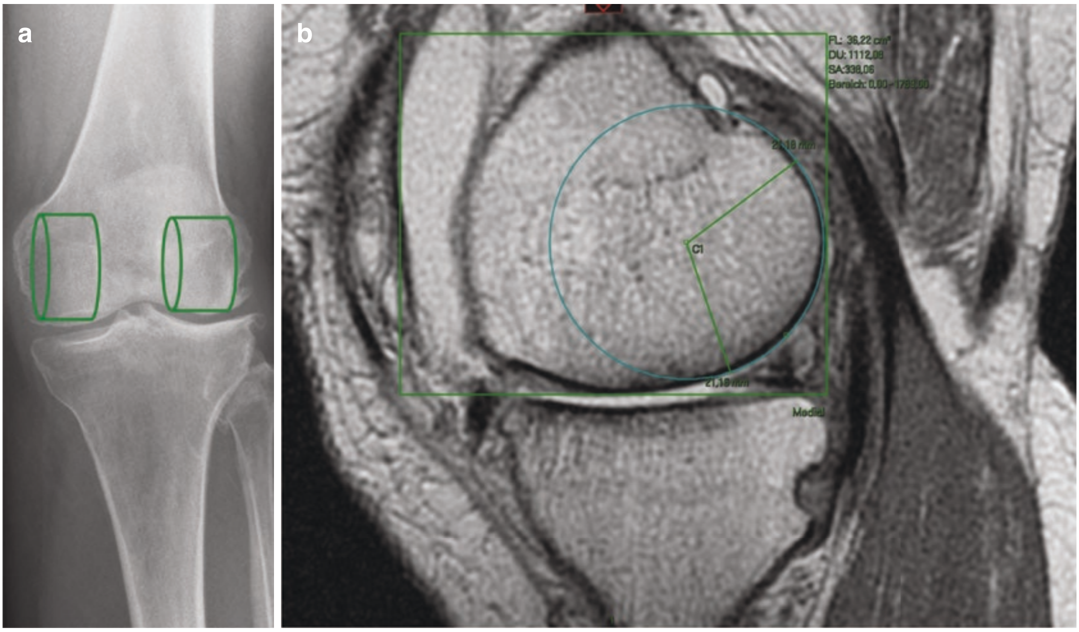

Fig. 29.9 (**a**) Radiological example to determine relevant radia differences between the medial and lateral femoral condylus in a valgus gonarthrosis. (**b**) Example of the evaluation of condyle radii and possible bone defects on MRI scans. Important is an orientation of the image planes perpendicular to the posterior condylar line. Then a best fitting circle is placed in the posterior condyles for the flexion range between 10° and 110°

what all these papers have in common is that the postoperative malalignment was not intended by the surgeon, but inadvertently in varus or valgus malposition. The meaningfulness of these studies to KA TKA in which a constitutional alignment is to be restored in questionable. In this context, we see the need to evaluate the specific effect of a tibia vara in a kinematically well-aligned knee. The clinical data is very limited. Howell et al. showed that at a mean of 6.3 years after KA TKA, varus-valgus alignment of the tibial component (mean − 1.9°, range −7°–7°), knee, and limb did not adversely affect implant survival or function [35, 43]. Nedopil et al. evaluated the same collective and indicate that tibial component failure after KA TKA was 0.3% and was caused by posterior subsidence or posterior edge wear and not varus subsidence [37]. Hence, the slope plays also a key role for implant survival. Recently, different groups have tried to address this research question from the biomechanical standpoint, mainly based on computer simulations. There are certain hints that KA leads to higher medial contact stresses in computer models mainly depending on tibial varus and overall limb alignment [44–46]. Nakamura et al. showed that a slight varus alignment up to 6° of overall varus did not lead to a significant increase in contact stress on the tibial insert and the stress to the resection surface and to the medial tibial cortex. However, when the resulting varus was more than 10° an unphysiological loading was observed. This again supports the idea to discriminate between physiological and pathological deformities and their suitability for KA TKA.

Interestingly, newer biomechanical analysis and especially the dynamic consideration of forces and loads to the knee joint led to the conclusion that restoring the physiological joint line obliquity and soft tissue envelop results in a reduced abduction moment during gait and (thus) lower loads on the medial compartment [47].

Side Summary
Until today there is no strong evidence that a physiological varus position of the tibia is associated with early failure of the TKA. Under discussion is the discrimination between constitutional alignment that can be restored and pathological situations that should be corrected.

29.6 Preoperative Planning and Analysis

Against the background of this current evidence as well as based on the current valid doctrine of a mechanical alignment ±3°, there is a discussion on true KA without any restrictions versus a restricted KA approach to meet the accepted range of deviation with KA TKA post-surgery [48]. The key in the preoperative planning is to analyze the physiological joint line obliquity and the natural flexion of the femur and tibia to get an idea of the resulting overall limb alignment. Therefore, the mDFA and the MPTA are evaluated on long leg standing x-rays. Today's accepted MPTA is between 85° and 90°. So, already some typical varus morphotype patients with an mDFA of 90° and an MPTA with 84° or less are excluded for true KA. In case of an abnormal tibia orientation correction is required to bring the alignment back to normal. Yet, it is not scientifically defined whether this should be done extraarticular with a tibial osteotomy or intraarticular with the prosthesis. This is ongoing research and our decision making is mainly based on the level of deformity and the grade of osteoarthritis present. However, the said patients very often present an isolated medial unicompartimental osteoarthritis and thus are suitable for unicompartimental arthroplasty. The mDFA appears to play a minor role for the implant survivorship so that no boundaries are defined in the algorithm. But it has an effect on the overall limb alignment. The sum of the MPTA and the medial mDFA represents the expected overall alignment and should be within 175°–183°. In the coronal plane the flexion of the distal femur is evaluated, ideally on a long leg lateral radiograph. The slope is best visualized on CT scans, because the important functional slope of the posterior two-thirds of the plateau is only visible here. This is important as (1) most TKA designs have a limitation in the component flexion to each other, mostly around 7°, and (2) it is known that a tibial slope of more than 7° has a high risk of secondary PCL insufficiency and a high slope is associated with a higher risk of tibia component loosening, as outlined above. Thus, a pathologically combined flexion in the sagittal plane needs to be discussed as an exclusion criteria, depending on the design features of the prosthesis used. However, as mentioned earlier there is evidence to reduce the tibial slope compared to the physiological situation as the loss of the ACL needs to be compensated, especially in low conforming TKA designs. If the physiological slope is more than 8°, to our experiences, a PS design should be used. The discussed condyle radii are—if in doubt—evaluated on MRI or CT scans. However, this is not included in the standard manual algorithm, but often helpful. In the image-based computer-assisted techniques it is standard to evaluate the condyle radii.

To summarize, from our today's point of view the ideal patient for KA TKA is a neutral to mild constitutional varus patient with a physiological joint line obliquity up to 5° that is restored in this concept. Interestingly, about 60%–70% of the patients for TKA do fit in this range and would be suitable for true KA. The pathologic varus alignment should be corrected with minor adaptations on the tibia and on femur or minor soft tissue releases. This concept was recently described by Alamaawi et al. as "Restricted Kinematic Alignment" [49]. The valgus patient should be indicated carefully due to other anatomic and functional concerns as outline above.

Side Summary
The traditional deformity analysis of the MPTA and LDFA helps to understand the phenotype and to predict the resulting alignment. At the moment, the ideal patient for KA TKA is a neutral to mild constitutional varus patient with a physiological joint line obliquity up to 5°. Also other parameters of the sagittal and coronal profile are of interest that can be evaluated in CT or MRI imaging.

29.7 Prosthetic Design Features for KA TKA

Finally, the specific design features of TKA and their suitability for KA should be briefly discussed. In this context, it has to be stated that (1) today there is no prosthesis specifically designed for KA on the market and (2) there is currently no clinical or biomechanical evidence favoring one or the other design feature. So, all the issues raised here are solely from a theoretical standpoint and might change with more evidence available.

Firstly, there is an ongoing discussion on the femoral component radius. In general, a single radius prosthesis is closer to the kinematic idea of KA than a J-curve design. The idea of an isometric tension of the ligaments is best reproduced with a single radius between 10° and 110° of flexion. However, we must be aware of the fact that there is a large heterogeneity of condyle radii in the patients and that the medial and lateral condyles are not necessarily symmetric [50]. So, the majority of the standard prosthesis would change the radius compared to the physiological joint. Some prosthesis only have two different radii for all sizes, whereas others have size depending radii, for example. Probably, choosing the implant design with respect to the physiological anatomy can have a kinematic benefit.

Secondly, the anterior aspect of the TKAs also shows a great variability with different design concepts. Apart from the general difficulty of reconstructing the anterior aspect of the femur and thus the physiological lever arm, the actual trochlea groove design is typically optimized for MA TKA.

Atraumatic patellofemoral instability was described as one complication after KA TKA with the component in more internal rotation compared to MA [15]. However, the incidence of patellofemoral instability was only 0.4% in the literature. Flexion of the femoral component and inccrease in external rotation of the tibial component increases the risk of patellofemoral instability. No difference was found regarding different prosthetic designs that were used. We favor designs with a low constrained trochlea groove and a broad patella introduction area (often referred as the Q-angle) to force the patella into an artificial tracking.

Thirdly, the tibial inlay design and the conformity are of major interest. One of the theoretical benefits of KA is the more natural soft tissue balance enabling a more physiological rollback and rotation kinematics. So, in our hands a low-conforming inlay with a high rotational freedom is beneficial for KA, whereas especially ultra-conforming inlays or mobile bearing platforms counteracting the KA idea.

Side Summary
Yet, there is not prosthesis specifically designed for KA on the market and currently no clinical or biomechanical evidence favoring one or the other design feature. Main discussion is about the condyle radii, the reconstruction of the anterior knee shape, and the inlay design.

Take Home Message
- Based on the today's knowledge, kinematic alignment appears as an interesting new concept for more natural total knee arthroplasty. Over the last years, a reproducible manual surgical technique has been established as well as computer- and robotic-assisted workflows.

Key is (1) the true measured resection principle, taking the wear into account, (2) the meticulous resection of osteophytes, and (3) the verification checks using a caliper during surgery.

- The current evidence shows that the patient outcome is at least as good as the standard mechanical alignment. Several studies and meta-analysis even report on better outcome with kinematic alignment. However, there are still many unknown parameters like the tibia slope or possible contraindications that make further research necessary. Especially for pathological but constitutional deformities it is questionable that the KA concept has an advantage over MA, but a higher risk of failure. Currently, the best patient to choose appears to be the neutral to constitutional mild varus patient.
- As several of the available studies point out that one limitation currently is the surgical precision to achieve the KA plan, this would be one of the major fields of research to more clearly define the surgical algorithm and to guarantee the necessary precision. Furthermore, research should focus on special design features of the prosthetic components when used for KA.

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30 Measured Resection Technique: How Does it Work?

Silvan Hess and Michael T. Hirschmann

Keynotes

1. The main purpose of a total knee arthroplasty (TKA) is to remove the worn cartilage and eroded bone and to replace it with metal and plastic. When cartilage and bone are removed, gaps form between the tibia and the femur.
2. Although a knee should be stable throughout the entire range of motion, during TKA a knee is predominantly assessed and balanced in extension and in 90° of flexion. Hence, one can distinguish between the gap in flexion (flexion gap) and the gap in extension (extension gap).
3. The extension gap is the result of tibial and distal femoral bone cuts. The flexion gap is the result of tibial and the posterior femoral bone cuts. The gaps should be rectangular, equally sized and equally balanced.
4. The tibial cut affects the extension gap and the flexion gap. Since a neutral alignment is the goal, the tibial cut should be perpendicular to the mechanical axis of the tibia.
5. The targeted posterior slope of the tibial cut depends on the used implant type (0°–3° for PS TKA and between 5° and 7° for CR TKA).
6. The distal femoral cut affects the extension gap and joint line height. It is placed perpendicular to the mechanical axis of the femur and ideally almost parallel to the tibial cut.
7. The anterior femoral cut affects the patellofemoral joint, and the posterior cut the flexion gap. Both cuts are made using a "4-in-1" cutting guide. The two cuts are parallel to each other and define the rotation of the femoral TKA component in the axial plane.

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30.1 Basics for a Better Understanding

The main purpose of a total knee arthroplasty (TKA) is to remove the worn cartilage and eroded bone and to replace it with metal and plastic.

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Thereby, the knee surgeon aims to remove only as much bone and cartilage as necessary to fit in the prosthetic components. The removed parts should therefore exactly match the thickness of the knee prosthesis in all dimensions. In general, the thickness of the prosthesis is between 9 and 11 mm. When cartilage and bone are cut away, gaps form between the tibia and the femur. Although a knee should be stable throughout the entire range of motion, during TKA a knee is mainly assessed in extension and 90° of flexion. Hence, one can distinguish between the gap in flexion (flexion gap) and the gap in extension (extension gap).

Side Summary
The goal of TKA is to replace the damaged cartilage and bone with metal and plastic. The gap between tibia and femur, which emerges after the bone cuts, is assessed with the knee in flexion (=flexion gap) and extension (=extension gap). These gaps should be equally sized and balanced to achieve a neutrally aligned limb. There are two methods to implant a TKA: measured resection and ligament balancing technique. The two differ in regard to used referencing system for the bone cuts.

With the goal of a neutral mechanical alignment of the lower limb, the knee surgeon aims to achieve symmetric gaps with parallel cuts, which are orientated perpendicular to the mechanical axis. Furthermore, these gaps should be equally sized and balanced, meaning the tension of the soft tissue should be similar on both sides (medial/lateral) as well as in both knee positions (flexion/extension).

There are two different methods to implant a TKA. The main difference between the two techniques is the reference system on which the position of bone cuts, thereby the components, is defined.

The first one purely relies on anatomical landmarks and is thus called the bone referencing or the measured resection method. The second one is the ligament balancing technique in which the bone cuts are based purely on the tension of the ligaments. In reality, most knee surgeons use a combination of both methods. For simplification, in this chapter a pure bone referencing or measured resection technique is described in detail.

30.2 Bone Cuts

All TKAs follow the same standardised workflow and only differ in order of preparation steps and instrumentation.

The extension gap is the result of tibial and distal femoral bone cuts (Fig. 30.1a). The flexion gap is the result of tibial and the posterior femoral bone cuts (Fig. 30.1b).

Side Summary
The extension gap is the result of tibial and distal femoral bone cuts. The flexion gap is the result of tibial and the posterior femoral bone cuts.

30.3 Measured Resection Technique

As mentioned above, when using the measured resection technique, the bone cuts are made independently from soft tissues and ligament tension. It purely relies on the accurate and reliable identification of anatomical bony landmarks. The necessary anatomical landmarks are presented in the following (Table 30.1).

Side Summary
The measured resection technique purely relies on anatomical landmarks. The most important landmarks for rotational alignment of the femoral cuts are the sTEA, the posterior condylar axis (PCA) and the antero-posterior axis (Whiteside's line).

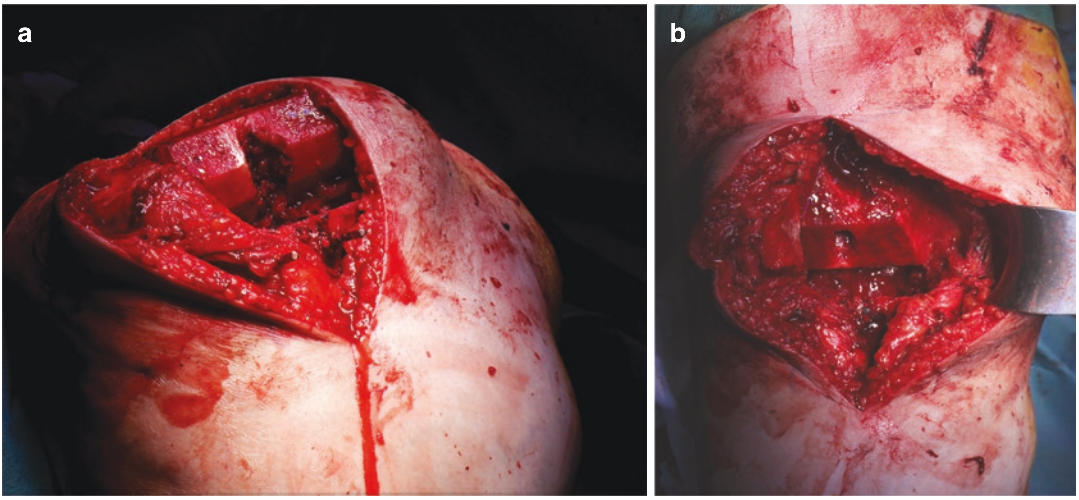

Fig. 30.1 (**a**, **b**) Intraoperative views on the flexion gap (**a**) and on the extension gap (**b**)

Table 30.1 Pros and cons of the measured resection technique

Pro	Cons
Landmarks are simple and reliable in most routine surgeries	Difficult to correctly identify the landmarks
Soft tissue tension does not need to be assessed	Landmarks might not be reliable in some cases due to a unique anatomy, arthritic changes and/or deformities

The most important landmarks for the rotational alignment of the tibial component are the Akagi line and the anterior tibial border.

Fig. 30.2 Coronal CT slice with surgical (sTEA) in red and the anatomical (aTEA) transepicondylar axis in yellow

30.3.1 Anatomical Landmarks

30.3.1.1 Transepicondylar Axis (TEA)

There are two relevant transepicondylar axes described: the surgical transepicondylar axis (sTEA) and the anatomical transepicondylar axis (aTEA).

The sTEA is defined as a line connecting the medial epicondylar sulcus and the most lateral point of the lateral epicondylus.

The aTEA is defined as a line connecting the most medial point of the medial epicondylus and the most lateral point of the lateral epicondylus. Both axes are used to approximate the flexion-extension axis of the knee joint. However, during surgery, the sTEA is used. Fig. 30.2 shows an axial CT slice at the level of the distal femur with the aTEA in yellow and the sTEA in red. Figure 30.3 shows a coronal CT slice with the aTEA in yellow and the sTEA in red.

30.3.1.2 Posterior Condylar Axis

The posterior condylar axis is defined as a line connecting the two most posterior points of the lateral and medial femoral condyles. Rotation of the distal femur in the coronal plane is usually defined as an angle between the posterior condylar axis and the TEA in the coronal plane. In Fig. 30.3 (right), the posterior condylar axis is highlighted in purple on an axial CT slice at the level of the distal femur.

30.3.1.3 Anterior-Posterior Axis

This axis is defined by a line connecting the anterior trochlear sulcus centre to the middle of the intercondylar notch's posterior aspect. Rotation of the distal femur in the coronal plane can be defined according to this line. It is also named after the knee pioneer Leo Whiteside as "Whiteside's line". In Fig. 30.3 (right), the anterior-posterior axis is highlighted in green on an axial CT slice at the level of the distal femur [1].

30.3.1.4 Akagi Line

The Akagi line is defined as a line running from the centre of the posterior cruciate ligament (c-PCL) anteriorly to the medial third of the tibial tuberosity (mb-ATT). It is an important axis for rotational alignment of the tibia. Figure 30.4 shows the Akagi line on the right [2].

30.3.1.5 Anterior Tibial Border

The anterior tibial border is used for the curve-on-curve technique. Thereby, the tibial component is placed on the tibia plateau in a way that the anterior curvature of component matches the curvature of the anterior bone cortex (after the tibial cut). Figure 30.4 shows the curve-on-curve technique on the left.

30.3.2 Bone Cuts

The bone cuts are performed in relation to these aforementioned axes. Five different bone cuts can be differentiated: proximal tibial cut, distal femoral cuts, chamfer cuts, anterior and posterior femoral cuts. There is some discussion in the community about which cuts (femur vs. tibia) are best performed first. However, most surgeons cut the tibia first.

30.3.2.1 Tibial Cut

An accurate tibial cut is essential since it affects extension gap, flexion gap and mechanical alignment. The cut is placed perpendicular to the mechanical axis of the tibia. In posterior cruciate retaining TKA (CR TKA), the surgeon aims to restore the native posterior slope which is generally between 5° and 7°. In posterior cruciate sub-

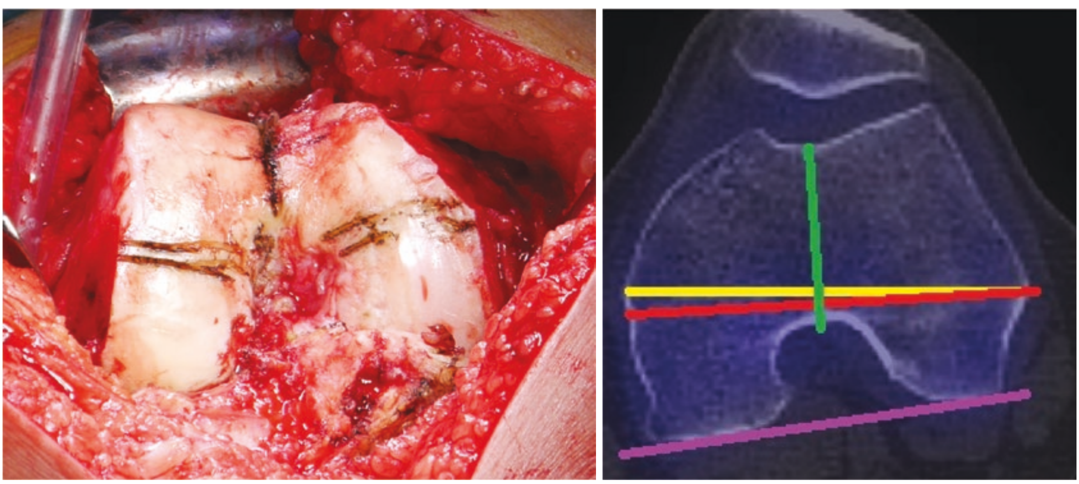

Fig. 30.3 On the right side, an intraoperative view on the distal femur with the knee in flexion and the reference axes for the rotational alignment in black. On the left side, an axial CT slice at the level of the distal femur with all important anatomical landmarks. The anterior-posterior axis in green, the sTEA in red, the aTEA in yellow and posterior condylar line in purple

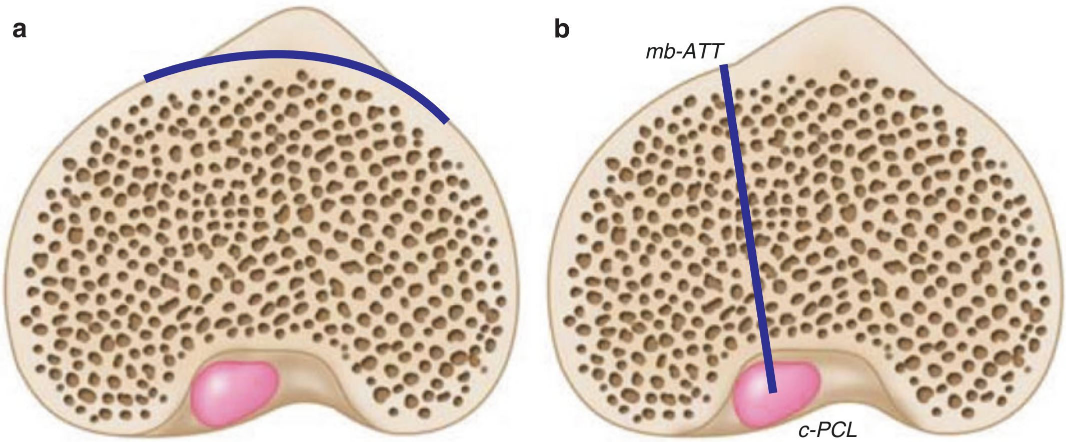

Fig. 30.4 Cranial view on two tibial plateaus. On the left side, the anterior tibial border (curve-on-curve technique) is shown (**a**), and on the right side, the "Akagi line" is shown (**b**)

stituting TKA (PS TKA), the surgeon aims for 0°–3° posterior slope to compensate for the sacrificed posterior cruciate ligament.

An extramedullary or intramedullary referencing system can be used. However, studies have shown better results when using an intramedullary system [3]. First, the varus-valgus orientation of the tibial cut is assessed. Second, the rotational alignment is assessed. This is crucial because the rotational alignment also has some influence on the posterior slope.

Several landmarks have been reported for orientation with regards to rotational alignment of the tibial cut. A review by Saffarini et al. found the following to be the most accurate and repeatable ones: "Akagi's line" and "anterior tibial border (curve-on-curve technique)". Both are explained in Sects. "30.3.1.4 and 30.3.1.5 Anatomical landmarks" [4].

The thickness of the tibial cut should at best match the thickness of the prosthesis in order not to change the joint line height. Figure 30.5 shows an anterior-posterior radiograph of the knee, illustrating the difference between the cutting plane (red) and the joint line (green).

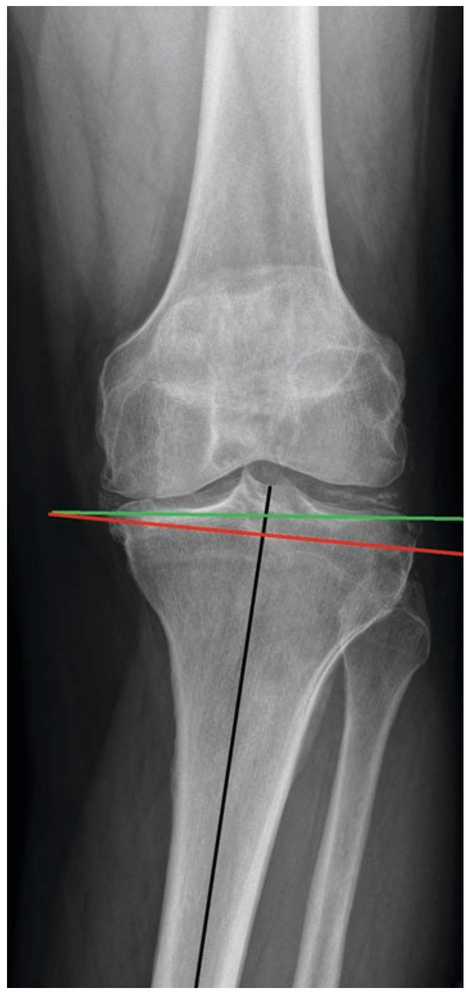

Fig. 30.5 Anterior-posterior radiography of the knee in full extension. In black the mechanical axis of the tibia, in green the tibia plateau and in red the cutting plane of the TKA

Side Summary
The tibial cut is placed perpendicular to the mechanical axis of the tibia. The amount of posterior slope depends on the type of TKA (5°–7° for posterior cruciate retaining TKA, 0°–3° posterior slope for posterior cruciate substituting TKA).

An intramedullary referencing system should be used. Rotational alignment of the cut is assessed according to the "Akagi's line" and the anterior tibial border (curve-on-curve technique). The thickness of the femoral cut should exactly match the thickness of the TKA.

30.3.2.2 Femoral Cuts

Distal Femoral Cut

The distal femoral cut equally affects the extension gap and joint line height. Again, since a neutral alignment is the goal, the distal femoral cut should be perpendicular to the mechanical axis of the femur and almost parallel to the tibial cut.

While the anatomical and mechanical axis are usually the same for the tibia (cave: extra-articular deformity), the anatomical axis of the femur is around 6° valgus to the mechanical axis. However, this angle, named as hip-knee-shaft angle (HKS), varies widely amongst patients [5].

The orientation of the distal cutting guide is based on an intermedullary referencing system. The referencing system is typically established by drilling from a point just above the posterior cruciate ligament origin into the medullary cavity and entering an intramedullary rod within the femoral canal. This guide then represents the anatomical axis of the femur, and the cutting angle can be placed according to the preoperative measured value of the HKS (usually around 6° valgus). Figure 30.6 shows an intraoperative view on the femur with an intermedullary referencing system in place. The thickness of the distal femoral cut should at best exactly match the thickness of the femoral component. Otherwise, the joint line might be shifted proximally (cut to thick) or to distally (cut to thin). Figure 30.7 shows a radiographic image of the femur with the femoral mechanical axis in green, the femoral anatomical axis in red, the tangent to the distal femoral condyles in blue and a cutting plane of the distal femoral cut in yellow.

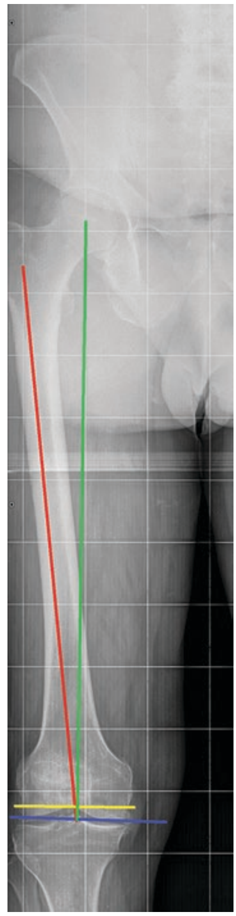

Fig. 30.6 Intraoperative view on the distal femur with the intramedullary rod for the placement of the distal femoral cut mounted to the femur

Side Summary
The distal femoral cut is placed perpendicular to the mechanical axis of the femur (approximately 6° valgus to joint line depending on HKS). The thickness of the distal femoral cut should at best exactly match the thickness of the femoral component.

Fig. 30.7 Anterior-posterior radiography of the femur. In red the anatomical axis of the femur, in green the mechanical axis of the femur, in blue the tangent to the distal femur condyles and in yellow the cutting plane of the distal femoral cut

4-in-1 Femoral Cuts (Anterior, Posterior, Oblique)

As mentioned above, the anterior cut affects the patellofemoral joint and the posterior cut the flexion gap. A correct placement of this cuts is therefore highly important as it strongly influences patellofemoral tracking as well as the flexion gap stability.

Both cuts are made using a “4-in-1” cutting guide (anterior and posterior femoral cuts + anterior chamfer and posterior chamfer cuts). There is a “4-in-1” cutting guide for each size of femur.

The two cuts are parallel to each other and define the rotation of the femoral TKA component in the axial plane. A correct orientation of the prosthesis is achieved by positioning the cutting guide in relation to the following anatomical landmarks:

– Anterior-posterior axis (AP-axis): cuts are placed perpendicular.
– Posterior condylar axis (PCA): cuts are placed in mean 3° external rotation.
– Surgical transepicondylar axis (sTEA): cuts are placed parallel.

Figure 30.8 shows an intraoperative, axial view on the femur after the distal femoral cut has been made. On the left side, the sizing guide is mounted to the femur and the rotation of “4-in-1” cutting guide is defined according to the previous mentioned landmarks. On the right side, the “4-in-1” cutting guide is mounted to the femur.

Side Summary

The anterior femoral cut affects the patellofemoral joint, and the posterior cut the flexion gap. Both cuts are made using a “4-in-1” cutting guide. Rotational alignment should be assessed using two or more of the following landmarks: sTEA, PCA and AP-axis. The thickness of the posterior and anterior femoral cut is defined by the chosen implant size. A posterior or anterior cortex reference system can be used to position the cutting guide.

30.3.3 Pros and Cons of the Measured Resection Technique

The measured resection technique relies fully on anatomical landmarks, which is an advantage and disadvantage at the same time. On one hand, these landmarks are reliable and simple to use in most routine surgeries. Furthermore, the bone cuts only rely on bony anatomy and are made independent of the soft tissue tension, which is more difficult to assess/interpret. On the other hand, several studies have shown that a) there is a big variation between the chosen landmarks amongst surgeons, and b) these landmarks might not be reliable in some cases due to a unique anatomy of the patient, arthritic changes and/or deformities [6].

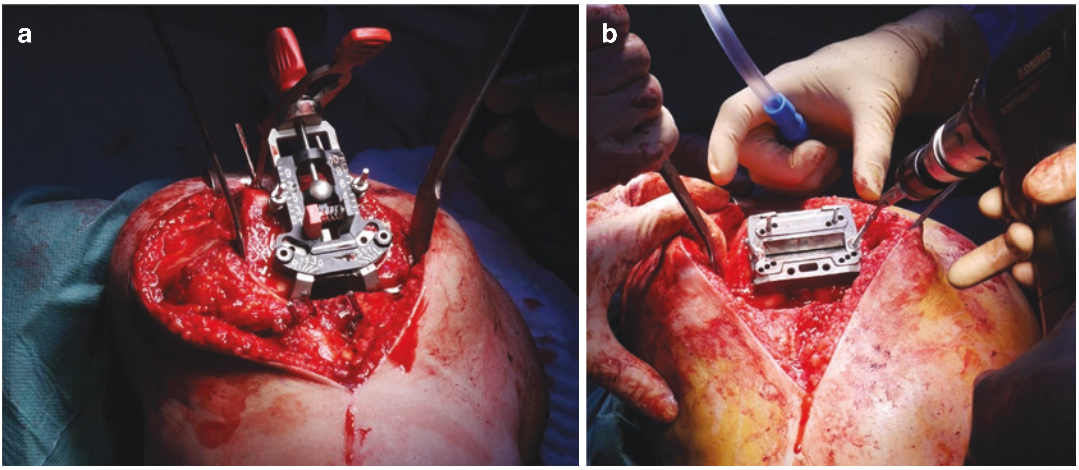

Fig. 30.8 (**a**, **b**) Intraoperative view on the distal femur after the distal femoral cut is done. The sizing guide is mounted to the femur and the rotation of "4-in-1" cutting guide is defined according to the previous mentioned landmarks (**a**). The "4-in-1" cutting guide is mounted to the femur (**b**)

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31 Ligament Balancing Technique: How Does It Work

Roland Becker

Keynotes

1. Ligament balancing in total knee arthroplasty (TKA) is essential for a well-functioning TKA.
2. The bone resection is determined primarily by the natural tensions of the medial and lateral collateral ligaments in both flexion and extension.
3. Since the technique follows the individual soft tissue envelope of the knee, individual bone morphology will be respected automatically, and bony landmarks become less relevant.

31.1 Introduction

Good knee function after total knee arthroplasty (TKA) strongly depends on adequate soft tissue balancing. The collateral ligaments as well as the posterior cruciate ligament in cruciate retaining (CR) femoral component designs require appropriate tensioning during both flexion and extension of the knee. Loose collateral ligaments cause instability, which is the second most common cause for revision surgery accounting for 10–25% of all revisions [1, 2].

Instability occurs not only in the frontal plane (varus/valgus-instability) but also in the transversal plane (internal and external rotation) and in the sagittal plane (anteroposterior translation). Both the medial and lateral collateral ligaments show a near isometric behaviour during knee flexion and extension [3]. Less than 2% of change in strain of the medial collateral ligament has been reported throughout the entire range of knee motion. The lateral collateral ligament is, on the other hand, isometric from 0° to 70° of flexion and slackens from 70° to 120° of flexion. Especially in osteoarthritic knees with a varus deformity, the medial soft tissue has a crucial role in term of the deformity. Correction of the varus alignment of less than 10° is correctable without soft tissue release during surgery. However, in valgus knees, bony morphology seems to be the main contributing factor to the overall deformity and less impact is caused by soft tissue [4].

Other soft tissue structures such as the popliteus complex also have a significant impact on knee stability in the transversal plane. Resection of the popliteus tendon increases external rotation of the knee and destabilises the lateral femorotibial

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compartment mainly in flexion [5]. Inferior functional outcome based on the Knee Society Score has been reported in these cases [6]. On the contrary, another study found little effect of popliteus tendon damage on the knee stability after TKA when all lateral collateral ligament was intact [7].

In contrast, overstuffing of the femorotibial or patellofemoral compartment show significant impact on clinical outcome after TKA due to pain and poor range of motion. A tight extension gap results in an extension deficit; a tight flexion gap or overstuffing of the patellofemoral compartment leads to decrease in knee flexion.

When discussing knee stability, all the three planes such as frontal, transversal and sagittal planes require discussion.

Two techniques are used in TKA to achieve good ligament tension, the *spacer technique* and the *ligament tensioning technique.*

The *spacer technique* uses spacers with 1 mm increments in thickness, which are inserted in order to evaluate the extension and flexion gaps. Varus and valgus stress are applied manually to estimate the stability of the medial and lateral collateral ligament. No defined force is applied using the technique, and objective information about ligament tension is missing. There seems to be a potential risk of overstuffing of the gaps.

The *ligament tensioning technique* (*ligament balancing technique or gap balancing technique)* uses a specifically designed tensioner. The femorotibial distraction force is displayed on a scale in Newtons (N), and the distraction of the femorotibial compartment is exactly measured and shown in millimetres (mm).

There are different philosophies to achieve correct alignment of the components and the lower limb in all three planes. Two major principles differ from each other by determining bone resections either on soft tissues or bony anatomy. When the bony anatomy of the knee is taken as a guide, the technique is called the measured resection technique. The bone cuts are performed according to the bony morphology using defined anatomical landmarks on both femur and tibia. In the ligament balancing technique, bone cuts are made in accordance to the tension of the surrounding soft tissue. Thus, the soft tissue determines the bone cuts.

Side Summary

There are two philosophies differing in determination of the bone resection; the measured resection and ligament balancing techniques.

The following chapter will focus on the ligament balancing technique. Currently a combination of both techniques has become popular using the measured resection technique for mechanical alignment of the knee in the frontal plane and the ligament balancing technique for correct femoral component placement in the transversal plane.

31.2 Surgical Technique

The gap balancing techniques can be performed either starting with the bony resections for the extension gap or flexion gap.

Side Summary

There are two ligament balancing techniques depending on the order of the bony resection starting either with the extension gap or flexion gap.

One of the standard approaches to the knee (parapatellar, midvastus or subvastus approach) can be used for access. Good exposure needs to be achieved before the jigs are positioned for bony resection. This includes the removal of the osteophytes on both the tibial and femoral sites.

31.2.1 Extension Gap First Technique

The extension gap first technique seems to be the more popular technique. The extension gap is

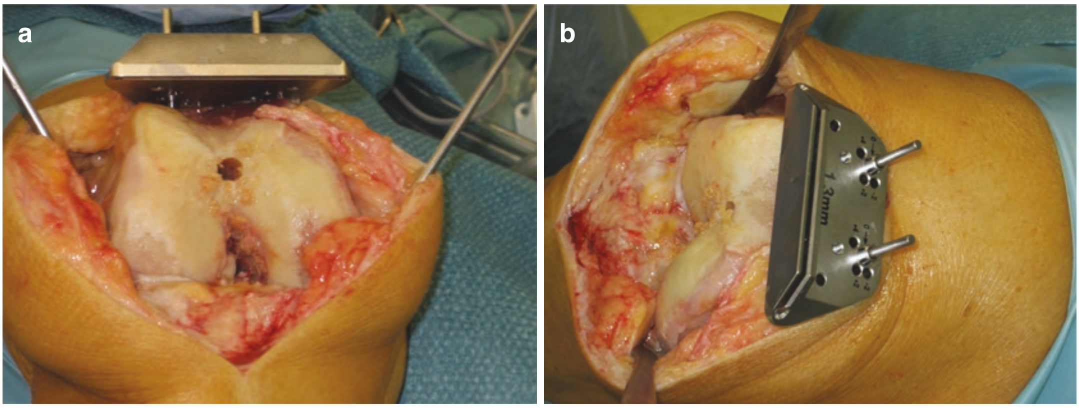

Fig. 31.1 Axial view (**a**) and anterior view (**b**) of the left knee with a cutting guide anteriorly fixed to the femur for distal resection. The guide should be aligned in the frontal but also sagittal planes especially when the cut is not performed perpendicular to the frontal plane

prepared by performing the distal femoral and proximal tibial cut first (Fig. 31.1a, b). Better exposure to the tibial plateau may favor the start with the distal femoral cut.

The distal femoral cut depends on the angle between the mechanical and anatomical axis of the femur. The angle between the two axis is in general 6° but should be measured on the long-leg standing radiograph prior to TKA (Fig. 31.2). The entire femur needs to be seen on the radiography for proper assessment of bone morphology. Especially patients presenting with coxa valga, extraarticular bony deformities of the femur or after total hip arthroplasty may show different angles. When the distal femoral cut is performed perpendicular to the frontal plane, the rotation of the cutting jig in the transversal plane can be neglected. Systems where the distal femoral cut is not performed perpendicular to the shaft of the femur, the rotation of the femoral cutting jig needs to be aligned correctly with the surgical transepicondylar line.

The distal femoral cut in a varus knee will be performed correctly when more bone is resected from the lateral condyle than from the medial condyle in case mechanically alignment is considered (Fig. 31.3). In a valgus knees, it is different due to the dysplastic lateral condyle. The natural joint line is slightly oblique and declines towards the medial site of the knee (Fig. 31.4). The joint line of the mechanically aligned knee is

Fig. 31.2 Weight bearing long-leg standing radiograph showing the mechanical and anatomical alignments of the femur

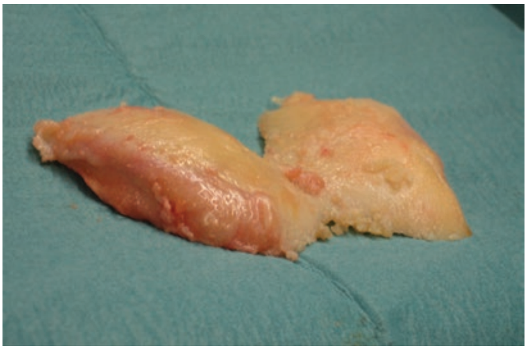

Fig. 31.3 Medial (left) and lateral (right) distal femoral condyle after resection

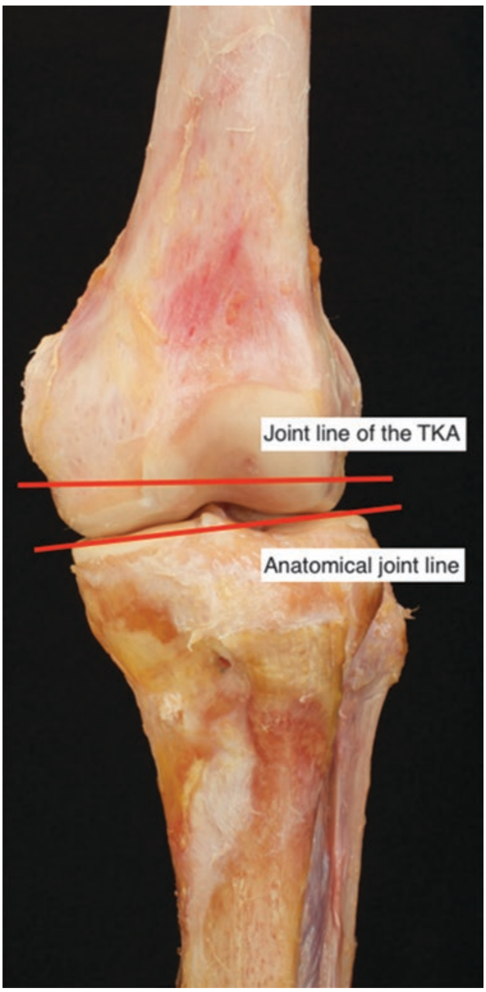

Fig. 31.4 Human knee specimen showing the anatomical joint line orientation and the joint line orientation after TKA

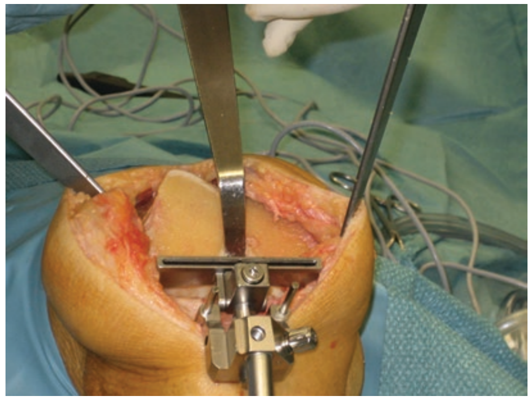

Fig. 31.5 Anterior view to a left knee. The extramedullary cutting guide with the alignment rod is fixed to the proximal tibia. A depth gauge is used referencing the most intact cartilage area on the tibial plateau in order to determine the level of bony resection

exactly 90° to the mechanical axis of the lower limb. The change of the joint line causes an asymmetrical resection of the distal femur and proximal tibia.

The proximal tibial cut follows the distal femoral cut (Fig. 31.5). Typically, for a varus knee, more bone will be resected from the lateral plateau than from the medial due to change of the joint line orientation. However, it depends on the medial proximal tibial angle.

All osteophytes from the medial, lateral and posterior femoral condyles and the medial and lateral tibial plateau need to be removed in order to achieve natural collateral ligament tension. Knee stability in full extension is predominantly provided by the posterior capsule. For this reason, the posterior osteophytes and loose bodies need to be removed and the posterior capsule should be slightly slack in order to analyse the tension of the collateral ligaments correctly. When the osteophytes are removed, generally there is no need for further soft tissue release in order to achieve a well-balanced extension gap. The extension gap needs to be perfectly balanced first before the rectangular extension gap can be transferred to the flexion gap. A rectangular gap is achieved when the medial and lateral collateral ligaments are tensioned equally.

Side Summary
A rectangular gap is achieved when the medial and lateral collateral ligaments are tensioned equally.

The ligament tensioner by Mathys® company (Bettlach, Switzerland) applies a defined force independently to the medial and lateral femorotibial compartments. The distraction force is displayed on the tensioner and the gap size of the medial and lateral compartments can be measured by the tensioning device (Fig. 31.6).

The knee is then positioned in 90° of flexion, the tensioner inserted and the same force applied to the medial and lateral compartment separately (Fig. 31.7). The distal femur rotates internally when the collateral ligaments are equally balanced. Thus, femoral component is rotated externally in regard to the distal femur.

To double-check the flexion gap, prior to the bony resection, the tensioner should be inserted again when the femoral cutting block is already fixed on the distal femoral cut (Fig. 31.8).

There is a very easy method to check correct femoral component placement providing the tibial component is placed correctly; knee flexion without closure of the medial retinaculum should allow a correct patellofemoral tracking without any subluxation. That means that the femoral component is correctly placed under the patella (Fig. 31.9, Video 31.1). The so called "thumb technique" where the surgeon pushes the patella medially in order to avoid subluxation is not recommended and may mask incorrect patella tracking.

31.2.2 Flexion Gap First

After horizontal resection of the tibial plateau, the knee is flexed to 90°. Correct resection of

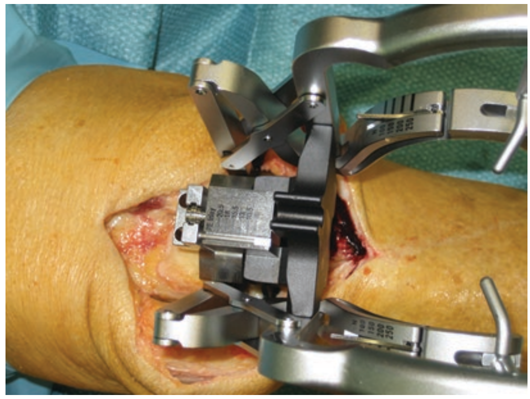

Fig. 31.6 The soft tissue tensioner is adjusted to an 8-mm polyethylene insert. There is a 150 N of distraction force applied to the medial and lateral compartments, and the medial and lateral gap sizes are measured. Zero means that the gap is correct in size for an 8-mm polyethylene insert. Less than zero means that the gap is to tight and further increase as indicated in mm shown is required

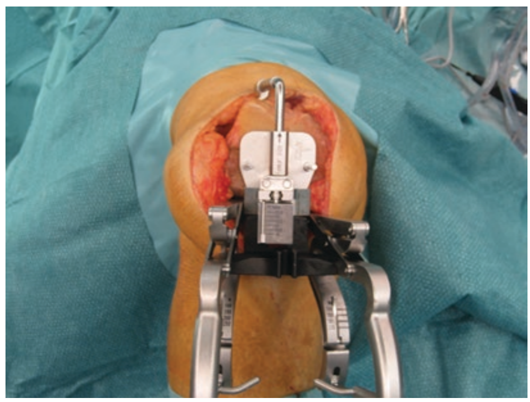

Fig. 31.7 Soft tissue tensioner in 90° of knee flexion. 100 N of distraction force is applied medially and laterally. The femur is externally rotated and one can see a larger gap on the lateral side compared to the medial side. The AP sizer determines the size of the femoral component measuring the distance from the posterior condyles (posterior referencing of the femoral component) to the anterior cortex of the femur

the tibial plateau perpendicular to the mechanical axis is mandatory in order to align the knee correctly in flexion (mechanical alignment). When the knee is appropriately tensioned, the tibial cut should be parallel to the transepicondylar line. Anterior and posterior femoral condylar resections are made using an anterior referencing cutting block. After accu-

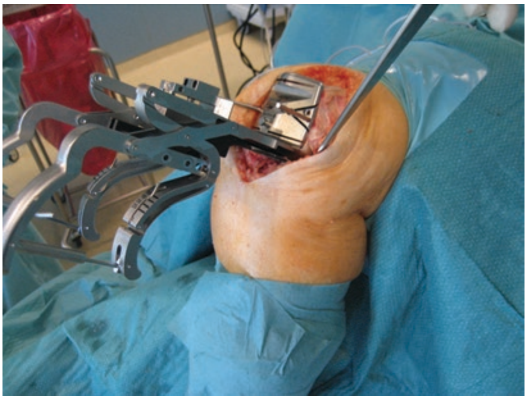

Fig. 31.8 The femoral cutting guide is fixed on the distal femoral cut. The tensioner is inserted again in order to double-check the flexion gap. A mismatch between the medial and lateral spreader would indicate a malrotation of the cutting block

Fig. 31.9 Passive flexion and extension of the knee should be performed throughout the entire range of knee motion prior the capsule is closed. Optimal patella tracking is achieved when there is no subluxation of the patella during knee motion

rate balancing in flexion, attention is directed towards the extension gap. The tensioner is inserted and the distal femoral cut is determined.

31.3 Discussion

The ligament balancing technique depends on the tensioning of the collateral ligaments. Nerve fibres are predominantly located in the ligaments, and medial and lateral retinacula [8, 9]. A neurosensory mapping of the knee revealed that the Hoffa's fat pad as well as the medial and lateral retinaculum belong to the areas with the most discomfort during palpation [10]. Consequently, an unnatural tension of the medial and lateral retinaculum may cause pain after TKA. Therefore, it makes sense to respect and follow the natural ligament tension during TKA.

The most important bony cut during TKA surgery seems to be the tibial cut, which should be perfectly aligned perpendicular to the mechanical axis of the lower limb. This cut will serve as the reference and will determine the following cuts during bone preparation. The following cuts will be performed in accordance to the tension of the collateral ligaments. All osteophytes need to be removed to avoid unpredictable tension in the medial or lateral collateral ligament. The medial collateral ligament is predominantly affected, because most of the knees present varus deformities and medial osteophytes. The medial collateral ligament is very close to the tibial bone. Osteophytes at the medial plateau stretch the collateral ligament and thus need to be removed. Due to the distance of the lateral collateral ligament, osteophytes at the lateral site are of lower relevance. Removal of osteophytes as well as loose bodies from the posterior compartment of the knee is mandatory in order to avoid unnatural tension of the posterior capsule [11]. Knee stability in extension is mainly caused by the posterior capsule, and its overstretching could cause lack of extension. It may also show an impact on the mediolateral balancing of the extension gap.

Very few studies have compared the clinical and functional outcome between ligament balancing and measured resection technique in TKA.

A meta-analysis comparing the gap balancing and measured resection techniques in TKA [12] found that the gap balancing technique seems to be superior in terms of mechanical limb alignment, the rotational alignment of the femoral component and mean Knee Society total and Knee Society function scores. A slight joint line elevation was noticed in the gap balancing group. Similar findings were reported in another meta-analysis, which focused primarily on the soft tissue balancing and femoral component rotation [13]. The femoral component was slightly more externally rotated, and the medial and lateral extension gap difference was smaller in the gap balancing group compared with the measured resection group. A recent randomised controlled trial between the two techniques also showed a decreased intercompartmental force difference throughout the range of motion when the gap balancing technique was used [14].

A spacer block or ligament tensioner can be used for the balancing technique. However, the evaluation by using the spacer block technique showed a potential risk of having a mismatch between the flexion and extension gap [15]. The extension gap might be tighter than the flexion gap, which may have an impact on extension ability. That can be avoided by using a ligament tensioning device, which shows the applied distraction force and the size of the gap at the same time. The exact quantification of the force is the reason that the tensioner device works more precisely than a manual spreader for instance [16].

Take Home Message

- Ligament balancing technique is used to perform the bone resections based on the tensions of the collateral ligaments.
- The combined technique using the measured resection technique for the proximal tibial and distal femoral cuts followed by the femoral component placement according to the ligament tensions seems to be the most frequently used technique.
- Extension gap symmetry seems to be superior with the ligament balancing technique in comparison to the measured resection technique.
- A ligament tensioning device should be used when surgery is performed in the ligament balancing technique. The device exactly quantifies the distraction force and the gape size created by the force allowing to perform the surgery more precisely.

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32 Posterior Femoral Referencing in Total Knee Arthroplasty

Roland Becker

Keynotes

1. Anterior and posterior referencing are the most common techniques for sizing and placement of the femoral component.
2. The anteroposterior sizing of the femoral component is either referenced to the anterior femoral cortex (anterior referencing system) or to the posterior femoral condyles (posterior referencing system).
3. The anterior cortex of the femur serves for the sizing of the femoral component. Undersizing may cause anterior femoral notching oversizing stiffness at the patellofemoral compartment.
4. The morphometry of the knee normal and osteoarthritis knee is discussed.
5. Advantages and disadvantages are discussed when using a posterior referenced knee system.

32.1 Introduction

Correct sizing of the femoral component is essential to achieve appropriate patellofemoral tracking and correct ligament balancing in both extension and flexion. Stiffness or instability causes poor outcome and unhappy patients after total knee arthroplasty.

Anterior referencing for femoral component sizing means that the anterior cortical bone of the distal femur serves for reference, and the sizing of the femoral component depends on the dimension of the medial and lateral condyle. The anterior resection is fixed regardless the size of the femoral component and lowers the risk of anterior cortical notching, while resection of the posterior femoral condylar is variable. Downsizing the femoral component, for example, does not influence the patellofemoral compartment but increases the flexion gap due to decrease of posterior femoral offset. Increase of the flexion gap may improve knee flexion but increases the risk knee instability.

Posterior referencing means that the posterior condyles serve as the reference and the sizing depends on the anterior cut of the femur (Fig. 32.1). In contrast to the anterior referencing systems, the advantage of the posterior referencing systems is changing of the component size without affecting the posterior condylar resection. There is no impact on the flexion gap size and thus knee stability in flexion (Fig. 32.2).

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Downsizing of the femoral component, for instance, results in an increase of patellofemoral mobility; however, there is an increased risk of anterior femoral notching.

Side Summary
Femoral component sizing can be performed by referencing either the anterior femoral cortical bone or the posterior femoral condyle. It depends on the philosophy and the design of the femoral sizer.

Component oversizing is one of the major problems in total knee arthroplasty (TKA) and has been identified in up to 24% of cases (Fig. 32.3A, B) [1]. The implant volume exceeded the resected volume by up to 16%. In contrast, knee instability accounts about 12% of all revision cases to emphasise the importance of proper ligament balancing during surgery.

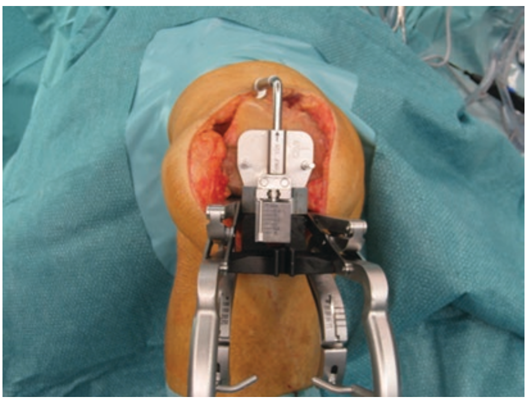

Fig. 32.1 Principle of posterior referencing for femoral component sizing during surgery. The AP sizer is positioned on the anterior cortical bone of the femur

32.2 Morphometry of the Distal Femur

The morphometry of the distal femur shows significant difference between the individuals. Changes in morphology occurs also due to lower limp deformities and osteoarthritis. The bone morphology differs between varus and valgus deformities before and after the development of osteoarthritis. Varus osteoarthritic knees show less distal femoral valgus than controls [2]. There is also a lateral opening of the joint line congruency angle when comparing with the valgus knees. The medial and lateral femoral condyles are approximately spherical except for the distal facet of the medial condyle. A strong correlation has been observed between the radius, the width, the relative positions of the centres of the condyles and the skeletal height [3]. In contrast, no correlation exists between the radius of the condyles and the position of the trochlea.

The varus knee shows a significantly larger distal medial femoral condyle than in normal knees [4]. No difference in the transepicondylar

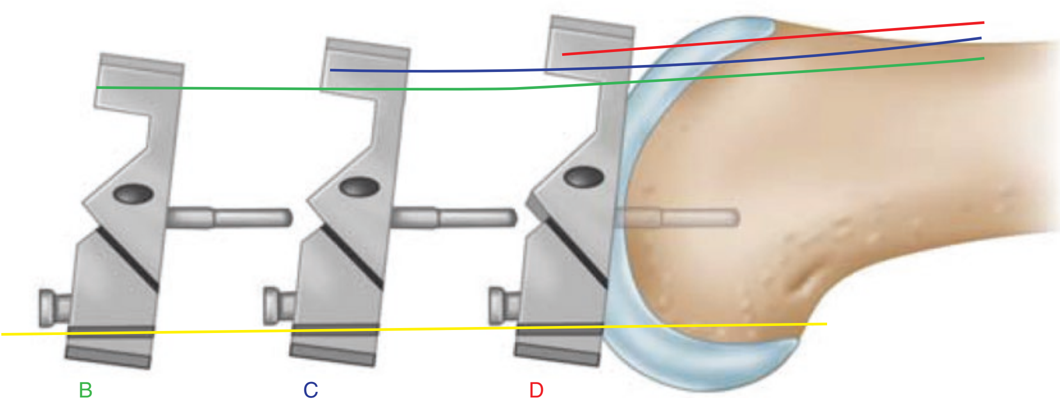

Fig. 32.2 Posterior referencing systems preserve the flexion gap, which is not affected from up- or downsizing

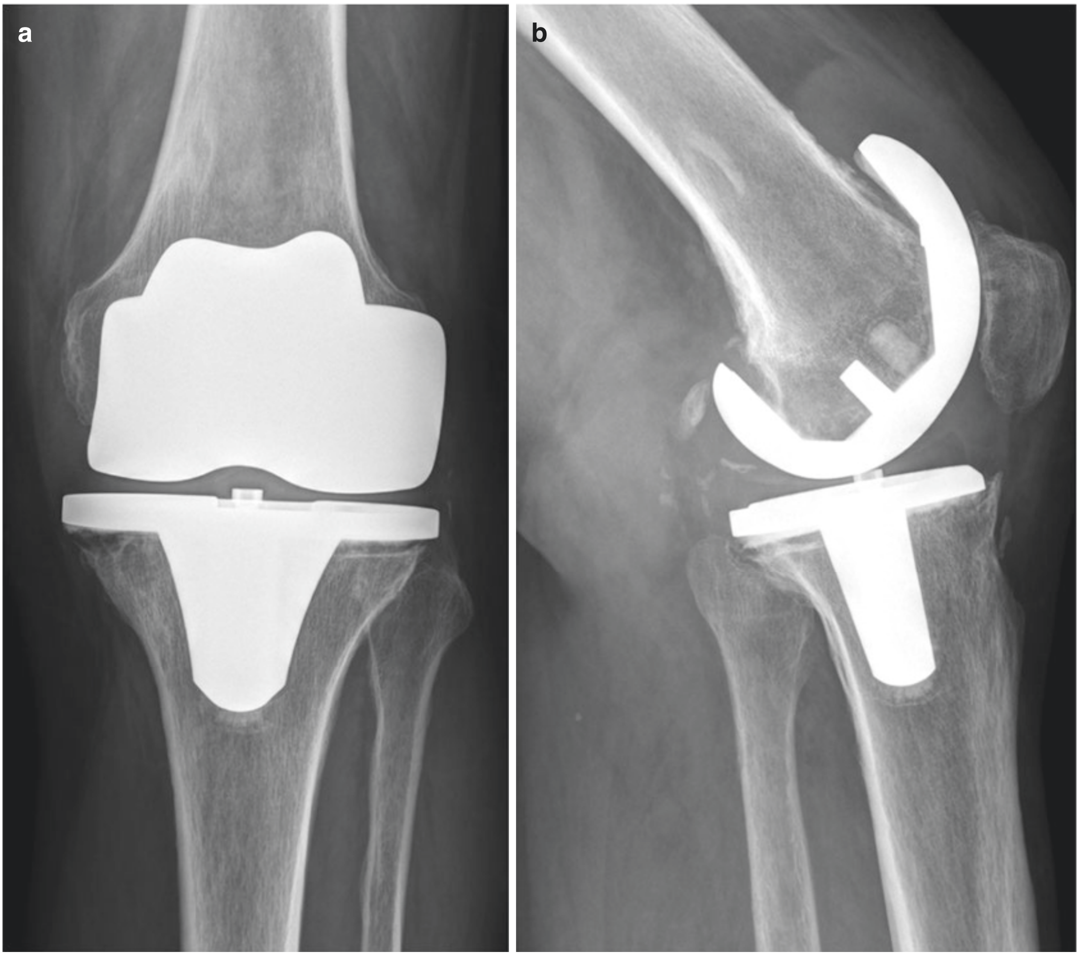

Fig. 32.3 (**a**, **b**) AP and lateral view of the left knee shows oversizing and aseptic loosening of both femoral and tibial component

axis and posterior condylar axis was found between varus and healthy knees. However, the tibial slope in the coronal plane is higher in varus knees than in normal knees. There is also a wide range between the anteroposterior dimension of the medial and lateral condyle influenced by the offset of the posterior condyle and the shape of the trochlea.

Attempts have been made to analyse the distal femoral or proximal tibial dimensions in term of prediction for osteoarthritis. It has been shown that the difference between the mediolateral and anteroposterior dimension is significantly higher in arthritic knees [5]. A greater difference might be a risk factor for developing osteoarthritis.

In general, the varus deformity is caused by a medial tibial disease and lateral joint distraction. The valgus deformity is mostly extraarticular and predominantly based on the femoral site [2, 6].

Side Summary
The varus deformity is caused by medial tibial osteoarthritis and the valgus deformity by extraarticular femoral deformity.

Furthermore, a large difference between the mediolateral and anteroposterior dimension of the distal femur may also be a risk factor for the development of osteoarthritis. Significant gender differences have been reported between both the anteroposterior and mediolateral dimension of the distal femur [7–10]. Based on these findings, some companies took the mismatch between the anteroposterior and mediolateral dimension into consideration and provide gender-specific femoral components. These implants show a smaller mediolateral dimension in comparison to the anteroposterior dimension with the aim to avoid mediolateral overhang of the femoral component. Clinical studies did not find any significant difference in outcome between the normal and gender-specific implants [11, 12].

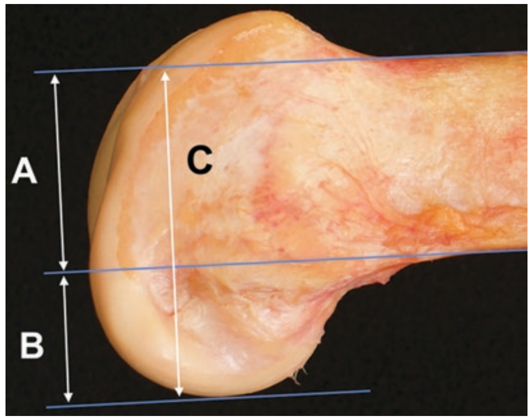

Fig. 32.4 Diameter of the lateral femur (A). Dimension of the posterior condyle (B). The entire anteroposterior dimension is the sum of A+B (C). The offset ratio of the posterior condyle is A/C

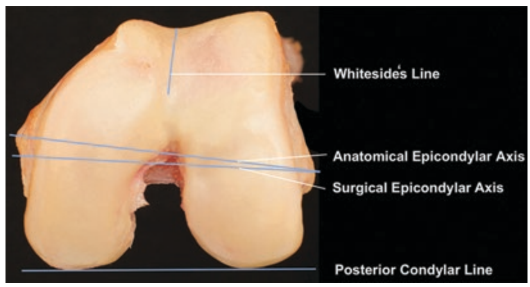

Fig. 32.5 Anatomical references used during surgery for correct femoral component placement of a left knee

32.3 Relation of the Posterior Condylar Line to Other Landmarks for Femoral Component Placement

The posterior condylar line connects the two most posterior points of the medial and lateral femoral condyles. It is one of the most reliable landmarks for femoral component placement and does not solely serve for anteroposterior component sizing but also for identifying correct femoral component rotation in the axial plane. Three other landmarks are important for femoral component placement especially in term of rotation, the anatomical and surgical epicondylar axis and the anteroposterior trochlea or Whiteside's line (Fig. 32.4). Anthropometric studies of osteoarthritic knees have shown that the average posterior condylar line runs in 4° of internal rotation (range of 11° of external rotation to 3° of internal rotation) to the surgical epicondylar line, which is considered of being the flexion/extension axis of the femur [13]. Thus, femoral component placement requires 3–4° of externally rotated in order to be parallel to the surgical epicondylar axis. However, there are 32% of patients who require femoral component placement in more than 4° and 7% less than 4° of external rotation [13].

The posterior condylar offset has been introduced as a ratio between the posterior condyle dimension (B) to a straight line connecting the distance between the anterior and posterior cortex of the femur (A) as shown in Fig. 32.5 [14]. The ratio C/B provides a true dimension of the posterior offset of the condyle regardless the magnification of radiographs and was 0.44 ± 0.02 for male and 0.45 ± 0.02 for female patients. Gender does not seem to show an impact on the posterior condyle dimension [15].

In contrast, difference is shown between the medial and lateral femoral condylar offset on MRI [14]. The posterior condylar offset (B) is larger in male patients than in females (30.7 ± 2.5 mm (male) versus 28 ± 2.7 mm (female)) and also the entire anteroposterior dimension (C) of the knee (male: 71 ± 5.2 mm versus 65 ± 4 mm). However, the authors reported a ratio of the medial femoral condyle of 0.48 and for the lateral femoral condyle of 0.38 without differences between gender. Recent measurements have shown mean posterior condylar offset medially of 34 mm (range 26–45 mm) and laterally of 29.6 mm (range 14–39 mm) [16]. A smaller posterior condylar offset may result in reduced flexion capability due to early posterior impingement.

32.4 Femoral Component Placement Referenced to the Posterior Condyles

The posterior condyles are easy to identify and show an excellent inter- and intra-observer reliability for component placement. However, in sever varus, but especially in valgus osteoarthritic knees, the posterior reference line is inappropriate to identify correct component placement in the axial plan. The mismatch may increase when the contralateral condyle shows intact cartilage posteriorly.

Variation in anterior femoral cortex morphology might also result in improper femoral sizing [17]. The entering point for intramedullary alignment influences the distal femoral cut in the frontal and sagittal plane [18]. This point should be identified clearly during surgical planning. A more posterior entrance point may risk distal femoral cutting in more flexion. Positioning the femoral component in more flexion shows an impact on the anteroposterior dimension of the component. The flexion position causes under-resection of the anterior femoral surface without significant interference with the flexion gap [19, 20]. The anteroposterior distance increases by 2 and 3mm with every 3° and 5° of femoral component flexion, respectively [21, 22].

The distal femoral cut defines the femoral component placement in flexion and extension but also the distal femoral joint line orientation. Because of the smaller size of the intramedullary rod in comparison to the femoral canal, malposition may occur in varus-valgus, anterior-posterior and flexion-extension orientation (Fig. 32.6).

Femoral sizer design can increase anterior notching during TKA [23]. Most of the sizing devices are made parallel to the posterior condylar line but the anteroposterior portion of the femur are resected in general in external rotation, which may cause anterior notching of the lateral distal femur. When the AP sizer is referenced to the posterior condylar line, 3–4° of external rotation is required in order to balance the knee correctly in flexion and to avoid patellofemoral maltracking. However, as already mentioned, there is a significant percentage of patients showing a posterior condylar line outside the 3–4° of external rotation related to the surgical epicondylar line.

Fig. 32.6 Anteroposterior view of the distal femur. The intramedullary rod is inserted for alignment of the distal femoral cut

Femoral component rotation influences the anteromedial sizing and mediolateral overhang. The amount of overhang may depend on the type of implant due to the significant difference in implant geometry. External rotation of the femoral component up to 5° increases the anteroposterior size up to 5 mm [24]. It should be kept in mind specifically when more external rotation of the femoral component is necessary. Patients may require a downsizing of the femoral component in order to avoid overstuffing. External rotation causes a more asymmetrical resection of the anterior femoral cortex. Therefore, the highest point of the anterior femoral cortex should be taken as reference to avoid notching [25]. However, it depends on the system but should have the surgeon's awareness.

Side Summary
Femoral component rotation shows an impact on femoral component sizing. Increase in external rotation increases the size of the component.

The clinical outcome between anterior versus posterior referencing TKA was compared recently [26]. No difference in Knee Society Score, SF-13 and quadriceps strength testing was reported. The proper understanding of the TKA system by the surgeon seems to be most important.

Take Home Message

- Posterior referencing femoral component placement preserves the flexion gap regardless the size of the component. Downsizing can easily be performed and does not affect the femorotibial compartment.
- Increase in component flexion increases AP dimension of the component. It is an alternative, when the surgeon prefers to avoid the usage of a larger component. However, there is a potential risk of mid-flexion instability.
- Increase in external rotation also shows an impact on the AP dimension. Care should be taken when femoral component placement requires external rotation of more than 5°.
- There is no difference in clinical outcome when comparing anterior and posterior referenced TKA.

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Anterior Femoral Referencing in Total Knee Arthroplasty

33

C. Batailler and E. Servien

Keynotes

1. Several bone cuts required in total knee arthroplasty (TKA). The accuracy of these cuts will determine the proper functioning after TKA.
2. The anterior femoral referencing uses a reference point on the anterior femoral cortex to determine the amount and geometry of the bone resected from the anterior surface of the distal femur.
3. The anterior part of the femur is respected allowing an optimal restoration of the femoropatellar compartment, while the posterior femoral condyle resection becomes variable. The choice of the implant size determines the level of the posterior resection.
4. An excessive posterior condylar bone resection will cause a potential increase of the flexion gap and thus a risk of instability in flexion. An insufficient posterior condylar bone resection will cause a tight knee in flexion.
5. By contrast, the anterior referencing allows to decrease the risk of femoral notching and of patellofemoral overstuffing. Based on current evidence, different authors did not find a significant difference of clinical outcomes between anterior and posterior femoral referencing.

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33.1 Introduction

A total knee arthroplasty (TKA) requires several bone cuts. The accuracy and quality of bone cuts determine proper positioning of TKA. Several ancillary instruments are used to perform these different steps and make these more accurate.

For the anterior and posterior femoral cuts, two major referencing systems can be used to ensure the optimal sizing and rotation in performing the corresponding femoral bone resections. These two cuts are linked, and depend on each other, with either an anterior or a posterior referencing. The depth of the femoral bone resected should be replaced by the equal thickness of the implanted femoral component with

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necessary ligament balancing to achieve balanced, well-functioning knees. Each referencing system should be known and mastered with the characteristics including the knowledge about the advantages and disadvantages.

Most of the knee instrumentations use anterior referencing systems for the femoral component. In this chapter, we present the concept of anterior femoral referencing in the TKA, the surgical techniques with the particular clinical scenarios, and the consequences of this referencing method.

33.2 Principles of Anterior Femoral Referencing in TKA

In anterior femoral referencing (AR), the anterior femoral cortex is used as a reference point to determine the amount and geometry of the bone resected from the anterior surface of the distal femur (Fig. 33.1). The anterior part of the femur is respected, while the posterior femoral condyle resection becomes variable. The posterior femoral condyles resection is determined with the size of the implant to reproduce as well as possible the anatomy of the posterior condyles. A significant variation of the posterior condylar offset makes flexion space balancing more difficult. Indeed, this step of TKA has an impact only on balancing in flexion.

In contrast to AR, posterior femoral referencing (PR) respects the posterior femoral condyles, thus reestablishing the joint line in flexion. The counterpart is that in case of downsizing the femoral implant, there is a risk of notching the anterior femoral cortex. Oversizing the femoral implant will risk an overstuffing of the patellofemoral compartment.

The advantages of AR include reduced risk of notching of the anterior femoral cortex and the optimal restoration of the patellofemoral joint. Indeed, the anterior part of the femur is preserved. The surgeon can thus anticipate the risk of notching and adapt the anterior cut to avoid it. Anterior femoral notching may increase the risk of postoperative periprosthetic fractures. It was established that notch depths of 3.0–3.5 mm produces full-thickness cortical defects [1, 2].

Fig. 33.1 Scheme of a left knee after distal femoral resection at step of femoral AP sizing. The anterior finger is placed to obtain the optimal anterior femoral reference. The change of the finger position changes the position of the pins and the femoral component size

Biomechanical studies revealed that notching significantly reduced the mean load to failure by 18% in bending strength and by 39% in torsion strength [2]. In the same way, the surgeon reproduces the anterior anatomy and thus avoids the overstuffing of the patellofemoral joint. Persistent anterior knee pain after TKA is a common problem with a rate of almost 5–10% [3]. One of the reasons is overstuffing of the patellofemoral joint by insufficient resection of the patella or the anterior femoral cut.

The disadvantages of AR include a risk of a flexion instability due to a potential increase of flexion gap as a result of excessive posterior condylar bone resection [4]. It is established that for every 1mm loss of posterior condylar offset, the degree of flexion is reduced by a mean of 6.1 degrees due to an earlier impingement [5]. In contrast, the flexion gap might also be too tight when posterior condylar bone is not enough resected. In these cases, patients complain about a painful knee and limited flexion.

A key to maximal flexion is to accurately reproduce posterior condylar offset. Flexion gaps are affected by the implant size, as a larger implant may inhibit flexion and a smaller implant may lead to flexion instability.

33.3 Surgical Technique of Anterior Femoral Referencing in TKA

AR is performed after the distal femoral cut. The tibial resection can be realized before or after according to the surgeon's strategy.

Firstly, a sizing guide is placed on the flat surface of the distal femur, and the femoral implant size is determined with the aid of a femoral finger which is placed on the anterior cortex. The resection guide is then fixed with two pins. Possible resections are checked to avoid excessive bone resection (Fig. 33.2a–e). Finally, the anterior cut is made, followed by posterior and chamfer cuts. After the posterior femoral resection, the surgeon can check the flexion gap and compares it with the extension gap secondary to the distal femoral cut.

In this AR technique, the surgeon must determine the optimal point on the anterior cortex, which will be the basis for AR. However, the anterior femoral cortex is highly variable. Hence, it might be difficult to have a sufficient exposure

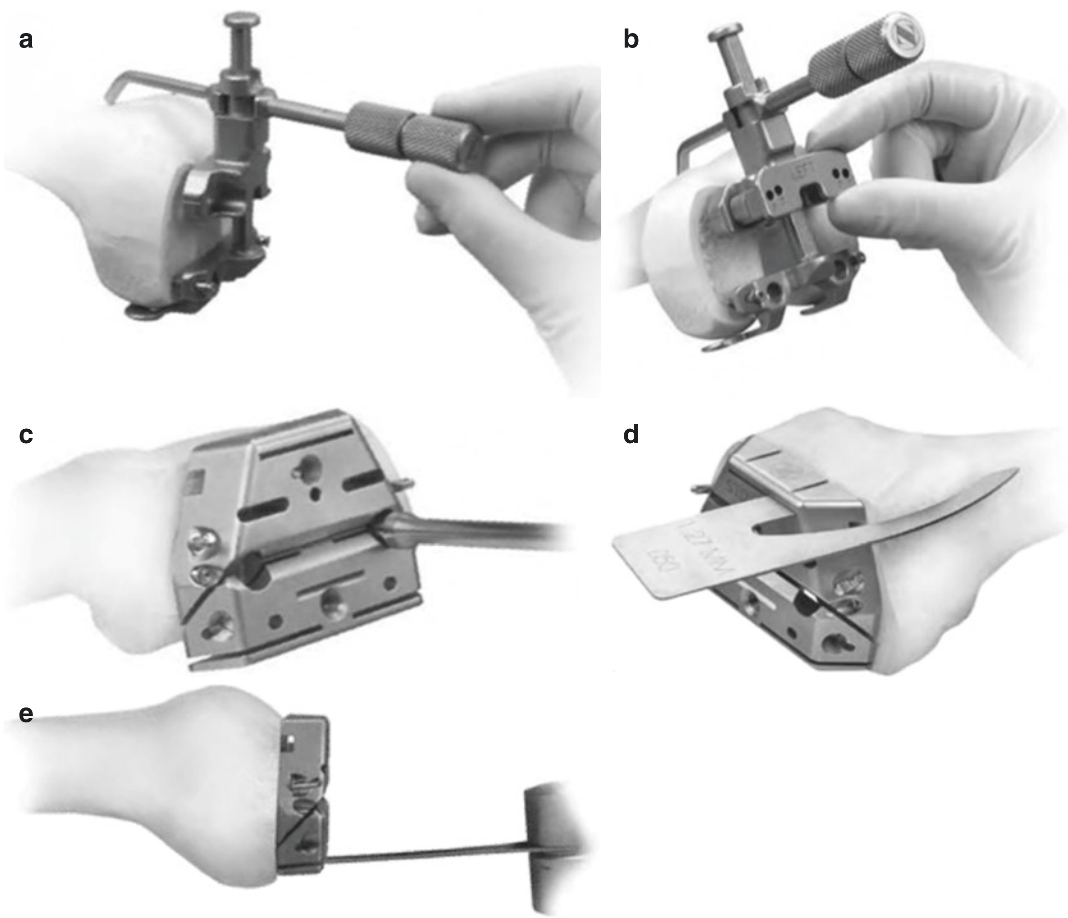

Fig. 33.2 (**a**, **b**) Anterior referencing at the anterior femoral cortex, and pin placement of position the resection guide. (**c**–**e**) The resection guide is fixed on the distal femoral cut. The depth of the anterior and posterior cuts is checked before the resection to avoid an excessive resection

when using a mini invasive approach [6]. The most common type of anterior femoral cortex is characterized by the highest points at the lateral aspect and the lowest on the medial aspect. The second most common anterior femoral cortex type has the central area as the lowest point with both medial and lateral sides being higher [7, 8]. Two other profiles are rarely seen: the "convex"-shaped anterior femoral cortex with the central area being the highest and the "twisted" shape of anterior femoral cortex when the highest point is on the medial side [9]. During positioning of the instrumentation, the surgeon should consider femoral asymmetry but also femoral external rotation to be aimed for. Usually, the femoral finger is positioned on a central point to obtain a mean. If the surgeon positions the femoral finger on the highest point, an overhang of the femoral implant at the medial side and an overstuffing of the patellofemoral joint with persistent anterior pain is risked. If the femoral finger is positioned on the lowest point, anterior femoral notching might occur. However, this also depends on the TKA system used.

Correct rotational alignment of the femoral implant in TKA is also important for anterior resection. Achieving correct femoral rotation in TKA can be difficult due to extensive wear or difficulty in identifying anatomical landmarks.

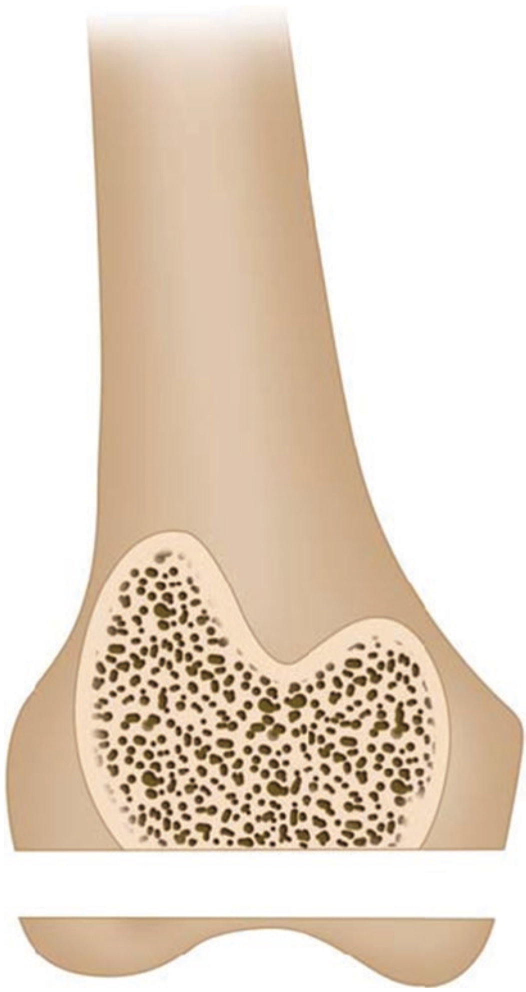

Fig. 33.3 Grand-piano sign at the anterior femoral cortex

33.4 Impact of External Femoral Rotation

An asymmetric anterior femoral resection due to 3° of external rotation causes an anterior femoral cut which mimics the shape of a piano and is called "grand-piano" sign (Fig. 33.3) [10]. When the external rotation is excessive, it leads to a reduction in the contact area between the anterior cut surface of the medial femoral condyle and the femoral component with the overhang of the latter. In this scenario, the classic "grand-piano sign" is transformed into the "boot sign" (Fig. 33.4). The new implant designs that allow narrowing of the medial–lateral width decrease the risk of overhang, especially in female patients. Middleton and Palmer found that a more externally rotated femoral component has a higher risk of anterior femoral cortex notching [11].

33.5 Typical Clinical Scenarios

In a simple case, the patient's femur exactly matches the size of a femoral component. However, very often the femoral sizer indicates a femoral component between two sizes.

Usually the smaller size of femoral implant component is typically recommended if the patient's femur appears to be in between femoral component sizes [4], to avoid a tight knee in flex-

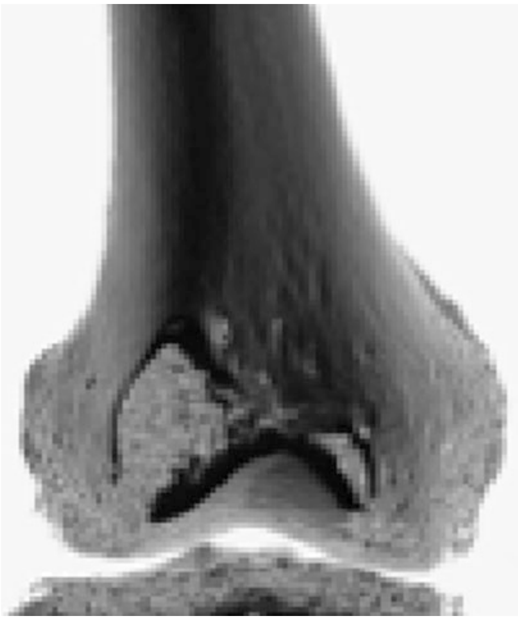

Fig. 33.4 Boot sign

ion. The counterpart is that the surgeon cuts more posterior femoral condyle off. That elevates the joint line in flexion and may lead to excessive flexion gap (Fig. 33.5a–d).

That is why the choice of implant size should also consider the extension gap. A smaller size component is chosen for an "in-between" sized femur if the flexion gap is smaller than the extension gap or is larger than an extension gap of ≤2 mm. If the flexion gap is more than 2 mm larger than the extension gap, the larger size femoral implant is chosen.

The anterior femoral resection plane is also sometimes flexed at 3–6 degrees in some implant systems to reduce the possibility of notching and under resection. Some contemporary implant's designs with not more than 3 mm between sizes in the sagittal plane also assist in the "right-sizing" capability in diverse anatomical landscapes.

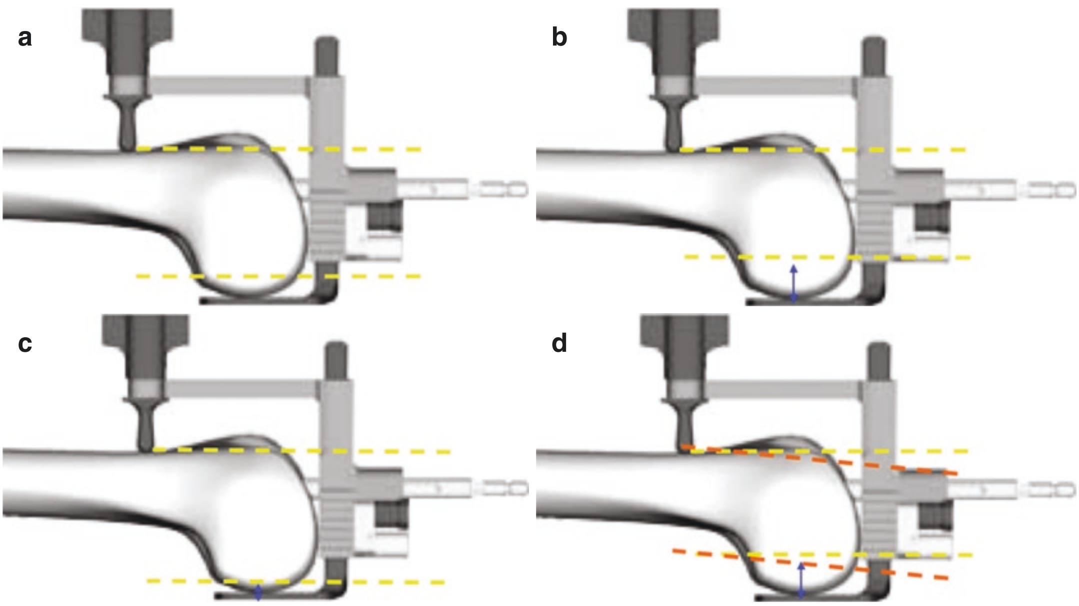

Fig. 33.5 (**a**) The femur corresponds to one size of a femoral component. The anterior resection is flush with the anterior cortex. The posterior resection has the same thickness as the femoral component. The flexion gap should be equilibrated with the extension gap. (**b**) If the femur appears to be in between two femoral component sizes, the smaller size of the femoral component is chosen. The anterior resection remains flush with the anterior cortex. The depth of the posterior resection is higher than the thickness of the implant. The flexion gap will be increased. There is a risk of TKA instability in flexion. (**c**) If the femur appears to be in between two femoral component sizes and the larger size of the femoral component is chosen, the anterior resection remains flush with the anterior cortex but the depth of the posterior resection is smaller than the thickness of the implant. The flexion gap will be decreased. There is a risk of postoperative pains with a tight knee in flexion. (**d**) If there is a risk of anterior notching, the femoral component is placed in 3° of flexion. This allows to increase the posterior offset in order to decrease the flexion gap without the risk of anterior notching (yellow lines: anterior and posterior resections without flexion; orange lines: anterior and posterior resections in 3° of flexion)

The resection guide can be put more anteriorly or posteriorly without changing the femoral component size, to avoid an excessive resection, in particular an anterior notch. Nevertheless, this reduction of anterior femoral bone resection causes the risk of an excessive posterior resection. This then might lead to TKA instability in flexion.

Several referencing systems allow to use both posterior and anterior referencing concepts. These are the jigs that have different placement of the pins depending on the measured size. These are still typically PR but allow secondary AR to avoid notching. This might have the advantage of allowing to downsize initially while cheating anteriorly to avoid notching.

33.6 Influence of AR on Outcome in TKA

A randomized study on 100 patients demonstrated that outcome is independent from the referencing system used. The same outcomes (Knee Society scores, range of motion, strength, SF-12 surveys) in postoperative period and at 1 years follow-up were seen [9].

In another randomized study on 20 patients undergoing bilateral TKA, one knee was operated using AR and the other using PR. The same results with similar range of motion and Knee Society scores were shown [12].

Although outcomes are similar with both referencing systems, these systems have different effects on the change of posterior condylar offset (PCO). Restoring PCO is rarely achieved with AR instrumentation [5]. With this AR system, PCO can decrease if a smaller femoral component is selected for "in-between"-sized cases, whereas PCO can increase if a larger one is selected. Theoretically, a PR system should accurately restore the offset because resection of the posterior condyle equals the thickness of the component [13].

Han et al. reported that postoperative medial and lateral posterior condyles offset values were significantly greater in the AR group than in the PR group [12]. The magnitude of the change in PCO after TKA was greater in the AR group than that in the PR group. Some authors have found that a postoperative decrease in PCO can reduce knee flexion, because of an early impingement after TKA [5, 14–16]. However, Fokin et al. [9] and Han et al. found no difference in range of motion between the two referencing systems, even with a significant difference of postoperative PCO.

Take Home Message

The end goal during TKA is to recreate an optimal knee function through precise bone resections complemented by appropriately positioned implants of right size. The anterior referencing system allows a satisfying restoration of the patellofemoral compartment, but the restoration of the posterior condyle offset can be more difficult. A good knowledge and understanding of the referencing systems and of the TKA balancing is primordial to obtain a well-functioning knee. No significant difference for the clinical outcomes has been found between the anterior and the posterior femoral referencing.

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34 Tibial Component Rotation in Total Knee Arthroplasty

K. M. Ghosh and David J. Deehan

Keynotes

1. Tibial component rotation plays a key role in tibiofemoral and patellofemoral kinematics.
2. Numerous landmarks exist with no consensus for an optimal reference.
3. The surgeon should pre-plan, as much as possible, component placement using all imaging modalities available.
4. Tailor the position to your patient—choosing an axis is better than using a single point.
5. Be familiar with the implant system, especially the tibial baseplate design and use it to your advantage.
6. Do not forfeit correct component rotation for maximal bone coverage.
7. Do not excessively externally rotate the tibial component to compensate for an internally rotated femoral component.
8. Your goal should be to create a stable, congruent articulation through a range of motion.

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34.1 Implications of Component Rotation on Tibiofemoral Kinematics

In general, native knee kinematics is complex, especially during flexion. Native deep flexion involves 10–15° of tibial internal rotation, little translation of the medial femoral condyle and 15–25 mm of posterior translation on the lateral side. Both fixed-bearings and rotating platform designs deviate from native knee kinematics. Many believe that restoring native knee kinematics could provide improved outcomes in TKA. However, with current implant designs this is unachievable. The goal should therefore be to create a stable, congruent articulation throughout a full range of motion.

Bonnin et al. noted that correct positioning of the tibial component requires that two criteria be fulfilled simultaneously: first, implant rotation ensuring optimal knee kinematics, and second, optimised prosthetic coverage ensuring uniform load transfer [1]. These goals can often be conflicting.

34.1.1 Internal Rotation of the Tibial Component

Numerous studies have highlighted the clinical and biomechanical consequences of internal rotation. Relative internal rotation of the tibial

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component effectively increases the Q angle and changes the force vector on the extensor mechanism. The abnormal stress on the patella and surrounding soft tissue explain the patellofemoral joint symptoms observed. Equally catastrophic is the significant articular mismatch that occurs against an externally rotated femoral component. Reports have mentioned flexion and mid-flexion instability due to poor matching between the tibial and femoral components through the range of motion. Retrieval and biomechanical studies have also shown a strong association between malrotation, abnormal polyethylene stress causing premature wear leading to component failure.

Barrack et al. reported that even small deviations (6.2°) towards internal rotation of the tibial component were associated with increased postoperative pain [2]. A literature review found an increase of internal rotation exceeding 10° has a negative impact on outcome [3].

Side Summary
Internal rotation of the tibial component of more than 10° shows negative prognostic factor. However, an exact cut off point does not exist.

34.1.2 External Rotation of the Tibial Component

External rotation of the tibial component equalises the flexion gap, medialises the tibial tubercle, improves patellar tracking and improves tibiofemoral congruence especially in extension. There is a common assumption that tibial external rotation is not a factor within the painful TKA and that there are no negative consequences to external rotation [4, 5]. However, the surgeon must remain cautious as this in not a benign manoeuvre. Excessive external rotation can just as easily lead to tibiofemoral incongruence as well as increased medial compartment load with accelerated postero-medial wear [6, 7]. The surgeon should not excessively externally rotate the tibial component to compensate for an internally rotated femoral component. This can lead to catastrophic failure.

The lack of consensus as well as the variability in the anatomical landmarks used in determining tibial component rotation makes it difficult to provide definitive guidance. Suffice to say there is a margin of error and the surgeon must avoid internal rotation. As such, we have described a number of techniques that the surgeon can choose to use, develop or modify to provide the best possible outcome for their patient.

Side Summary
External tibial component rotation improves patella tracking and femorotibial congruency.

34.2 Bony Landmarks of the Proximal Tibia

The transepicondylar axis (TEA) has been the established medial lateral axis of the femur, and setting the femoral component parallel to the transepicondylar axis is considered reasonable. However, the lack of accuracy of femoral component rotation derived from the TEA is well documented. Stoeckl et al. measured the intra-observer errors and repeatability with which surgeons identify the TEA. They found a mean change of the epicondyles was >3 mm leading to a rotational change of the femoral component by up to 8° [8]. Even so, compared with the femur, there is little consensus given to establishing guidance for alignment and orientation of the tibial tray.

In this section, observations of the tibial landmarks in TKA are reported, and evidence for reproducible landmarks that are useful for tibial preparation are identified.

Side Summary
Change of the epicondyles of more than 3° leads to change of the femoral rotation of 8°.

The **intraarticular anatomical references** including

- Posterior condylar line
- Transcondylar line of the tibia
- Midsulcus line of the tibial spine
- Anterio-medial border of the tibial plateau

are used to determine the rotational orientation of the tibia. However, osteophyte formation, destruction of the tibial articular surface and general anatomic variations can make it difficult to correctly determine this reference axes in an operating field.

Similarly, the conventional **extraarticular anatomical references** such as

- Tibial tuberosity
- Transmalleolar axis of the ankle and the second metatarsal bone of the foot

vary amongst patients and are not necessarily reliable. Ethnic considerations as well as severity of osteoarthritis may result in a wide variation of rotatory profiles, which the surgeon must plan for prior to surgery.

The goal of arthroplasty is not necessarily to restore the kinematics of the native knee, but to provide a congruent, stable construct with a centrally tracking patella. As such, a favourable requirement is that tibial rotation complements femoral rotation in order to avoid rotational mismatch, equalise load, avoid point loading and impingement through the arc of motion.

Side Summary
The goal of arthroplasty is to provide a congruent, stable knee with centrally tracking patella.

34.2.1 Tibial Tuberosity (Fig. 34.1)

The junction of the medial and mid third of the tibial tuberosity remains the most popular and easily identifiable landmark. Described by Insall [9], this landmark has been adopted most frequently with recent evidence showing positioning of the tibial component in this location produces the lowest retropatellar pressures [10]. However, evidence for using this landmark in relation to tibio-femoral kinematics remains empirical at best. In CT studies, the position of the tibial tubercle varied more than any other point in the mediolateral plane [11]. Furthermore, a number of studies have shown that rotatory mismatches of up to 19° can occur when compared to the axis of the femoral component [6, 12].

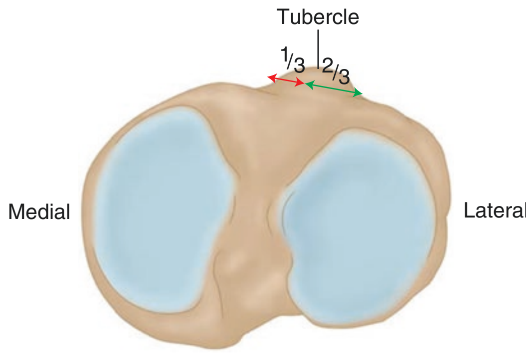


Fig. 34.1 Tibial tuberosity landmark (junction between medial one third, lateral two thirds)

Side Summary
The junction of the medial and mid third of the tibial tubercle remains the most popular landmark.

34.2.2 Posterior Tibial Condylar Axis (Fig. 34.2)

This is defined as the line joining the two most posterior points of the tibial plateau. This landmark can be used as a reference to prevent posterior overhang of the baseplate and improve implant coverage. With the knee in extension, this axis lies between 5 and 10° of internal rotation relative to the femoral epicondylar axis depending on the relative size of the condyles and the level of resection. An MRI study by Graw et al. [13] concluded that, assuming the normal posterior condylar line of the tibia is visible (e.g. in a revision setting), the tibial component at 10° external rotation with respect to the posterior

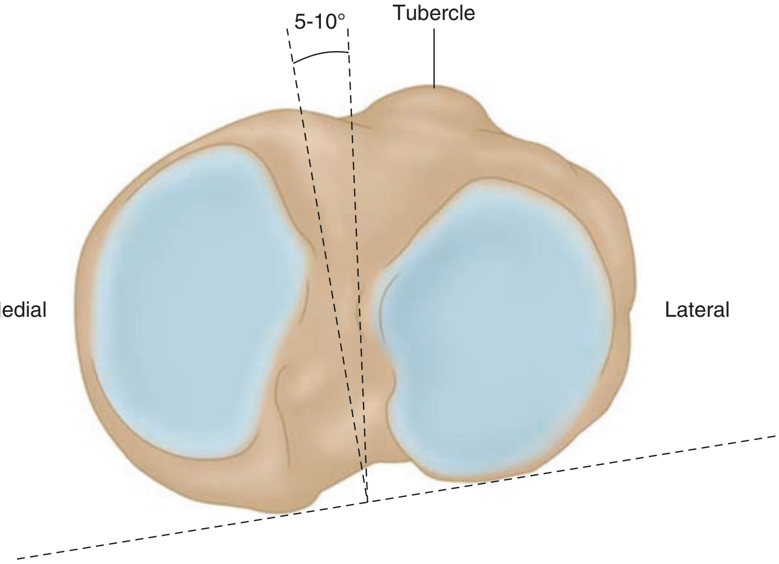


Fig. 34.2 Posterior condylar axis

condylar axis gets the tibial component within 10° of proper rotation in 86–98% of patients, even with resection levels to the distal part of the proximal tibiofibular joint.

> **Side Summary**
> When using the posterior condylar line, tibial component placement should be in 10° of external rotation.

34.2.3 Transtibial Axis (Fig. 34.3)

This is defined by a line joining the midpoint of lateral and medial compartment of the tibial plateau. This axis can be used as a guide for maximal implant coverage and has been defined in anatomical studies as the true neutral axis of the knee serving as a proximal reference point for measuring tibial torsion [14]. This axis is often referenced during knee navigation but can be difficult to identify in osteoarthritis especially with the presence of osteophytes or severe wear. Anatomical studies have shown this landmark to have the least variability of all intra-articular landmarks and result in a rotatory mismatch of approximately 5° to that of the femoral component aligned to the transepicondylar axis [6, 11].

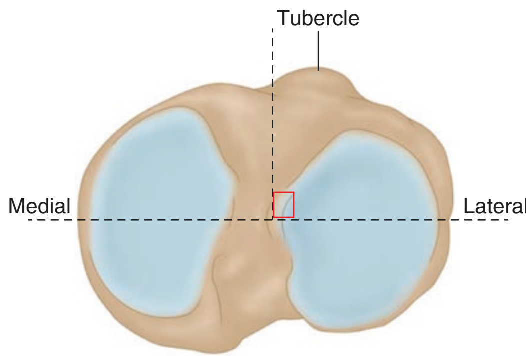


Fig. 34.3 Transtibial axis

34.2.4 Anterior Surface of the Tibia (Fig. 34.4)

This bony landmark was investigated using both MRI and CT studies with the assumption that a single area would be a more readily identifiable landmark than a single point or a line, when setting component rotation [15–17]. Rotation of the component in both studies was measured after placing a 'tracing' of the implant so that it conformed to the anterior surface of the tibia on axial

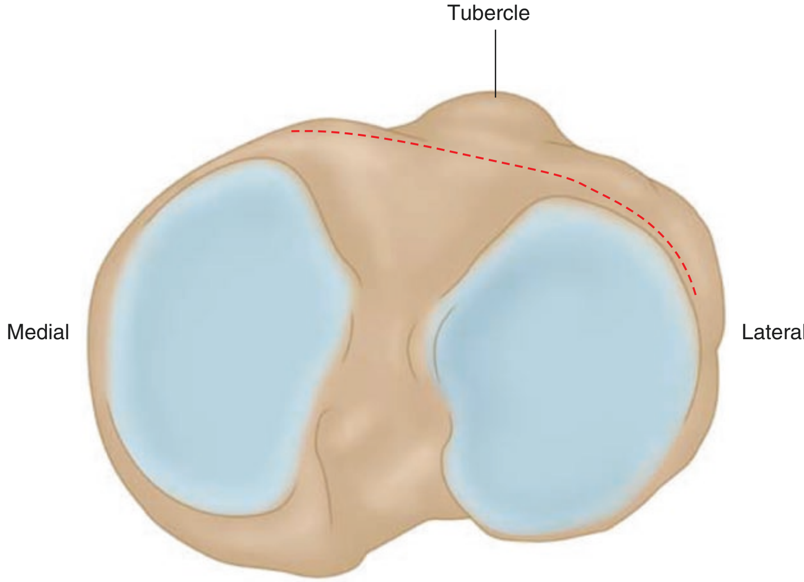


Fig. 34.4 Anterior border of tibia

slices. This landmark was found to be both reliable and reproducible when compared to other alignment techniques. However, the practicalities of using this region intraoperatively may depend on access (e.g. obese patient, small knees). This landmark may therefore be useful in pre-operative planning, for example, patient specific implant systems.

34.2.5 Patellar Tendon to PCL Axis (Akagi's Line) (Fig. 34.5)

This is a line projected from the centre of the PCL to the medial edge of the patellar tendon. Initially proposed by Akagi et al., based on CT studies, they reported that the mean angle between this line and a line perpendicular to the clinical epicondylar axis of the femur in normal knees was 0°, ranging from 6.3° of internal rotation to 5.2° of external rotation. Several studies have also reported that Akagi's line was the least affected by inter-observer inconsistency, and, therefore, provided the most reliable guidance for determining tibial rotational alignment [16, 18–20].

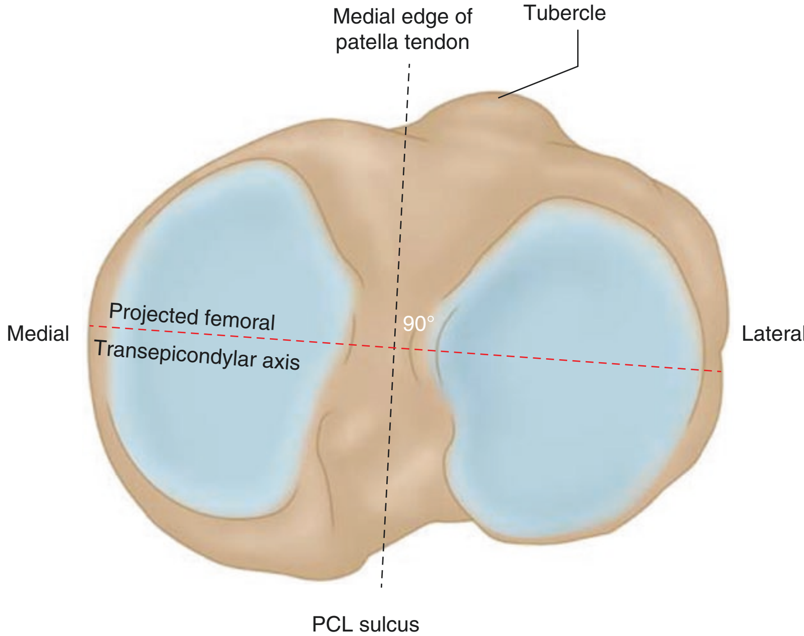
Side Summary
Akagi's line is the most reliable line for determining tibial rotational alignment.

34.2.6 Other Extra-Articular References

The trans-malleolar axis and the second metatarsal can also act as a guide when referencing overall tibial rotatory alignment and are commonly used in extra-medullary conventional as well as navigated knee systems. When using these references, one has to bear in mind the effect of osteoarthritis on the joint being referenced joint. Furthermore, patients with varus pattern OA have reduced tibial torsion compared to healthy counterparts. This is also made worse with severity of disease [18, 21].

Each of the described landmarks has their strengths and weaknesses and as yet there is no agreement in the literature. To that end, it is beneficial for the surgeon to be aware of all of these landmarks and utilise them when necessary in order to achieve the primary goal of a stable, congruent articulation.

Fig. 34.5 'Akagi' line



34.3 Surgical Techniques Used to Determine Rotational Alignment

34.3.1 Single Point/Single Axis

As highlighted in the previous section, numerous landmarks are available as a frame of reference for component alignment. Tables 34.1 and 34.2 offer a summary of just some of the studies that have offered a solution to optimal positioning of the tibial baseplate. The surgeon must decide depending on planning, exposure and implant system used which point or axes to utilise to achieve their goal. In general, use of an axis is more reliable than a single point. Siston et al. demonstrated a high variability in tibial rotation when using these techniques so a pragmatic approach is needed [29].

Side Summary
There are single anatomical landmarks and lines connecting different landmarks used as references for component placement.

Table 34.1 Anatomical references based on points for tibial component placement

Study	Anatomical reference
Incavo et al. [22]	Medial third of the patella tendon
Lutzner et al. [23]	Medial third of the tibial tubercle
Matziolis et al. [24]	Most prominent point of the tibia
Ikeuchi et al. [25]	Medial border of patella tendon attachment
Rossi et al. [26]	Postero-lateral tibial corner

Table 34.2 Anatomical references based on connecting lines of landmarks for tibial component placement

Study	Anatomical reference
Akagi et al. [12]	Project TEA line starting a medial aspect of the PT to centre of PCL
Dalury et al. [27]	Mid-point of tibial spines passing 1 mm medial to tibial tubercle
Luo et al. [28]	Line perpendicular to posterior joint surface passing to medial third tibial tubercle
Graw et al. [13]	10° external rotation from the posterior condylar tibial axis
Cobb et al. [11]	Line joining the centre of three best-fit circles of the medial tibial condyle, tibial spines and lateral tibial condyle

34.3.2 Range of Motion/Self-Adjustment Method

This technique does not require the use of anatomical landmarks, but instead uses the implanted femoral condyles upon which the tibial baseplate self aligns. Two techniques have been described. The first where the knee is flexed and extended through a full range of movement, and the second where the baseplate positions itself to the femur with the knee in extension—described by Eckhoff et al. as the 'coupled component' technique [6]. The strengths of this technique mean anatomical references are ancillary. The femoral and tibial components remain parallel, theoretically providing congruent articulation and equal distribution of load through a single arc of rotation across the transepicondylar axis. However, this 'dependent' method of alignment relies entirely upon the correct rotation of the femoral component. Any malalignment would therefore lead to a compound error. Further, the tibia rotates independently of the femur in flexion, as such more conforming implant designs or PCL substituting polyethylene posts may be subject to abnormally high loads leading to early failure.

Side Summary
A major concern when using the self-adjustment method tibial component placement relies on the position of the femoral component. Incorrect femoral component position will automatically cause an incorrect tibial component position.

34.3.3 Navigation

Computer navigation provides a reliable and reproducible method of performing bone cuts and certainly, reduces outliers for sagittal and coronal alignment. The workflow on most navigation systems also requires the registration of a number of key tibial landmarks, and all systems do provide the ability to attach an optical tracker to the tibial baseplate in order to dial out the tibia. Despite this, there is conflicting evidence as to whether computer navigation improves the accuracy of component rotation. A prospective randomised controlled trial by Schmidt et al. compared alignment and patient-reported outcomes in navigated versus non-navigated TKRs. On post-op CT, they found more tibial components were 'optimally' rotated in the navigated series (56% vs. 32%), but this did not reach statistical significance [30]. They found no difference in clinical outcomes. Another recent randomised controlled trial compared two registration methods between 220 navigated TKRs and found tibial component rotation to have the widest variation in component alignment [31].

Side Summary
Navigation improves accuracy in component placement.

34.3.4 Symmetric Versus Asymmetric Tibial Baseplates (Fig. 34.6a, b)

Maximising tibial coverage has been proposed to provide increased fixation by improving load transfer from the implant to the proximal tibia to avoid subsidence and/or loosening. Martin et al. studied four different tibial component designs and found that the practice of implanting symmetrical tibial trays in the orientation that maximises fit and coverage of the exposed tibial bone led to malrotation of the implant in internal rotation in a majority of cases [32]. Anatomic/asymmetric tibial component designs have been proposed to increase morphological fit to the proximal tibia compared to non-anatomic designs and produce significantly less malrotation [33]. For the surgeon using a contemporary (symmetrical) design, the size of the tibial baseplate should be selected in preference to achieving correct rotation first before achieving maximal tibial coverage. Numerous authors have reported that no more than 75% tibial coverage is required to achieve adequate tibial fixation.

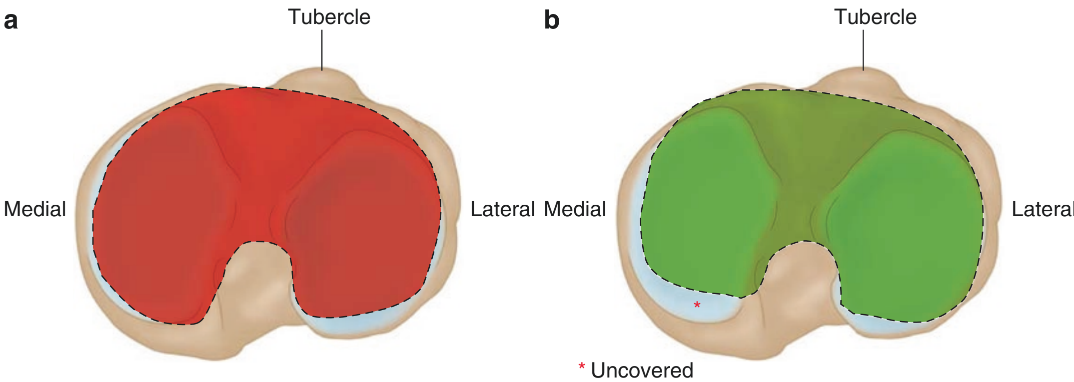


Fig. 34.6 (**a**) Asymmetrical tibial component. (**b**) Symmetrical tibial component

34.3.5 Rotating Platform TKA

The principle behind mobile bearings is to create a rotational articulating surface, thereby uncoupling the translational and rotational forces about the knee. The popularity of rotating platforms stems largely from the results of early in vitro wear studies that showed less cross-shear forces and better wear characteristics than their fixed bearing counterparts [34, 35]. Though these findings are largely refuted, particularly with modern polyethylene, there is a compelling argument that improved axial rotation would appear to provide greater forgiveness to rotational malalignment. The concerns with rotating platform/mobile bearing inserts have largely been reported in their behaviour over time or in deep knee flexion where reversed or divergent axial rotation has been noted between the femur and the polyethylene. The possible reasons given have been reduced rotation and loss to congruence after 2 years [36] or excessive rotation that exceed the limits of the implant [37].

Take Home Message

- There are different single anatomical landmarks, which may be used for correct tibial component placement. Lines connecting different anatomical landmarks are also used. Akagi's line is the most reliable line for achieving tibial rotational alignment.
- The usage of two different landmarks or lines may help to improve accuracy in component placement.

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35 Patient-Specific Instrumentation in TKA

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Keynotes

1. Patient-specific instrumentation is individually produced for one patient and relies on CT or MRI data. It aims to help with optimal alignment and position of prosthesis.
2. Literature on patient-specific instrumentation (PSI) is contradictory as mid- and long-term clinical follow-up studies are scarce.
3. Most recent literature shows favorable radiographic outcome using PSI when compared to conventional instrumented knee arthroplasty in high-volume surgeons.
4. When using PSI, each individual preoperative planning should be approved by the operating surgeon.
5. Optimized logistics inside and outside the operating room will potentially reduce hospital costs.
6. No difference in clinical outcome has been reported between conventional knee arthroplasty and PSI. However long-term data are not available yet.

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35.1 Introduction

Correct alignment of individual components within the range of three degrees varus or valgus perpendicular to the biomechanical axis is one of the key factors to improve longevity of total knee arthroplasty (TKA) [1]. During conventional TKA, correct position of the components is determined intraoperatively with the use of alignment rods. However, several studies reported about postoperative malalignment of over 25% of outside the range of +/−3° using conventional alignment rods in TKA [2–6].

Due to the development of new technologies and the aim to improve implant alignment, TKA has been developed significantly over the last decades. Computer-assisted surgery (CAS) was introduced to cope with malalignment and instability in conventionally placed prostheses [7]. CAS eliminates the use of traditional intra- and/or extra-medullar rods and recreates the anatomical axis by accurate landmark registration of the center of the femoral head, knee, and ankle joint [2, 4]. Recently a meta-analysis showed that

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malalignment was reduced from 28.3% after conventional surgery to 12.2% after CAS [3].

Patient-specific instrumentation (PSI) is one of the latest innovations in TKA. PSI means that for the implantation of the total knee prosthesis, specific jigs are designed based on patient's anatomy. These jigs fit optimally on the patient's knee. There are two different concepts, one providing the patient-specific disposable cutting blocks and the other providing jigs, which guiding pin hole placement for the standard cutting blocks. Appropriate sizing of the femoral and tibial component and the lower limb alignment in all three planes is included in the planning. A concern that arises with any new technique is whether it will improve clinical and function outcome in a long term.

Side Summary
Malalignment is associated with poor implant survival.

Side Summary
Patient-specific instrumentation means cutting blocks produced for each individual patient.

35.2 Preoperative Considerations

PSI requires a preoperative MRI, CT-scan, or a combination of MRI and a long-leg standing radiograph [8, 9]. The method of image acquisition and preoperative planning is not standardized between the different manufacturers. Using computer-mapping algorithm software, based on the imaging protocols of the different manufacturers, a preoperative patient-specific virtual 3D computer model of the knee is generated by a technician showing the proposed bone cuts, alignment, and sizes of the femoral and tibial components. This default templates are sent to the operating surgeon, who can then make adjustments to the plan as preferred. Based on this 3D computer model, well before the surgery, the operating surgeon is able to see the knee joint from multiple angles using multiple visual options. Final component position and size of the prosthesis should always be validated digitally and approved by the surgeon before manufacturing the 3D rapid prototyped disposable cut or pin guides [10–14]. Studies have shown that the reliability of templating ranges between 23% and 95%. Once approved, polyamide pin guides/cutting blocks are created, using rapid prototype technology, for the surgeon to use. These guides fit at best perfectly on the native anatomy of the individual patient in order to place the cutting block. Thus, the surgeon is able to carry out the bony resections of the femur and the tibia reliably [9, 15].

There is still a controversial discussion whether CT or MRI is the more preferable imaging modality for PSI. While a recent review showed that MRI might be slightly higher accuracy than CT, the authors claim that current evidence is rather weak and does not allow to favor one or the other imaging modality [13, 16].

Side Summary
PSI requires preoperative planning based on MRI or CT.

Side Summary
Planning is performed by the manufacturer, and it should be mandatory for the surgeon to give final approval for the planning. The usage and correctness of the PSI-jigs lie in the responsibility of the surgeon.

Side Summary
There is still no evidence whether CT or MRI should preferable for PSI planning.

35.3 Perioperative Considerations

Using PSI, the surgeon can predict the bony resections, component sizing, and alignment and can prevent unknown constraints during surgery (e.g., extreme implant size, special implant orders). All this makes the logistics in the operating room (OR) more efficiently, resulting in a reduction in the total number of surgical instruments from 9 to 3 trays, depending on the manufacturer, which are necessary for TKA surgery. That may lower associated operational costs. These costs also include the sterilization of instruments, storage of implants, man-hours, and the time OR staff is busy preparing the OR [17–19]. However, when discussing cost-effectiveness, there are also additional costs for CT or MRI and for the patient-specific instruments [20].

The procedure might be simplified because PSI eliminates the usage of intra- and extramedullar rods or the additional equipment which is required for CAS during surgery. However, surgery does not become easier because the surgeon has to control each step of the procedure in order to adjust when necessary [14]. A recent review of the literature showed that PSI reduces the deviation in axial alignment of the femoral component of 0.4°, reduction in OR time of 7 min, and loss of perioperative blood of approximately of 90 mL [21].

Side Summary
PSI does not compensate the surgeons lack of experience.

35.4 Postoperative Considerations

Controversy exists regarding the radiological differences in outcomes between conventional instrumented and PSI. To date, numerous studies have compared conventional surgery and PSI including RCTs with a variety of systems from different manufacturers. Pooled data from a meta-analysis showed that the relative risk (RR) of mechanical axis malalignment by >3° was significantly lower for PSI (RR = 0.79; $p = 0.013$) [22]. Only two studies found significantly fewer outliers of the individual components in the coronal plane with use of PSI [23, 24]. Four other RCTs resulted in significant more outliers in the coronal [25, 26] and sagittal plane [26–28] after PSI. Increased outlier after PSI was also seen in tibial component placement [25, 26, 28]. Regarding component rotation, the individual studies on this topic yielded different results. Favorable outcomes were found with PSI resulting in significantly reduced rotational outliers of the tibial [29, 30] and femoral component [31], while the other reported no significant difference [32, 33].

A meta-analysis including 21 RCT studies involving 1587 TKA, which compared PSI and conventional surgery, showed no clinically relevant difference in terms of component placement except outliers in the coronal plane for tibial components in the PSI group [34]. Operating time, blood loss, and transfusion rate were similar. Hospital stay was shortened by 8h and surgical trays were reduced by 4 in the PSI group.

Side Summary
Pooled data show significantly lower risk of malalignment after PSI.

35.5 Clinical Outcome

Published clinical results on PSI are still scarce. PSI showed comparable clinical results to conventional instrumentation after 2 years of follow-up [27, 35]. It has been stated that PROMs represent the best subjective measurement of clinical outcome [36]. However, there is no single best outcome measurement tool after TKA. Besides the comparable results of PROMs on PSI TKA, various scores are not capturing the changes due to a lack of power of the scores as averse to a lack of change (e.g., floor and ceiling effects) [37]. The PROMs in these studies failed to detect subjective changes after a period of 2 years. Moreover, there is still a lack of reliable data on the survival of TKA and clinical evidence, which is associated with the use of PSI. This need to be investigated at a later follow-up interval.

35.6 Discussion

The preoperative planning is a crucial step in avoiding recuts that can cause angular deviations in prosthesis position, especially in tibial component rotational position, in vivo compared with the plan. Excessive tibial rotation deviations can be explained by an extra 2 mm tibial resection, because of rotational references for tibial components change with level of resection [27]. It is advised to avoid recuts and to consider this while planning your PSI procedure. On the other hand, there is no clear consensus regarding the tibial rotation outliers, since previous cut-off values <8° internal tibial rotation are within the accepted "limits" [38–40].

It can be argued that most of the research is mainly performed by high-volume surgeons who probably adapt to a new surgical technique more easy than low-volume surgeons or residents [18]. This also could raise questions about the general applicability of PSI.

On the other hand, PSI could be an added value in less-experienced surgeons due to their simplicity [18]. Based on the experience with TKA, the use of PSI, and a possible learning curve, implementation of a new implant system may be a potential bias in the outcome [14], especially in cases with posttraumatic osteoarthritis and in case of retained metal hardware [41].

There may be some concerns regarding the postoperative radiological measurements performed in studies. A variety of analyses were used to objectively assume the postoperative coronal and sagittal alignment of the individual femur and tibia components. Most of the studies used conventional long-standing radiographs and a small group used CT scans only. The manufacturer of PSI provides a planning tool with the instrumentation. The suggested planning settings made by a technician should always be approved by the operating surgeon.

PSI is a helpful tool in TKA and may have a lot of potentials for the future.

Take Home Message

- PSI is based on MR or CT. Both imaging modalities can be used. Outliers in alignment and component placement are significantly reduced after PSI; however, there is no evidence for clinical or functional improvement when PSI is compared to conventional surgery. There is also no difference in blood loss, transfusion rate, and operating time between the two surgical techniques.
- It remains an open question whether PSI might be of help in less-experienced surgeons. However, the surgeon should be aware of the responsibility when PSI is used for TKA. Finally, the surgeons decide during the surgery whether to follow the PSI algorithm throughout the procedure.

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36 Patient-Specific Partial and Total Knee Arthroplasty: An Update

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Keynotes

1. Patient-specific arthroplasty (PSA) is available for both unicondylar and total knee arthroplasty.
2. PSA relies on magnet resonance imaging (MR) or computer tomography (CT) data and is manufactured for one individual patient. The manufacturing includes both the individual components of the arthroplasty and the instruments.
3. The instruments are single-used which saves also storage place in the operating room.
4. PSA facilitates a completely individualized approach to knee arthroplasty.
5. Clinical outcomes after PSA are to date comparable to those after standard off-the-shelf knee arthroplasty.
6. As PSA is a resurfacing procedure, bone resection is significantly reduced when compared to standard off-the-shelf implants.
7. PSA for total knee arthroplasty allows an optimal fit according to the patient's anatomy, morphology, and lower limb alignment.

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36.1 Introduction

Patient-specific instrumentation (PSI) and patient-specific arthroplasty (PSA) are among the innovations in partial and total knee arthroplasty and have gained increased popularity over the last decade [1]. PSI was developed firstly by using personalized cutting guides and standard off-the-shelf components in order to increase accuracy of component placement in all three planes. However, off-the-shelf components do not always fit to the patient's anatomy. Thereby, PSA proposes one step further in the evolution of recognizing the anatomy and alignment of the individual patients.

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Side Summary
Patient-specific arthroplasty is currently the most individualized technique in knee arthroplasty using both personalized instruments and implants.

Based on preoperative imaging, both the femoral and tibial components are personalized in size and shape. The main goals of this innovation were to achieve better fit of the components matching the patient's anatomy, to simplify knee arthroplasty by improving component placement accuracy, and to increase surgical efficiency in terms of time and cost-effectiveness [2]. In theory, cost reductions were attributed to the decreased number of instruments and trays needed during surgery, which consequently reduces the sterilization burden. Another argument in favoring PSA was reduction of OR time. However, in reality, this has not been proven yet. PSI has shown to achieve an average of 5 min reduction in OR time per patient [3]. Clearly, the clinical and economical relevance of this result is questionable. Furthermore, the increased costs caused by additional CT-imaging, the production cost of single used cutting blocks, and patient-specific components appear to significantly outweigh the apparent aforementioned cost savings.

The cutting guides and implants are manufactured based on the images obtained from a preoperative CT scan or MR imaging. Most companies use their own specific imaging protocol. These have in common that imaging includes scanning of the hip, knee, and ankle joint in order to analyze the lower limb alignment.

MRI is the better suited option for the analysis of soft tissues, and its ability to scan articular cartilage enables design of instruments based on the cartilage surface. CT scan on the other hand is better suited for the imaging of bone, whereas all cartilage tissue should be removed prior to instrument placement due to the lack of ability of CT to scan articular cartilage. A meta-analysis about the accuracy of MRI- and CT-based PSI showed less outliers in the coronal plane when MRI-based PSI was used [3]. Another major advantage of MRI is that patients are not exposed to ionizing radiation. However, no difference in component placement has been reported in the sagittal and coronal planes between MRI- and CT-based PSI.

These findings were based on seven randomized studies including 259 patients in total. Both CT and MRI are routinely used in PSI nowadays.

Side Summary
There is no difference in accuracy between CT- and MRI-based PSI.

One major concern in PSI is the suboptimal preoperative planning regarding the design of implants with the involvement of engineers from the manufacturing company. It should be noted that in all cases, the surgeon carries the responsibility regarding the match of the implants to the patient's anatomy. Recently a significant difference between the accuracy of the implants to the patient's anatomy designed by engineers and surgeons was reported [4]. In this retrospective study, authors showed that the designs by engineers differ from the final component placement of the femoral and tibial component in 20% and 51%, whereas the percentages were lower with 13% and 27% when surgeons were involved in the process.

This chapter discusses important aspects regarding the use of patient-specific knee arthroplasty including unicompartmental (UKA), bicompartmental (BKA), and total knee arthroplasty (TKA).

36.2 Patient-Specific UKA

Partial knee arthroplasty procedures are increasingly adopted by knee surgeons resulting in an increased number of procedures. However, the implantation is more challenging because the replacement of only one compartment necessitates a more precise match to the patient's anatomy. The tension pattern of the cruciates and collateral ligaments strongly depend on the shape of the medial and lateral femorotibial condyles. Patient-specific arthroplasty offers a more personalized implantation. The customized UKA components can be designed in all dimensions to obtain the most optimal fit respecting the individual patient's anatomy. Exact preservation of soft tissue tension is likely to be achieved as a result of the preserved anatomical shape of the bone. However, there is a potential risk of overstuffing the compartment due to insufficient bone resection.

Side Summary
Meticulous bony preparation is important when CT-based technology is used in order to avoid overstuffing of the knee due to insufficient bony resection.

36.2.1 Surgical Technique of Patient-Specific Medial UKA

A meticulous preparation of the bone is required (Fig. 36.1). All remaining cartilage tissue covering the bone should to be removed using a cartilage curette (Fig. 36.2). Otherwise, there is a high risk of overstuffing the compartment due to incorrect placement of the cutting blocks and thus bony resection. Following removal of the cartilage, a patient-specific femorotibial spacer, which is available in three sizes, is inserted into the joint in order to assess joint stability (Fig. 36.3). The tibial cutting guide is then fixed to the spacer and the tibial cut is determined (Fig. 36.4). The extramedullary tibial alignment rod, which can be fixed to the cutting block, serves as an additional control for tibial coronal and sagittal alignment. After fixation with pins, the vertical and horizontal tibial cut is performed (Fig. 36.5a, b). Then after removal of remaining cartilage, Meticulous removal of the remaining cartilage from the femoral condyle is required in order to allow correct placement of the customized femoral cutting guide (Fig. 36.6). A little spacer is inserted underneath the cutting

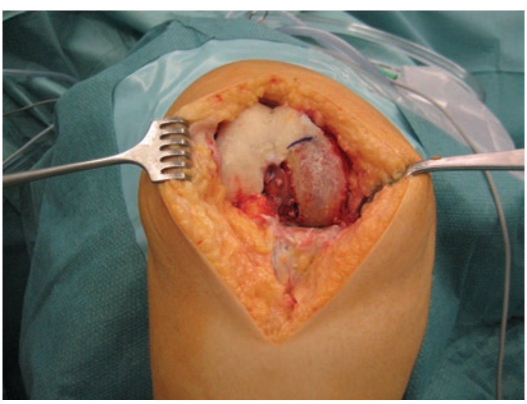

Fig. 36.1 Bony preparation of the medial femoral condyle for UKA

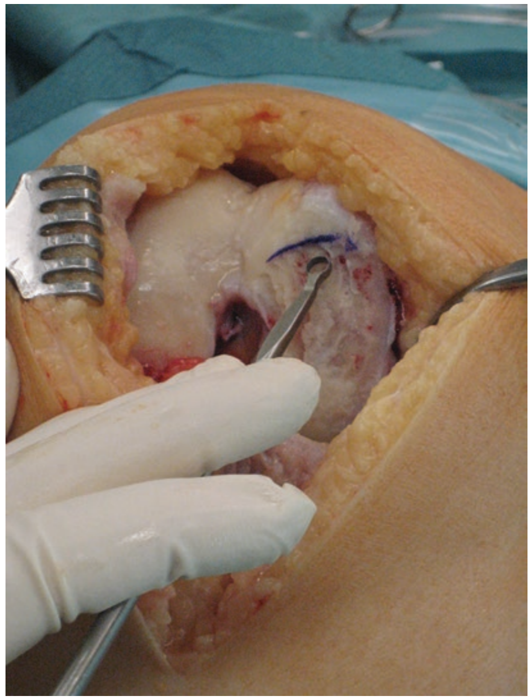

Fig. 36.2 A bone curette is used for complete cartilage removal

Fig. 36.3 The anatomic spacer is placed into the medial joint space and collateral ligament tension is evaluated

guide. The dorsal surface of the spacer should be flush with the dorsal aspect of the femoral condyle. The spacer helps to identify the correct placement of the cutting guide. The center of the cutting guide should match with the center of the femoral condyle. A line which marks the center of the condyle needs to be visible through the two drill holes of the cutting guide. Considering these aspects central component placement of the component on the femoral condyle is most likely (Fig. 36.7a, b). The femoral cutting guide is firmly fixed to the condyle and the dorsal cut is performed (Fig. 36.8). No distal or oblique cut is required and thus preserving most of the bone of the femoral condyle.

Fig. 36.4 The cutting guide is fixed on the spacer and an extramedullary alignment rod serves for final control.

Side Summary
Draw a reference line at the center of the femoral condyle in order to achieve correct three-dimensional placement of the femoral cutting guide.

No further bone cuts are required at the femur. Next, the tibial plateau is prepared using the tibial template, which matches exactly in size and shape the surface at the level of the resected tibia (Fig. 36.9). It has been shown that bone coverage of the component is significantly better when PSI is used [5].

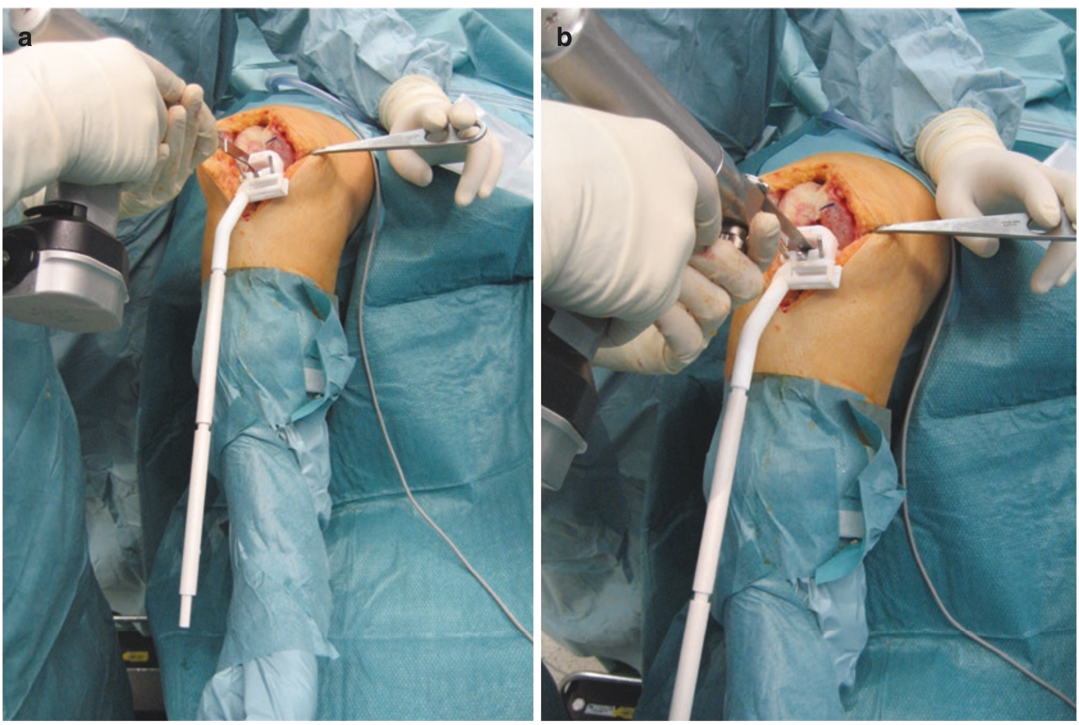

Fig. 36.5 (**a**) A vertical cut is performed first close to the medial tibial spine. The saw blade is left in space in order to avoid damage to the tibial eminence during the horizontal cut. (**b**) The horizontal cut is performed next. The resected bone should be match with the shape of the tibial base plate

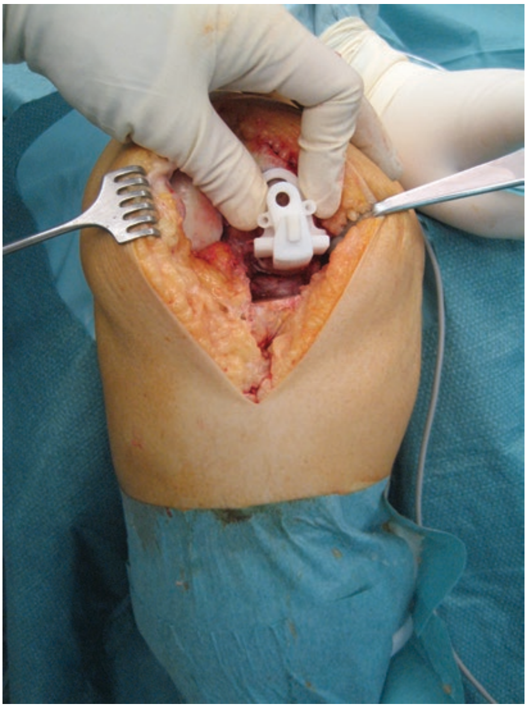

Fig. 36.6 The femoral cutting guide is placed on the condyle and the dorsal spacer should flash with the dorsal condyle

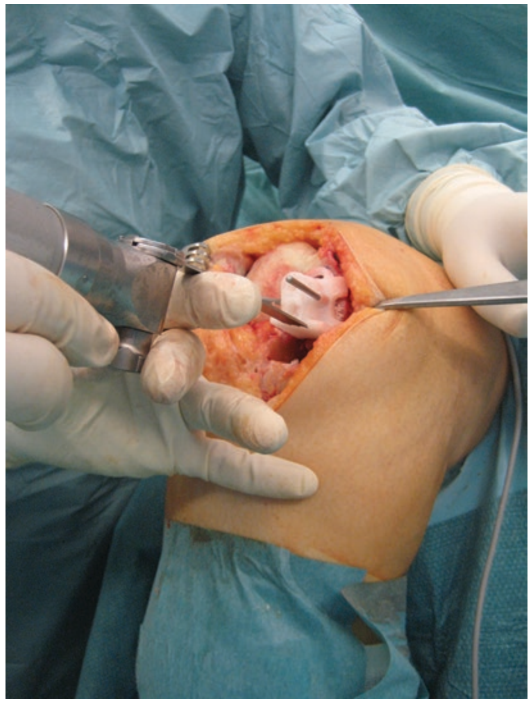

Fig. 36.8 The dorsal cut is performed at the femur

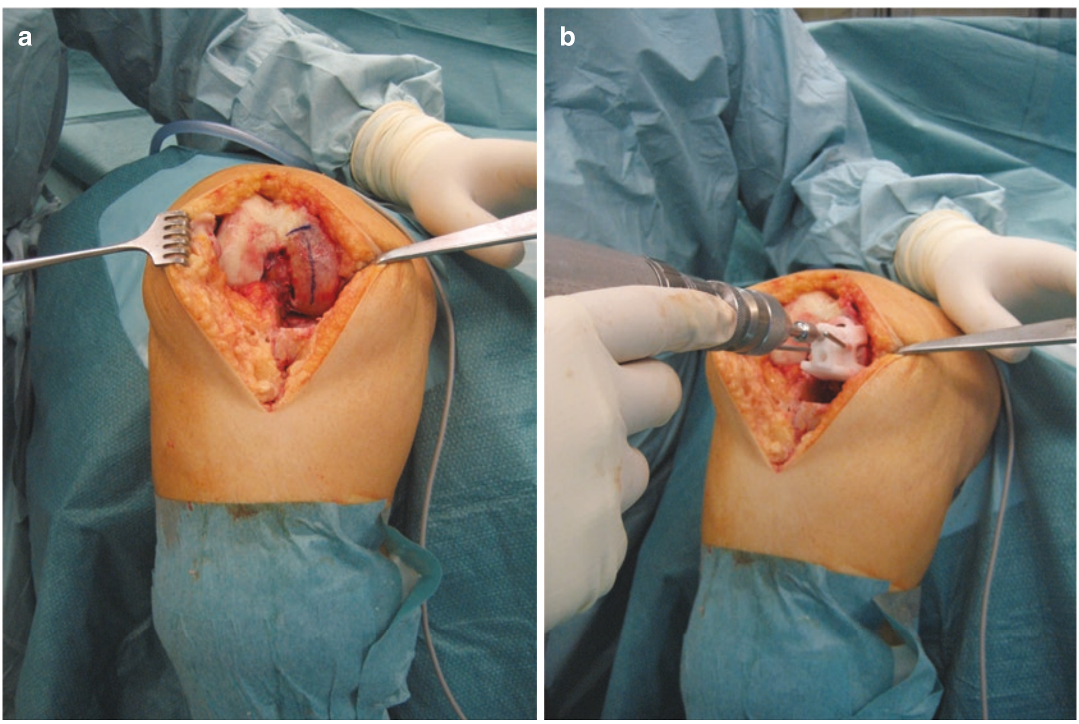

Fig. 36.7 (**a**) A central line drawn on the medial condyle will additionally help to position the femoral cutting guide correctly. (**b**) The femoral cutting guide is fixed with two pins

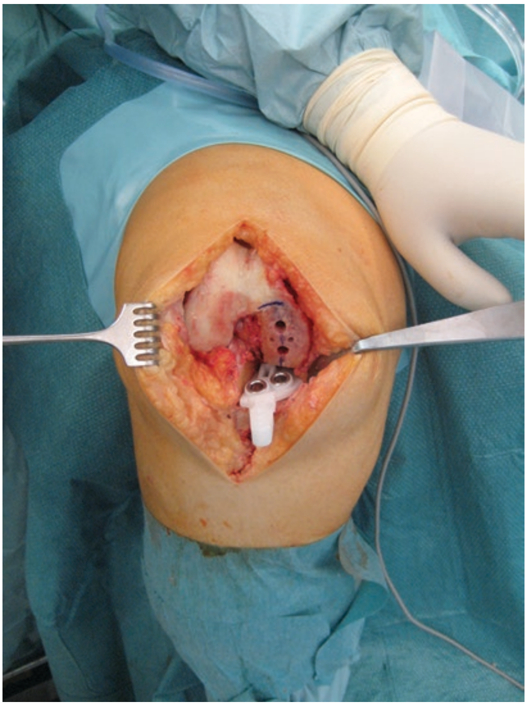

Fig. 36.9 The tibial base plate matches the shape of the tibial plateau. Final preparation for component fixation is performed

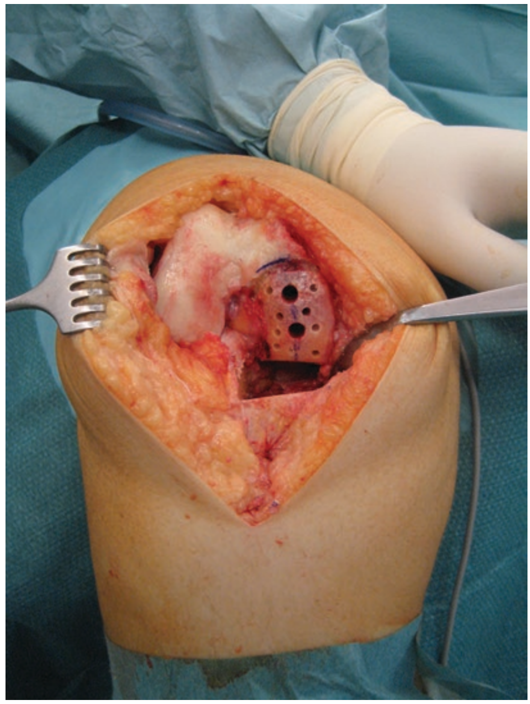

Fig. 36.10 Additional drill wholes on both femur and tibia improve component fixation

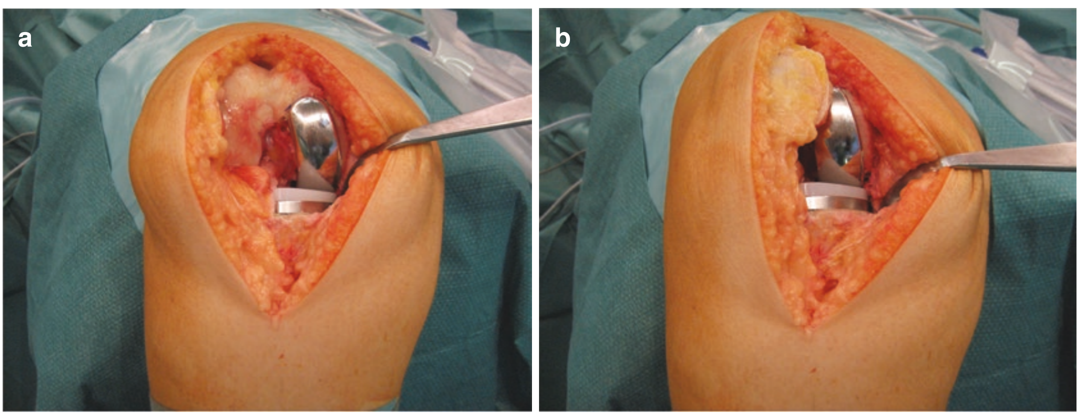

Fig. 36.11 (**a**) Intraoperative view after final implantation. (**b**) Intraoperative view after final implantation and reposition of the patella

Additional drill holes might improve the fixation of the components to the bone (Fig. 36.10). The implants are fixed with bone cement. Figure 36.11a, b shows the surgical results.

Video 36.1 shows the complete procedure.

36.2.2 Surgical Technique of Patient-Specific Lateral UKA

The surgical steps are similar to a customized medial UKA. However, the exposure of the lateral compartment is more difficult due to the lower mobility of the patella. The skin incision should be performed slightly laterally. Special care has to be taken in order for correct femoral and tibial component placement.

On the tibial side, the lateral tibial tubercle is a reliable landmark. Better tibial plateau coverage after PSI was reported compared with standard implants [6].

The positioning of the femoral component is performed in 90° of knee flexion. Due to the "screw home" mechanism of the femur during the last 20° of extension of the knee, the component needs to be placed in slight external position because the tibia performs external rotation close to extension. The lateral collateral ligament gets under tension and both the medial and lateral collateral ligament stabilizes the knee.

The surgical procedure can be seen in Video 36.2.

36.3 Bicompartmental Patient-Specific Knee Arthroplasty (BKA)

Bicompartmental arthroplasty replaces the patellofemoral compartment and one of the femorotibial compartments (Fig. 36.12). The incidence of bicompartmental OA is more common than expected. In a consecutive group of 259 patients, 59% had osteoarthritis in all three compartments and were candidates for TKA, 28% presented bicompartmental OA, and 4% unicompartmental OA [7]. The ideal indication for bicompartmental arthroplasty is in patients who present OA of grade IV in one of the femorotibial compartments (medial or lateral) with accompanying advanced OA compromises patellar tracking.

Fig. 36.12 Bicompartmental prosthesis for replacement of both the trochlea and medial femorotibial compartment

The anthropometry of the knees shows large interindividual variability. Recent analysis of the survival rates of bicompartmental arthroplasty has shown that the sizes of the standard off-the-shelf implants do not match with patients' anatomy. Early loosening and poor outcome have been reported [8]. Thus, a more personalized approach for bicompartmental arthroplasty may recommended.

Clearly, the three-dimensional variability of all knees makes optimal implant fit almost impossible with only a limited number of component sizes. Anthropometric studies of the knee have shown that the medial and lateral dimensions of the knee, the radii of the medial and lateral femoral condyles as well as the distances between the trochlear groove, and the center of the medial or lateral condyles are highly variable [9].

PSA implants fit precisely to the anatomy of the individual patient and in theory provide a more natural knee kinematics. The components fit perfectly to the bone (Fig. 36.13a, b).

An ideal indication is osteoarthritis of Grad IV of both the medial or lateral femorotibial compartment and on addition of especially the lateral patellofemoral compartment (Fig. 36.14).

Side Summary

Bicompartmental arthroplasty may considered when one of the femorotibial compartment is affected in conjunction with the patellofemoral compartment.

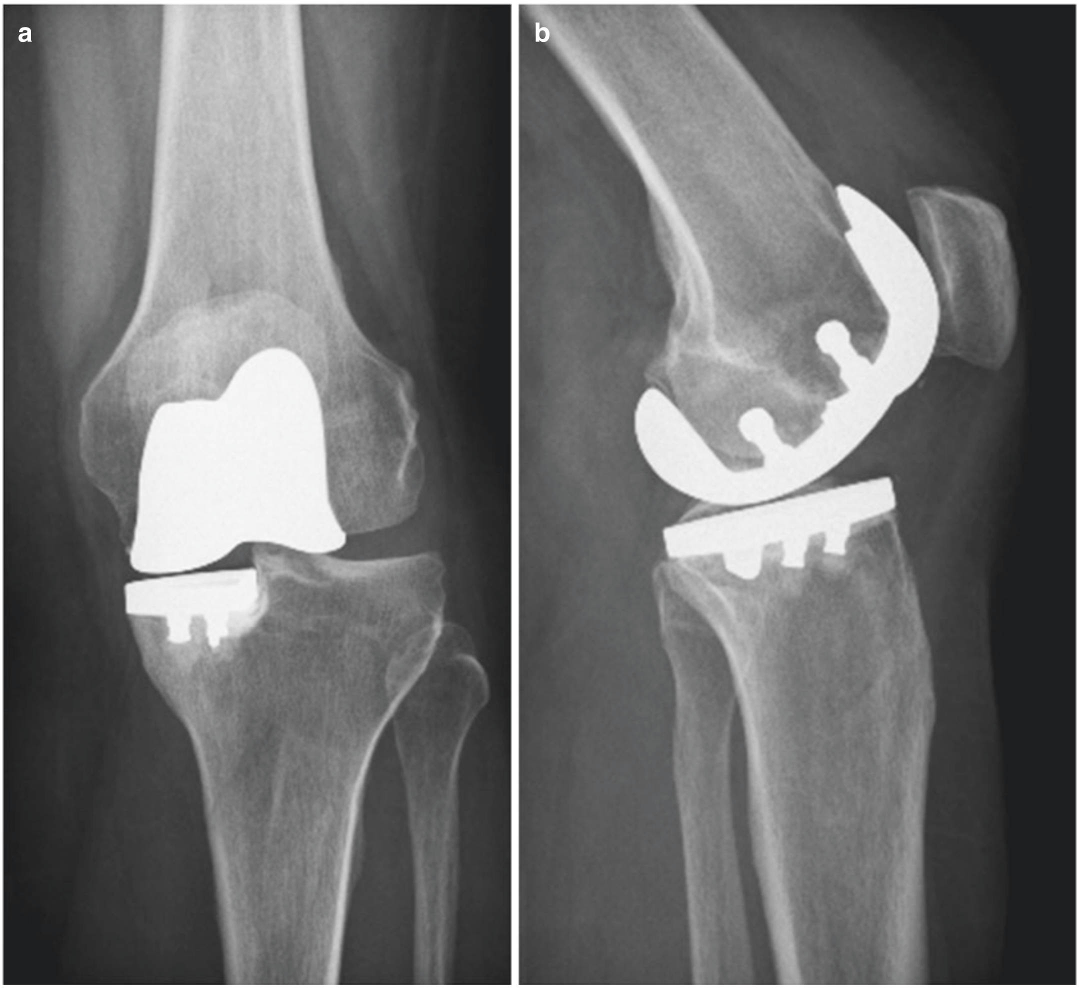

Fig. 36.13 (**a**, **b**) Anteroposterior and lateral view after bicompartmental knee replacement of a left knee

Natural knee kinematic can be expected due to preservation of both cruciate ligament ligaments.

36.3.1 Surgical Technique of Bicompartmental Arthroplasty

A standard approach to the knee is performed similar to that of a total knee arthroplasty. The cartilage of the two affected compartments such as the trochlea and one of the femorotibial compartment are completely removed. A space is inserted in the femorotibial joint gap in order the measure the space according to the I-Uni technique. The tibial cutting block is fixed to the spacer and the alignment is controlled by an extramedullary rod (Fig. 36.15). The vertical and horizontal cut is performed on the tibial plateau again according to the I-Uni technique (Fig. 36.16). The tibial jig is placed on the medial plateau. Final bony preparation of the tibial component is performed (Fig. 36.17). The femoral cutting guide is positioned to the bone and the anterior and posterior cuts of the femur (anterior = trochlea, posterior medial femoral condyle) are performed (Fig. 36.18). No distal femoral cut is required. Pegs and drill holes in the bone improve component fixation (Fig. 36.19). Trial components are used before final cementing of the implants (Figs. 36.20 and 36.21).

The surgery requires a very limited number of instruments and disposable cutting guides, spacer, and femoral trial component (Fig. 36.22).

Fig. 36.14 Intraoperative view shows chondromalacia of Grad IV of the medial compartment and lateral trochlea

Fig. 36.15 The tibial cutting guide is fixed to the spacer as performed for the unicondylar implantation

The entire surgical procedure can be seen in Video 36.3.

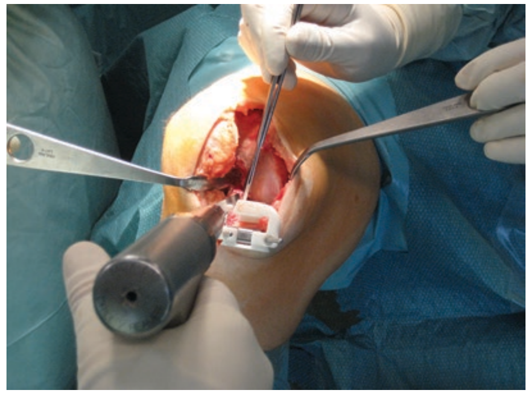

Fig. 36.16 The vertical cut is performed on the tibial plateau first in the same fashion as for the UKA

Fig. 36.17 The femoral cutting guide is placed on the femur and the anterior resection of the femur and posterior resection of the medial condyle performed

36.4 Patient-Specific TKA

Patient-specific total knee arthroplasty (PSA) was introduced in 2013. The femoral and tibial implant is designed to cover the bone precisely. The planning by the manufacturer provides detailed information about the amount of bony resection at each step during the surgical proce-

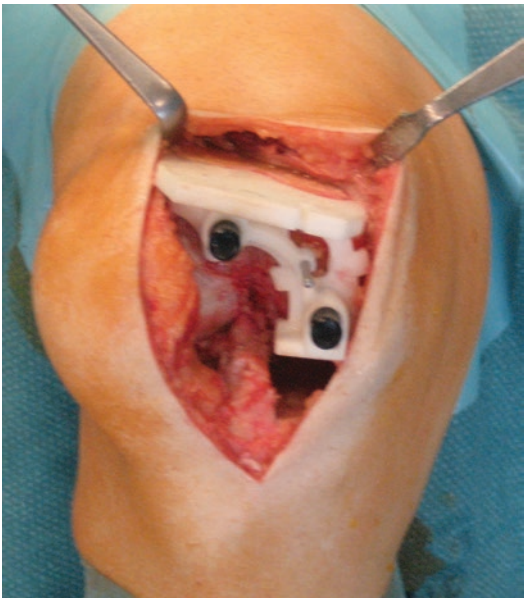

Fig. 36.18 The tibial baseplate is positioned on the medial tibial plateau and finally prepaired

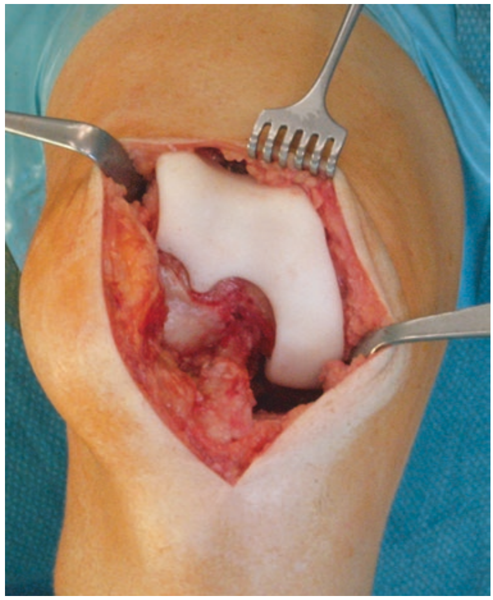

Fig. 36.20 The trial component is placed on the femur. Spacer at the medial femorotibial gap will help to identify correct ligament tension

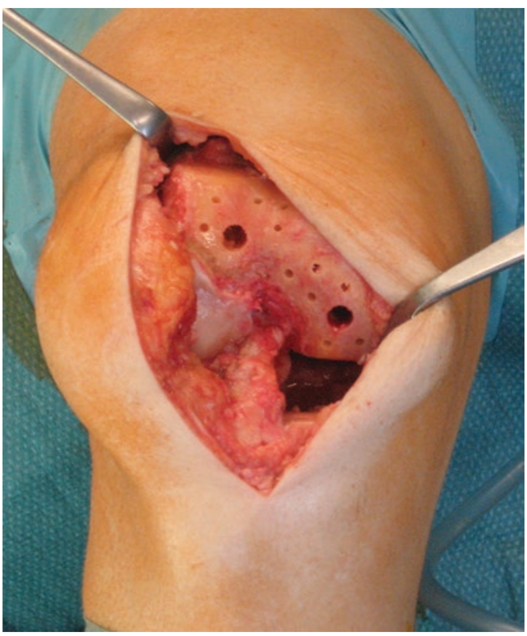

Fig. 36.19 Additional drill holes improve cemented fixation

Fig. 36.21 Bicompartmental implants in place after cemented fixation

Fig. 36.22 Instruments required for bicompartmental knee arthroplasty

dure and resected bone should be measured all the time in order to identify any mismatch immediately (Fig. 36.23a, b). Optimal component fit avoids over- or undersizing of the components [10]. There is one additional cut on the femoral condyle in order to minimize the total amount of femoral bone resection and to improve the component fit. A posterior cruciate-retaining design was released first followed by the posterior-stabilized design in 2016.

Required bone resection is significantly less than that of the standard surgical technique (Fig. 36.24). Surgery can be performed with a very limited number of instruments (Fig. 36.25a). The cutting guides and trial components are disposable (Fig. 36.25b).

36.4.1 Surgical Technique

The standard approach to the knee for PSA shows no significant difference to that of a standard implantation. The surgical algorithm is decided by the surgeon within the meaning of femur first or tibia first order.

The author's surgical algorithm is the same as in the standard technique, starting with the distal femoral cut, followed by the tibial cut and resuming with the remaining femoral cuts, and finally finishing the preparation of the tibia. This algorithm allows to control the extension gap prior to the remaining femoral cuts. A correction of the distal femoral or tibial cut is easily possible in the next step using this order.

In contrast to the aforementioned uni- or bicompartmental techniques, the cartilage and osteophytes will not be removed from the femur and tibia prior to the placement of the cutting guides. The first femoral cutting guide is used to identify the two bony reference points on the distal medial and lateral femoral condyles (Fig. 36.26). The cutting guide for the distal cut can be positioned in relation to these two reference points. At that stage, two holes are drilled (arrow) for the pins which determine the position of the cutting guide later used for the anterior and posterior femoral cuts (Fig. 36.27). The distal cut is separately performed for the medial and lateral condyles (Fig. 36.28). After the distal femoral cut, the tibial cut is performed. Remnants of cartilage need to be removed from both the medial and lateral tibial plateau in order to proper bone reference (Fig. 36.29). After the tibial cut, all osteophytes should be removed from both femur and tibia, and special attention need to be payed to osteophytes at the dorsal femur, because these osteophytes may cause lack of extension. The extension gap is tested using a spacer. Care should be taken not to overstuff the extension gap, which could cause an extension deficit after surgery.

The knee is then flexed to 90° and the flexion spacer helps to identify the correct rotation of the fourth femoral cutting guide and flexion gap size in combination with the two pinholes, which were drilled while the second femoral cutting guide was in place (Fig. 36.30). The next three cuts are performed. There is one additional posterior chamfer cut, which safes additional bone at the femoral side (Fig. 36.31). When all cuts are finished, both the femoral and tibial trial components can be placed. Ligament stability is tested after complete removal of the osteophytes (Fig. 36.32). The tibial trial component is adjusted to the tibial plateau, and the bone is prepared for the final component using a central drill and chisel. After the complete preparation of the bone, the components are cemented (Fig. 36.33a, b).

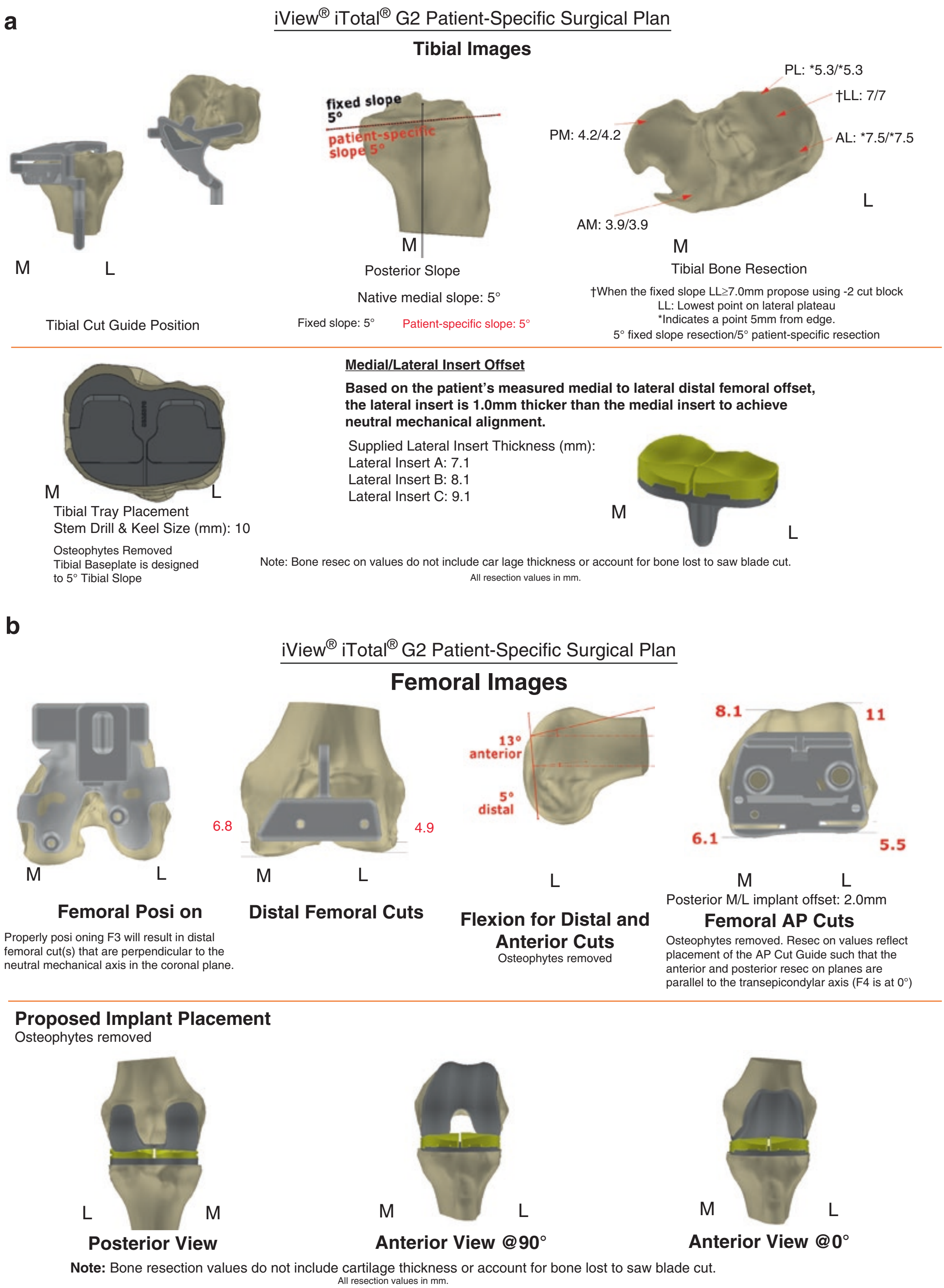

Fig. 36.23 Tibial (**a**) and femoral (**b**) surgical planning for total knee arthroplasty. The amount of bony resection is given for each cut. The resected bone can be checked using a caliper

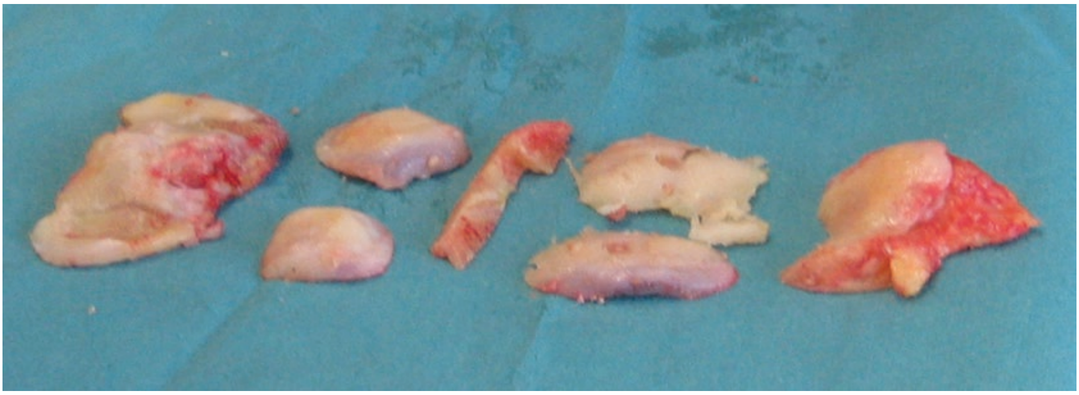

Fig. 36.24 Complete amount of bone which needs to be resected during preparation for the implants

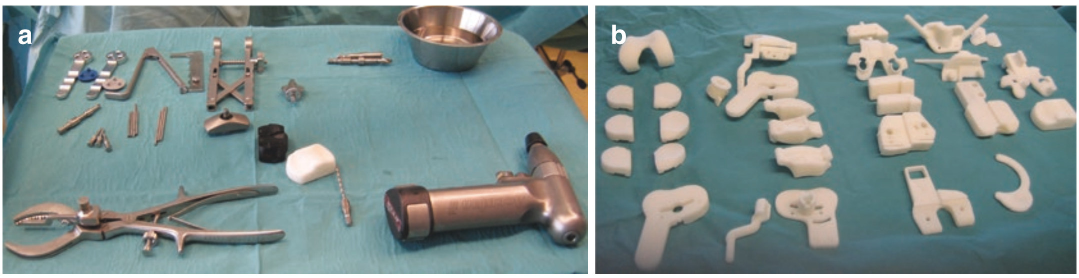

Fig. 36.25 (**a**) Instruments which are reusable for the surgery. (**b**) Disposable instruments and trail components

Patella resurfacing can be performed when needed using a dome-shaped patellar component, available in different sizes. Patella resurfacing is not customized, because the trochlea of the implant is not patient specific.

36.5 Discussion

The use of PSA facilitates a completely personalized TKA. In dysplastic knees or in knees where a significant mismatch between the dimensions of the medial and lateral condyles exist, PSA can be useful for optimal bone preparation and component placement. However, the question is whether there is need to personalize all TKA's or should the technology rather used for specific indications where standard implants will not fit well.

Studies are scarce analyzing the clinical outcome after PSA. Recently an analysis was conducted of the knee kinematics in human cadaver knees comparing patient-specific implants with standard implants [11]. The study reported nonsignificant differences in kinematics for active femoral rollback, active femorotibial adduction, and passive testing for varus and valgus stabilities when PSA was used. In terms of clinical outcome, no significant changes were reported favoring of PSA. A consecutive series reported reduction in blood loss of 45 mL and reduction in length of stay of 0.39 days [12]. However, these results are questionable in terms of clinical relevance.

Regarding the PSI, more information exists in the literature. A systematic review showed that PSI improves neither clinical outcome nor the overall accuracy of component placement [13]. Another meta-analysis about the efficacy of PSI in TKA including almost 2900 cases showed that the risk of mechanical femorotibial malalignment was significantly lower after PSI. However, there seems to be an increased risk of tibial malalignment in the sagittal plane.

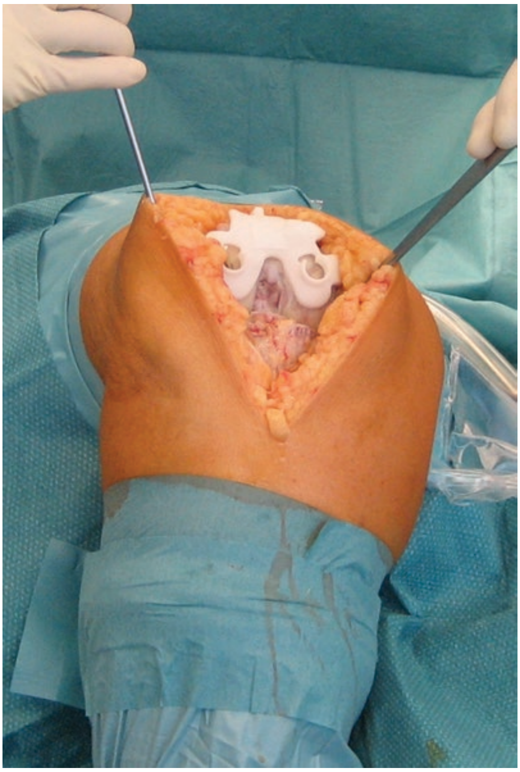

Fig. 36.26 First femoral cutting guide is placed on the femur. At that stage all osteophytes are still in place, because they serve as reference

Fig. 36.27 The second and third femoral cutting guide is in place. The third femoral cutting guide can be fixed at that stage and the second cutting guide is removed

Minor reduction in operating room time and blood loss was found.

Furthermore, patients after PSI show an increase risk of manipulation under anesthesia [14]. For this reason, it seems to be very important to check meticulously the extension and flexion gap during surgery in order to avoid overstuffing of the compartments, which may cause stiffness.

Currently, PSI uses cemented fixation. More recent studies have shown that cemented as well as uncemented UKA provide promising survival rates [15–17]. The 5 years survival rate of the uncemented UKA ranged from 90 to 99%, and the 10 years from 92 to 97% according to a meta-analysis of 10 papers and 1199 knees which is comparable to the outcome after cemented UKA. However, the current standard seems to be the usage of cement for component fixation.

PSA is a novel and individual approach to restore patients' anatomy of the knee. More data will help to understand clinical and functional performance better. Based on the current data, there is no justification for routine use [18].

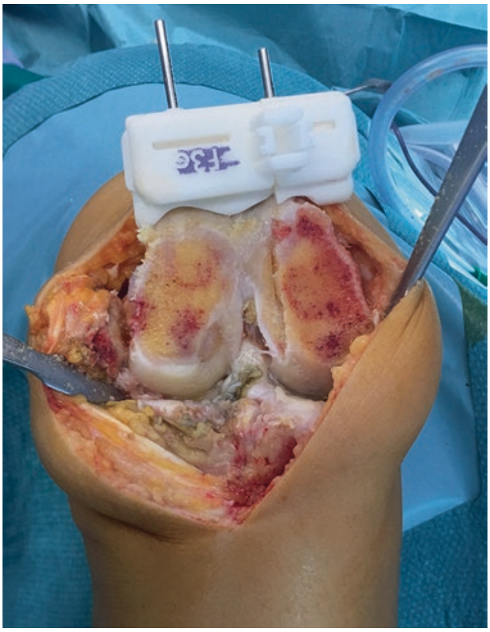

Fig. 36.28 The distal cut at has been finished at the femur. The cuts are separated between a medial and lateral condylar cut

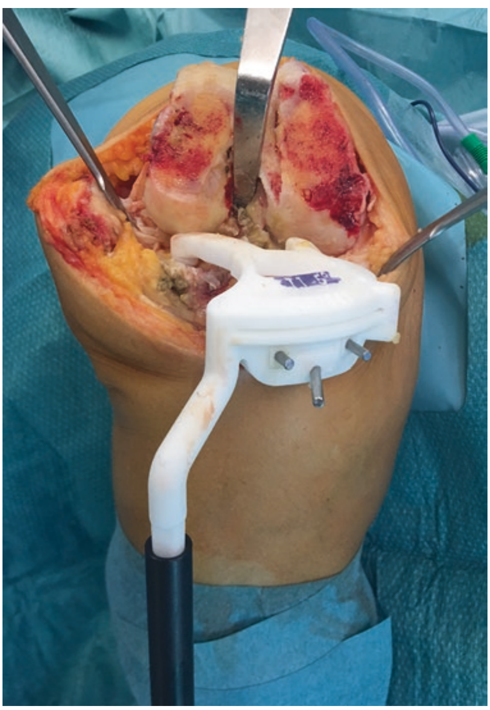

Fig. 36.29 The tibial cutting block is positioned on the tibial plateau. The extramedullary rod serves to final asses the posterior slop, varus−/ valgus alignment and rotation of the cutting block

Fig. 36.30 The fourth femoral cutting block is in place for the anterior and posterior cut of the femur and the anterior chamfer cut. The cutting block can be fine-tuned especially in rotation

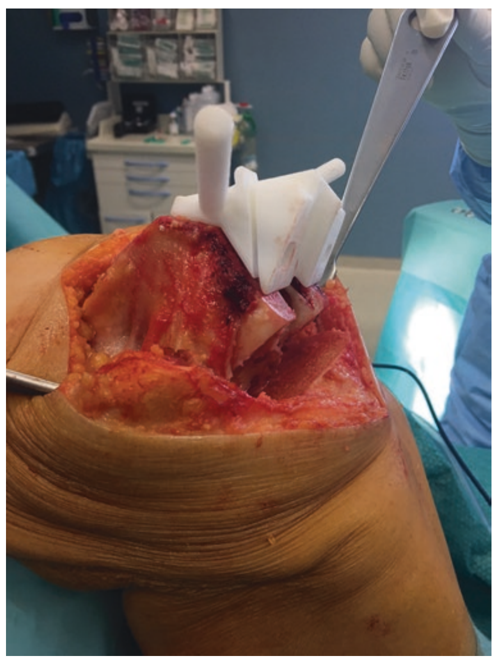

Fig. 36.31 The chamfer cutting block is in place

Fig. 36.32 The trial component is inserted. Three different tibial sizes are available in thickness to have appropriate ligament stability

Take-Home Message

- Patient-specific arthroplasty is entirely individualized TKA. Both cutting blocks and implants are designed and manufactured for each patient. Implants can be designed for unicompartmental, bicompartmental, and total knee arthroplasty. The novel approach allows to mimic the anatomy three dimensionally very closely. The implants cover the bone entirely and the natural joint line orientation is preserved.
- The number of instruments is significantly reduced. However, surgery has to be performed very accurately, and special attention should be paid on firm placement of the cutting guides. Otherwise, there might be potential undercutting causing overstuffing of the compartment. Three different liners in thickness are available to provide knee stability.

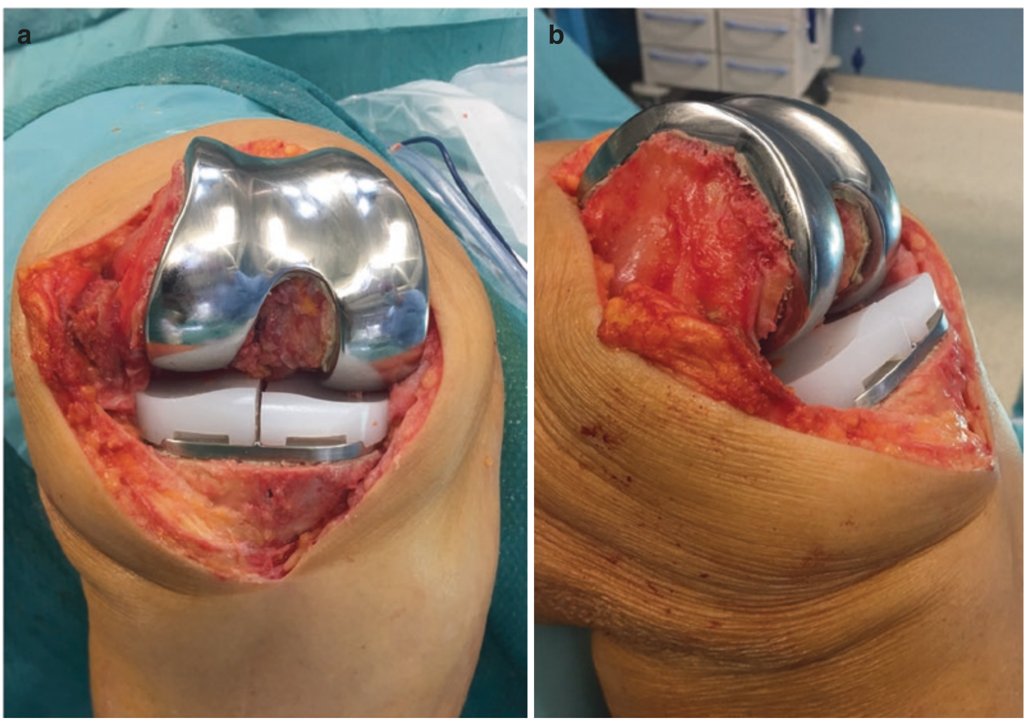

Fig. 36.33 (**a**, **b**) The implanted components from anterior and lateral

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37 Navigation in Total Knee Arthroplasty

Francesco Poggioli, Norberto Confalonieri, and Alfonso Manzotti

Keynotes

1. Greater than 3° varus or valgus malalignment in TKA can result in a shorter implant survivorship, while correct alignment has been associated with improved clinical outcome according to some studies.
2. Several authors have shown that traditional hand-guided alignment systems can produce potential errors in the bone cutting process even when performed by experienced surgeons.
3. Beginners and those who have low-volume of computer-navigated cases (CAS), thanks to continuous feedback, help to reduce cutting errors and ligament balance, especially for young orthopedic, and furthermore, quantify numerically the results allowing you to create a standardized procedure.

37.1 Introduction

Despite the continuous development of design, materials, and biomechanical improvements, the percentage of patients not satisfied by TKA is substantially not changed. In a recent study, about 20% of patients gave a negative response to the question "How satisfied are you with your knee replacement?" compared to 19% dating back to 1995 [1]. The correct positioning of the components is surely one of the reasons. In fact, it is a basic requirement for good and satisfactory long-term outcome [2–5].

Following this purpose, at the end of the 1990s, active robots have been created. These systems were able to independently perform bone cuts through an elaboration of a preoperative CT scan and prepositioned markers. The difficulty of preoperative and operative preparation and cost have led to its almost total abandonment [6, 7].

Few years later, computers and digital imaging were combined with stereotaxis to develop computer-assisted surgery or navigation. Its purpose is to allow the surgeon to perform the best and repeatable maneuvers constituting the pivot around which all the principles of robotic surgery revolve.

The use of computer-assisted navigation (CAS) for TKA has been shown to be a valuable tool for an accurate positioning of both femoral and tibial components to achieve the

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objective of a neutral mechanical axis [8] and avoid rotational malalignment [9]. Furthermore, it reduces cutting errors and the learning curve [10–12].

The aim of this chapter is to define the basics of navigation in TKA and the necessary steps for those approaches for the first time in this fascinating field [1].

> **Side Summary**
> Correct positioning of TKA components is crucial for patient satisfaction. CAS does offer a substantial support for the surgeon to achieve a neutral mechanical axis and avoid rotational malalignment.

37.2 What Is Computer-Assisted Surgery (CAS)?

Computer-assisted surgery includes a large group of devices ranging from simple preoperative digital planning up to semi-active robots. Pure navigation is an ancillary system which allows the surgeon to work in a virtual space, with better information.

Currently, navigation is the area more supported by scientific literature [13–17].

CAS was developed to assist surgeons in the various phases of the joint replacement, for standardization and for surgical prosthetic implantation control. Although its fields of application are several, it remains underused probably due to expensive cost and user-friendliness of the system [18].

Currently, the area of greatest use is knee and hip arthroplasty surgery, but software also exists for cruciate ligament surgery, knee osteotomies, vertebral surgery, and traumatology.

There are different systems on the market, which fall into two main groups:

- Systems acquiring data at the preoperative stage, usually by means of a spiral CT scan; they process the data, prepare the operating plan and the software, and input them into the dedicated computer in the operating theater before the operation.
- Systems acquiring do everything during the operation, as described above, at the perception stage.

These systems can also be divided into closed and open. Closed systems are dedicated; they can only apply the software of one orthopedic products manufacturer and are therefore only used to implant a single type of prosthesis. Open systems can use different software programs, including those developed by competitors, which give more options.

Marketing reasons have made that most of the current systems are closed, allowing the implantation of a single type of prosthesis. The systems in the first group include BrainLab (BRAINLAB AG Olof-Palme-Straße 981829 Munich Germany), Praxim (OMNIlife science, East Taunton, MA), Medtronic (710 Medtronic Parkway Minneapolis, Minnesota 55432-5604 USA), etc. Those in the second group include Stryker, Galileo (Endoplus) and Orthopilot (Aesculap Braun) (Fig. 37.1).

> **Side Summary**
> CAS includes a large group of devices which can be divided into closed and open. Furthermore, these systems are subdivided in to systems acquiring data at the preoperative stage and systems acquiring do everything during the operation. Currently, the area of greatest use is knee and hip arthroplasty surgery, but software also exists for cruciate ligament surgery, knee osteotomies, vertebral surgery, and traumatology.

37.3 Basic Concepts of Navigation

The acquisition of the patient's biometric and morphological data is the first goal during a computer-assisted TKA. Compared to the past,

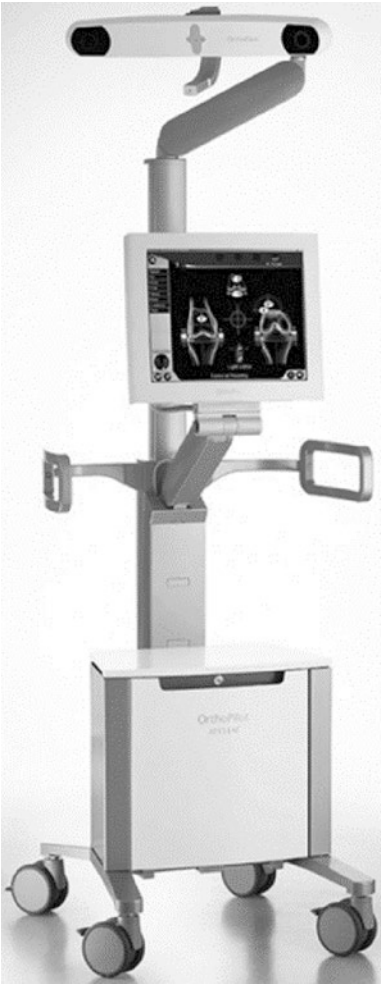

Fig. 37.1 Example of computer-assisted navigation system: infrared camera, computer screen, transmitters, and mobile marker instrument

when the data were collected through a CT scan or fluoroscope [19, 20], now it can be acquired directly in the operating room. For example, the mechanical axis and rotation centers of the joints can be acquired through fixed and mobile trackers and limb movements. This was possible because of the introduction of optical reference systems, derived from other industrial applications (alternatively, by electromagnetic or reference systems based on ultrasound). Such technology involves the use of intraoperative cameras, for the acquisition of markers, in a three-dimensional system, comparable to the satellite system, used for the GPS. The system requires at least three fixed and noncollinear points, visible from the computer, for the acquisition of "virtual references." Classically defined markers are LEDs and it can be active, when are the same diodes to emit light in the direction of the camera or passive when merely reflect a light emitted from the camera itself. These virtual references are implemented by the registration of all anatomical and instrumental landmarks, needed by computer for processing the procedure according to a model in the software.

The model includes both specific references to the procedure (type of intervention, type of prosthesis, etc.) and an "universal" anatomical model, from which will be extracted the necessary references to the navigation of the specific case. Matching between anatomy of the patient and the computer model is done with two methods: acquisition of precise anatomical references, through bony bulge: epicondyles, tibial plateau margins, intercondylar eminence, etc., or acquisition of numerous points of surface to outline the contours (bone morphing). The computer, once processed with the acquired data, is able to suggest during surgery the numbers for the correct positioning of the cutting templates to correct the joint deformity and ligament balance.

Side Summary
The system requires at least three fixed and noncollinear points and involves the use of intraoperative cameras, for the acquisition of markers, in a three-dimensional system, comparable to the satellite system, used for the GPS.

37.4 Why Navigation (CAS) in TKA?

The median survival of the current TKA is between 80 and 95% at 10 years [21]; however, some authors have pointed out that the percentage decreases significantly in case of malalignment or ligamentous imbalance. Several studies have shown that the implant components which do not differ by more than 3° with respect to the mechanical axis of the knee reduces the risk of abnormal wear and the premature failure of the implant (decrease of survivorship of about 20% at 10 years [4, 22–25], as well as ligamentous instability plays an important role in the early failure [26]). Using traditional intramedullary and extramedullary TKA systems, a number of studies have shown correct alignment was achieved in between 73 and 82% [27–29]. Navigation, "talking" to the surgeon, allows a real-time error correction. Recent studies using computer-aided alignment do appear to produce superior results compared to hand-guided techniques [3, 5, 30–33]. These computer-assisted systems have been shown to improve mechanical alignment in the frontal and sagittal femoral axis and the frontal tibial axis. It was reported a post-operative mechanical alignment within 3° varus or valgus in 96% and 100%, respectively, in navigated implants [5, 34].

So, why CAS in TKA? First of all because it increases the accuracy of the proximal tibial cut [35] and offers the capability to track-independent lengthening and shortening of the collateral ligaments to facilitate the sizing of a femoral component that properly tenses these ligaments through a full range of motion [29, 36–38]. Secondly, with the most modern software, it helps in ligament balancing, a key part for success. Acquiring the joint space of the compartments, in flexion and extension, through distractors equipped with sensors, you can proceed to the release of ligaments or bone cuts, identifiable by the computer. Last but not least is the assessment of patellar tracking. An opportunity offered by the navigation, also in this case using a sensor located on the patella, able to assess the sliding of the patella during all phases and in relation to the system, in the various degrees of ROM. It is known that TKA also alters normal patellofemoral joint (PFJ) kinematics resulting frequently in PFJ disorders and TKA failure. More importantly, patellar tracking in case of resurfacing is further affected by patellar bone preparation and relevant component positioning [39].

Side Summary
Traditional intramedullary and extramedullary TKA systems produce a correct alignment in 73–82%. CAS increases the accuracy of the proximal tibial cut, helps in terms of ligament balancing, and assists to achieve correct patellar tracking.

37.5 Why Navigation Is Useful for Young Surgeons?

Performing a TKA surgery requires a long learning curve. Instrumentation for total knee arthroplasty implants, such as resecting guides and cutting blocks, differ, and surgeons need to be familiar with each distinct form of instrumentation [40].

It was also demonstrated that patients undergoing TKA in low volume hospitals (1–25 procedures/year) had a higher risk of early revision at 5 and 8 years compared with those performed in the highest volume hospitals (>200 procedures/year) [41]. TKA performed with computer-aided alignment appears to produce superior radiological results compared with hand-guided techniques. These computer-assisted systems have been shown to improve both mechanical alignment and reduce outliers. Both these outcomes are linked to a potential decrease of the TKA revision rates.

Using CAS reduces the influence of cutting block stability and saw blade movement in the final result [42]. Recent studies have also demonstrated that computer navigation may play a role in reducing the learning curve in joint replacement surgery [11, 12]. Superior alignment and clinical results have been shown with computer-guided TKA when compared to traditional techniques even in experienced hands [10, 17]. Last but not least, navigation allows young surgeons to speak a "universal language" derived from mathematical algorithms, processed by a computer, and allows the most experienced surgeons to explain in the fastest and educational way the complex mechanisms of ligament balancing and the joint biomechanics, in relation to different prosthetic solutions.

Side Summary
TKA surgery requires a long learning curve; patients undergoing TKA in low volume hospitals (1–25 procedures/year) had a higher risk of early revision at 5 and 8 years; TKA performed with CAS produces superior radiological results compared with hand-guided techniques.

37.6 (CAS) Navigation in TKA: Surgical Technique

Navigation does not impose a change in surgical technique; in fact, it behaves as an assistant during surgery, like a "Jiminy Cricket" that helps you during each phase of the intervention. It is to be interpreted as a means that provides real-time numeric data, and then the possibility of corrections. It is also the fastest way and teaching to explain the complex mechanisms of the budget ligamentous and articular biomechanics, according to the different prosthetic solutions. As already mentioned above, the navigation consists of a hardware and software that communicate during all phases of surgery. The first step in a navigated knee replacement is to allow the computer to be able to "talk" with the surgeon. This is starting to determine the bony landmarks necessary for reconstruction of the virtual space.

After the part of the articulation approach, depending on the operator's preferences, it is necessary to position the femoral sensors in such a way that the infrared camera (in the case of using reflectors LEDs) can identify them. Generally, this is achieved with a tilt with respect to the axis of the diaphyseal about 60°–70°.

The second screw is inserted into the tibia, at the same distance, and on the medial side, perpendicular to the tibial axis. A superficial support is applied and secured with a perforated rubber ligature to the back of the foot to allow attachment of a transmitter diode, without any skin incision. The transmitter diodes are attached to the screws (Fig. 37.2).

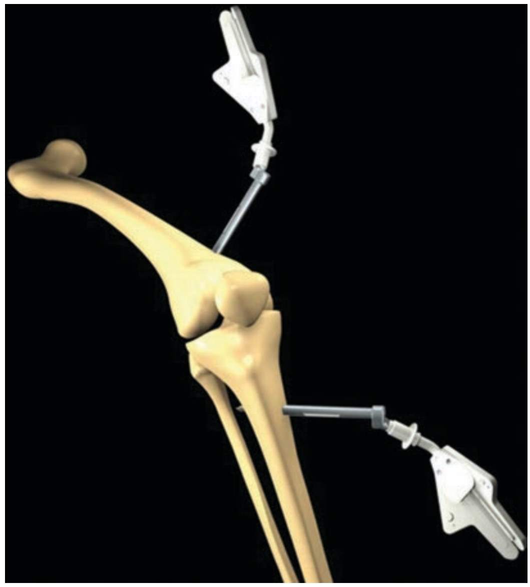

Fig. 37.2 Screws placement for infrared reflectors

The data acquisition then begins. The first part consists in a dynamic phase where you acquire the hip, knee, and ankle rotation centers. The femur is spatially mobilized with wide rotary, circumduction, and flexion/extension movements. The resulting truncated cone shape identifies the mechanical axis of the limb. Next, the center of the ankle is identified by performing flexion/extension movements of that joint. The same procedure applies to the center of the knee, with the addition of intra- and extrarotation in flexion (Figs. 37.3 and 37.4).

The second stage adds additional data arising from static points. The "mobile" diode on the back of the foot is subsequently applied to the palpating finger, which detects the least worn and deepest points of the tibial plate for acquisition of the cutting height, the lowest point of the medial and lateral femoral condyle, and the upper femoral cortex for determination of the size of the prosthesis, and the medial and lateral epicondyle for femoral rotation. Palpation of the medial and lateral malleolus and the center of the ankle adds joint movements to the data already collected (Figs. 37.5 and 37.6).

The success of a knee replacement is based on five key pillars:

- Correct mechanical axis.
- Restoration of the joint line.
- Equalizing flexion and extension gap.

Fig. 37.3 Computer interfaces illustrating motion necessary to acquire kinematic information to localize the hip rotation center

- Balancing soft tissues.
- Correct patellofemoral kinematics.

A neutral mechanical axis, as already discussed above, is the first goal to be attained. Our technique provides first tibial correction. The amount of bone to be cut is dictated by simple and reliable rule of minimal bone cut: *thickness of prosthesis (mm) – degrees of deformity = amount of resection (mm) (femur and tibia)* (Fig. 37.7).

The tibia is dislocated forward for positioning of the tibial cutting guide fixed to the tibial tuberosity with two small nails. The guide is equipped with a three-screw system which, by means of micrometric movements, allows the varus/valgus, cutting height, and posterior slope to be regulated.

Another support in the center of the cutting guide allows attachment of the transmitter diode, which informs the computer of its spatial position; this guides the correct orientation of the instrument by means of an image on the screen.

Cutting is performed with an oscillating saw with 0° of varus/valgus and posterior slope, while

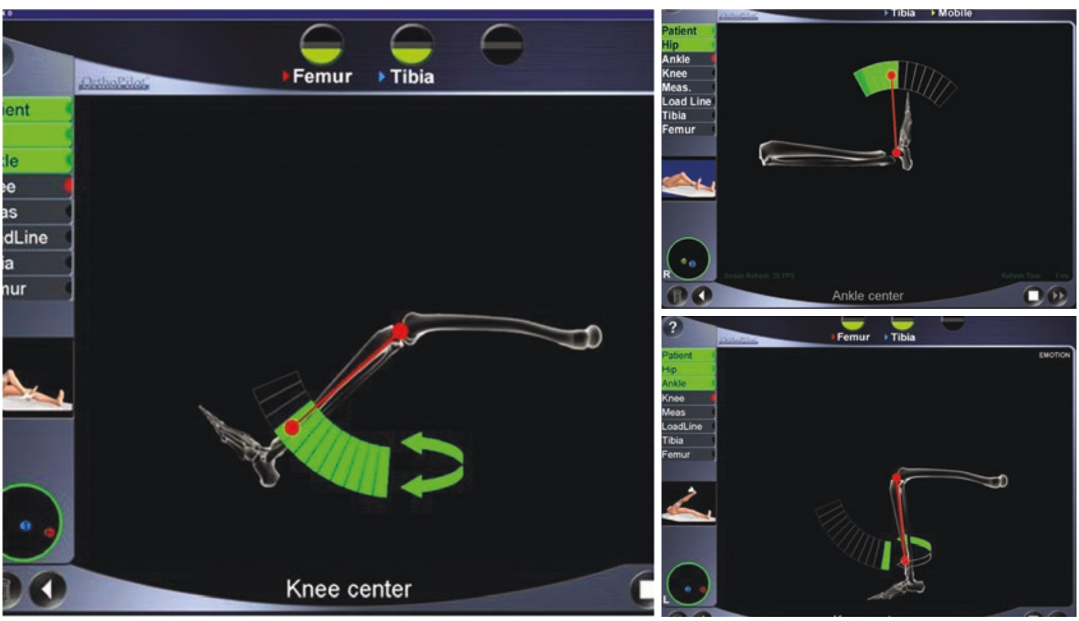

Fig. 37.4 Computer interfaces illustrating motion necessary to acquire kinematic information to localize the ankle (A-B) and knee (C-D) rotation center

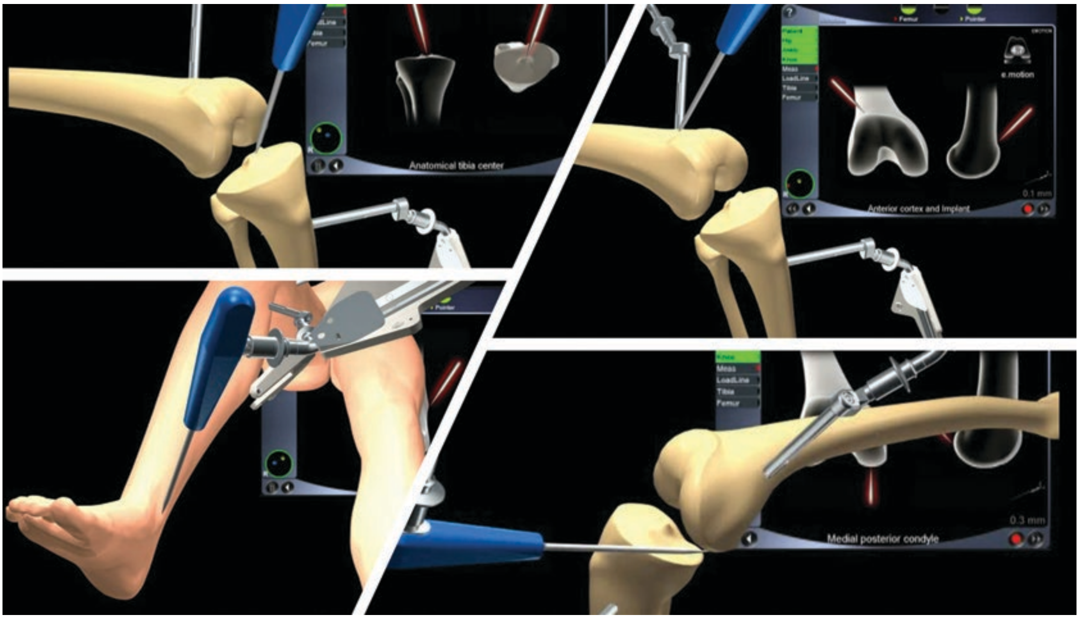

Fig. 37.5 Computer interfaces illustrating acquisition of surface points for medial and lateral tibial articular surface (A-B-C), femoral articular surface, anterior cortex, and posterior condylar line (D-E-F), and center of the ankle joint (G-H-I)

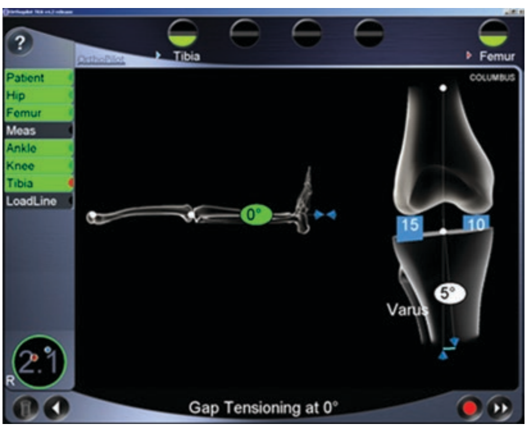

Fig. 37.6 Mechanical axis determination

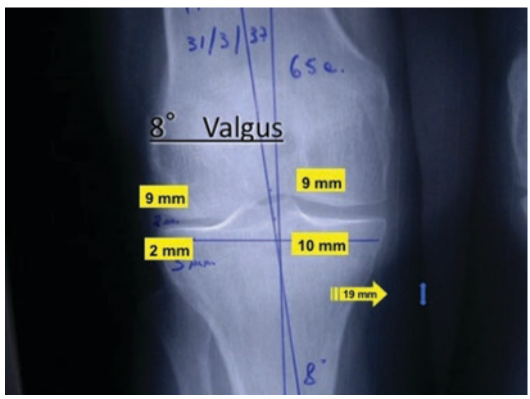

Fig. 37.7 Planning example according to the rule of minimal bone cut: 19 mm (thickness of implant) − 8°(deformity) = 11 mm (bone resection). 11 mm = 9 of femur (to respect joint line) and 2 of tibia

the height must be not less than 8 mm, corresponding to the minimum size of the tibial prosthetic component (Fig. 37.8).

At this point, you can switch to the planning of the femoral cuts and the relative rotation of the femoral component.

The system tells us how much is angular deviation between distal epiphysis and femur and mechanical axis; furthermore, we can know how much is extension and flexion spaces in medial and lateral compartment (Fig. 37.9).

With all these data available, you can plan size, thickness of poly, femoral distal cut, joint line, extension spaces, rotation of femoral component, and flexion spaces.

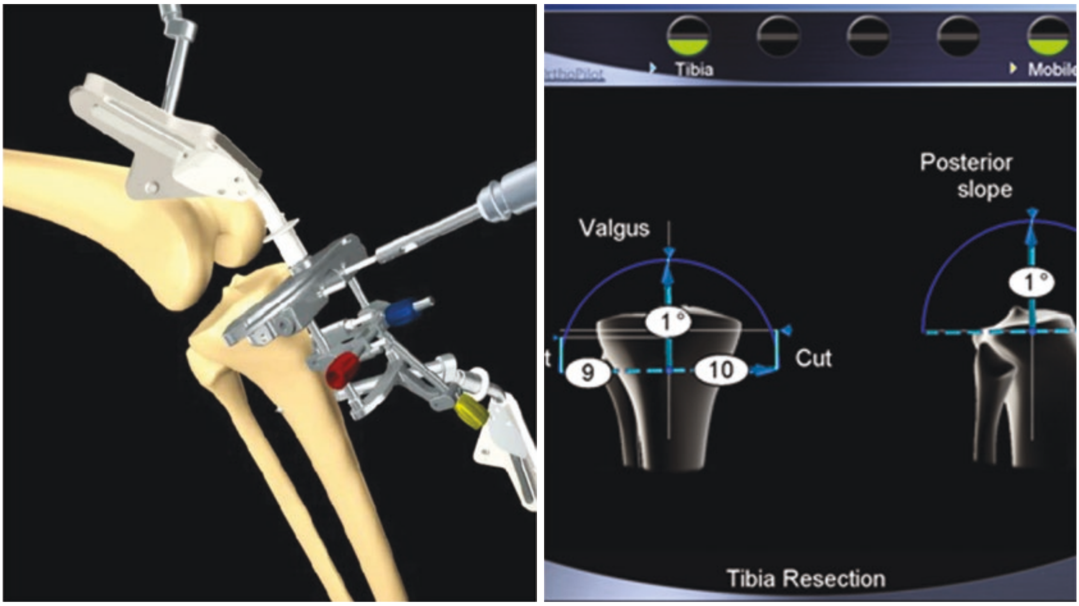

Fig. 37.8 Resection of proximal tibia; computer interface shows position of proximal tibial cutting block in spatial planes and final check

Fig. 37.9 Evaluation of femoral mechanical the slope

Fig. 37.10 Femoral cuts planning: how and how much cut (D-E-F) and ligament balance (A-B-C)

Before the femoral cuts, fundamental is the ligament soft tissue balancing.

The balance can be achieved through:

- Modifications of bone cuts.
- Thickness of polyethylene inlay.
- Prosthesis size.
- Ligament release.
- Central hinge.

Our protocol can be summarized as follows (Figs. 37.10 and 37.11):

Fig. 37.11 Dynamic evaluation of the gap tensioning

	Extension space balanced	Extension space is tight	Laxity in extension space
Flexion space is balanced	Perfect	Release posterior capsule Increase distal femoral cut with the same polyethylene thickness Removal of osteophytes and posterior condyles	Distal femoral wedges Increase tibial slope with higher polyethylene thickness Decrease femoral size component with higher polyethylene thickness
Flexion space is tight	Undersize femoral component with the same polyethylene Release PCL in CR implant Increase tibial slope with the same polyethylene thickness	Increase tibial cut with the same polyethylene thickness	Decrease femoral size with higher polyethylene thickness Distal femoral wedges and increase distal cut and/or tibial slope
Laxity in flexion space	Increase tibial cut and decrease tibial slope with higher polyethylene Increase femoral size with the same polyethylene thickness Increase distal femoral cut with bigger polyethylene	Increase distal femoral cut with bigger polyethylene thickness Increase femoral size component and/or augmentation with posterior femoral wedges with the same polyethylene thickness	Bigger polyethylene thickness

The cutting guide is positioned with the knee flexed to 90°. Again, by means of a transmitter diode attached to the instrument, the screen indicates the correct position for the varus/valgus and anterior slope, in lateral projection. The guide is secured with nails, and distal cutting of the femur is performed with 0° of varus/valgus and slope. The instrument for determination of the size of the femoral component (verification of data supplied by the computer) and the extrarotation instrument is rested on it. Two central holes are drilled, and the guide is positioned for the chamfers.

Another important step is the evaluation of the patellar tracking. Even in this case, using sensor placed on the patella, able to assess both the sliding of the patella during all phases in the various degrees of ROM in relation to the implant.

The test components for the ligament balance, patellar tracking, plate orientation, and height of the polyethylene are then applied. The correction of the axis of the prosthetized lower limb can be viewed on the screen in both flexion and extension, and an external check performed with a long rod and metal guide.

The last step is to verify the stability of the implant in dynamics.

37.7 The Future of CAS

The development of computer-assisted surgery basically proceeds in two directions: a simplification of navigation technique in order to make it more easily accessible to the surgeon and toward a technological improvement of the software capable of providing data more and more accurate to the surgeon [43, 44].

Many companies have realized that obstacle to spread this method is caused by the complexity of technical movements sometimes associated with new complications and longer surgical time. Therefore, improvements have been made in existing software that led the acquisition time to shrink, due to the possibility of an acquisition of a smaller number of reference points without influencing the accuracy of the system with the overall extension of the surgical time that, in our experience, wanders to no more than 10 min.

Attention is also paid to the development of new tools that simplify the procedure. Have been proposed in fact such trackers that no longer need to be placed on fiches anchored in the bone but simply glued to the skin with transparent films with the obvious benefit of reducing both the surgical time and the potential complications [45].

As part of the significant technological improvement, attention is currently given to the creation of new software that can also navigate unicompartmental and patellofemoral arthroplasty [43].

The surgery of small implants is, however, the best field for the development of new technologies related to computer-assisted surgery, such as the use of semi-active robot in unicompartmental and bi-unicompartmental arthroplasty implant; some reports are already published in the literature [9, 46].

Another area of great importance where navigation can help the surgeon is in revision surgery. Even today the revision of knee prostheses is a demanding procedure because of the simultaneous difficulties to be faced, such as loss of bone stock, the ligament balance, and the restoration of normal joint line [47].

Despite the limited data, the computer-assisted surgery can theoretically offer many advantages in dealing with these complex cases, especially if associated with the development of dedicated software [48–50].

Take Home Message
Navigation is definitely an evolving field that, if it will be able to evolve in the right direction, will allow orthopedic surgeons to "speak" a common language, the language of numbers, and at the same time projecting in a more modern surgery.

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38 Optimal Sizing of the Femoral, Tibial, and Patellofemoral Components in TKA

Michel Bonnin, Tarik Ait Si Selmi, and Jean Langlois

Keynotes

1. The importance of optimal sizing of both femoral and tibial component is discussed.
2. Over- and undersizing of the component show significant impact on clinical and functional outcome after total knee arthroplasty (TKA).
3. There are different reasons for component mismatch.
4. Anteroposterior malsizing is in general a surgical error and can be avoided.
5. Limitations by the manufacturer has to be taken into consideration such as mismatch between the anteroposterior and mediolateral dimension but also between the size of the tibial component and the femoral component. The surgeon should be aware about the possible options for combination of different sizes.
6. Oversizing of the component often ends up in persistent pain after TKA and causes limitation in ROM.
7. Correct sizing is important for best function of soft tissue envelop.

38.1 Introduction

At first glance, due to the wide range of sizes available in contemporary total knee arthroplasty (TKA), the choice of the appropriate implant's dimension seems to be an easy task. However, during surgery, size decision depends not only on knee anatomy but also on several technical considerations such as ligament balancing, patellar tracking, and implant positioning, which increase the complexity (Table 38.1). Thus, recent literature demonstrates that malsizing is a frequent cause of failure in TKA [1–3].

Table 38.1 Correct sizing of both femoral and tibial component depends on anatomy, implant design, and surgical technique

• Dimensions of the distal femur	***Anatomy***
• Dimensions of the proximal tibia	
• Possibility of tibia/femur mismatch	***Implant design***
• Increment between sizes	
• Rotation of femoral implant	***Surgical technique***
• Rotation of tibial implant	
• Balancing in flexion	
• Anterior vs. posterior referencing	
• Level of bone resection	
• Patellofemoral tracking	

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Side Summary
Component mismatch can be caused due to the anatomy, implant design, or surgical technique.

If TKA would be pure resurfacing procedure, "optimal sizing" should be understood as "optimal shaping," that is, the perfect reproduction of the three-dimensional shape of the native knee. However, "contemporary" TKA diverges from this idealistic concept in many ways. TKA rarely reproduces the highly variable contours of the human knee, and the range of sizes is still too limited. Therefore, during surgery, the surgeon needs to compromise and—in terms of sizing—the goal is mostly limited to matching the resected surfaces with the implants and to avoid prosthetic overhangs.

This chapter aims to describe optimal sizing and focuses on the optimal bone-implant fit.

Side Summary
The main goal is to avoid oversizing the femoral or tibial component during surgery in order to prevent component overhang.

38.2 Is Oversizing Frequent in TKA?

The frequency and consequences of malsizing—mostly oversizing—have only been recently investigated. A high proportion of prosthetic overhang with currently available implants has been reported (Fig. 38.1). In 2010, Mahoney and Kinsey intraoperatively measured the prosthetic overhang around

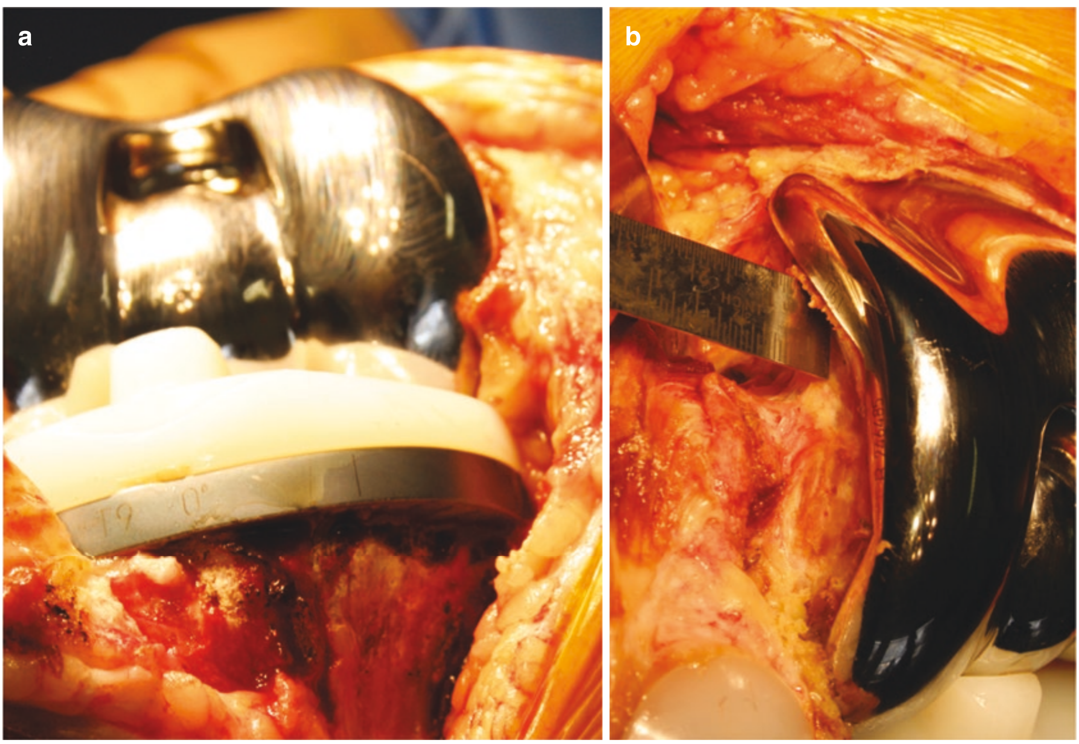

Fig. 38.1 Example of an oversized TKA revised for residual pain. The prosthetic overhang is well seen on the anteromedial aspect of the tibial component (**a**) and on the lateral margin of the femoral component (**b**)

the femoral component of the Scorpio posterior-stabilized prosthesis (Stryker Orthopaedics, Mahwah, New Jersey) [2]. They reported a femoral overhang >0 mm in at least one area in 76% of their patients and overhangs ≥3 mm in 40% of their male patients and 68% of their female patients. The oversized areas were mostly observed in the antero-distal and distal zones of the component. Similarly, using CT scan measurements with the HLS-Noetos prosthesis (Tornier SA, Montbonnot, France), Bonnin et al. reported in 2013 femoral overhang >0 mm in 66% of the patients in the anterodistal area, with a greater proportion of oversized implants in women [1]. On the tibia, they reported an anteroposterior overhang in 92% in females and 80% in males at the lateral plateau, with a mean overhang of 3.2 ± 2.7 mm. A mediolateral overhang was also found at the tibia in 81% for females and 40% for males, with a mean overhang of 1.9 ± 2.7 mm for females [4].

Side Summary
Component overhang occurs frequently in TKA.

38.3 Does Oversizing Influences Outcomes in TKA?

These studies both demonstrated that the pre- to postoperative improvements of the pain and function as well as the final range of motion are significantly greater in patients without prosthetic overhang. Mahoney and Kinsey found that "a knee with an overhang ≥3 mm in at least one zone on the femur had a 90% increased risk of having clinically important pain two years postoperatively compared with a knee without overhang" [2]. They demonstrated also that the more overhanging zones, the higher the risk of residual pain and that "a patient with an overhang ≥3 mm in at least four zones on the femur had double the odds of clinically important pain compared with an individual of the same age without an overhang in any zone."

Bonnin et al. reported that patients with oversized femoral components had significantly lower pain scores at follow-up compared with normally or undersized femoral components. In addition, lower improvements of pain levels, worse KOOS scores, and lower postoperative flexion were noted [1]. The pre- to postoperative pain score improvement was 43±21 in the group without any overhang and 31 ± 19 in the group with overhang in each of the four zones studied ($p = 0.033$). For the KOOS score, this gain was 36 ± 18 and 25 ± 13, respectively ($p = 0.032$). Linear regression analysis demonstrated less improvement in the pain score and decreased knee flexion in case of oversizing in anterodistal femur ($p = 0.004$), distal femur ($p = 0.003$), and mediolateral tibia ($p = 0.012$) (Fig. 38.2). The knee flexion was also reduced in patients with oversizing in the distal ($p = 0.022$) and posterior ($p = 0.010$) femur (Fig. 38.3). Using a structural equation model, the two latent variables "prosthetic fit" and "postoperative outcome" were found to be negatively correlated ($p = 0.005$) (Fig. 38.4). Anteroposterior oversizing of the tibial component had also lower postoperative pain scores ($p = 0.006$) and flexion ($p = 0.024$) [4].

The consequences of anteroposterior malsizing of the femoral component in the anteroposterior dimension should not be ignored, but these mostly due to technical errors. In case of under- or over-resection of the posterior condyles, the "flexion gap" is affected, with pain or stiffness in case of oversizing [5] (Fig. 38.5) and laxity in flexion in case of undersizing [3, 6–8] (Fig. 38.6). Limitation of the flexion may be also due to a decreased posterior offset, secondary to an excessive resection [9]. These situations may be encountered when the femur is prepared with an anterior referencing technique. In case of under- or over-resection of the trochlea, the "anterior gap" is modified with a cortical notching in case of over-resection [10–14] and an overstuffed patellofemoral joint in case of under-resection [15]. This situation may be encountered when the femur is prepared with a posterior referencing technique.

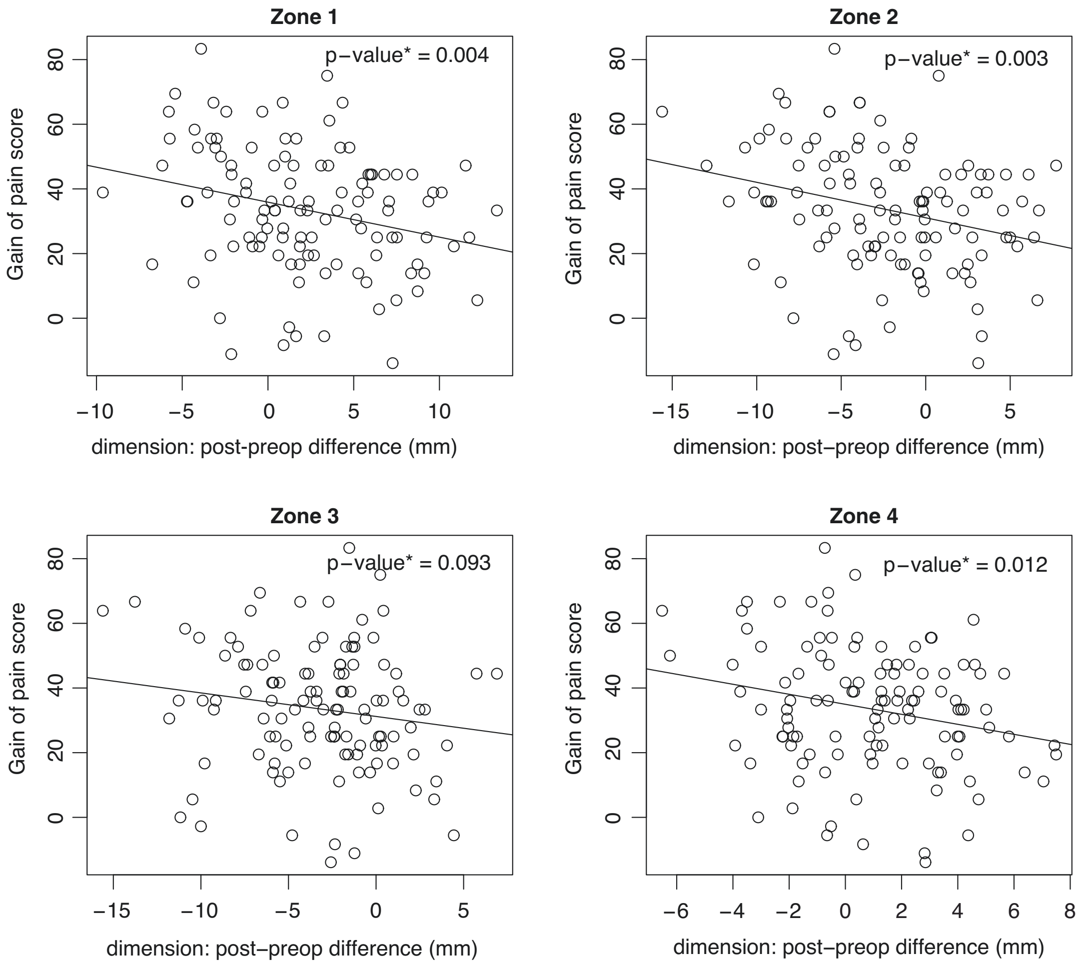

Fig. 38.2 These scatterplots show a linear correlation between sizing and gain of pain score in three areas of the TKA. The *x*-axis represents the dimensional difference (in mm) between the prosthesis and the preoperative knee (positive means prosthetic overhang in this area and negative means prosthetic under-coverage). The *y*-axis represents the gain of pain score measured with the KOOS. (From reference [1])

> **Side Summary**
> Component overhang may cause significant more pain, stiffness after TKA. Patients gain less improvement in KOOS.

38.4 Why Oversizing Is So Frequent in TKA?

An outside observer would be surprised to realize how difficult it is—in our highly technological world—to match a prosthetic component to the contours of the resected bone and how frequently surgeons miss their target. This phenomenon has several (nonexclusive) explanations.

38.4.1 Manufacturing Limitations

Historically, the design and the range of sizes has been limited in TKA due to industrial reasons. The manufacturing of chromium-cobalt is a complex process due to the hardness of the alloy, and in the 1970s, machining was hardly usable. The process was traditionally based on molding technology, which explains the reluctance of manufacturers to develop an exces-

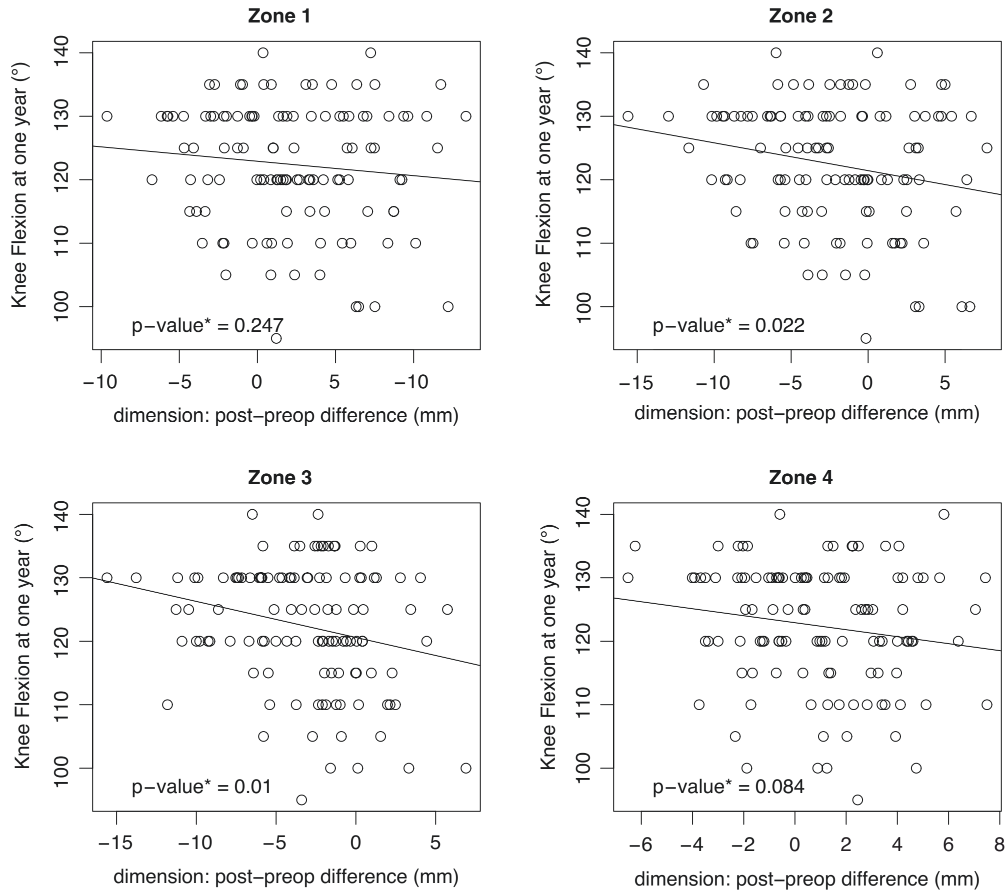

Fig. 38.3 These scatterplots show a linear correlation between sizing and knee flexion measured 1 year after surgery. (From reference [1])

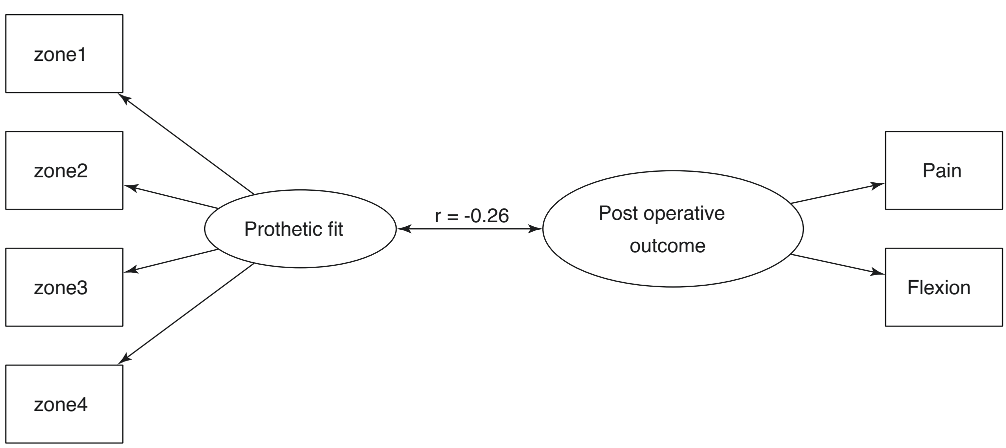

Fig. 38.4 In the Latent Class Analysis, the first latent variable was defined as the "prosthetic fit" in the four defined zones. The second latent variable was defined as the "postoperative outcome" including postoperative pain score and knee flexion. The two latent variables, "prosthetic fit" and "postoperative outcome," were found to be negatively correlated ($r = -0.26$ with a $p = 0.005$). (From reference [1])

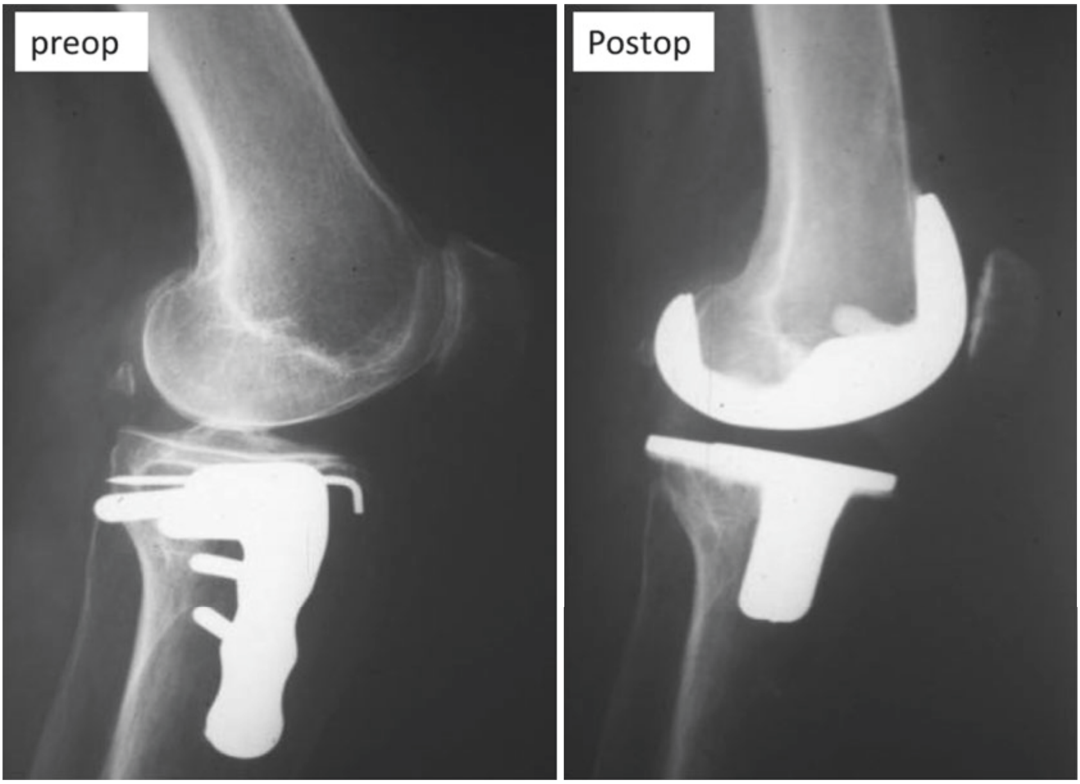

Fig. 38.5 Insufficient resection at the posterior condyle by oversizing the femoral component caused increase in the posterior offset leading to a stiff and painful knee

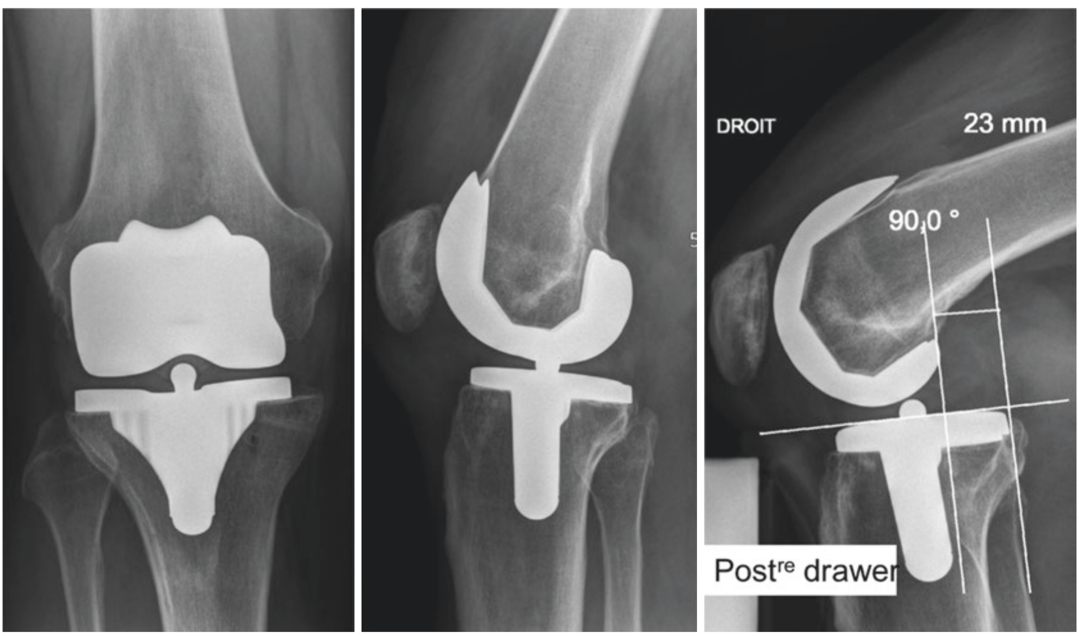

Fig. 38.6 In this patient, the components on both femoral and tibial site were undersized. The posterior condyle resection was excessive, leading to a painful knee due to instability in flexion

sively expensive range of sizes. In example, during the first decade of the total condylar knee, only one femoral size was available [16]. Our knowledge of knee joint anatomy was also limited, based mostly on cadaveric measurements in a limited number of specimens [17]. From the 1990s, CT scan-based morphometric analysis became possible with series of hundreds of subjects [18]. In the 2000s, MRI or CT scan from large populations provided series reaching a thousand people [19]. More recently, the database used for patient-specific instrumentation and gave access to several thousands of scans, coming from different continents [20].

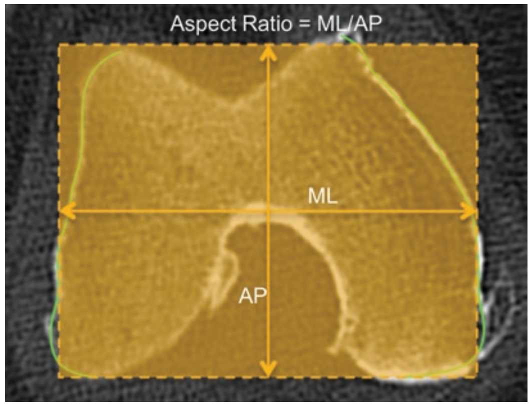

Fig. 38.7 The "aspect ratio" quantifies the narrow-large shape of the distal femur

> **Side Summary**
> Historically there were only few component sizes available, and more frequent compromises were required. Due to large CT- and MRI-databases, the number of different component sizes has increased.

38.4.2 Anatomic Variability

Initially designed in western countries for western population, TKA is now a worldwide procedure, and therefore needs to address several populations whose anatomy differs from the original ones. Particularly, the use of TKA in Asian population revealed differences in the shape of the distal femur [21] and proximal tibia [22]. In the 1980s and 1990s, the range of sizes of TKA increased in a proportional way from the original designs, assuming that the shape of the knee was strictly identical among populations and patient's sizes. It is only in 2003 that Hitt et al. [23] introduced the concept of "aspect ratio" in the orthopedic community (Fig. 38.7) and demonstrated, followed by other researchers, that the shape of the distal femur and proximal tibia is largely variable in the human population, depending on gender, ethnicity, morphotype, and size [19, 24–26]. Following these findings, several manufacturers developed additional "narrow versions" in their range of femurs, known also as "gender knees" [26–29].

The newly defined "trapezoidicity" ratio revealed that "rectangular-trapezoidal" variability of the distal femur is of fundamental importance and that most prosthetic overhangs are observed in trapezoidal femurs, with excessively rectangular prosthesis [30] (Fig. 38.8). Many femoral implants are too rectangular when compared with the bony contours of the distal femur, and it is only a recent evolution in implant designs to have more anatomic trapezoidal femoral components (Figs. 38.9 and 38.10).

> **Side Summary**
> Trapeziodicity defines the rectangular-trapezoidal variability of the femur. A more trapezoidal femur in shape shows most prosthetic overhang.

38.4.3 Influence of Implants Orientation on Sizing

In the last decades, the surgical technique has evolved, in particular the orientation of the TKA components. In the early times, most textbooks taught to align the femoral component with the posterior condylar line [31–33], but it has been lately demonstrated that external rotation

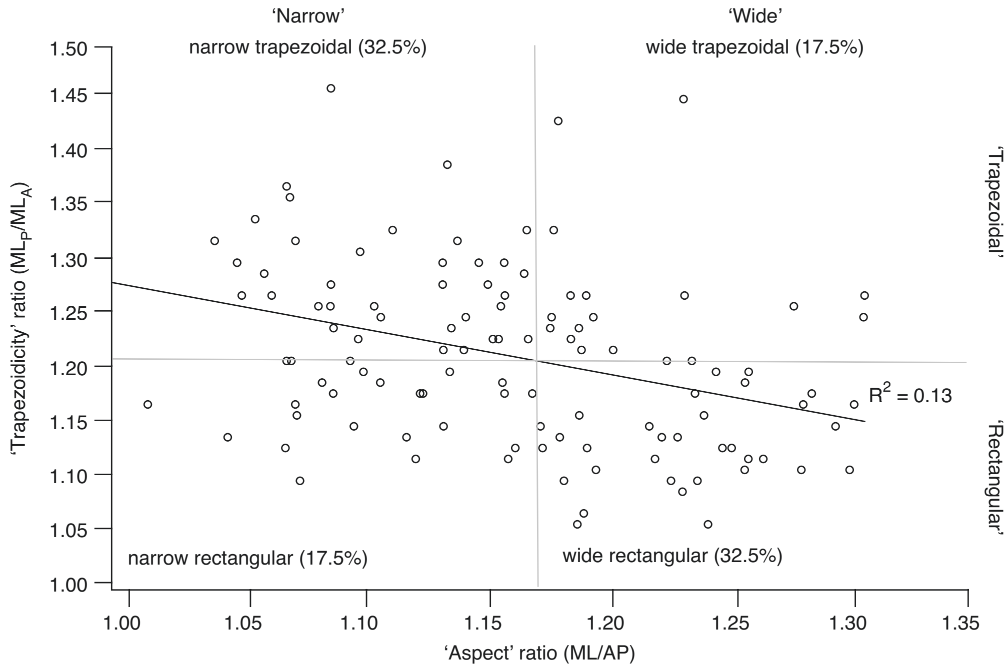

Fig. 38.8 The "trapezoidicity ratio" quantifies the trapezoidal-rectangular shape of the distal femur. (From reference [30])

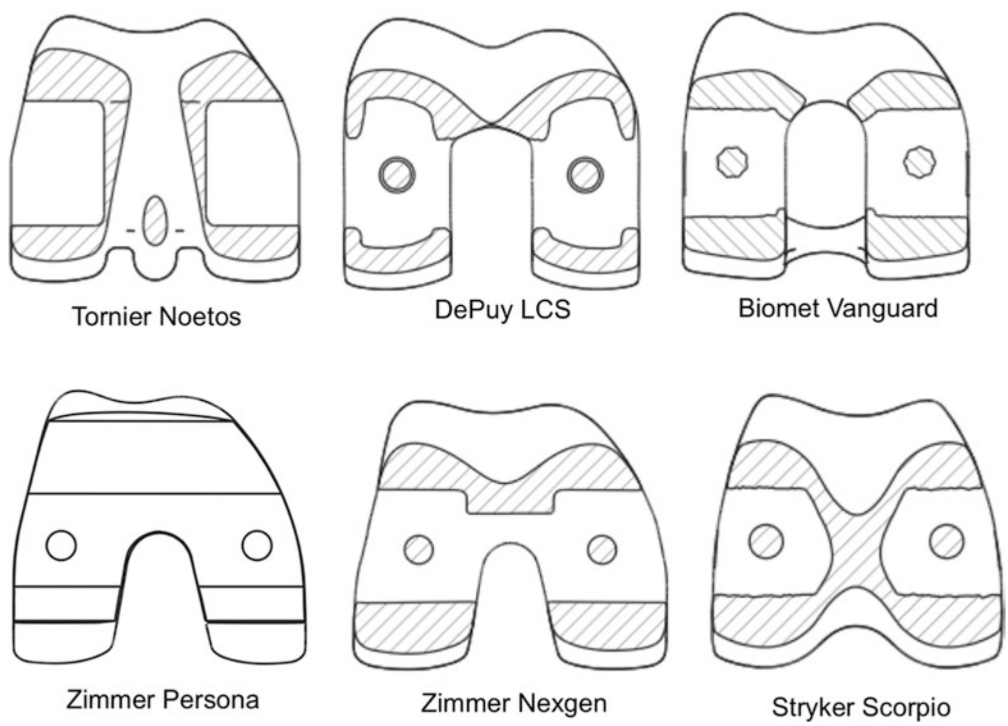

Fig. 38.9 The shape and the trapezoidicity of femoral implants, obtained by digitization of implant is highly variable, with rectangular implants (LCS™ and Vanguard™) and trapezoidal implants (Nexgen™ and Persona™)

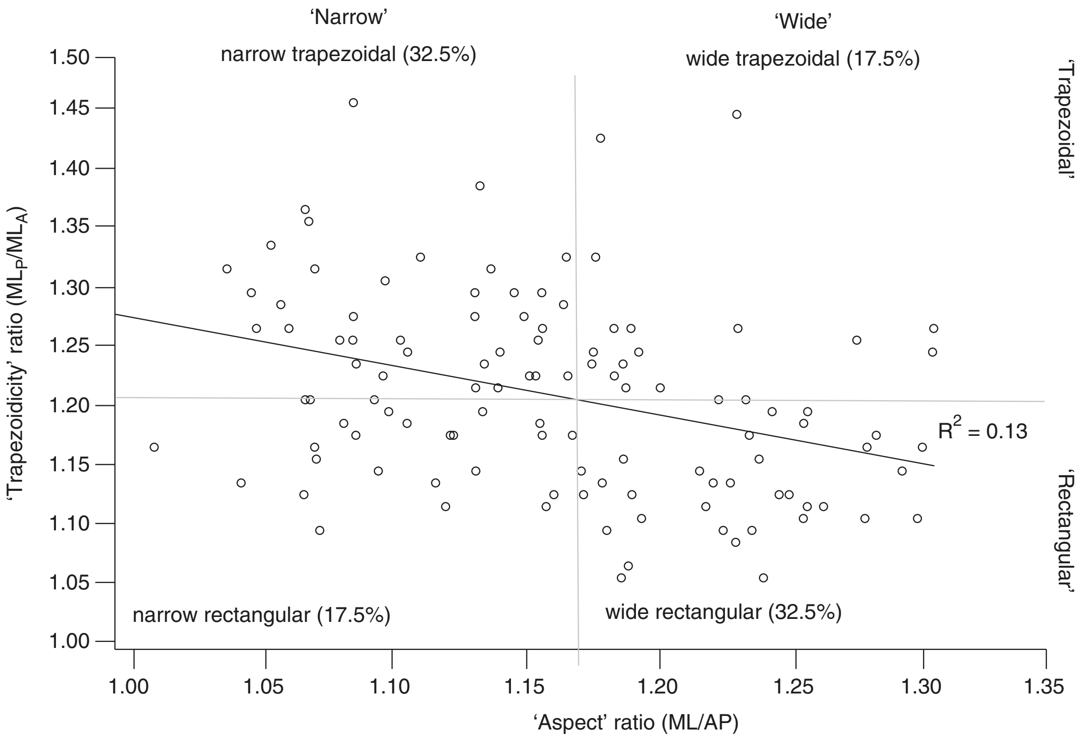

Fig. 38.10 This histogram shows the trapezoidicity ratio in the native knees and in different prosthesis after digitization of explants. (Modified from reference [30])

improves patellofemoral tracking [34, 35] and ligament balancing [36–38]. Therefore, most instrumentation introduced some degrees of femoral external rotation, which modifies the level of posterior resection and influences sizing. Any decreased resection of the posterior condyle(s) may increase the anteroposterior dimension of the femur and consequently implant size. This phenomenon may be particularly significant when using a "medial-referencing" technique for rotation (Fig. 38.11). Conversely, any increased resection will potentially oblige the surgeon to decrease the implant size. The consequences differ depending on the surgical technique: risk of anterior cortical notching with a posterior referenced technique and risk of laxity in flexion in case of anterior referencing technique. External rotation of the posterior femoral cut induces also some height and width asymmetry in the posterior cuts, up to 12 mm with 5° of external rotation [39]. The effects of this asymmetry could be a prosthetic overhang at the lateral condyle and/or under-coverage at the medial condyle. The amount of asymmetry depends on the axis of rotation reference (Fig. 38.11).

At the tibia, the posterior tibial margin was the historical reference axis for rotation [31, 40, 41], but it has been proven that this landmark may induce internal malrotation causing patellar pain and instability [17, 18, 34, 42]. Even if there is no consensus on the best rotational landmarks on the tibia, there is a general agreement to externally rotate the implant with respect to the posterior tibial margin, but this slight modification also influences the bone-implant fit [43]. The surgeon is then frequently obliged to accept a compromise, that is, undersizing on the medial plateau and/or overhanging on the posterolateral plateau [4] (Fig. 38.12). The asymmetry and the variability of the tibial plateau aspect ratio can also create difficulties to obtain simultaneously a good rotational alignment with an optimal bone coverage and therefore can contribute to oversizing of the tibial component [44].

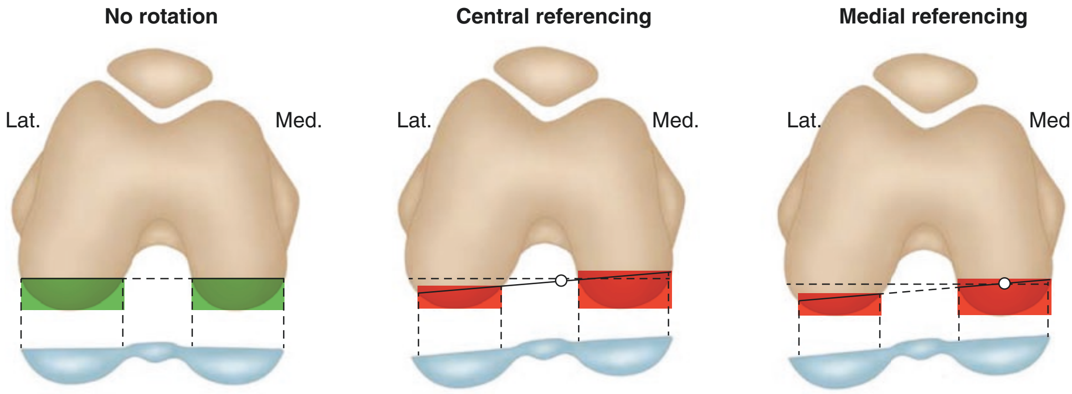

Fig. 38.11 External rotation of the femoral component requires modification of the posterior cut and influences the dimensions and asymmetry of the resected posterior condyles. With "central-referencing" guides, the rotation is performed around the intercondylar notch, resulting in both medial over-resection and lateral under-resection. With "medial-referencing" guides, the rotation is performed around the medial condyle, resulting mainly in lateral under-resection. (From reference [39])

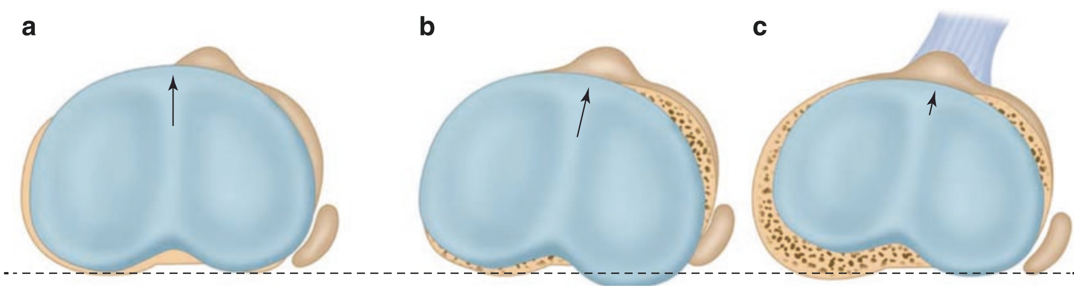

Fig. 38.12 Illustration of the difficulties encountered while positioning the tibial baseplate in TKA. This well-sized symmetric tibial plateau is aligned on the posterior tibial margin (**a**). If the surgeon tries to align the tibia with the anterior tibial tuberosity, a posterolateral overhang appears (**b**). To prevent this overhang, the surgeon can undersize the tibial component, but this option decreases mediolateral bone coverage and can be source of mismatch in sizes between femur and tibia (**c**). (From reference [4])

38.5 Why Oversizing Is Painful in TKA?

Any prosthetic overhang at the femur [1, 2] or the tibia [4] generates soft tissue impingements, source of residual pain and stiffness. Various anatomic structures such as the medial collateral ligament, the iliotibial band, the popliteus tendon, the patellar tendon, and the medial and lateral patellar retinaculum may be involved [1, 2, 44, 45]. However, because the imaging of the soft tissue around metallic implants is challenging, these impingements are poorly diagnosed and their role in residual pain after TKA has been largely underestimated. In total hip arthroplasty (THA), the first iliopsoas impingements were described in 1995 by Trousdale [46], and in TKA, painful impingements between the popliteus tendon and the lateral condyle were described by Barnes and Scott in 1995 and by Allardyce et al in 1997 [47, 48]. Generally speaking, the influence of component overhang on residual pain after TKA has been investigated only in the last decade, and we can guess that the real rate of such impingements is largely underestimated [49].

Having in mind the role of the soft tissue impingement in TKA, the "optimal sizing of implants" should be understood in three dimension rather than with the traditional two-dimension vision, that is, matching the implants with the contours of the resected bone. From that point of view, the popliteus tendon is of particular interest due to its intraarticular location and its close contact with the posterolateral tibial plateau and the lateral condylar margin [50, 51]. It has been recently demonstrated in vitro that an apparently well-sized tibial component—matching the contours of the resected plateau—modifies popliteal tracking, while an undersized tibial component maintains more physiologic patterns [52] (Fig. 38.13). From these findings, it is recommended to slightly undersize the tibial components in order to avoid posterolateral impingement with the popliteus tendon (Figs. 38.14 and 38.15).

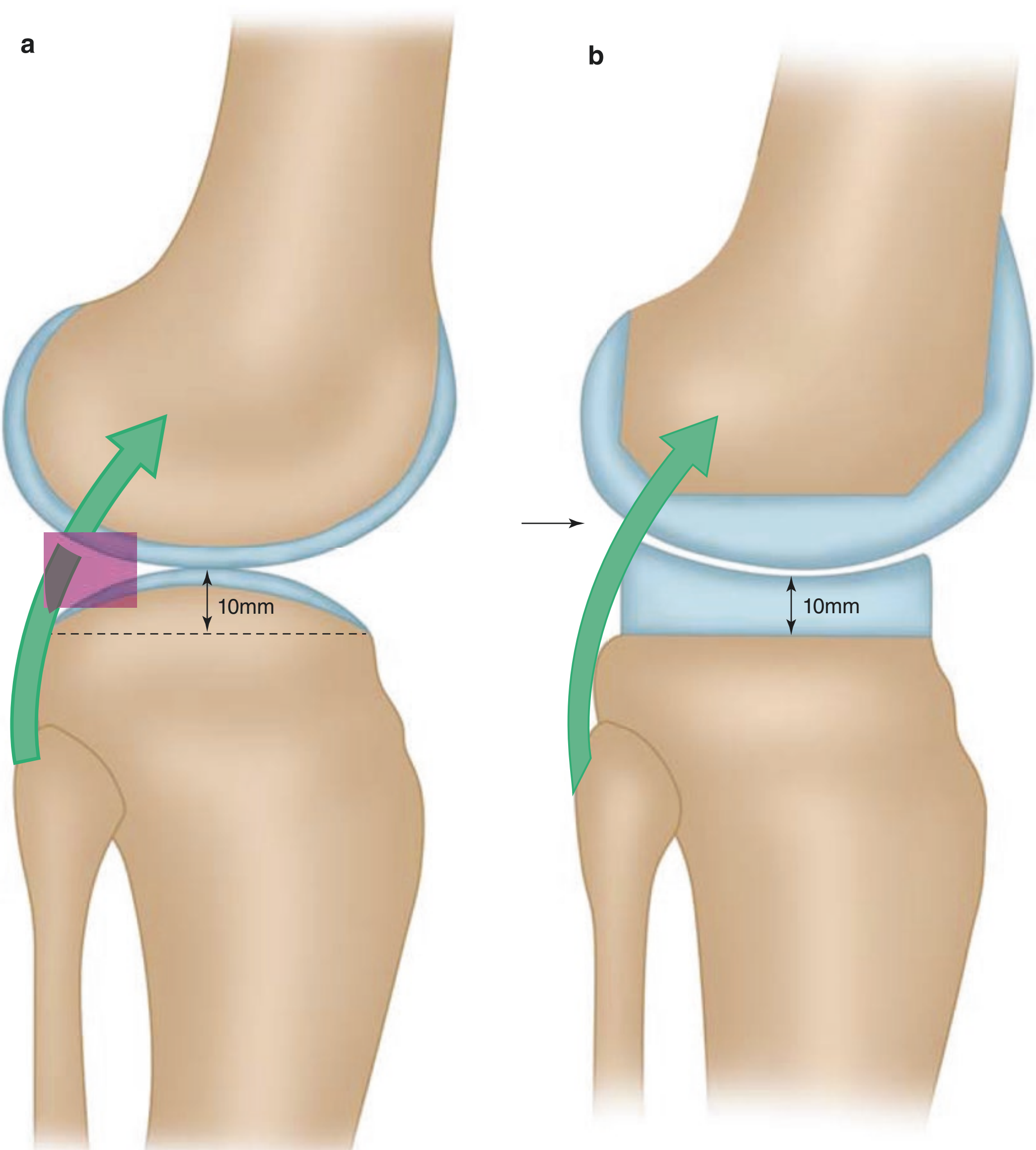

Fig. 38.13 In a TKA, the thickness of the tibial component is selected to restore joint line and to match the contours of the resected surfaces (**a**). Therefore, a superstructure of polyethylene is generally built above the posterolateral area of the tibial plateau, leading to a potential risk of popliteus impingement (**b**). (From reference [52])

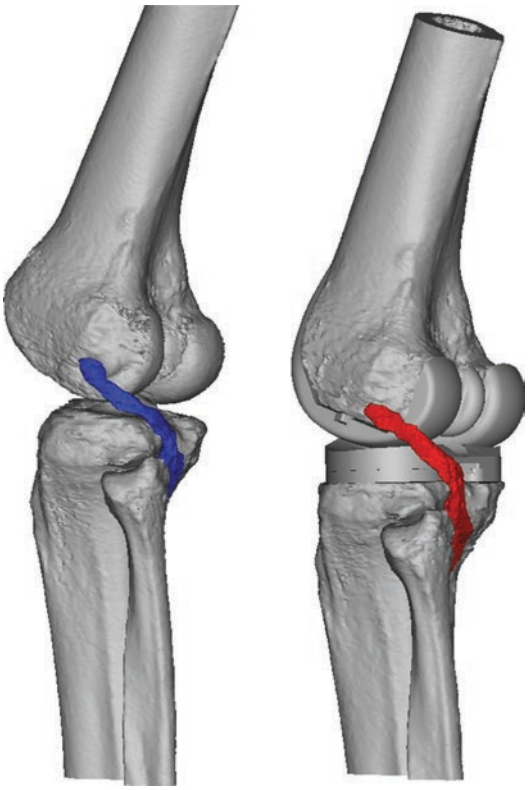

Fig. 38.14 Three-dimensional reconstruction of the knee, before and after implantation of an "apparently normosized" TKA. The popliteus crosses the posterolateral aspect of the tibial plateau. Bone reconstructions were obtained using Mimics™ software (MaterializeT) and implant models (STL files) were superposed. (From reference [52])

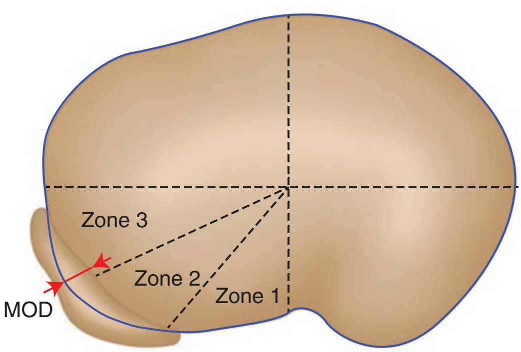

Fig. 38.15 Representation of the tibial plateau (cortical contour in blue) with the area where it is covered by the popliteus in gray. The maximum overlap distance (MOD, red arrow) was measured separately in three sectors of the posterolateral quadrant: Zone 1 (0°–30°), Zone 2 (30°–60°) and Zone 3 (60°–90°). Measurements obtained using Matlab™ from reference [52]

Take Home Message

Sizing the components in TKA appears to be a complex task, influenced not only by the bony dimensions but also by surgeon's options for implant positioning and ligament balancing. Surgeons must be aware that ligament balancing in flexion may influence significantly the implant size when using a gap-balancing technique. Conversely when using an anterior referencing system, femoral size adjustment may affect the amount of resected posterior condyles and the balancing in flexion. The possibility of mismatching femoral and tibial sizes is also of critical importance; otherwise, femur size might be imposed by tibia size or vice versa. Finally, optimal sizing results from a compromise that needs a clear understanding of the consequences of several intraoperative decisions and that should respect some guidelines.

(a) Any prosthetic mediolateral overhang, both at the femur and the tibia, should be avoided. Even an apparently minimal overhang observed on the trials requires to recut and downsize the implant by one size.
(b) The condylo-trochlear junction, at the level of the anterior chamfer, is the higher risk area for oversizing [1, 2]. This zone must be checked meticulously on the trials, and if necessary, a revision of the cuts in order to downsize the femur may be considered.
(c) The "anterior gap" should not be forgotten, and any overstuffing of this area may lead to anterior pain [5, 15]. This anterior gap must be respected both at the patella and at the trochlea [53, 54].
(d) Because the amount of posterior condyle resection influences the final sizing, surgeons using a gap-balancing technique must pay attention to the amount of resected lateral condyle. A minimal lateral condyle resection, as

done in some patients in order to avoid lateral liftoff, can induce femoral overhangs because (i) the increased anteroposterior dimension of the lateral condyle obliges to oversize the femur size and (ii) because of the mismatch between the resected condyle and the prosthetic posterior condyle [39].

(e) Attention must be paid when positioning and sizing the tibial baseplate (i) to avoid any anteroposterior overhang at the tibia, as it may create painful impingements with the surrounding soft tissue and (ii) to avoid any internal malrotation of the implant.

(f) It is recommended to slightly undersize the tibial baseplate in the posterolateral corner and respect a 2–3-mm "security margin" of uncovered bone in order to avoid any popliteus impingement.

(g) The amount of tibio-femoral mismatch depends on the implant design, and while an excessive mismatch may be dangerous, it is recommended to respect the manufacturer's guidelines [55]. In some cases, it may be mandatory to compromise and adapt femur size to tibial size (or vice versa).

(h) The anteroposterior dimension of the patella must be precisely reproduced, which requires caliper measurements before and after resection. Any overstuffing of the patella must be avoided.

(i) Sizing the implants is too critical to rely exclusively on calipers, and the subjective visual appreciation of the bone implant-fit with the trials is of fundamental importance. Whatever the implants and the instrumentation, it may occur that the sizing appears suboptimal at the end of the procedure. In such cases, downsizing should be considered.

(j) Trying to match the implants with the cortical contours of the resected bone (two-dimensional analysis) is an oversimplified procedure. When choosing the appropriate size, surgeon should think in three dimension in order to avoid impingements with the soft tissue envelope.

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Optimal Implant Fixation in Knee Arthroplasty: Cemented Versus Cementless Knee Arthroplasty

39

Reha N. Tandogan, Senol Bekmez, and Metin Polat

Keynotes

1. Cement fixation provides immediate primary stability, is useful to fill small defects, delivers local antibiotics, and acts as barrier to wear debris from the joint. Cement fixation is performed in the majority of knee arthroplasties although geographical differences exist.
2. Newer implant geometries with keels and better surface properties for osteo-integration have led to better outcomes with cementless TKA. Modern cementless implants have comparable clinical outcomes and survival rates with cemented designs.
3. Cementless implants are ideally indicated for younger patients with osteoarthritis and good bone stock. However, good results have also been reported with older patients and inflammatory arthritis. Fixation in unicondylar knee arthroplasty has followed the same trends; with cemented fixation being the most popular and a growing interest in cementless fixation.
4. Cemented TKA shows superior survival rate compared to cementless TKA and is predominantly performed worldwide.

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-58178-7_39) contains supplementary material, which is available to authorized users.

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39.1 Introduction

The long-term functional outcome of knee arthroplasty depends on optimal and durable fixation of implants to the bone. Cement fixation has been used extensively for total knee arthroplasty (TKA) and unicondylar knee arthroplasty (UKA). It is still the most widely used form of fixation. Cement fixation provides excellent primary stability for decades; however, it carries the risk of failure at the bone cement interface in time. The success of cementless designs in the hip have led to cementless implants in TKA. However, the results have been mixed, with worse outcomes in earlier designs. Newer generation of cementless TKA with improved surface coatings and better designs showed promising short-term results; however, long-term durability of these implants has not been published. This chapter reviews the current knowledge and future trends on fixation methods in knee arthroplasty.

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39.2 Cemented Fixation

Bone cement (polymethyl methacrylate, PMMA) is widely used to fix orthopedic implants to the bone. PMMA is made up of a liquid MMA monomer and a powdered MMA-styrene copolymer [1]. Zirconium dioxide (ZrO_2) or barium sulfate ($BaSO_4$) is added to the compound to make it radio-opaque. Bone cement is not adhesive but interdigitates with the cancellous bone to form a micro-interlock. Once polymerization is complete, the primary stability of fixation is excellent and immediate weight bearing and range of motion exercises are possible.

The polymerization of cement occurs with an exothermic reaction and temperatures up to 82–86 °C. However, due to the thin layer of cement, large surface area, and the cooling effects of blood circulation, this value is lower in the body and has been reported to be less than 48 °C in total hip arthroplasty [2]. This is well below the level of protein denaturation of 56 °C. PMMA may cause transient hypotension during the curing phase; this side effect may be accentuated in patients with hypovolemia and may lead to cardiac arrhythmias and myocardial ischemia.

Cement fixation of TKA is much more common compared to cementless fixation. Excellent clinical outcomes and survival rates of over 95% have been reported with different implant designs [3]. Cement fixation provides immediate primary stability and is useful to fill small defects and cover imperfect bone cuts. Cement acts as barrier to wear debris from the joint and prevents the particles from reaching the bone-cement interface. Cement can also be used to deliver local antibiotics.

The use of cement has several disadvantages. One is prolonged operative time (and tourniquet time if used) needed to prepare bone surfaces, waiting for cement polymerization and clearing the excess cement. Third body wear from retained cement particles and extraarticular impingement on the tibial liner might also be a problem. Bone-cement interface carries a risk of failure in time resulting in aseptic loosening. Other proposed disadvantages are an increased risk of deep vein thrombosis (DVT), fat embolism, thermal necrosis during polymerization and an additional interface for wear particles [4].

39.2.1 Surface Preparation

The cementation technique is of great importance to achieve a good clinical outcome (Video 39.1).

A deep penetration of the cement into the trabecular bone helps to avoid micromotion and increases longevity of the implant. Precise bone cuts are important to achieve a flat surface and avoid toggling of the implant under load. The quality of cancellous bone decreases when the tibial cut is moved more distally. Therefore, the minimum amount of bone should be removed to achieve adequate flexion and extension gaps. The surface should be cleaned of any debris and blood and dried thoroughly. Majkowski has shown in a cancellous bone model that active bleeding reduces the shear strength of bone-cement interface by 50% although cement penetration is not affected [5]. Therefore, even if the penetration depth of the cement into bone is not affected, the presence of blood in the bone-cement interface carries the risk of inferior fixation and possibly early failure of the implant.

Pneumatic tourniquets are commonly used to improve visualization and achieve a bloodless field during TKA. The use of pneumatic tourniquet might affect cement penetration. Pfitzner et al. found an increased cement mantle thickness (13 vs. 14.2 mm) when a tourniquet was used, but this difference did not reach statistical significance in 90 cases [6]. However, the use of a tourniquet was associated with a significantly higher postoperative pain. Liu et al. also compared cement mantle thickness in patients with & without tourniquet and could demonstrate no significant difference [105].

In contrast, Vertullo and Nagarajan performed a single blinded randomized study comparing cement penetration in TKA with and without tourniquet and could not find any significant difference [7]. If surgery is performed without a tourniquet, hypotensive anesthesia with or with-

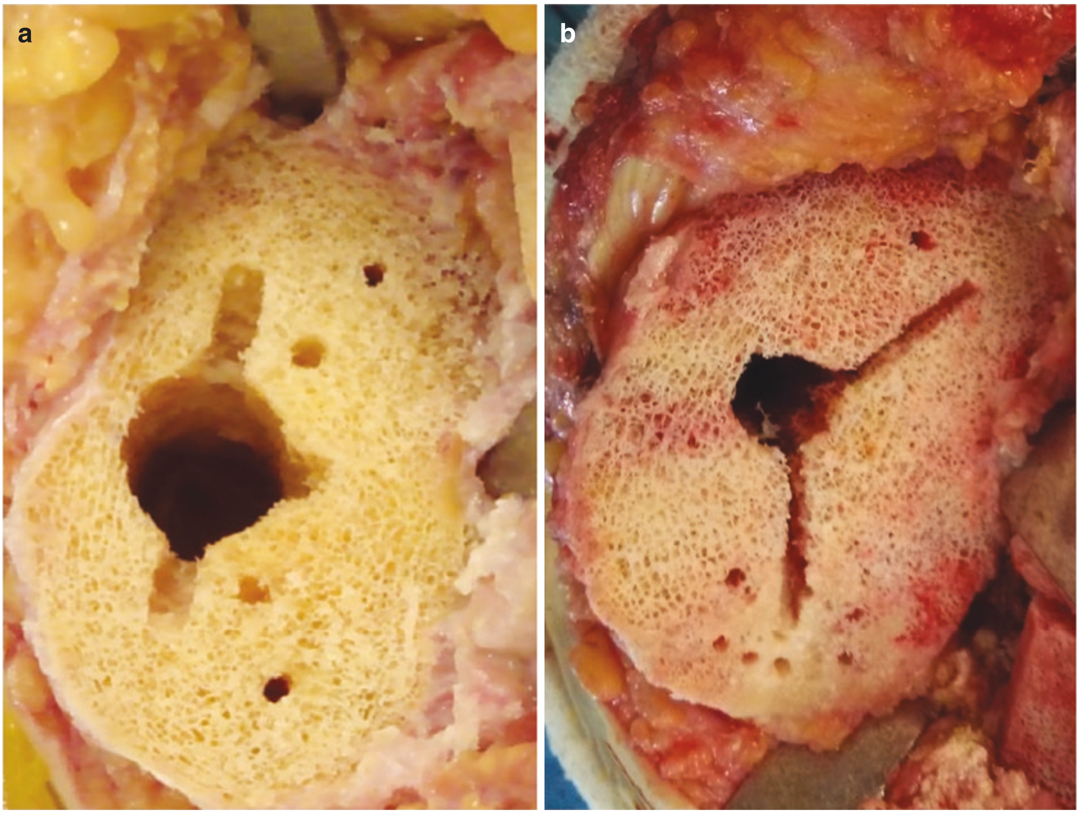

Fig. 39.1 (**a**, **b**) Application of a thigh tourniquet is not essential for good cement penetration. Final tibial surface after pulsed lavage and drying. (**a**) Patient under tourniquet. (**b**) Patient under hypotensive anesthesia and no tourniquet, note similar surface preparation

out adrenalin-soaked sponges are helpful to achieve a bloodless field (Fig. 39.1). This is important both for improved visualization and cement penetration.

Clean and dry cancellous bone surfaces free of debris, blood, and marrow elements are important to achieve good cement penetration. Cleaning of the cancellous surface can be done manually using a syringe or more commonly with a disposable pulsed high pressure lavage system (Fig. 39.2). Pulsed lavage has been shown to increase the cement mantle thickness and penetration into the cancellous bone compared to lavage with a syringe in both TKA and UKA [8, 9]. Pressurized filtered carbon dioxide jets have also been used to prepare bone surfaces in TKA. The proposed advantages are a better and drier surface cleaning compared to pulsatile lavage. A few studies presented as abstracts only have reported good clinical outcomes with adequate cement penetration.

Sclerotic bone impedes cement interdigitation to trabecular bone. Multiple drill holes have been used to induce cement interdigitation in sclerotic bone (Fig. 39.3). 4.5 mm holes have shown less radiolucent lines at 2 years and improved cement penetration compared to 2 mm drill holes [97]. However, larger holes increase the risk of a stress riser, and should be used judiciously.

Side Summary

A clean and dry cancellous bone surface is mandatory before cementation. This can be achieved without a tourniquet providing hypotensive anesthesia is performed.

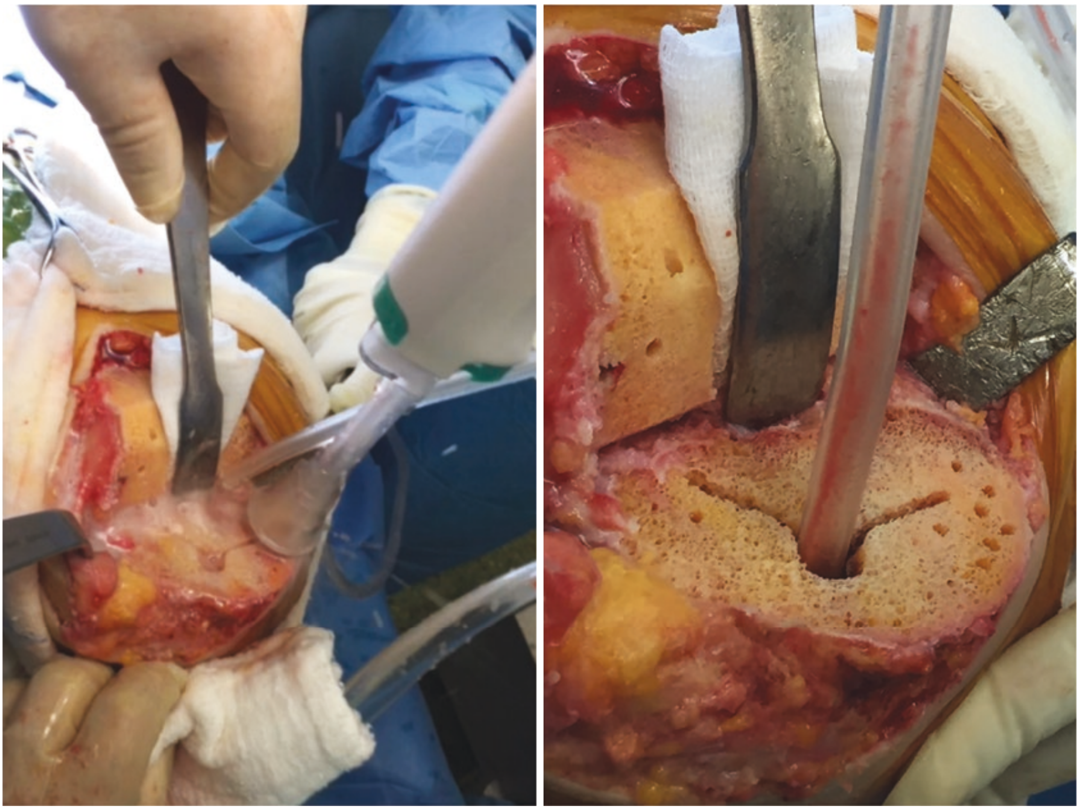

Fig. 39.2 Tibial surface after pulsed lavage cleaning. The surface is cleaned of all debris, blood, and fat and is ready for cement intrusion

39.2.2 Cementing Technique

Cement intrusion in cancellous bone is affected by the viscosity of the cement, the porosity of the bone, and the pressure gradient during application. The minimum amount of cement penetration needed for a stable fixation is unclear; however, one study pointed out 1.5 mm as a cut-off point for failure during pull-out testing [9]. Other studies have shown that at least 2 mm penetration is necessary to achieve micro-interlock with transverse trabeculae [10]. The ideal cement penetration during TKA is thought to be 3–4 mm [11, 12]; more than 5 mm penetration may cause thermal injury to cancellous bone [13].

Side Summary
The ideal cement penetration into the bone at TKA should be between 2 and 4 mm.

Various combinations of tibial cementing have been analyzed by Vanlommel et al. using a saw-bone model [14]. The best cementing was achieved when cement was applied to both the undersurface of the components and to the bone with finger packing. When a cement gun was used, cement penetration was excessive.

Side Summary
The best cementing is achieved with a double cementing technique, in which cement is put on the bone and on the prosthesis.

Few studies have analyzed cementing techniques on the femoral side. Radiolucent lines are frequently seen in well-fixed femoral components on posterior condyles, as cement penetration in that region is difficult to achieve. A study on open-pore sawbones found the best cementation

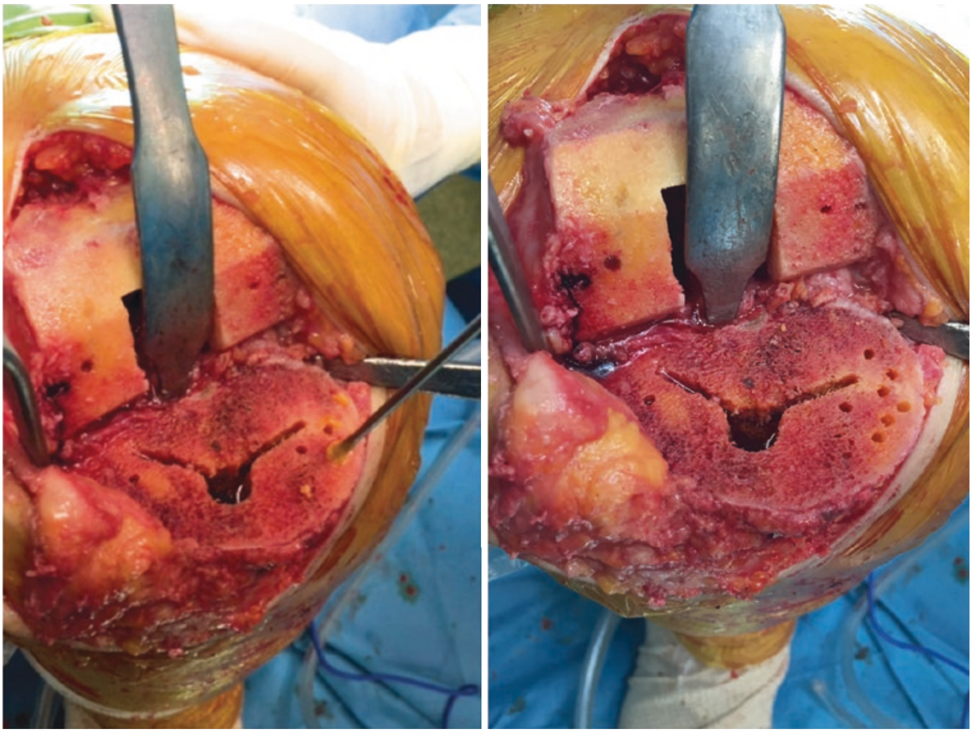

Fig. 39.3 Multiple drill holes are placed in sclerotic bone to improve cement penetration

when the cement was placed on the anterior and distal femur and the posterior condyles of the femoral implant [15]. No cement should be placed on the posterior femoral condyles, since this may lead to retained cement in the posterior compartment and cause limitation of flexion and polyethylene wear.

Cement may be applied with a spatula/finger packing or with a cement gun (Fig. 39.4). Finger packing typically results in 2–3 mm while cement gun usage results in 4–7 mm cement penetration.

Side Summary
Cement may be applied with a spatula/finger packing or with a cement gun. Finger packing typically results in 2–3 mm while cement gun usage results in 4–7 mm cement penetration.

Fig. 39.4 Cement application with a spatula achieves a more uniform penetration pressure

Unlike total hip arthroplasty, the use of cement pressurization guns in TKA is controversial. The clinical consequences of cementing technique have been analyzed in several studies. Ritter found less radiolucent lines under the tibial component in 363 knees at 1–3 years follow-up when a pulsed lavage and cement gun had been used compared to syringe lavage and finger packing of cement [16]. Lutz has shown a twofold increase in penetration of the cement when a cement gun was used, resulting in less radiolucent lines [17]. However, the authors compared a low viscosity cement to standard viscosity cement.

Kopec et al. compared vacuum mixing and gun pressurization versus hand mixing and packing in the proximal tibia in 82 patients undergoing TKA [18]. Cement penetration was marginally better in some but not all zones around the tibial component, and the difference was too small to be of clinical importance. No difference in outcomes was observed at short-term follow-up. It can be concluded that finger packing is adequate for most patients to achieve adequate cement penetration. Some authors have advocated the use of a cement gun in dense sclerotic bone [11].

In a comparative study, cement penetration with pressurization alone was worse compared to pulsed lavage and manual packing of the cement [19]. This study showed that pulsed lavage combined with finger packing improves bone cement penetration by a factor of 4 and interface strength by a factor of almost 12 when compared with syringe lavage combined with pressurizing-gun cementing. The authors concluded that the effect of high pressure lavage was more important than that of cement pressurization with a gun.

Another method used to increase cement penetration is applying negative pressure in the proximal tibia by using a cannula through the holes created during tibial jig fixation [20, 21]. Depending on surgeon preference and dexterity, the components can be cemented separately or in one setting using a single packet (40 g) cement. Cooling the cement increases the working time but also delays curing.

Side Summary

Pulsed lavage is helpful to increase cement penetration into cancellous surfaces. The use of a cement gun with pressurization is not necessary.

39.2.3 Cement Type

High viscosity cements have been associated with lower cement penetration and early failures and should be avoided [22, 23]. Standard and low viscosity cements are routinely used in TKA. If a cement gun is used, two 40 g packets of low-viscosity cement are needed and vacuum mixing if possible. Different types of cements may have different penetration depths even when using the same technique. Walden has shown penetration depths between 2.8 and 3.7 mm using finger packing for three cement types [24]. The brand of cement does not seem to influence the outcome and survival of TKA. Birkeland et al. have analyzed over 26,000 patients in the Norwegian registry, comparing different types of cement. No clinical difference between different types of cement used in this large cohort was found [25].

39.2.4 Surface Versus Full Cementation

Fully cementing the tibial baseplate versus surface cementation is controversial. The proponents of fully cementing the tibial component cite better stability in biomechanical studies, less micromotion, and effective seal for intraarticular debris. Advocates of surface cementing claim adequate stability of the component, and greater loading of the proximal tibial bone avoiding loss of bone stock in case of revision [11]. Some biomechanical studies have shown increased stability and less micromotion and strain in patients with fully cemented baseplates [26]. Other biomechanical studies showed no difference between surface cementation versus full cementation of the tibial tray as long as adequate cement penetration is achieved on the cancellous surface [27]. Fully cementing the baseplate may result in difficulties in removal and possible bone loss if revision surgery is required. Fully cementing the tibia may also cause proximal bone resorption under the tibial tray. A finite element analysis has shown that surface cementation without cementing the tibial stem would produce the least amount of bone resorption [28].

The effect of bearing type on tibial cementation is controversial. Luring et al. found increased micromotion and lift-off in surface-cemented tibias using a conforming mobile bearing design. The author cited increased rotatory forces on the tibial cement bone interface in mobile bearing articulations and advocated fully cementing the stem [29]. In contrast, Rossi has shown excellent early outcomes and no radiological loosening in 70 patients using a mobile bearing TKA and surface cementation [30].

The surgeon should also be aware of the tibial implant design and instrumentation. Some tibial instrumentations are designed for a press fit-keel preparation, while others leave a space around the keel for a cement mantle (Fig. 39.5). It would be a mistake to use surface cementation in keels prepared for a cement mantle, as this would leave a void around the keel (Fig. 39.6).

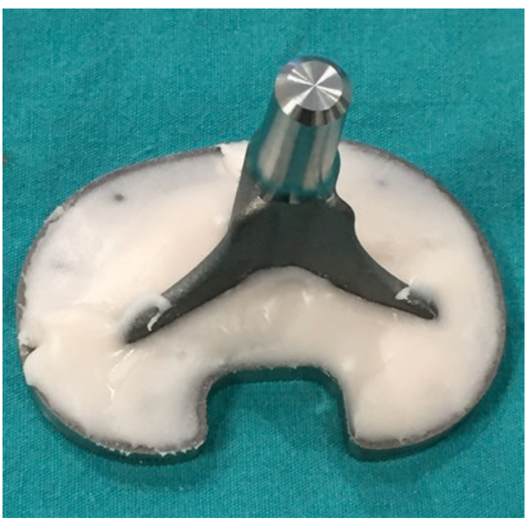

Fig. 39.5 This implant achieves a press fit implantation around the keel; therefore, surface cementing is performed, avoiding cement around the keel

No significant clinical differences in functional outcome or survival have been reported in surface cemented implants compared to full cementation. Galasso et al. compared 232 patients who underwent TKA using full or surface cementation of the tibial baseplate [31]. The cumulative survival rate at 8 years was 97.1% with no difference in clinical outcomes and aseptic loosening. Similar conclusions were reached by Schlegel in a matched pair analysis of patients at 10–12 years follow-up [32]. Aseptic loosening rates were similar even in rheumatoid patients.

In conclusion, it can be stated that surface or fully cementing the tibia result in the same clinical outcomes, provided a 3 mm cement mantle is created under the baseplate and the keel design is appropriate for the chosen technique.

Side Summary
There is no difference in aseptic loosening rates between surface and complete cementing of the tibia component.

39.2.5 Implant Surface and Design Properties

Bone cement must also provide a strong interlock with the implant. Increasing the surface roughness of the cement-implant interface is beneficial for primary stability. Pittman et al. have shown that common surface treatments such as grit-blasting produce interface strengths similar to plasma-spray, porous-coated implants [33]. The authors advocate avoidance of macro surface textures due to concerns for failure during rotational loads.

The addition of a peripheral lip or cement pocket under the tibial baseplate increases cement penetration by decreasing escape of the cement under the metal during implantation. Vertullo et al. have shown that a peripheral lip significantly increases cement penetration in the periph-

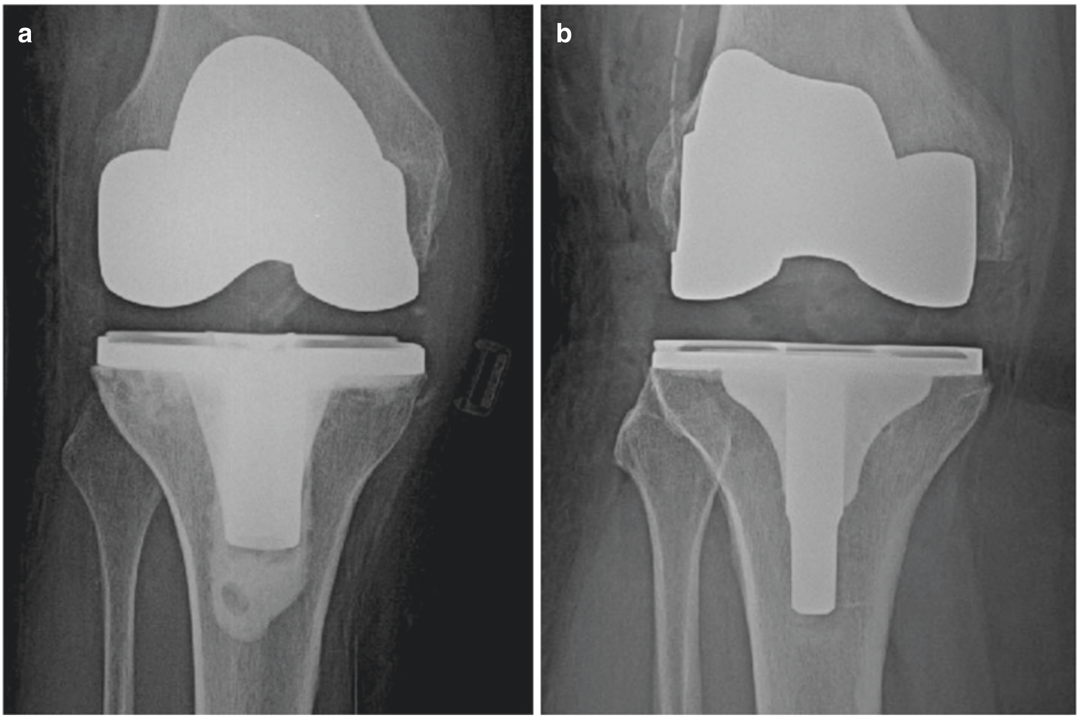

Fig. 39.6 (**a**, **b**) Surface versus full cementation on the tibia. (**a**) The keel of this implant (Zimmer Next-Gen) allows for a cement mantle and is fully cemented. (**b**) The keel of this tibia (Smith & Nephew Genesis 2) is designed for press-fit implantation, only surface cementing is performed

eral part of the cement mantle compared to implants without a lip [34]. However, this effect is true only for the peripheral 5mm of the cement mantle, which equalizes in the central part of the mantle.

High flexion designs have been reported to have a higher early failure rate of the femoral component due to high stresses on the bone cement interface. The addition of drill holes under the anterior flange of the femoral implant to increase cement penetration has been shown to decrease the risk of loosening in biomechanical studies [35].

39.2.6 Antibiotic-Loaded Cement

The addition of antibiotics to bone cement in primary TKA is controversial. Antibiotic elution from the cement is similar regardless of antibiotic type, with high elution in the first week, followed by a dramatic decrease thereafter. This chronic low-dose elution may not be enough to kill pathogen bacteria and may result in antibiotic resistance. Antibiotics up to 2 g per standard packet of cement can be mixed with the powder without compromising its mechanical properties [36]. However, antibiotics must be thermostable to withstand high temperatures. Gentamycin, Tobramycin, Erythromycin, Clindamycin, Oxacillin, Cefuroxime, Vancomycin, Lincomycin, Colistin and Teicoplanin can be mixed with cement for antimicrobial effect [1, 36, 37]. Doses higher than 2 g may be used to manufacture spacers in infected knees where mechanical strength is not an issue.

Proponents of antibiotic use cite decreased deep infection rates as the main advantage. Opponents of antibiotic usage in primary TKA cite the risk of systemic toxicity, hypersensitivity, loss of mechanical strength, expense, and emergence of resistant bacterial strains as disadvantages. Hypersensitivity to the antibiotics in the cement is rare but has been reported [38]. Nephrotoxicity has been reported with high dose antibiotics in spacers but is very rare in the doses used for primary TKA [37]. Randelli has shown that a 1.2% decrease in deep infection rates would be necessary to justify its routine use in primary TKA [36].

The use of antibiotic-loaded cement is guided more by practice patterns than scientific evidence. Registry data and prospective randomized studies also show conflicting results. Outcomes from the Finnish registry have shown decreased deep infections in antibiotic-loaded cements in primary TKA [39]. In contrast, data from the Australian and Canadian registries have shown no difference compared to cement without antibiotics [40, 41]. A recent meta-analysis of seven randomized controlled trials on hip and knee arthroplasty showed decreased deep infection rated when antibiotic-loaded cement was used [113]. Gentamycin was found to be superior to Cefuroxime in this study. The cost-effectiveness of antibiotic-loaded cement has also been discussed.

The limited evidence on the effect of antibiotic-loaded cement on deep infection rates has led some surgeons to advocate a selective use of antibiotic in high risk patients [13]. These include diabetics, immunocompromised patients, morbidly obese, and patients with previous history of fracture or infection around the knee. The effectiveness of antibiotic-loaded cement in revision TKA and established infection is undisputed. The dosage of antibiotic depends on the formulation but should not exceed 2 g per standard packet of cement to prevent mechanical failure.

Side Summary

Routine use of antibiotic-loaded cement in primary TKA is controversial and should be preferred in selected patients with risk factors.

39.3 Cementless Fixation

The concept of direct osteointegration of the host bone to the implant is attractive. However, the higher rates of earlier failure in cementless TKA designs led to an initial unpopularity. Early cementless tibial component designs using screw or pin fixation, with poor osteoconductive surface properties, had increased rates of failure and loosening [43]. The screw holes were also a conduit for debris material and a risk for osteolysis. Osteolysis is an inflammatory reaction to particulate debris and may sometimes lead to catastrophic cystic formation. Although osteolysis is multifactorial and is seen in both cemented and cementless TKAs, it occurred more frequently in earlier cementless designs of the nineties [44]. Newer cementless designs with fully porous coatings have decreased rates of osteolysis compared to older designs. Metal-backed patellae led to catastrophic failures and were discontinued [45]. This led to an initial abandonment of cementless fixation. Higher failure rates of the tibial component led to the utilization of hybrid fixation, in which the femur was uncemented and the tibial tray was fixed with cement. Better results of hybrid techniques led to a resurgence of interest on cementless implants.

Newer implant geometries with keels and better surface properties for osteointegration have led to better outcomes with cementless TKA. The use of mobile bearings has been cited as an advantage to decrease stress on the implant-bone interface [4]; however, similar results have also been achieved with fixed bearings in modern TKA designs. Modern cementless implants have comparable clinical outcomes and survival rates with cemented designs. Cementless implants are ideally indicated for younger patients with osteoarthritis and good bone stock. However, good results have been reported with older patients and inflammatory arthritis.

The proposed advantages of cementless fixation in TKA are preservation of the bone stock in younger patients and ease of revision. Other cited advantages are shorter operative time, decreased risk of DVT [46], and avoidance of complications associated with cement such as third body wear and retained cement. Unless osteolysis occurs, uncemented components are expected to stay fixed for a long period of time once initial osteointegration is established. This is not the case for cemented components where there is excellent initial stability; however, loosening is a definite risk with longer term follow-up. This has been shown in many studies including a Cochrane Database review of 5 randomized controlled trials including 297 patients [47]. This review concluded that although cemented implants demonstrated less migration in the first 2 years, they presented with more risk of aseptic loosening at longer term follow-up. Cementless implants exhibit early migration in RSA studies during the first year, then stabilize and show no further migration if osteointegration is achieved.

Cementless implants are more expensive and require precise bone cuts and perfect ligament balance as cement is not available to fill minor defects to provide primary stability. Given the similar clinical outcomes of cemented implants, the increased cost of cementless designs seems hard to justify in older patients.

Side Summary
Cementless fixation may provide durable fixation in younger patients with good bone stock; however, the added expense is prohibitive.

39.3.1 Initial Stability and Osteointegration

The initial stability of cemented and uncemented tibial baseplates under cyclic loading was measured by Crook [48]. Although uncemented baseplates exhibited more micro-movement, this was less than 150 μm at all the locations tested, and the authors concluded that this difference was not clinically significant. Bone mineral density has been found to correlate with migration of cementless TKA. In a 2 years study of 92 patients with uncemented tibial components, Andersen found a significant correlation with low preoperative bone mineral density of the tibia and migration of the implant measured with radiostereometric analysis (RSA) [49].

Side Summary
Due to increased micromotion of the cementless implants, the initial stability of cemented implants is better in the first year after implantation. Micromotion equalizes after the first year and may be less in cementless implants at longer term follow-up.

39.3.2 Bearing Type

Most of the reported series on uncemented TKAs have utilized either a mobile bearing or cruciate retaining design. This is due to concern about high stresses being transferred to the bone-implant interface in a fixed bearing PS design with a tibial post. However, good outcomes have been reported recently with an HA-coated fixed bearing PS design without osteolysis or loosening [50]. In contrast, National Joint Registry data for England and Wales show an increased risk of revision for fixed bearing posterior stabilized implants after 4 years [51]. An unconstrained mobile bearing or a cruciate retaining fixed bearing implant should be preferred if uncemented fixation is chosen.

39.3.3 Patient Age

Given the possibility of durable fixation, cementless implants are ideally suited for younger patients. A recent review of studies in patients younger than 60 years with mostly osteoarthritis, Franceschetti could not find a significant difference between cemented and cementless implants in terms of clinical outcomes and loosening [52]. Radiolucent lines of <2 mm were seen with both fixation methods. A survival rate of over 90% was reported in the majority of the studies at a mean follow-up of 8.6 years (range 5–18 years).

Kim et al. compared cemented and cementless implants of the same design (Zimmer Next-Gen CR) in simultaneous bilateral TKAs in patients younger than 55 years [53]. Clinical outcomes were similar at minimum 16 years follow-up. There was no femoral loosening in either group, tibial component survival was 100% for cemented and 98.7% for uncemented tibias.

Although cementless implants are advocated for younger patients with good bone stock, good results have been obtained in elderly patients as well. In a group of 134 patients with cementless TKAs, Newman has reported excellent outcomes with 98.6% survivorship at 4 years, as well as no progressive radiolucencies or subsidence in patients older than 75 years [54].

39.3.4 Obesity

Obesity does not seem to be contraindication to cementless TKA. In a comparative multicenter review of 298 TKAs in morbidly obese patients, a higher revision rate (13% vs. 0.7%) and aseptic loosening rate (6% vs. 0) were found in cemented implants when compared to cementless TKA [55]. The authors actually advocated the use of cementless implants for morbidly obese patients. Another study by Lizaur-Utrilla found similar clinical outcomes and implant survivorship at 7 years in 171 uncemented TKAs in obese and nonobese (BMI < 30) patients [56]. Conversely, in a comparative study of 100 matched knees followed for 9.2 years, Jackson et al. found inferior outcomes in obese patients undergoing cementless TKA, although implant survival was similar in both groups [57].

Side Summary
Patient age and obesity does not adversely affect the outcome of cementless TKA at mid-term follow-up.

39.3.5 Cementless Patellar Implants

Cementless fixation of the patella is controversial. Earlier studies have shown increased complication rates and catastrophic failures with metallosis using metal-backed patellae [58]. This has been attributed to poor locking mechanisms, thin polyethylene, poor tracking, and minimal femur contact in earlier designs [59]. Newer generation implants with hydroxyapatite coatings and thicker polyethylene have shown better results at short-term follow-up [58, 60]. However, the problems still persist as one study reported 20% fracture rate of tantalum-backed patellar components in 30 patients at 5.5 years follow-up [61].

Due to these concerns, cementless TKA is usually performed without patellar resurfacing or with a cemented all poly patellar button.

Side Summary
Cementless patellar resurfacing is not recommended.

39.3.6 Inflammatory Arthritis

Cementless fixation is not usually advocated for patients with inflammatory arthritis due to concerns about bone quality and risk of failure of osteointegration. However, many authors have reported good results with an acceptable survival rates in patients with inflammatory arthritis. Sizing is important as the tibial tray should cover the resected surface as much as possible to prevent subsidence in osteoporotic bone [62]. Buchheit et al. have reported a 97% survival rate at 6 years in 55 patients with RA [63]. There was only one loosening of the tibial tray in this series. Sharma, using low contact stress mobile bearing implants, reported 94% survival at 16 years in patients with rheumatoid arthritis [64]. Woo et al. reported 10 years outcomes of cementless TKA in rheumatoid patients [65]. Only one case of loosening was found in 179 knees, although radiolucent lines less than 2 mm were seen in 12% of the femoral and 24 % of the tibial components.

Although functional outcomes in RA patients are inferior to OA patients due to poor soft tissues, contractures, and multijoint involvement, survival of cementless systems seems to be unaffected.

39.3.7 Hybrid Fixation

The higher rate of tibial component failures in cementless TKA led to the introduction of hybrid fixation, where the femur is fixed without cement while the tibia is cemented. The results of hybrid TKA have been mixed, with some older studies reporting higher failure rates and newer studies with better results. Duffy reported a 27% revision rate at 15 years, mostly for the femoral component, for hybrid TKA and advised against its usage [66]. In contrast, good clinical outcomes have been reported with hybrid fixation in other studies. McLaughlin reviewed the 16 years results of 148 hybrid TKA and reported only one aseptic loosening with 99% implant survival [67]. Pelt et al. compared 111 cemented CR TKA to 174 hybrid TKA using either a Maxim or Vanguard system (Biomet) [68]. Knee Society Scores and implant survival was similar in both groups at 7 years, with 99.2% survival of the femoral component in hybrid knees. Interestingly, radiolucent lines were more frequent in cemented femurs. Yang reported on 235 hybrid TKA of 5 different designs [69]. Implant survival rates were 92% for the femur and 95% for the tibia at 10–15 years follow-up, and the authors concluded that their results were no different than cemented implants. Lass et al. compared 60 hybrid TKAs with 60 uncemented TKA [70]. Survivorship of the tibial component was 96% in both groups at 5 years follow-up, with similar clinical outcomes. Radiolucent lines were much less frequent in uncemented tibias, suggesting that once osteointegration was achieved, fixation was durable.

Side Summary
High aseptic loosening rates of the tibial component of earlier cementless designs led to the concept of hybrid fixation; an uncemented femur combined with a cemented tibia.

39.3.8 Surface Coating

39.3.8.1 Hydroxyapatite

Hydroxyapatite is an osteoconductive material that has been extensively used for fixation in cementless total hip arthroplasty. The addition of HA coatings has improved fixation of total knee implants [71]. In a meta-analysis of 14 trials including 926 TKA, Voigt and Mosier have shown that the addition of hydroxyapatite coating to metal-backed tibial trays improves fixation and durability [72]. This is especially helpful in patients over 65 years. However, no difference in functional outcome could be demonstrated comparing trays with or without HA coating.

Several studies have shown excellent long-term survivorship and outcomes of hydroxyapatite coated TKA (Table 39.1). Comparative studies using the same implant with cemented fixation have shown that uncemented implants perform equally well, and sometimes better than cemented implants.

39.3.8.2 Porous Tantalum

Another method of improving tibial fixation is the use of highly porous tantalum implants. Also named trabecular metal (Zimmer-Biomet, Warsaw, IN, USA), this newly developed metal has a similar elastic modulus with native bone and is highly osteoconductive. In a meta-analysis of six studies involving 977 patients, porous tantalum monoblock tibial components were associated with higher functional scores, fewer radiolucent lines, and shorter operation times compared to cemented implants [73]. However, no significant differences were seen in range of motion, functional scores, complications, reoperation, and loosening rates between the two groups. The durability of trabecular metal implants has been shown in long-term studies. After an initial migration up to 2 years, these implants have shown excellent fixation without loosening at 10 years [74], making them an attractive choice in younger patients. Several studies using monoblock tantalum tibial components have shown over 95% survivorship at 5–11 years with very few revisions for loosening (Table 39.2). Early failures have been reported in tall, heavy male patients with sub-

Table 39.1 Survivorship of hydroxyapatite-coated cementless TKA

Author	Year	Implant type	No. of patients	Follow-up (years)	Survival	Notes
Hydroxyapatite						
Cross [99]	2005	Fixed bearing CR	1000	10	99%	
Tai [111]	2006	Fixed bearing CR	118	5-12	97.5%	2 tibial tray revisions
Beaupré [98]	2007	Fixed bearing CR	75	5	100%	More pain in the cementless group compared to cemented at 6 months, equalized at 5 years
Epinette [101]	2014	Mobile bearing PS	270	15-22	97.1%	
Prudhon [109]	2017	Mobile bearing PS	100	11	95.4%	Similar outcome and survivorship compared to cemented implant
Melton [106]	2012	Fixed bearing CR	325	10	96%	2.3% aseptic loosening

CR Cruciate retaining, *PS* Posterior stabilized

Table 39.2 Survivorship of monoblock tantalum tibial components

Author	Year	Implant type	No. of patients	Follow-up (years)	Survival	Notes
Monoblock tantalum tibia						
Henricson [74]	2016	Fixed bearing CR	21	10	95.5%	No revision for loosening, 1 infection
DeMartino [100]	2016	Fixed bearing CR	33	11.5	96.9%	No revision for loosening or osteolysis
Niemelainen [108]	2014	All tantalum monobloc implants	1143	7	97%	No revision for loosening
Pulido [110]	2015	Fixed bearing PS	132	5	96.7%	No revision for loosening
Gerscovich [102]	2017	Fixed bearing CR	58	10.2	96.5%	2 tibial revisions
Kwong [104]	2014	Fixed bearing PS	115	7	95.7%	No revision for loosening

CR Cruciate retaining, *PS* Posterior stabilized

sidence of the component, so patient selection criteria for these implants continue to evolve [75]. The cost of this newly developed implant is still prohibitive.

39.3.8.3 Other Surface Coatings

Other porous osteoconductive coatings have recently been introduced for cementless TKA implants. Regenerex (Regenerex Biopharmaceuticals, USA) is a novel porous titanium construct with a three-dimensional porous structure and biomechanical characteristics close to that of normal trabecular bone. Biofoam (MicroPort Orthopedics Inc., Arlington, TN, USA) is a porous reticulated titanium material with a compressive modulus similar to that of native bone. Tritanium (Stryker Orthopedics, Kalamazoo, MI, USA) is a highly porous titanium surface coating manufactured using a 3D printing technology. Encouraging early results have been achieved with these coatings; however, longer follow-up is needed to define their value and justify the expense (Table 39.3).

Side Summary
Modern cementless designs with improved surface coatings have comparable outcomes to cemented implants.

Table 39.3 Outcomes of new porous coatings

Author	Surface coating	Year	Implant type	No. of patients	Follow-up (years)	Survival	Notes
Winther [114]	Regenerex	2016	Fixed bearing CR	61	2	n.a.	Similar clinical results with plasma sprayed implants
Waddell [112]	Biofoam	2016	Medial pivot CR	104	2	n.a.	One tibial radiolucency, no revision for loosening
Harwin [103]	Highly porous titanium	2017	Fixed bearing CR	219	4.4	99.5%	Outcomes and survival similar to periapatite coated implants
Nam [107]	Highly porous titanium	2017	Fixed bearing CR	38	1.4	n.a.	Early results similar to cemented implant of the same design

CR Cruciate retaining

39.3.9 Clinical Outcomes and Survivorship of Cementless TKA

The outcomes of large series and registry data for uncemented compared to cemented TKAs have reported conflicting results. Earlier registry data favor cemented implants with lower revision rates and higher implant survival. However, recent data with modern implants have shown similar results in systematic reviews and registry studies. The 13th Report of the National Joint Registry for UK and Wales including 737,759 patients showed a decline in the use of uncemented or hybrid knees compared to cemented implants [51]. In this dataset, the usage of uncemented/hybrid knees declined from 9.5% in 2003 to 2.7% in 2016. Cumulative revision rates of uncemented designs were still higher at 12 years for uncemented implants compared to cemented fixation (4.74% vs. 3.82%). The Swedish Knee Arthroplasty Register's 2016 Annual Report demonstrates no significant change in the use of cementless implants over the years [76]. However, cemented implants comprise more than 90% of arthroplasties. The cumulative rate of revision for uncemented tibias implanted before 1995 show a high rate of revision compared to cemented ones. However, this may be due to the failure of older cementless designs and may not reflect the performance of current implants.

In a meta-analysis of 3568 TKAs, Mont et al. found comparable survivorship for both types of fixation [77]. Survivorship at 10 years for cementless TKA was 95.6% compared with 95.3% for cemented TKA. At 20-years follow-up, implant survivorship had decreased to 76 and 71%, respectively. No difference was observed between fixation with or without screws. Petursson et al. compared 4585 hybrid TKAs to 20,095 cemented TKAs with risk of revision for any cause as the primary endpoint for the patients in the Norwegian Arthroplasty Register [78]. Survival at 11 years was 94.3% in the cemented TKR group and 96.3% in the hybrid TKR group. Depending on implant type, hybrid TKA performed equal to or better than cemented TKA. The National Joint Replacement Registry of the Australian Orthopedic Association's 2016 Annual Report finds lower cumulative rates of revision in hybrid TKA, compared to cemented and cementless implants (6.6%, 7.3% and 8.1%) at 15 years follow-up [79]. Constraint is another factor that should be taken into consideration as fixed bearing PS implants have lower rates of revision in cemented implants compared to uncemented ones. Wang et al. performed a comparative meta-analysis of registry data on cemented and uncemented fixation in TKA [42]. The method of fixation had no effect on the rate of infection. Pooled data of the registries showed a higher rate of revision for uncemented knees, although rates of aseptic loosening were similar.

Regional differences also play a role in the use of uncemented implants. An analysis in Nordic countries reveals that uncemented components are more frequent in Denmark (22%) than in Norway (14%) and Sweden (2%) [80]. This difference may be due to a variety of factors including training, surgical philosophy, availability of implants, and reimbursement.

Several conclusions can be drawn from registry data. Despite good results from specialized centers using newer generation uncemented implants, cemented fixation is still more frequently performed throughout the world for TKA. Hybrid fixation has been shown to be superior to either cemented or cementless fixation in two registry studies. Uncemented and hybrid implants perform better with mobile bearing and cruciate retaining designs, while cemented fixation is more durable for fixed bearing posterior stabilized implants. Newer implants with better geometry and coating may improve the results of uncemented fixation, but this has not been reflected in registry data that usually report the results of older designs.

Side Summary
Cemented fixation is still the most frequently performed type of fixation in TKA. Uncemented and hybrid implants perform better with mobile bearing and cruciate retaining designs, while cemented fixation is more durable for fixed bearing posterior stabilized implants.

39.4 Cemented Unicondylar Knee Arthroplasty

Cement fixation results in a more predictable fixation and survival in unicondylar arthroplasty. Excellent clinical outcomes have been reported at 10 years follow-up for both mobile and fixed bearing UKA [81, 82]. However, if designer series are excluded, registry-based studies indicate that the survival of UKAs are inferior to those of TKA. Niinimäki et al. reported on 4713 UKAs from the Finnish registry [83]. The survivorship of UKAs was 89.4% at 5 years, 80.6% at 10 years, and 69.6% at 15 years; the corresponding rates for TKAs were 96.3%, 93.3%, and 88.7%, respectively. The National Joint Registry of England reports similar results; the revision rate for unicondylar (medial or lateral UKR) is 2.9 times higher than the observed rate for all types of knee at 12 years [51].

Epinette et al. analyzed the modes of failure in a retrospective review of 418 revision UKAs in a multicenter French Society for the Hip and Knee study [84]. Eighty percent of the implants were fixed bearing UKAs and 85% of the implants had been cemented. The most common reason was aseptic loosening and 48% of them occurred during the first 5 years. Loosening of the tibial component was more frequent than the femoral implant. This highlights the importance of appropriate surgical technique, including precise bone cuts, good alignment/sizing, and cementation especially on the tibial side during surgery. Surgeon experience and volume are important factors for success in UKA. Registry studies have shown increased survival and lower revision rates with increased surgeon volume [85].

The limited exposure and working window increase the risk of retained cement in the posterior compartment in UKA. Excess cement should be avoided when placing the tibial component; most surgeons would apply a thin mantle of cement on the tibia but place cement only under the anterior half of the tibial component to prevent retained cement in the posterior compartment. The same is true for the posterior condyle of the femoral implant; only a thin layer of cement should be placed in the pocket of the implant to avoid retained cement in the difficult to reach posterior compartment (Figs. 39.7 and 39.8). Current instrumentation systems usually include curved hooks and dental pick like instruments to clean excess cement from the posterior compartment and adjacent to the medial collateral ligament (Video 39.2).

Biomechanical studies have shown a significantly higher wear rate of cement particles compared to bone debris [86]. Therefore, every effort should be made to avoid retained cement particles in UKA (Fig. 39.9).

Adding multiple drill holes to dense bone increases cement penetration and implant stabil-

Fig. 39.7 Very thin cement is placed on the posterior third of the tibial implant and posterior femoral condyles to avoid retained cement in the posterior compartment

ity in UKA [87]. Cementing to a flat surface without a possibility for cement interdigitation should be avoided. Pulsed lavage is also important in unicondylar arthroplasty to ensure adequate cement penetration. High pressure lavage is superior to syringe lavage for cement penetration. Jaeger et al. have shown that although cement mantle was adequate with both techniques, pulsed lavage led to an increased cement penetration distance and volume [8]. The same authors have shown less subsidence in biomechanical testing in cadavers when pulsed lavage was used in unicondylar arthroplasty [88]. Pulsed lavage is also helpful to decrease interface temperature between cement and bone. Cadaver studies have shown significantly lower interface temperatures in pulsed lavage specimens compared to syringe lavage (21 °C vs. 24 °C). However, both levels were far lower than thresholds for thermal damage [89].

In conclusion, cement fixation is still the gold standard for UKA. Meticulous surgical technique, focusing on precise sizing, bone cuts, ligament balance, and cementing technique is necessary to ensure a successful outcome.

Side Summary
Cement fixation is still the gold standard for UKA.

39.5 Cementless Unicondylar Knee Arthroplasty

Cementless fixation has also been used for UKA and offers the same advantages and drawbacks seen in cementless fixation of TKA. Cementless designs require a metal tibial tray, and this has

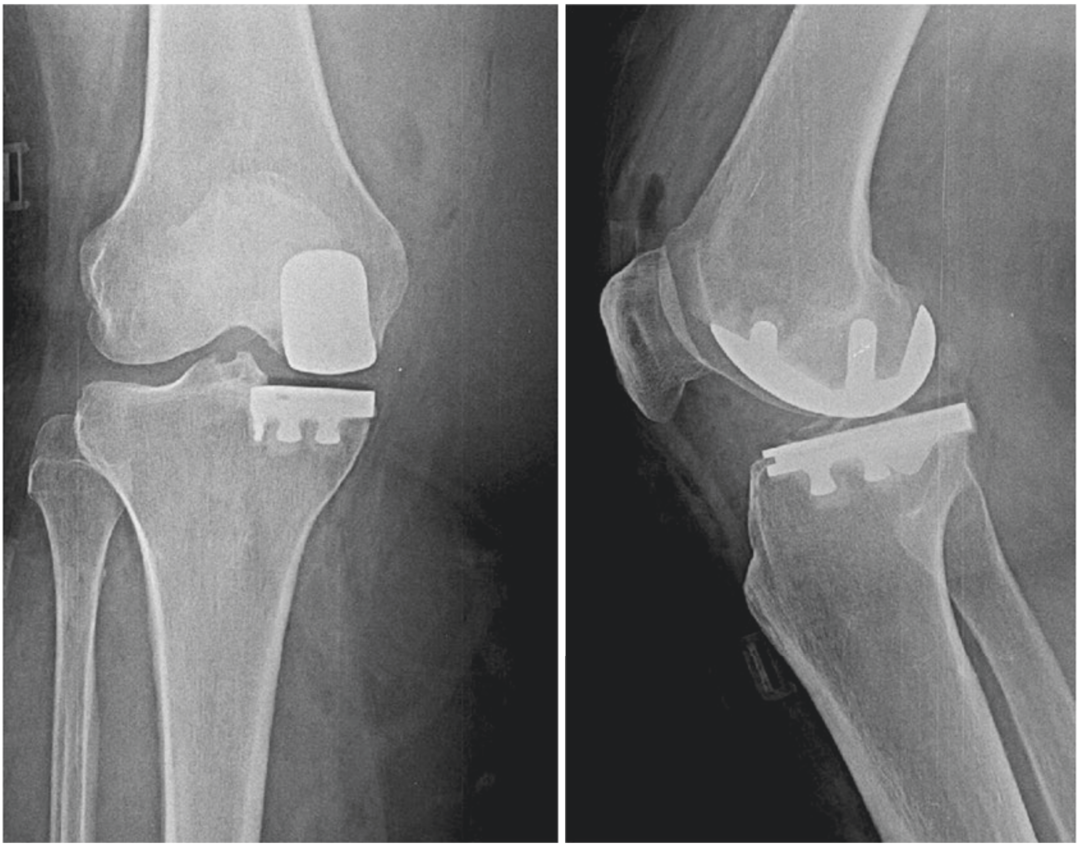

Fig. 39.8 Cemented fixed bearing medial unicondylar arthroplasty (ZUK, Zimmer). Cement is placed both on the bone and under the implants. Note minimal cement under the posterior femoral condyle

been criticized for requiring a more generous tibial cut and potentially sacrificing dense subchondral bone supporting the implant. However, Walker has shown that metal tibial trays show superior load distribution when using metal-backed implants compared to all-poly tibial components [90]. Metal-backed implants are also necessary if a mobile bearing design is used. Early cementless designs had an increased rate of revision at 10 years and fell out of favor [91]. Improvements in design and surface coatings have led to a resurgence of cementless fixation. Primary stability was improved with press-fit implantation followed by secondary stability with bone ingrowth/ongrowth into porous surfaces (Fig. 39.10).

Several studies have shown good outcomes of cementless UKAs at mid-term follow-up. Blaney reported on 238 cementless medial mobile bearing Oxford UKA [92]. No patient had progressive radiolucent lines or loosening at 5 years follow-up, and the cumulative survival rate was 98.8 % with only seven patients requiring revision. Six years follow-up results of 1000 mobile bearing cementless UKA were reported by Liddle et al. in a multicenter study [93]. 1.9% of the knees required revision; however, none were for tibial or femoral loosening. Implant survival at 6 years was 97.2%, and there was a partial radiolucency at the bone-implant interface in 72 knees (8.9%), with no complete radiolucencies. The authors could not find a specific contraindication to cementless unicondylar arthroplasty and found better radiological evidence of fixation in cementless implants compared to cemented ones.

RSA analysis of migration is an important tool to predict loosening. All cementless implants exhibit migration during the first 3 months until

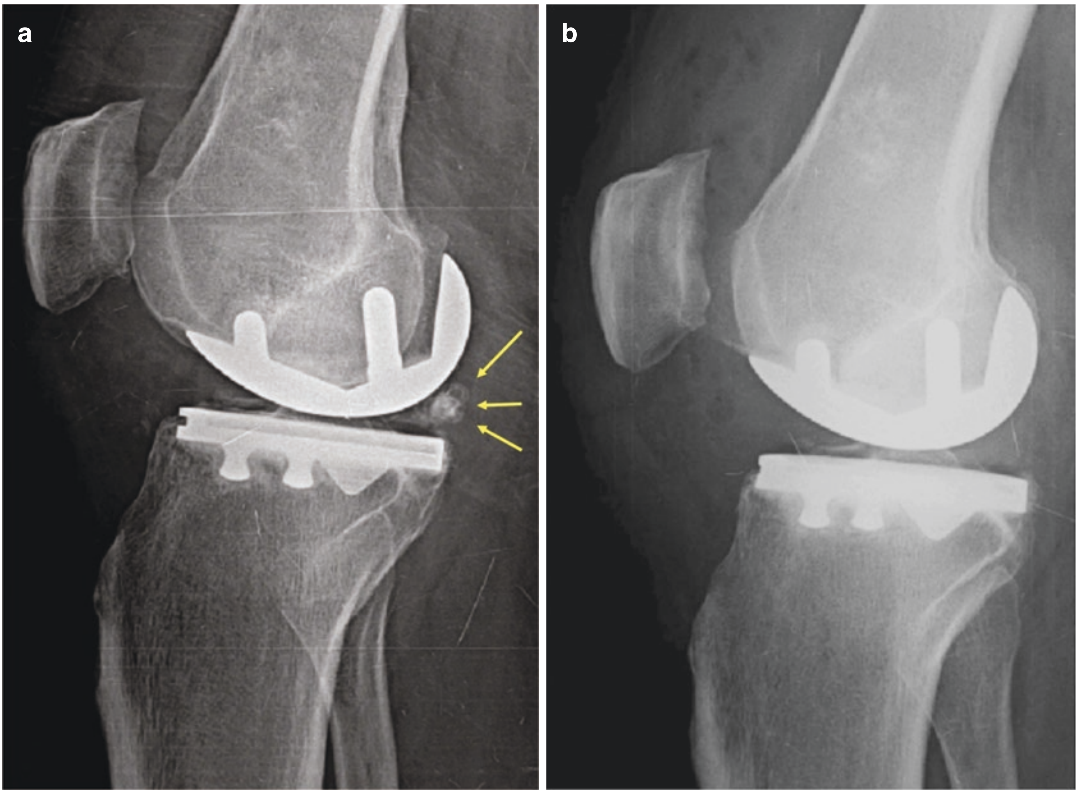

Fig. 39.9 (**a**) Retained cement in the posterior compartment after unicondylar arthroplasty causing mechanical symptoms. (**b**) Symptoms resolved after removal of the free cement particle

they stabilize at 1 year. Migration after 2 years is predictive for failure. In a comparative study of the same Oxford mobile bearing UKA, Kendrick et al. compared the migration of 43 cemented and cementless implants using RSA [94]. Femoral radiolucencies and tibial radiolucencies were significantly less in uncemented implants.

A recent meta-analysis evaluated the outcome of uncemented UKAs analyzing 10 studies including 1199 knees [95]. The 5-year survival ranged from 90 to 99% and the 10-year survival from 92 to 97%. The most common cause of revision was progression of OA in the unresurfaced compartment. The complication and revision rates were found to be similar with cemented implants. In a comparative systematic review of the survivorship of cementless 10,309 TKAs versus 2218 cementless UKAs, Van der List et al. showed better outcomes for UKA [96]. Aseptic loosening was more common in cementless TKA (25%) when compared to UKA (13%). The 5-, 10-, and 15-year survivorship of cementless UKA in this study were 96.4%, 92.9%, and 89.3%, respectively.

In conclusion, cementless fixation with modern designs have shown good mid-term results in UKA. Once durable fixation is achieved with cementless implants, aseptic loosening is not expected and other failure modes such as progression of OA in the contra-lateral compartment, dislocation (mobile bearings), and poly wear (fixed bearings) become an issue. Long-term follow-up studies are necessary to confirm the durability of cementless fixation.

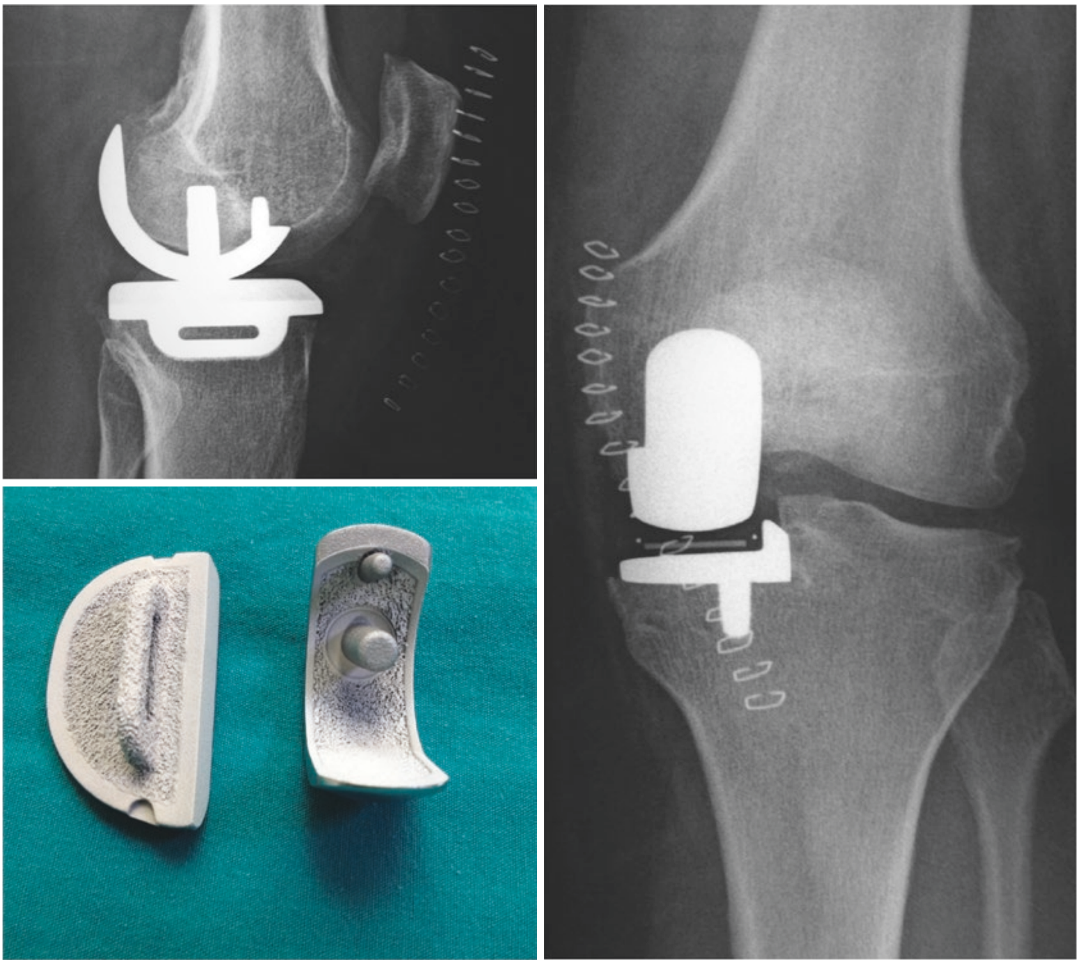

Fig. 39.10 Uncemented mobile bearing unicondylar arthroplasty. Note the porous-coated surface with keels and pegs for primary stability (Oxford Partial Knee with Porous Plasma Spray & HA coating, Zimmer-Biomet). (Figure Courtesy of Assoc. Prof. Burak Akan, Ufuk University, Ankara)

Side Summary

Cementless fixation with modern designs have shown good mid-term results in UKA. Once durable fixation is achieved with cementless implants, other failure modes such as progression of OA in the contralateral compartment, dislocation (mobile bearings), and poly wear (fixed bearings) are the determinants for revision.

Take Home Message

Cemented fixation is still the most widely used technique in knee arthroplasty. Meticulous surgical technique, including precise bone cuts, pulsed lavage, and avoidance of blood in the interface during implantation, is important to achieve adequate cement penetration. Early cementless designs had unacceptable failure rates, especially for the tibial and patellar components. Comparable short- to mid-term outcomes with cemented fixation have been reported with newer cementless implants with improved surface coatings and increased porosity. Cementless implants may be an attractive option in younger patients with good bone stock. However, cementless implants are more expensive, and superiority to cemented fixation in survival and outcomes have not been demonstrated at this time.

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Wound Closure in Total Knee Arthroplasty

40 Wound Closure in Total Knee Arthroplasty

A. Schiavone Panni, M. Vasso, M. Vitale, G. Toro,
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Keynotes

1. Risk factors for wound closure complications are classified as patient-related, surgery-related, or soft tissue-related.
2. Optimal wound closure should be done as anatomical as possible (layer by layer).
3. Capsule closure starts from the medial angle of the "L"-shaped arthrotomy.
4. The use of nonabsorbable sutures for the capsule layer allows for long-lasting tensile strength.
5. Staples in primary TKA are associated with lower time to closure and infection risk.
6. The use of interactive dressings might be associated with a lower infection rate.

40.1 Introduction

Often senior knee surgeons leave the wound closure to their less experienced residents. Clearly, this does not reflect the importance of proper and meticulous wound closure. Optimal wound closure helps to minimize complications such as extensor apparatus insufficiency, wound leakage, and periprosthetic joint infection. It also improves postoperative function, while simultaneously reducing surgical time and costs.

For prevention of wound complications, three key points have to be considered:

1. Patient-related risk factors such as varicosis, obesity, vascular status, diabetes
2. Meticulous surgical wound closure technique
3. Optimal postoperative care

Side Summary
Key factors for prevention of wound complications are consideration of preoperative risk factors as well as patient selection. In addition, wound closure and postoperative care need to be optimal.

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40.2 Risk Factors for Wound Complications

Preoperative risk factors for wound complications following TKA are generally patient-related: advanced age, diabetes (mainly due to delayed collagen synthesis), connective tissue diseases and rheumatoid arthritis, peripheral vascular diseases, chronic renal failure, smoking, malnutrition, obesity, use of steroid or immunosuppressive drugs (which decrease fibroblast proliferation), and chemotherapy [1–6].

Side Summary
Patient-related factors influencing wound healing are advanced age, diabetes, connective tissue diseases and rheumatoid arthritis, peripheral vascular diseases, chronic renal failure, smoking, malnutrition, obesity, and use of steroid or immunosuppressive drugs.

Local risk factors include previous scars and skin incisions, posttraumatic dystrophic skin, prior skin irradiation or chemotherapy, hematoma, and superficial and deep infections [7, 8].

Side Summary
Local factors include previous scars and skin incisions, posttraumatic dystrophic skin conditions, prior skin irradiation, or chemotherapy and hematoma.

Risk factors for wound healing problems which are related to surgical handling and technique have been evaluated by several authors. These factors include location and length of incision, surgical time, tourniquet use, soft-tissue handling, patella resurfacing, patella eversion, type of sutures, and suture material used for wound closure [8–12].

Side Summary
The knee surgeon can influence wound healing by the location and length of incision, surgical time, tourniquet use, soft-tissue handling, patella resurfacing, patella eversion, type of sutures, and suture material used for wound closure (Table 40.1).

Table 40.1 Risk factors for wound complications

	Risk factors
Patient-related factors [1–6]	• Age • Diabetes mellitus • Connective tissue diseases (i.e., rheumatoid arthritis) • Peripheral vascular diseases • Chronic renal failure • Smoking • Malnutrition • Obesity • Use of steroid or immunosuppressive drugs • Chemotherapy
Knee-related factors [1, 8]	• Previous scars and skin incisions • Posttraumatic dystrophic skin • Prior skin irradiation • Hematoma • Superficial and deep infections
Surgical-related factors [8–12]	• Incision location • Incision length • Surgical time • Tourniquet use • Soft-tissue handling • Patella resurfacing • Patella eversion • Type of sutures

A medial parapatellar incision appears to be better in line with the skin cleavage lines than a midline incision. In theory, it therefore leads to reduced skin tension during knee flexion in the early postoperative period. However, major blood supply for anterior knee skin originates medially, so that medial incision results in a larger area of compromised oxygenation [1]. Furthermore, a more medial skin incision makes necessary to prepare a larger subcutaneous area, which then increases the risk for possible bleeding and wound healing problems.

Careful handling of the distal part of the skin incision is advised, in fact we have to consider that this part of the skin incision could be significantly more hypoxic than the proximal one [9, 13].

Tourniquet is widely used by orthopedic surgeons, but its role is still debated. To prevent wound complications, several studies have shown that the tourniquet should be inflated to the lowest possible pressure and time. At best, no tourniquet should be used at all. It is also well established that high tourniquet pressure leads to a more pronounced wound hypoxia than low tourniquet pressure [9]. Furthermore, it has been demonstrated that releasing tourniquet intraoperatively before wound closure is better than releasing the tourniquet postoperatively after wound closure and wound dressing.

The role of increased intraoperative bleeding due to no tourniquet use is still not fully understand. However, a large hematoma is associated with a higher incidence of wound healing problems such as erythema, marginal skin necrosis, cellulitis, infection, significant leg swelling, deep vein thrombosis, stiffness, and pain [10].

Side Summary
Tourniquet use, if necessary, should be limited to a minimum with regards to time and pressure.

Surgical time is another important factor. It has been shown that lower surgical time leads to fewer complications after TKA, particularly a lower rate of periprosthetic joint infection.

In several studies, the minimally invasive technique without patella eversion results in earlier recovery of range of motion, earlier discharge from the hospital, and less pain compared with the conventional TKA, without any wound complication [8, 14] (Table 40.2).

40.3 Optimal Wound Closure

Traditionally, wound closure is done layer by layer. A considerable number of different suture material can be used. Standard suture technique is to place knotted sutures (KTS) in an interrupted fashion, requiring the surgeon to tie several knots to secure each stitch.

Capsule suture starts from the medial angle of the "L" arthrotomy, then the proximal part of the capsule is closed with interrupted sutures. The distal part of the arthrotomy is finally sutured.

The subcutaneous layer is sutured starting from the half of the incision, in order to divide the wound in two parts. After that, each half part is further divided by the suture, until the layer is completely closed.

The skin is preferably closed using staples.

Recently, uni- or bidirectional barbed sutures (knotless barbed sutures (KBS)) have been introduced. These sutures allow to close soft tissue layers in a running fashion without the need for knot tying. Moreover, the bidirectional nature of the barbs allows for simultaneous closure from the wound center, reducing operating time. Additional potential advantages of using KBS include enhanced biomechanical strength, increased resistance to catastrophic arthrotomy failure, and a more watertight closure [15, 17–19]. The recent review by Zhang et al. [15] confirmed that closure of arthrotomy and subcutaneous [19] tissues by KBS provides similar postoperative function and lower complications when compared to KTS. In contrast, Campbell et al. [16] showed that KBS should not be used as they come along with increased wound complications such as superficial and deep infection, wound dehiscence, stitch abscesses, skin necrosis, severe effusion, arthrofibrosis, and keloid formation.

Table 40.2 Commonly used type of sutures for wound closure in TKA [11, 12, 15–20]

Layer	Suture	Pros	Cons
Capsule	Absorbable	• Complete resorption • Higher biocompatibility	• Decrease of suture strength with time
	Nonabsorbable	• Persistent tensile strength	• No resorption • Lower biocompatibility
	Knotted	• Cost saving	• Inconsistent suture tension
	Knotless	• Time saving • Proper suture tension • Less wound leakage	• Expensive
Subcutaneous	Absorbable	Complete resorption Higher biocompatibility	
	Nonabsorbable	• Cost saving	• Time consuming • Foreign body reaction
	Knotted	• Cost saving	• Time consuming
	Knotless	• Time saving • Water-tight closure	• Higher costs • More complication
Skin	Absorbable	• Complete resorption • Less postoperative pain and better skin oxygenation in comparison to staple	• Time consuming
	Nonabsorbable	• Complete resorption • Less postoperative pain and better skin oxygenation in comparison to staple	• Time consuming • Suture removal required • More postoperative pain
	Staples	• Lower incidence of superficial wound complications	• Staple removal required • More postoperative pain
	Adhesive	• Skin friendly • No change of dressing required • Better wound environment for healing	• Expensive

40.4 Technical Tips and Tricks

One might prefer closing the wound in deep flexion (100°–120°), assuming that this knee position would avoid stretching of the soft tissues and would lead to less patient discomfort. In addition, it would prevent shortening of the extensor mechanism and skin [21, 22]. On the contrary, closing the knee in full extension may lead to soft-tissue misalignment resulting in increased tension on the extensor mechanism when the knee is moved into deep flexion. This could also lead to decreased postoperative ROM and increased anterior knee pain [21, 23, 24]. Nevertheless, in a recent systemic review by Cerciello et al. [25], it has been found that closing the knee in deep flexion does not significantly influence postoperative knee range of motion, functional outcomes (KSS, VAS), pain, or complications rates compared to closure in full extension. It would be useful to confirm the data of increase of muscle strength with closure in knee flexion found in this review.

The use of drainage has not been mentioned because no advantage of suction drainage versus no drainage use has been found in primary TKA [26]. Although the use of drainage can prevent postoperative hematoma formation, fertile soil for bacteria, the drain lumen could be a pathway of retrograde bacterial colonization, causing deep-seated infection. The usage of drains may reduce the risk for secondary aspiration in case of hemarthros. Although the use of drainage reduces the postoperative ecchymosis and the need for dressings reinforcement, many studies have shown more blood loss and the need for blood transfusion postoperatively among the drain users [26, 27].

Finally, regarding to the cutaneous closure, several devices are used: tissue adhesives, stapling, and suturing. Staple-based closure proves the fastest and least-expensive TKA wound clo-

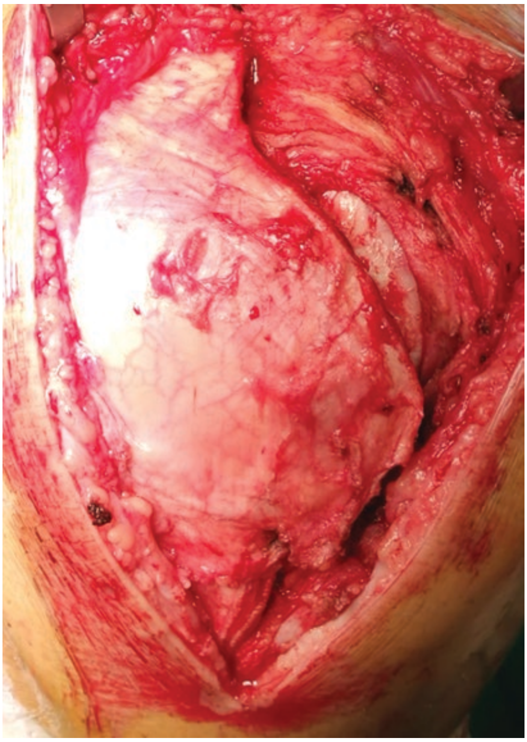

Fig. 40.1 Vertical incision of the rectus tendon angulated medially forming "L"-shaped cut

sure technique in the operating room, yet it could be associated with a statistically significant longer hospital stay in comparison with tissue adhesives and suturing [28].

40.4.1 Closure of the Capsule

Closure of the capsule is crucial for wound healing. Only a water-tight wound closure prevents wound leakage. In addition, the extensor apparatus needs to be optimally restored.

Generally, the medial arthrotomy is performed using a L-shaped incision (Fig. 40.1). The angle created by the incision serves as an excellent landmark in order to allow proper capsule adaptation during closure. The closure should typically start in knee extension. Here, at the angle of "L" incision, the first suture is placed (Fig. 40.2). This allows a near perfect approximation of the tendon. After the first knot, the knee is flexed to 100°–120° and sutures are placed at an interval of 1.5 cm proximally and distally from this starting point. Closure of the capsule should be done with interrupted, absorbable, braided No.2 sutures. Instead of absorbable sutures interrupted, nonabsorbable, braided No.2 sutures can be used as well (Figs. 40.2, 40.3, and 40.4).

Fig. 40.2 First knot of capsule with nonabsorbable No. 2 suture in the angle of "L" incision

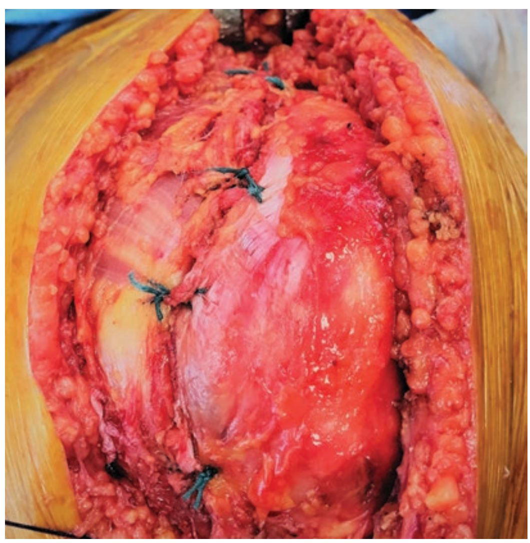

Fig. 40.3 Knots of the capsule with nonabsorbable sutures

Fig. 40.4 The capsule is sutured with interrupted absorbable braided No.2 sutures (VICRYL®, Ethicon, Johnson & Johnson Medical N.V., Belgium), interspersed with nonabsorbable braided No.2 (PROLENE®, Ethicon, Johnson & Johnson Medical N.V., Belgium) suture in correspondence of the attachment of the vastus medialis

40.4.2 Closure of Subcutaneous Layer

Closure of the subcutaneous layer depends on the thickness of this layer. In obese patients, closure in two layers might be required in order to minimize the risk of subcutaneous hematoma. Typically, interrupted, absorbable, braided No.2-0 sutures are used. As alternative continuous sutures using absorbable, braided No.2-0 suture material can be performed.

40.4.3 Skin Closure and Wound Dressing

It is still a matter of debate if staples or sutures should be used for skin closure.

However, two recent meta-analysis showed that staples are associated with a lower surgical site infection rate but a higher level of postoperative pain [11, 12]. Most often, staples are recommended for primary TKA. For revision surgery or in patients with nickel hypersensitivity, stiches should be used. In general, nonabsorbable monofilament, No. 2-0 sutures are used.

Various types of dressing materials are available for primary wound dressing in TKA.

Sharma et al. [29] classified dressing materials in three types: (1) passive (materials serving solely for protection); (2) active (materials that promote wound healing and creating a moist wound environment); (3) interactive (materials that promotes wound healing both creating a moist wound environment and interacting with the wound bed components) [29] (Table 40.3).

The active dressing materials presents fewer wound complications and better fluid handling capacity, compared with passive ones. Anyway, it is not clear if active dressings are able to decrease surgical infection rate, compared with passive ones [29].

For the primary medication in surgery room, we use Aquacel Ag with Hydrofiber, a silver-impregnated antimicrobial dressing. It is a soft, sterile, nonwoven pad or ribbon dressing composed of sodium carboxymethylcellulose and ionic silver. The silver in the dressing serves for antibacterial environment. The dressing absorbs a high amount of wound fluid and bacteria. It creates a soft, cohesive gel that intimately conforms to the wound surface, maintains a moist environment, and supports the removal of nonviable tissue from the wound (autolytic debridement). Moist wound healing environment and control of wound bacteria within the dressing supports the body's healing process and helps reduce the risk

Table 40.3 Common wound dressings (adapted from Shama et al. [26])

Classification	Type	Product and manufacturer
Passive dressing	Gauze Absorbent pads	Zetuvit E (Hartmann), Mesorb (Monlyke), Sorbact absorbent pads (ABIGO), Interpose (Smith&Nephew), Steripad (Johnson&Johnson)
	Impregnated gauze	Parafin gauze: Jelonet (Smith&Nephew), 3% bismuth tribromophenate: Xeroform (DeRoyal)
	Adhesive tape	Hypafix (Smith&Nephew), Mefix (Monlyke), Micropore (3 M)
	Bandage	ACE (3 M)
	Fabric (Island dressings)	Mepore (Monlyke), Primapore (Smith&Nephew), Cutiplast (Smith&Nephew), Cosmophor E (Hartmann), Microdon (3M)
Active dressing	Films	Opsite (Smith&Nephew), Sorbact (ABIGO), Tegaderm plus pad (3M), Opsite visible (Smith&Nephew)
	Hydrocolloid	Comfeel, Duoderm (Convatec)
	Hydrofiber	Aquacel (Convatec)
	Alginate	Tegaderm alginate (3M)
	Foam	Mepilex border (Monlyke)
Interactive dressing	Antimicrobial dressing Biomaterial dressings Larva therapy Negative pressure Wound therapy	Aquacel Ag (Convatec)

of wound infection. In general, the wound does not need further dressing for 14 days, after that we proceed with removal of the staples (or the monofilament sutures).

Take Home Message

- The technique for wound closure has to be time-efficient, inexpensive, durable, microbial resistant, and cosmetically pleasing. It should be stressed that the suture of capsule is the most important step in this procedure.
  – Suture the capsule alternating absorbable with nonabsorbable sutures.
  – In obese patients, the subcutaneous should be closed in two layers, to reduce dead space.
  – For primary TKA, use staples. In case of revision surgery or nickel hypersensitivity, use stiches.

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41 Pros and Cons of Drains for Wound Drainage in Total Knee Arthroplasty

Bernhard Christen

Keynotes

1. A systematic review of the literature shows advantages in using closed drainage after total knee arthroplasty (TKA) to prevent skin ecchymosis and post-operative hematoma.
2. Concerning thromboembolic events, periprosthetic joint infection there is no difference between the drainage and the non-drainage group.
3. Blood loss and the necessity for transfusion are significantly higher in the drainage group.
4. Drain clamping does not reveal any advantages comparing to non-clamping drainage nor to non-drainage after TKA.
5. The potential disadvantages of not draining the operated knee post-operatively may be compensated by using tranexamic acid and dressings with sealing effect which should be applied also in the drainage group.

41.1 Introduction

Total knee arthroplasty (TKA) is associated with a significant post-operative blood loss for which blood transfusion might be necessary when tranexamic acid (TA) is not used systematically.

The role of wound drainage remains controversial. The use of drainage was believed to be effective in decreasing hematoma formation [1–3]. Less hematoma theoretically helps to decrease post-operative pain, swelling, and incidence of infection. However, a closed suction drainage system inevitably increases bleeding. This is due to the fact that the tamponade effect of a closed and undrained wound is eliminated.

Although some studies have shown that drainage after TKA is unnecessary, it is still commonly used by orthopaedic surgeons [4–10].

This chapter reviews the literature existing on drainage and non-drainage use after TKA reflecting on connected issues as wound healing, hematoma, blood loss and need for transfusion, influence on post-operative thromboembolic events, early post-operative function or periprosthetic infection and economic impact.

41.2 Wound Healing, Hematoma

The probably most established benefit of drainage in TKA is the reduction of dressing reinforcement compared to the non-drainage group

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Fig. 41.1 Different closed wound drainage systems with vessels under vacuum with a button in green which indicates low pressure by closer distance between the folds. Systems include a sterile tube and the drain itself with a trocar to pass it through soft tissues and the skin

Fig. 41.2 Closed drainage system for lower liquid volume where the low pressure is established by compressing the folded vessel before connecting to the tube and drain. By regaining the original form with time, the system maintains a certain suction effect

[2, 11]. This might lead to less weight of the dressing in other comparative studies [6, 12].

The area of ecchymosis is smaller in the drainage compared to the non-drainage group [2]. This is also true for the post-operative hematoma which is smaller in the drainage group [1–3, 13]. This may reduce the post-operative leakage of the wound. The mentioned studies did not evaluate the effect of tranexamic acid on post-operative wound healing in drainage and no-drainage patients (Figs. 41.1 and 41.2).

41.3 Post-operative Function and Duration of Hospital Stay

Only recently early post-operative function and length of hospital stay came into interest comparing drain versus non-drain by introduction of the concept of faster recovery after TKA. According to Wang et al. in a prospective randomized trial of 80 patients with and without drainage the use of drainage after TKA negatively influences early post-operative rehabilitation after TKA. It showed a reduced ROM, delayed ability to actively raise the leg and lengthened the hospital stay [14]. These results were confirmed by Sharma et al. including 135 TKA in 120 patients of which 59 were selected for no drain and 61 in the control group (drain used) [15].

> **Side Summary**
> No drain may prolong early recovery such as ROM and active leg raise.

41.4 Blood Loss and Transfusion Rate

Most of the blood loss in TKA occurs during the first few post-operative hours [16, 17]. According to these two studies 37% of the drain volume is collected after 2 h, 55% after 4 h. Zamora-Navas et al. (1999) found that 90% of post-operative bleeding is collected by the drain within the first 24 h [18]. Respecting the possibly increase in risk of bacterial colonization due to the remaining drain, it is recommended to remove the drain 24 h after the surgery, although the evidence is not clear [19].

Several comparative studies confirmed that the blood loss in the drainage group is higher than in the non-drainage group [4, 6–9, 20]. This was confirmed in a systematic review [21] and a meta-analysis [9]. Tai et al. could demonstrate a lower drop of post-operative haemoglobin in the non-drainage patients [22]. The increased blood loss leads to a higher blood transfusion rate in the drainage group [6, 9, 11, 21, 23].

Side Summary
Blood loss is higher in the drainage group and causes increased transfusion rate.

41.4.1 Effect of Drain Clamping

Theoretically temporary clamping of the drain should reduce blood loss and maintain the reduced need for dressing reinforcement and less risk of ecchymosis. Shen et al. [24], Tsumara et al. [25], Raleigh et al. [26] and Stucinskas et al. [27] found a decreased drained volume by temporary clamping. The total drained blood volume ranged from 297 to 807 mL in the clamping group and 586 to 970 mL in the non-clamping group in the literature. Kiely et al. (2001) found no difference when comparing the clamping and the no clamping groups [28]. A meta-analysis including the randomized controlled trials showed that the blood loss in the clamping group could only be reduced when the drain was clamped 4 h or more [29]. The advantage of less blood loss could also eliminate the advantage of the drainage. Additionally, long clamping is not different to the non-drainage of the wound [10]. A second meta-analysis including nine randomized controlled trials including 850 patients with TKA confirmed that temporary clamping of the drainage for 4 h or more significantly reduces blood loss, drop of haemoglobin and number of transfusions post-operatively [30]. Post-operative range of motion, wound-related complications and deep vein thrombosis were not changed significantly in the two groups.

In most studies [24, 25, 28, 31] post-operative haemoglobin levels were equal in the clamped and non-clamped groups. Only Raleigh et al. (2007) found a higher haemoglobin level in the clamping group [26]. Shen et al. [24] found similar transfusion rates in the two groups, and Tsumara et al. [25] and Stucinskas et al. [27] revealed slightly lower transfusion rates in the clamping group. Eum et al. had not performed any transfusion in both groups [31].

When injecting diluted epinephrine solution in TKA, Jung et al. found no difference in total blood loss, post-operative drop of haemoglobin or haematocrit between clamping and non-clamping drainage in 100 TKA [32]. This was confirmed by Wu et al. (2017) using 10 mg/kg tranexamic acid intravenously before tourniquet release in 121 randomized patients of which 60 were clamped [33]. The drainage volume was significantly lower in the clamped group whereas haemoglobin, haematocrit, wound-related complications, ROM, pain on VAS scale, thromboembolic and hospital length did not differ.

Side Summary
No difference in blood loos reported in most of the studies between clamping or no clamping of the drain.

41.4.2 Use of Tranexamic Acid (TXA)

Independently of using drain or not after TKA the surgeon should reduce blood loss by the use of systemic tranexamic acid (TXA). Based on seven available systematic reviews and meta-analyses [34–40], administration of TA reduces the amount of blood loss in THA and TKA patients almost by half and therefore the need for blood transfusion. In a double-blind randomized control trial with 60 TKA patients without drainage the reduction of blood loss could be confirmed by Wang et al. by administrating 500 mg of intra-articular tranexamic acid [41]. The post-operative drop in haemoglobin and transfusion rate were statistical significantly reduced as well. Applying 1 g of TXA 1 h before and 2 g 12 h after surgery lead to less change of dressing and ecchymosis in the drain group (135 TKA in 120 patients) but longer duration of hospital stay compared to the no drainage group. Post-operative haemoglobin was not differing in the two groups [15]. The authors concluded that using a closed suction drainage after TKA brings no advantages and can be abandoned. The use of tranexamic acid is safe as there has been no study to demonstrate that use of either topical or intravenous TXA results in a higher incidence of thromboembolic episodes which enables the systematic use of TXA.

Side Summary
Tranexamic acid reduces blood loss significantly regardless of administration.

41.4.3 Thromboembolic Events

Thromboembolism is one of the most common complications after TKA. It is of great concern due to the associated increase in morbidity and mortality. Using a drain in TKA theoretically reduces post-operative knee swelling and may reduce the risk of deep vein thrombosis (DVT) and embolism. However, all of the studies comparing the incidence of DVT between the drainage and the non-drainage group found no significant differences [2, 4, 42].

41.4.4 Periprosthetic Joint Infection (PJI)

By decreasing post-operative swelling, ecchymosis and hematoma drainage would be expected to reduce the risk of PJI [5]. On the other hand an increased drainage time would increase the risk of PJI by colonization of the drain which should be removed as soon as possible [18]. Scientifically, there is no evidence that the use of closed drains would increase or lower the risk of PJI after TKA [2, 6, 11, 12, 19, 22, 23, 43]. A meta-analysis showed that the incidence of infection was 0.5% in the drainage group and 1.2% in the non-drainage group, but pooled data demonstrated no significant difference [44]. At the Philadelphia consensus meeting in 2013 delegates agreed by 88% that closed drainage after TKA has no influence on the rate of PJI [19]. There is also no conclusive evidence at which time drainage should optimally be removed [19]. This was confirmed at the second Philadelphia consensus meeting in 2018. Although the level of evidence remains limited, the agreement reached 90% (7% disagreed, 3% abstained) [45].

Side Summary
No difference in infection rate with or without using drains.

Take Home Message

- In a Cochrane systematic review [21] 36 randomized or quasi-RCTs comparing the use of closed suction drainage systems with no drainage for all types of elective and emergency orthopaedic surgery including 5464 patients and 5697 surgical wounds no statistically significant differences in the incidence of wound infection, hematoma, dehiscence or re-operations between patients with or without drains could be detected. Blood transfusion was required more frequently in the group with drains whereas using no drainage increased the need for reinforcement of wound dressings and the risk of bruising.
- In a meta-analysis [9] 18 studies on the use of drainage after THA and TKA with 3495 patients and 3689 wounds indicated that closed suction drainage increases the transfusion requirements after elective THA and TKA and has no major benefits.
- In summary literature does not clearly support the benefit for using post-operative drainage after TKA nor has strong arguments against non-drainage.
- The systematic perioperative intravenous application of tranexamic acid reduces significantly blood loss after TKA [34–40]. Together with new wound dressings with sealing effect TA will reduce the rate of ecchymosis and post-operative hematoma and make the

systematic use of drainage unnecessary and enable the introduction of optimized post-operative rehabilitation programs including early mobilization of the patient and the knee joint [14, 15].

- The abandonment of drainage will additionally save costs for the drainage system itself and the surveillance including repetitive changes of dressings and reduces the economic risk for blood transfusion to an absolute minimum. In fact, Bjerke-Kroll et al. [46] calculated additional costs of $538 per THA and $455 for TKA when using drains.

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42 Pain Management After Total Knee Arthroplasty

Alexander Zeh

Keynotes

1. Acute postoperative pain as an important issue in TKA contributes to chronic surgical pain and psychological stress symptoms such as anxiety and helplessness.
2. Postoperative pain therapy after TKA should include different multimodal options and start as early as during surgery.
3. Sufficient pain management is essential for early rehabilitation and patient's satisfaction.
4. Patient-controlled analgesia (PCA) is an effective part of multimodal pain regime.
5. There are several supplemental options like corticosteroids, gabapentin, and pregabalin, which are not evaluated conclusively.
6. There is a tendency of moving from epidural anesthesia to peripheral nerve blocks and local infiltration therapy.
7. At present, no recommendation for a particular PNB (peripheral nerve block) for pain management after TKA can be given.
8. There is not enough evidence for conclusive recommendation regarding PNB or LIA andand/or combined techniques of regional anesthetic after TKA.
9. Multimodal analgesia consists in combinations of analgesics acting via different mechanisms to use additive or synergistic activity while minimizing dose-dependent adverse events.

42.1 Introduction

Pain is a complex and multifactorial experience and involves multiple organ systems. The International Association for the Study of Pain (IASP) defined pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage" [1]. One has to consider that pain is always a subjective feeling [2].

Postoperative pain is still a major issue after total knee arthroplasty (TKA), and some patients may develop severe postoperative pain despite modern analgesic therapy. Severe acute postoperative pain is more frequently in younger, obese female patients and those suffering from central

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pain sensitization. Preoperative pain, in the knee or other areas, predisposes to central pain sensitization [3].

Sufficient postoperative pain management after TKA is of fundamental importance. Postoperative pain influences patients recovery and rehabilitation [1] and overall satisfaction [2].

Furthermore acute postoperative pain is one of the predictors contributing to chronic surgical pain besides preoperative pain at the operated area, preoperative pain elsewhere in the body, capacity overload, psychological stress symptoms such as anxiety and helplessness, and others [4].

Currently multimodal analgesia concepts are implemented for assessing different mechanisms of pain and minimizing narcotic consumption to reduce adverse effects of narcotics as nausea, vomiting, and sedation. The aim is to increase patient's participation in early physical activity and patient's satisfaction to utilize rapid patient rehabilitation in terms of fast track protocols. These therapy strategies are not expected to reduce costs and length of hospital stay only. These also lead to enhance recovery and a decreased intake of analgesic drugs [5, 6].

Multimodal concepts in orthopedic surgery may include pre- and postoperative oral/i.v. opioid and/or nonopioid analgetics supplemented by different regional analgesic techniques [5]. Sufficient pain management starts already during surgery.

Studies on the effectiveness of analgesic therapy options after TKA report on different methods of measuring therapy effects. In general morphine consumption after different therapy strategies is analyzed to describe the analgesic potential of alternative therapy options. Opioids are frequently converted to i.v. morphine equivalents in order to establish comparability between study results [7, 8].

Studies on postoperative pain treatment administer a variety of opioids in different dosage forms like fentanyl i.v./i.m, oxycodone, hydromorphone, sufentanil, and additionally different NSAIDs like ibuprofen, celecoxib, and acetaminophen including gabapentanoids like gabapentin. Frequent administration of pain medications starts preoperatively [9].

In addition, therapy effects are reported in terms of different pain scores, visual analog scale for pain (VAS) 0-10 or 0-100 [10], verbal pain score (VPS) [10], and WOMAC pain scale [11] at rest and at mobilization covering postoperative periods from 0 to 72 h [9].

These differences of pain regimes and measuring therapy effects as well as small study populations complicate the evaluation of various therapy options for postoperative pain management. Therefore, currently a globally recognized gold standard analgesic treatment for TKA has not been established [9, 12].

> **Side Summary**
> Sufficient pain management starts already during surgery as a multimodal procedure.

42.2 Preoperative Patient Education

It was hypothesized that the outcome of total hip (THA) and TKA may be optimized through preoperative patient education (PPE).

McDonald (2004) found in their meta-analysis of nine studies involving 782 participants less evidence for an advantage of preoperative education versus standard care to improve postoperative outcomes in patients undergoing hip or knee replacement surgery.

> **Side Summary**
> Preoperative education does not improve outcome after TKA.

In particular no general recommendation could be given with respect to pain and function [13]. This statement is underlined by a further meta-analysis on the outcome after THA and TKA [14]. No effect was found, except for a significant reduction in preoperative anxiety, which was confirmed by others [13]. The significance of this conclusion was limited by a general heterogeneity of the studies.

It was stated that there is a strong need for properly designed randomized and controlled studies that are sufficiently powered to draw general conclusions [14].

42.3 Oral or Parenteral Systemic Analgesia

42.3.1 Postoperative Conventional NSAIDs (Nonsteroidal Anti-inflammatory Drugs, COX-2-Selective Inhibitors and Paracetamol)

Conventional NSAIDs are recommended because of their ability to spare opioids and their analgesic effect. Typical NSAIDs which were evaluated for pain are ketoprofen, piroxicam, tenoxicam, acetaminophen, and diclofenac. They should be administered in combination with strong opioids (e.g., oxycodone, oxymorphone, or buprenorphine).

Currently no recommendation is given for exclusive combination of NSAIDs with regional analgesia.

The use of conventional NSAIDs should consider patient-specific risk profile in particular regarding bleeding disorders, gastroduodenal ulcer history, cardiovascular morbidity, aspirin-sensitive asthma, and renal and hepatic functions [15].

Previous studies have shown that conventional preoperative nonselective NSAIDs increase the bleeding risks [16]. Conventional nonselective NSAIDs reversibly inhibit the cyclooxygenase (COX) and interfere with platelet functions. Selective COX-2 inhibitors have less anti-platelet effects than conventional nonselective NSAIDs [17]. Therefore, selective COX-2 inhibitors could be a better choice for multimodal analgesia. Additionally selective COX-2 inhibitors may be associated with decreased gastrointestinal adverse effects and less cardiovascular risk [18].

There are concerns about disturbance of bone healing processes by COX-2-selective inhibitors. At present, no evidence exists to confirm detrimental effects in knee arthroplasty. Their potential of negative influence on bone healing could be an issue for postoperative treatment of fractures [19].

Paracetamol is recommended in combination with other potent analgesic drugs but not as sole agent for pain management after TKA [15].

42.3.2 Opioids

Strong oral opioids (e.g., oxycodone, oxymorphone, or buprenorphine) but not weak opioids (like tramadol) are regarded as appropriate for postoperative pain therapy after TKA. They should be administered in combination with other nonopioid analgesia in order to reduce opioid consumption and associated adverse effects like sedation, dizziness, nausea, vomiting, and obstipation.

No recommendation is given for i.m. application because of inferior pharmacokinetics, injection-associated pain, and therefore patient discomfort [15].

Orthopedic surgery represents a frequent opioid prescribing specialty, and up to 40% of patients with osteoarthritis are already opioid users before surgery. Because of the side effects of opioids, their potential for drug addiction but also the evidence that preoperative opioid use is associated with higher postoperative morbidity and mortality and worse clinical outcomes in total knee arthroplasty prescription of opioids for analgesia after TKA should follow strict indications. One has to consider that there is a considerable risk for chronic postoperative opioid use in patients who received preoperative pain therapy with opioids [20–22].

This, in particular, underlines the importance of a multimodal regime for analgesia after TKA to reduce the use of opioids.

Currently no time point is defined at which patents are expected to wean off their pain medications after TKA, although three months are regarded as an appropriate period [23].

> **Side Summary**
> There is a considerable risk for chronic postoperative opioid use in patients after TKA, therefore wean off of pain medication and particularly opioids should not exceed three months.

42.3.3 Intravenous Patient-Controlled Analgesia (PCA)

Patient-controlled analgesia (PCA) is recommended in preference to other inflexible analgesic opioid regimes because of its potential of improved pain control and higher patients satisfaction [15].

Despite different approaches of analgesia, PCA is still used frequently as one component of multimodal pain therapy after TKA as reported by many trials [24].

PCA empowers patients to have an important degree of control over their pain which is a benefit to reduce anxiety which will in turn reduce pain experience. One considerable advantage is the immediate effect and patient's independency.

However, it is necessary that patients are able to understand the principle to be compliant.

Preferred opioids for PCA should have a rapid onset of effect, a middle effect duration, and a wide therapeutic margin, such as piritramide or morphine [25].

PCA management is complex, and monitoring of patient's compliance as well as pain monitoring is necessary to define the individual setting for loading dose, bolus dose, and lockout interval and background infusion. The optimal dose is the minimum dose to produce appreciable analgesia consistently without producing objective or subjective side effects [26].

> **Side Summary**
> PCA is still used frequently as part of a multimodal pain management.

42.4 Continuous Epidural Analgesia (CEA)

Epidural analgesia is widely used after TKA and can be performed as continuous epidural infusion (CEI), patient-controlled epidural analgesia (PCEA), or intermittent epidural bolus (IEB) [27]. Continuous epidural infusion or patient-controlled epidural analgesia (PCEA) with local anesthetic or local anesthetic-narcotic is one of the standard regimes for postoperative analgesia after TKA [28].

This is reflected by the fact that CEA is frequently used as a control against other regimes to investigate the efficiency of pain management strategies in TKA [29, 30].

Choi et al. (2003) concluded that CEA may be useful for postoperative pain relief following major lower limb joint replacements. They found that benefits may be limited to the early (four to six hours) postoperative period compared to systemic analgesia or long-acting spinal analgesia. From their meta-analysis they deducted that epidural infusion of local anesthetic or local anesthetic-narcotic mixture may be better than epidural narcotic alone.

One of the disadvantages of CEA is the difficult evaluation of potential postoperative neurologic deficits. Therefore, the dose has to be carefully titrated to prevent complete sensible and motoric blockage of lower extremities. Severe complications are more frequently associated with regional spinal anesthesia than with peripheral nerve blocks for which reason the trend goes toward those techniques [25].

The differences between CEA and systemic analgesia in the frequency of nausea and vomiting or depression of breathing seem to be not statistically significant. Sedation occurred less frequently with epidural analgesia, otherwise retention of urine, itching, and low blood pressure were more frequent compared to systemic analgesia. It was pointed out that the frequency of rare complications from epidural analgesia, postoperative morbidity or mortality, functional outcomes, or length of hospital stay is inconclusive [31]. The finding of a higher occurrence of adverse effects like retention of urine, itching, and low blood pressure compared to peripheral nerve blocks (PNB) was also confirmed by others [32].

Anderson et al. (2010) observed superiority of peri- and intra-articular infiltration analgesia with multimodal drugs for postoperative pain relief and reduction of morphine consumption compared with CEA with ropivacaine combined with intravenous ketorolac after TKA. On the other hand, they noted that the concept of CEA varies. There is no "gold standard" of CEA to which all other treatment regimens can be compared, and therefore the epidural regime chosen for their study may not be optimal [28].

In conclusion, one has to consider that analgesic regime with PNB or local infiltration/intra-articular infiltration is superior [28, 30, 33] or at least similar to CEA [34–36] regarding reduction of pain and consumption of opioids or even knee flexion [30].

Current discussion of pain management options after TKA shows that the trend runs toward PNB and periarticular/intra-articular infiltration techniques to avoid immobilization and specific adverse effects of CEA [25].

Side Summary
Currently, epidural anesthesia seems to be superseded by LIA or PNB.

42.5 Peripheral Nerve Blocks (PNB)

Regional techniques of pain management are particularly appropriate for TKA to gain optimal reduction of pain and spare systemic use of opioids to avoid adverse effects. Central neuraxial blockade (CAN, spinal and epidural analgesia) was proven to provide excellent intraoperative anesthesia and postoperative pain management [37].

However, there are side effects such as retention of urine, itching, and low blood pressure. Recently PNB are regarded as potentially optimal postoperative pain management after TKA because of the more specific effect, reduction of adverse effects, and appropriate anesthesia [32].

Several studies have shown that anesthesia by PNB can be as effective as CNA [35, 37, 38] and are associated with improved rehabilitation, reduced hospital stay, sparring effect for opioids, and even superior postoperative anesthesia 0–24 h compared to PCA [9, 32]. One has to note that meta-analyses showed only a low or moderate grade of evidence for pain, reduced hospital stay, and reduction of morphine consumption (GRADE) [9, 39]. However, there is also evidence that PNB may be inferior regarding pain management compared with CEA [30, 40].

Side Summary
PNB after TKA are associated with improvement in postoperative pain control and reduction of opioids.

Furthermore, a block failure rate of 0–67% depending on particular block, experience, and method of nerve localization has to be considered [37].

A review of regional anesthesia following TKA includes 28 trials from 1990 to 2007 with 1538 patients included in 17 trials reported on the effectiveness of different PNB for pain management (of these: 9× single-injection femoral nerve block (sFNB), 7× continuous catheter-based femoral nerve block (cFNB), 7× CEA, 1× obturator nerve block). These treatment options were compared with PCA ($n = 9$), i.m. morphine ($n = 1$), obturator block ($n = 1$), placebo/sham block ($n = 4$) or CEA ($n = 2$), or a combination of these in terms of different study arms. In summary this meta-analysis illustrates very impressive heterogeneity of postoperative pain therapy following TKA [24].

The authors concluded that the level of evidence is rather low due to methodology and small sample sizes. If focusing on prevention of cardiovascular morbidity, hypotension, mortality, DVT, or reduction of blood loss, no conclusion could be made on one analgesic technique that should be preferred. This is reflected by limited study numbers on these issues or not reported outcome parameters in the included studies.

In conclusion, it was stated that regional anesthesia reduced postoperative pain and opioid consumption (21 of included 28 trials), even when no significant differences could be shown in this review [24].

In general, this reflects the difficulties to evaluate different techniques of analgesia regarding their potential of pain and opioid consumption due to heterogeneity of studies, low numbers of patients in therapy arms, or lack of adequate numbers of studied to conclude on techniques like adductor canal block (ACB) and sciatic nerve block (SNB) [9].

There is a controversial discussion about a potential increase of falling induced by PNB after TKA. While some retrospective studies could not prove an increased risk of falling [41], a meta-analysis showed more falls in patients with lower extremity continuous peripheral nerve blocks (cPNB) with ropivacaine [42]. Potential risks of PNB are vascular puncture and bleeding, nerve damage, and local anesthetic systemic toxicity (LAST). PNB placement using ultrasound guidance is associated with a lower risk of vascular puncture [23]. Neurologic complications like tingling, pain, or pins and needles are crucial because they can persist for weeks or months after surgery [43].

Side Summary
There is an ongoing discussion about increased risk of fall events associated with femoral nerve blocks.

PNB for pain management after TKA can typically be applied as FNB, as sFNB or cFNB, ACB, and FNB in combination with SNB [9, 24].

In one meta-analysis FNB in combination with SNB did not reveal conclusive results regarding superiority compared with FNB alone [44]. Sciatic nerve block (SNB) is commonly performed in combination with FNB after TKA [45]. FNB provides analgesia of the anterior and medial part of the knee. Therefore, SNB is regarded as an important and useful supplement for analgesia after TKA. There is evidence that the combination of FNB with SNB may be more effective than FNB alone and is therefore recommended [46, 47]. However, a meta-analysis showed no superiority of combining FNB with SNB compared with FNB alone after TKA [48].

Side Summary
PNB for pain management after TKA can typically be applied as FNB, as sFNB or cFNB, ACB, and FNB in combination with SNB.

The rationale behind the cFNB for pain management after TKA is an extended effect of analgesia. On the other hand, cFNB did not show superiority compared with sFNB in meta-analyses [9, 44]. In addition performance of cFNB is more time consuming an invasive [9].

Because of excellent pain relief and opioid-sparing effect, FNB is regarded as standard PNB after TKA [44]. However, there are concerns regarding negative influence on quadriceps strength which may delay mobilization and increase the risk of falls during the early postoperative period [42].

ACB is regarded as a potential alternative which offers almost selective block of sensory without influencing motor function [49]. Like FNB ACB also is performed as single shot or continuous block. ACB leads to complete sensory loss of the medial, anterior, and lateral region of the knee including an area from the superior pole of the patella to the proximal tibia [50]. Recent meta-analyses provide evidence that ACB has the same potential of analgesia compared with FNB without negative effect on muscle strength and with improved mobilization ability [12, 51].

On the other hand, superior functional recovery was limited to 24–48 h, patient satisfaction did not differ, there was no evidence for prevention postoperative falls with ACB, and length of hospital stay was not reduced [12].

Unfortunately, Koh et al. (2017) could not prove significance for these conclusions or state a specific consensus due to heterogeneity of the analyzed studies regarding drug composition, infiltration techniques, and concomitant pain therapy and outcome variables [12].

PNB after TKA is associated with improvement in postoperative pain control and reduction in the use of opioids [9]. At this point in time no specific recommendation can be given regarding a best option for PNB for analgesic pain management after TKA. However, FNB is widely accepted and seems to be a reliable and effective procedure for multimodal pain management after TKA. Study results suggest that sFNB and cFNB are comparable regarding the effect on pain scores [9, 44]. Furthermore, a combination of FNB with SNC may offer advantages for pain management [47]. ACB appears as alternative option compared to FNB with same potential for pain management after TKA and to avoid negative effect on quadriceps strength [51].

Further studies are required to provide conclusive information which PNB is preferable for pain management following TKA.

Side Summary
In summary, there is no proof for preferable PNB for pain management after TKA.

42.6 Periarticular/Intra-articular Infiltration Analgesia and Continuous Intra-articular Analgesia

Local infiltration analgesia (LIA) has established as an alternative technique for pain management after TKA, was shown to be effective for pain relief, and provides a sparing effect for opioids in combination with low rate of infection and local anesthetic toxicity [52].

LIA is administered as peri- or intra-articular injection. The latter can be performed intra- or postoperatively. In addition, postoperative intra-articular catheter placement for prolonged LIA can be used [52].

Periarticular infiltration commonly covers subcutaneous tissue, the capsule including posterior capsule, periosteum, deep tissues around the medial and lateral collateral ligaments, and the fat pad. LIA is a very heterogeneous technique, and infiltration sites, dosage, and drugs differ considerably among different trials [53].

Seamgleulur et al. (2016) performed a meta-analysis including 38 studies to assess the efficiency of LIA in the early postoperative period after TKA. They analyzed 28 trials which compared LIA against no injection or placebo and 10 studies comparing LIA with no injection or placebo with additional use of systemic or regional anesthetic technique. Of these 28 studies, in 11 intraoperative intra-articular injection and in three postoperative intra-articular injection were used. In 12 studies, intraoperative periarticular injection was performed including four studies which used additionally postoperative intra-articular catheter placement. Several substances and dosages were used for infiltration: ropivacaine 190—400 mg, levobupivacaine 150 mg, bupivacaine 30 mg–150 mg–300 mg or 2 mg/kg body weight, morphine 1—5 mg, ketamine 0.25–0.5 mg/kg body weight, and patients with bilateral and unilateral TKA were included in the meta-analysis. Furthermore, several substances were additionally used for LIA: epinephrine, diclofenac, ketorolac, betamethasone, morphine, ketamine, dexamethasone, and methylprednisolone. A mixture of ropivacaine (2.0 mg/mL)–ketorolac (30 mg)–adrenaline (10 µg/mL) diluted in a total of 150 mL with normal saline is well accepted [54]. LIA was performed with different volumes depending on additional substances and the particular solution in saline [52]. This reflects the considerable heterogeneity of studies and different understanding and administration of LIA—there is no consistent concept.

Especially when considering the usage of different mixtures, surgeons should be aware that the injection of a combination of different drugs at the same time means that they design a new drug. For legal reason one should discuss the usage of mixtures with the pharmacist of the hospital beforehand.

It could be shown that LIA compared with placebo or no injection LIA provides better pain control associated with better range of motion (ROM) and shorter LOS and reduces adverse effects of systematic opioid use like nausea and vomiting [52].

In this meta-analysis, a significant better pain control was found for periarticular infiltration than for the intra-articular group. In fact, only periarticular injection led to better pain control after 24 h, greater reduction of opioid consumption was found, and ROM after 24 h was better in the periarticular group. This conclusion is supported by the findings of another meta-analysis [55].

Intra-articular infiltration was shown to be very effective in a meta-analysis of 1338 patients compared with a placebo group. Significant lower pain score with rest up to 48 h and less opioid consumption up to 72 h postoperatively [56]. On the other hand, this meta-analysis appears to have methodical limitations as two studies did not meet inclusion criteria, two studies included postoperative intra-articular infusion, and one did not administer LIA intraoperatively [52]. Other meta-analyses missed to pool all included studies for their analyses or did not include all available studies due to their inclusion criteria [52, 57].

However, the reduction in VAS in this meta-analysis for periarticular infiltration after 24 h was small (0.89) and disappeared after 48 h when two studies were excluded which used opioids in only one study group of LIA [55].

Also, no conclusion could be drawn for choice of several substances and different doses and administration sites whereas high-dose local anesthetic use seems to be safe. In three studies the plasma concentration was measured which was less than the toxic level. However, it stays questionable if higher doses are associated with better pain relief.

Side Summary
There is no conclusion regarding several suggested substances and dosages for LIA.

The question, if continuous LIA by catheter placement (CLIA) would have superior effects on pain relief and opioid consumption is still unsolved [52]. In one meta-analysis, only two trials were included which compared conventional LIA with CLIA concluded that CLIA can possibly reduce pain up to 48 h during rest and activity. However, the small number of trials and considerable heterogeneity makes it impossible to draw sufficient conclusions [58].

Infection was reported in four of the included total of 735 patients receiving LIA, three of them had intra-articular catheter placement [52].

One unsolved issue is whether the infiltration of the posterior capsule would provide a benefit for pain relief. No conclusion could be drawn from the abovementioned meta-analysis [52]. Pinsornsak et al. (2017) reported no difference between two groups after TKA of which one was provided with posterior capsule infiltration when performing LIA regarding pain relief and reduction of opioid consumption [53]. They concluded that local anesthetic might infiltrate the posterior capsule by following gravity in supine position. Therefore posterior capsule infiltration seems to have no advantages about LIA of the other commonly infiltrated structures of the knee and is therefore not recommended to avoid possible risks like intravascular application of local anesthetic and nerve injury [53].

Side Summary
Infiltration of the posterior capsule did not show superiority compared with LIA without infiltration of the posterior capsule.

PNBs have been proven to be effective for pain management after TKA. However, it is inconclusive if LIA could be beneficial if additively performed to PNB. Following the results of the meta-analysis performed by Seangleulur et al. (2016), one can expect little benefit by adding LIA to PNB which is probably due to the high efficiency of regional anesthetic techniques [52].

One meta-analysis comparing LIA or SNB as an adjunct to FNB which included seven clinical trials did not reveal conclusive differences and therefore concluded that LIA may be an alternative to SNB when combined with FNB [59].

In an attempt to increase the duration of local anesthetic action also, liposomal bupivacaine was used for LIA. Liposomal bupivacaine (LB) is an amide local anesthetic and consists of vesicles of bupivacaine loaded in the aqueous chambers using DepoFoam® technology (Pacira Pharmaceuticals Inc, San Diego, CA). The particles are structured like a honeycomb and contain numerous internal aqueous chambers containing encapsulated bupivacaine. This very cost-effective anesthetic is supposed to provide increased duration of analgesia compared to standard local anesthetic solutions [60].

Mont et al. (2017) performed a prospective randomized trial comparing LB with standard bupivacaine (SB) for LIA after TKA and concluded a considerable opioid-sparing effect when LB was administered [61]. Furthermore, there is evidence that the high costs could be compensated by lower opioid consumption and overall hospital costs for USA health care system [62].

However, meta-analyses are unable to conclude about the usage of LB for LIA after TKA [52].

In addition, it was investigated whether LIA in combination with steroids could decrease surgical pain by reduction of prostaglandin production and increased vasodilation. In summary, the current meta-analysis is not conclusive enough regarding the use of steroids for LIA due to a low number of trials and heterogeneous results and outcome parameters [63].

The situation of inconclusive results about several issues of LIA like catheter placement, sites of infiltration and volumes, substances, and dosages is further complicated by different meta-analyses which have different priorities.

In fact, LIA was proven to be effective as part of a multimodal pain management after TKA at least up to 24 h [52] and is regarded as an alternative option among others in particular PNB [52, 55, 57].

Side Summary
LIA is regarded to be effective as a part of pain management.

42.7 Comparison of LIA and PNB and Combining Techniques

The technique for peripheral pain management during the perioperative periode in TKA remains controversial. Concerns regarding the quadricpes muscle function to facilitate early mobilisation favors the usage of LIA alternatively to PNB.

LIA was frequently evaluated against FNB as this regional anesthesia is regarded as one of the standard PNB after TKA. LIA has shown to be at least as effective as sFNB [64–66], but less effective as cFNB [67] which might be comprehensible by the enhanced effect of regional anesthesia in a continuous nerve block.

As expected there are controversial results, and Mei et al. [65] included trials with partially conflicting results in their meta-analysis even though overall quality of FNB and LIA was concluded.

Some studies compared the combination of FNB and LIA with FNB and SNB as this is regarded as useful combination after TKA.

As already stated, no evidence is presented to prove superiority of combining FNB with SNB compared with FNB alone after TKA [49].

The evaluation of analgesic effect of FNB/SCB versus FNB/LIA by meta-analysis showed no difference [59] despite there being single trials with conflicting results [68]. However, the evidence of the prospective study by

Nagafuchi et al. (2015) to evaluate analgesic potential of FNB/SCB vs. FNB/LIA was rather low. Seventeen patients were included. Furthermore in this trial a combination of periarticular and intra-articular infiltration was administered, 70 mL for subcutaneous/periarticular infiltration was used [68], and outcome parameters (pain scores) were assessed for 24 h only.

Currently, there is not enough evidence for conclusive recommendation regarding PNB or LIA and combined techniques of regional anesthetic after TKA.

42.8 Corticosteroids

Steroids are applied for postoperative pain management in TKA as peri-/intra-articular infiltration or systemically (in general intravenously). The use of steroids and its possible advantage was discussed under paragraph 42.5.

The mechanism of modulation by which steroids may influence pain after TLA is not completely understood. It is hypothesized that steroids reduce the nociceptive input into the spinal cord [69]. Furthermore, steroids may act by suppressing CRP, which is involved in the modulation of nociception [70]. It was found that perioperative use of single, low-dose corticosteroids significantly decreased inflammatory markers after TKA [71].

Among several trials with smaller sample sizes, Koh et al. (2013) randomized 269 patients undergoing TKAs and received dexamethasone (10 mg) 1 h before surgery and ramosetron immediately after surgery (n = 135), or ramosetron alone (n = 134). They assessed the incidence of postoperative nausea and vomiting (PONV), pain level, and opioid consumption.

The Dexa-Ramestron group had a lower incidence of PONV during the entire 72-h evaluation period. In addition, lower pain and less consumption of opioids during the 6–24-h period was observed. No differences were found regarding wound healing disturbances or periprosthetic joint infection.

Other studies on efficiency of corticosteroids for reduction of pain after TKA involved only smaller sample sizes of about 25 patients per group and showed considerable heterogeneity regarding type, dosage (dexamethasone single dose 4–25 mg i.v.), and administration protocol of corticosteroids and concomitant pain control regime [72–74]. These differences make it difficult to evaluate beneficial effects of corticosteroid use after TKA.

Also, one has to consider a potential risk for infection associated with the use of corticosteroids during the perioperative period [75].

Side Summary

At present, no recommendation can be given for general use of systemic corticosteroids to supplement analgesic regime after TKA.

42.9 Gabapentinoids

Gabapentin and pregabalin are gabapentinoids and act at the α 2 δ subunit of a calcium channel which is involved in the regulation of neurotransmitter release.

Both are assigned to the group of antiepileptic drugs and are additionally administered for treatment of neuropathic pain and for generalized anxiety disorder. The effects are based on a decrease in neuronal excitability [76, 77].

In addition, gabapentin and pregabalin are administered for conditions of acute postoperative pain and are administered as supplemental analgesic therapy in TKA. Commonly gabapentin is given preoperatively but also may be used pre- and postoperatively [77].

Zhai et al. (2016) included six trials and 769 patients in their meta-analysis about the effect of gabapentin on acute postoperative pain after TKA [78]. They included studies with administered doses of 400–600 mg gabapentin preoperatively and 200–1200 mg postoperatively. Intraoperative pain management was different and consisted of local infiltration, general and spinal analgesia. Likewise the postoperative analgesia showed differences and included acetaminophen, celecoxib, PCA, NSAIDs, and morphine. VAS at 24 and 48 h rest showed a mean difference of −3.47 at 24 h and −2.25 at 48 h for the gabapentin group. With mobilization, no significant differences were found. The analysis of the cumulative morphine consumption after 24 and 48 h via PCA did not reveal significant superiority of gabapentin treatment.

One limitation of this meta-analysis is the inclusion of one non-RCT [79]. Furthermore, the study population was low in particular in one trial [80], including a therapy group of only 29 and a control group of only 7 patients. The average age of patients in one included trial was 36 years, which is an unusual age for osteoarthritis treated by TKA and may have influenced the results [79].

In contrast Han et al. (2016) who partially included the same trials [80–82] concluded that there was no significant difference in VAS after 12, 24, and 48 h postoperatively. Furthermore, no difference for postoperative knee flexion was found between gabapentin and control groups [77].

Both research groups conclude that the number of studies and included patients is low. They stated that there is no consensus regarding the dosage and duration of gabapentin when administered for postoperative pain management in TKA [77, 78].

There is one meta-analysis on the efficiency of pregabalin for the management of THA and TKA. In this analysis, four trials of TKA were included, which represents a study population of 510 patients. The dosage of pregabalin for TKA patients was 150 or 300 mg preoperatively and daily postoperatively. Only one trial for TKA showed significant difference for morphine consumption between the pregabalin and control groups [83]. Only one study reported superior results for VAS at movement at 24 h [83]. There were only two studies reporting on flexion results among the TKA trials. Flexion results were significantly different at 48 and 72 h, but clinical relevance was low (improvement of 2 and 7 degrees respectively after 72 h) [76].

Side Summary
At present, no recommendation can be given for additional use of gabapentin and pregabalin for supplemental analgesia after TKA.

Take Home Message
Multimodal analgesia refers to the use of combinations of analgesics acting via different mechanisms and thus taking advantage of additive or synergistic activity while minimizing adverse events with larger doses of a single analgesic [3]. Evidence-based multimodal techniques are procedure specific and may include combinations of systemic analgesics (e.g., opioids, acetaminophen, nonsteroidal anti-inflammatory drugs), neuraxial analgesia (spinal, epidural, and combination spinal/epidural), local infiltration, and peripheral nerve blocks [84].

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43 How to Handle Complications in Unicompartmental Knee Arthroplasty

Roland Becker

Keynotes

1. Complications occur either during or after surgery and are either directly or indirectly related to the procedure.
2. There are specific complications for each knee compartment (medial, lateral patellofemoral).
3. Most common complications are fracture, collateral ligament injury, and inappropriate component placement.
4. There remains a few number of patients with unexplained pain after unicompartmental knee arthroplasty (UKA). This number is significantly higher than after total knee arthroplasty (TKA).
5. While intraoperative and early postoperative complications require more often revision after TKA than after UKA, mid- and long-term revision rate seems to be higher after UKA.

43.1 Introduction

Complications are unpredicted events, and surgery becomes more difficult. It may prolong the rehabilitation time, and there is a potential risk of lower outcome. These events should be distinguished to errors, which are caused by wrong judgment during surgery or divergency between the planned and performed procedure. Both complications and errors are sometimes difficult distinguish.

Complications in UKA can be divided into events prior to surgery, during surgery, and after surgery, while most of them occur either during or after surgery.

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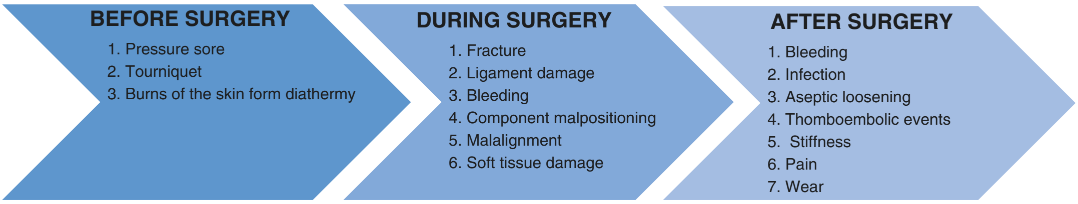

Unicompartmental knee arthroplasty (UKA) is a demanding procedure because the components have to be implemented respecting the bone morphology and the soft tissue of the knee. The accurate component placement is essential in order to preserve the anatomical function of all four ligaments and the capsule.

The most common complications and errors during surgery are fracture of the medial or lateral tibial plateau, damage of the medial or lateral collateral ligament, cutting errors during bony preparation, malposition of the components, or poor cementing technique. Some complications may not become obvious during or immediately after surgery but will show a negative impact on patient's outcome in terms of range of motion, clinical outcome, and pain. This will occur mainly when the soft tissue is not respected. The complication rate was analyzed of a cohort of 246 patients after UKA and showed that 2.5% occurs during UKA surgery and 7% after surgery [1].

The analysis of failures after UKA according to the Swedish Knee Arthroplasty Registry showed 3.4% of aseptic loosening of the medial UKA and progression of osteoarthritis of the lateral compartment in 1.92%. In contrast, the failure after lateral UKA was in 2.38% due to aseptic loosening and in 2.66% due to osteoarthritis of the medial compartment [2].

Aseptic loosening after UKA occurs most of the time at the tibial side. There are two options for revision surgery, either preservation of the UKA and revision to another UKA by replacing the loose component or revision to TKA. The incidence for second revision is significantly higher when revision of UKA to another UKA is performed than revision to TKA (Fig. 43.1a, b).

Side Summary
Aseptic loosening is the most common complication in UKA.

Other complications unrelated to the implantation of the components but caused by surgery are bleeding, myocardial infarction, thromboembolism, nerve injury, and infection. The risk for these complications in UKA is lower than in TKA.

This chapter discusses complications in medial, lateral, and patellofemoral unicompartmental arthroplasty and potential options for solution.

Side Summary
Most common surgical complications are cutting error, fracture, and poor cementing.

43.2 Medial Unicondylar Knee Arthroplasty

The most frequent complications when operating medial UKA seem to be the alteration of the joint line, fracture of the medial tibial plateau, damage of the medial collateral ligament, and early aseptic loosening due to poor cementing technique.

Medial tibial plateau fracture may be caused during implantation of the tibial component. The design specifically of the tibial component may partially contribute to the complication. Most of

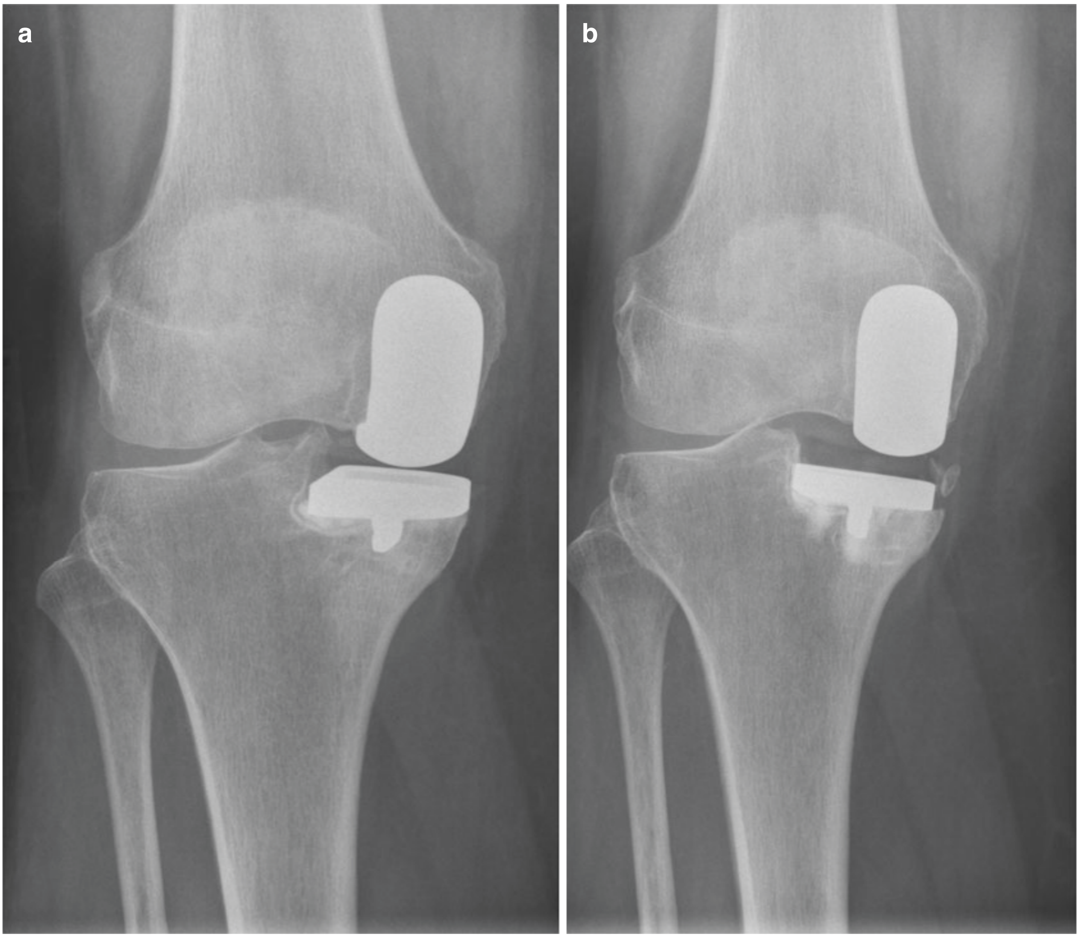

Fig. 43.1 (**a**, **b**) Aseptic loosening of the tibial component after UKA. Revision of the tibial component was performed, because of the minor bone loss during tibial preparation (**a**). Postoperative radiography after revision of the tibial component (**b**)

the tibial components have a keel for improvement of the stability. While some components have the keel more in the center of the tibial plateau which increases the risk of fracture during insertion, other components show a more laterally positioned keel close to the tibial eminence.

Side Summary
The most common complications during medial UKA are joint line alteration, poor cementing, damage of the medial collateral ligament, and fracture of the tibial plateau.

There are four major reasons which cause fracture of the medial tibial plateau: First, excessive impaction on the tibial component during implantation, and second, a deep vertical cut close to the tibial spine may weaken the medial tibial plateau (Fig. 43.2a–d). A cadaveric study was performed using six matched, paired fresh-frozen tibiae. In case of an extended sagittal tibial cut with a posterior slope of 10°, the depth of the cut is between 8 and 10.7 mm and thus reduces. Fracture load from 3.91 kN (2.35–8.50 kN) to 2.62 kN (1.08–5.04 kN) [3].

Comparing the load to failure after cemented and uncemented UKA, significant less load was

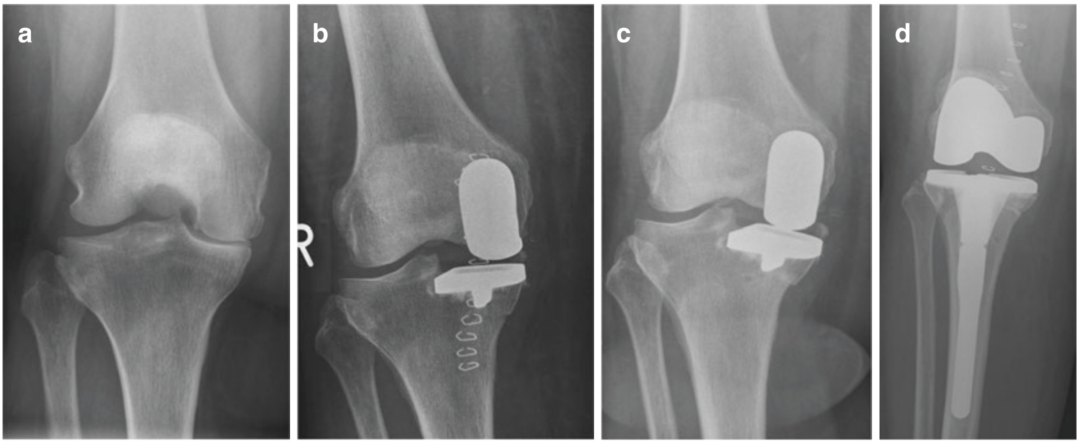

Fig. 43.2 (**a**–**d**) Medial joint space collapse is shown in the 45° weight bearing view (Rosenberg view) (**a**). Postoperative anteroposterior view after UKA. There is an interruption of the cortical bone on the medial side of the tibia (**b**). Fracture and dislocation of the tibial followed 5 days after surgery (**c**). Revision to TKA was performed using a tibial component with stem (**d**)

required to cause a fracture after uncemented implants (1.6 kN) in comparison to the cemented ones (3.7 kN) [4].

The second failure mode is related to the bone preparation and may occur during creation of the trough for the keel of the tibial component. Care needs to be taken not to weaken the dorsal cortical bone, an important stabilizer for the tibial component (Fig. 43.3a–j).

Third, pinholes placed for fixation of the tibial cutting block may act as a stress riser and cause fracture of the tibial plateau [5]. These fractures occur in general shortly after surgery.

Finally, it has been shown that valgus inclination of the tibial component will increase the risk, of medial condylar fracture as well [6],

In case of fractue there are different treatment options. First one may use screws in order to stabilize the fracture. However, it requires a well-fixed tibial component, which is often not the case. The fracture load was compared between screw and angle stable plate fixation after fracture in a biomechanical study [7]. The maximal load was 1.5 kN (0.27–3.51 kN) after two 6.5 mm cannulated screws. Significantly higher when an in contrast angle plate fixation (Königsee Implante GmbH, Germany) resistes significantly higher loading (2.64 kN (0.45–5.65 kN)).

Another option is revision of the implant to total knee arthroplasty using a stemmed tibial component in general for adequate fixation.

Component malposition or inappropriate sizing especially of the tibial component may cause early subsidence and loosening (Fig. 43.4a–f). The stability of the tibial component relies on the cortical bone. Osteoporosis is likely in female patients and may increase the risk of aseptic loosening [8].

The cementing technique may also have an impact on implant survival; however, no difference was shown in a cadaveric study comparing cement application on the implant only with cement application on both the implant and bone [9]. The cement mantle thickness may increase when a tourniquet is used [10, 11]. Jet lavage prior to cementing should be obligatory in UKA and TKA. Significant greater cement penetration and higher interface strength is achievable [12].

Fixed and mobile bearing UKA show different failure modes [13]. While early failure is related to to the risk of bearing dislocation in the mobile bearing design later failure may caused by wear in the fixed bearing design. No significant difference in revision rate was observed. However, bearing dislocation is the most frequent complication in mobile bearing UKA, caused by an inappropriate ligament balancing or tibial slope of the component

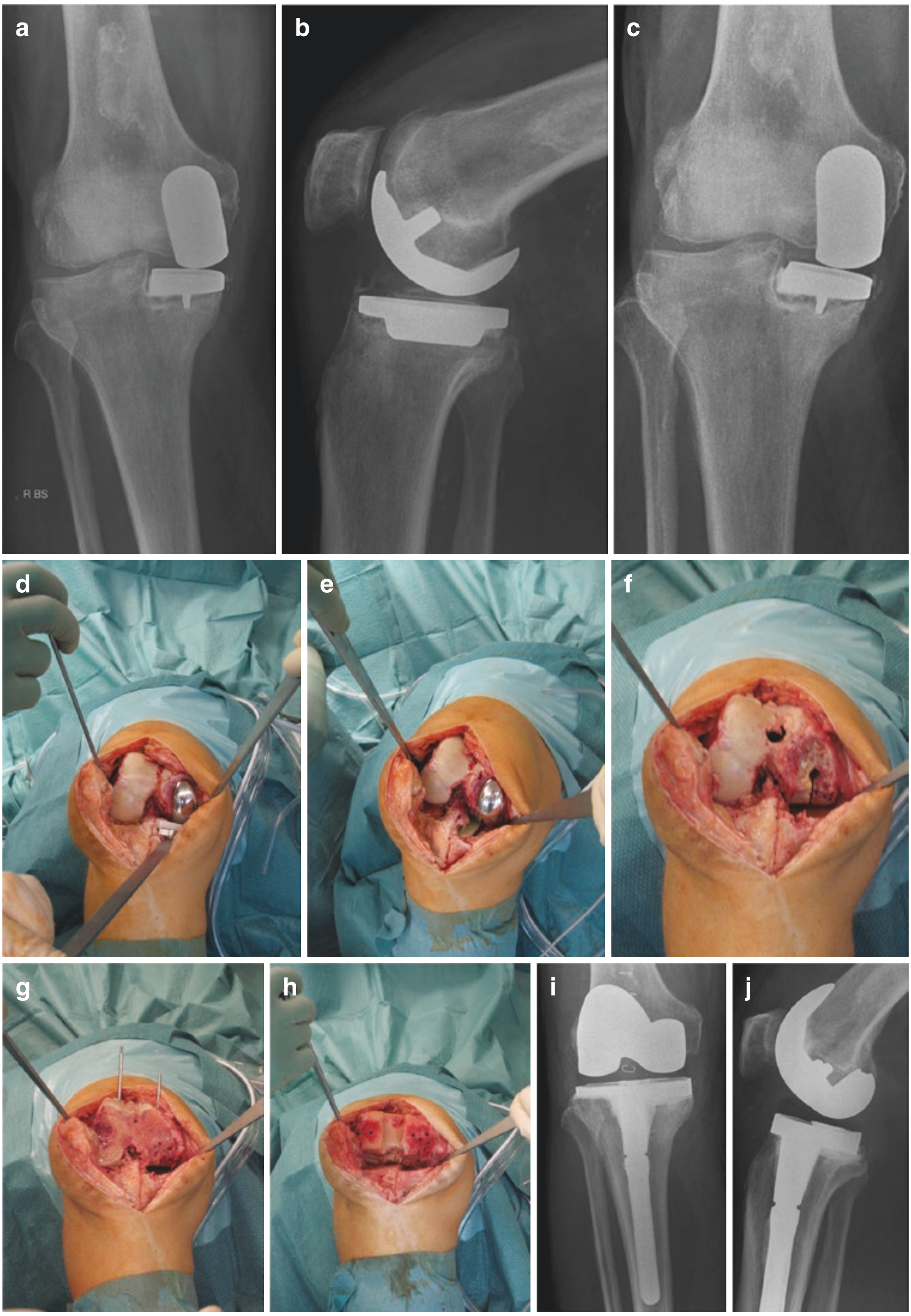

Fig. 43.3 (**a**–**j**) Anteroposterior and lateral view after UKA shows aseptic loosening of the tibial component (**a**, **b**). Increase of the aseptic loosening with displacement of the component (**c**). Loose tibial component is shown during revision surgery, which could easily be removed (**d**). The cement was well fixed only close to the tibial spine (**e**). The femoral component was removed showing the bony defect of the medial condyle (**f**). The distal femoral defect was completely resected by the distal femoral cut for TKA (**g**). Only minor bony defect was left at the dorsal medial condyle after preparation of the femur was completed (**h**). Postoperative anteroposterior and lateral view after revision of TKA. A 5 mm spacer was used on the medial side of the tibial plateau (**i**, **j**)

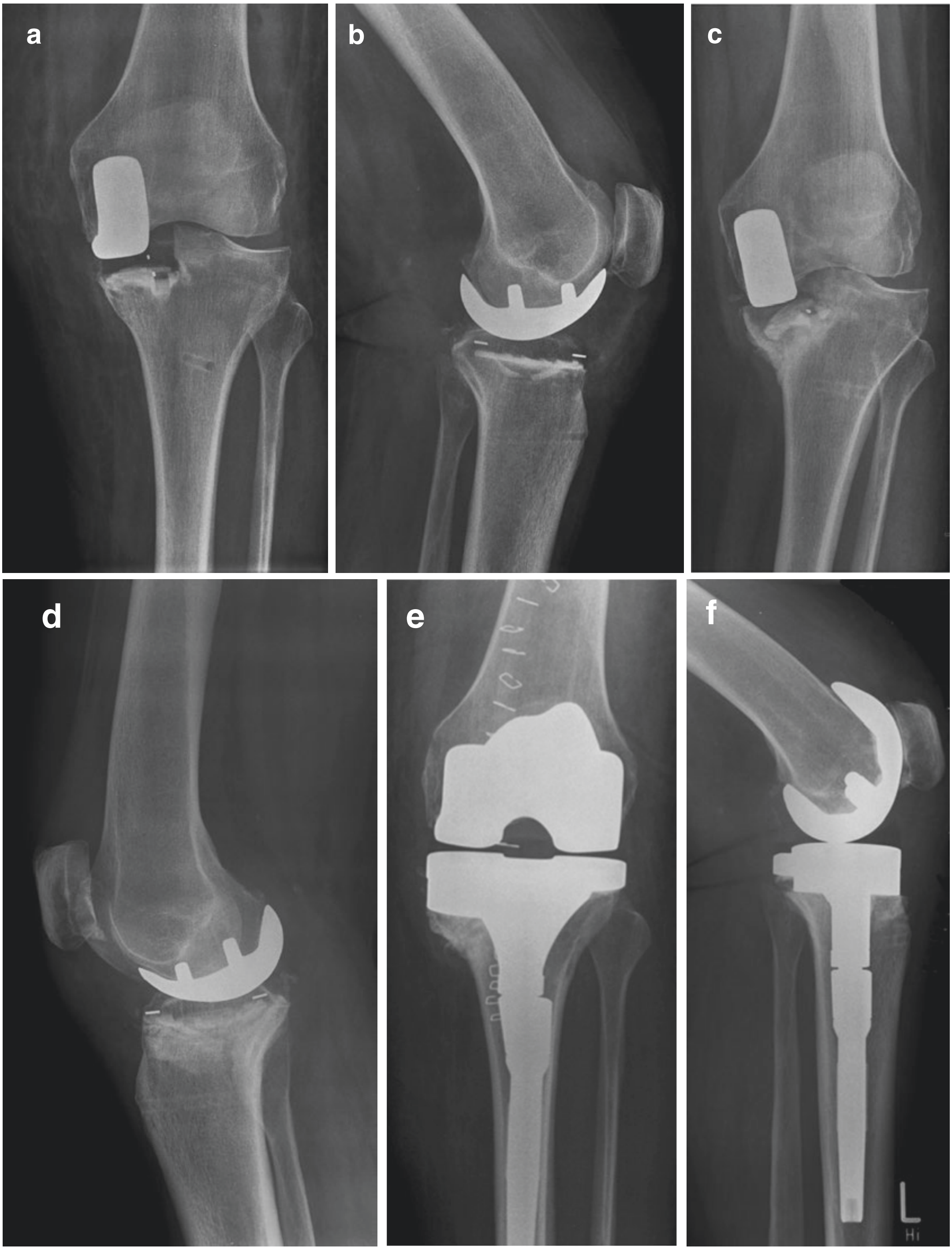

Fig. 43.4 (**a**–**f**) Anteroposterior (AP) and lateral view after UKA using full poly-tibial component. The AP view shows correct mediolateral placement of the component. The lateral view shows that the tibial component is not supported by the dorsal cortical bone of the tibia (**a**, **b**). One year later the tibial plateau collapsed (**c**, **d**). Revision to TKA was performed using medial spacer and stem on the tibial site (**e**, **f**)

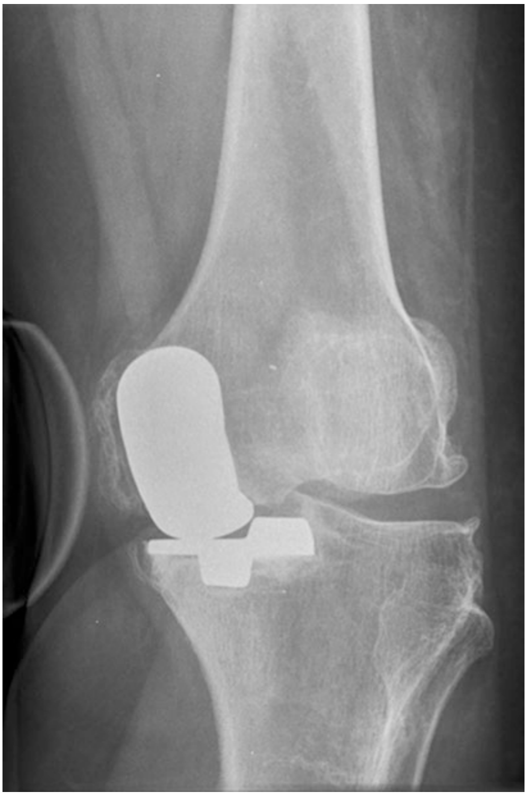

Fig. 43.5 Anteroposterior stress radiography of left knee showed luxation of the mobile bearing. The medial compartment was completely collapsed

(Fig. 43.5) [14]. The reoperation rate in mobile bearing UKA due to bearing luxation is about 0.2% [15].

Often primary TKA implants can be used, when revision of UKA to TKA is required (Fig. 43.6a–c). The medial femoral component should stay initially in place and may serve as a reference providing correct resection during the preparation of the femur. After removal of the components, the defect on the femur is contained or can be filled with cancellous bone taken from the lateral condyle. More critical is the tibial site. There is always some bone loss, which may require significant resection on the lateral tibial plateau as well. The medial spacer helps to avoid increased lateral bone resection. In case of a tibial spacer, the usage of an intramedullary stem is recommended to improve primary implant stability [16].

Side Summary
When spacers are required, additional stems for medullary fixation should be used.

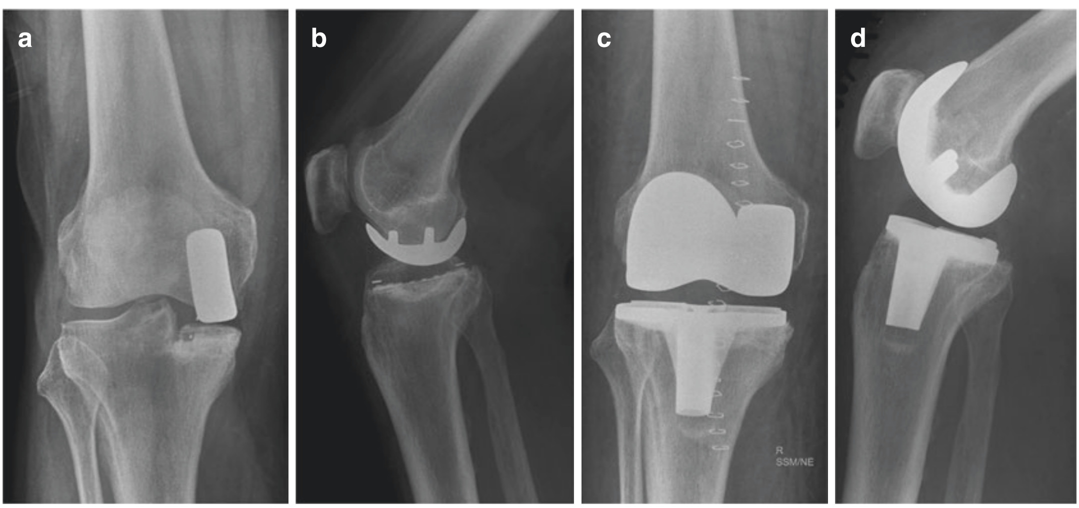

Fig. 43.6 (**a**–**c**) Revision of UKA to primary TKA. Aseptic loosening of the fully poly-tibial component (**a**, **b**). There is sclerotic bone reaction below the tibial component. Revision to primary TKA was performed (**c**, **d**). In general, more bone resection is required on the tibial site in order to undercut the defect on the medial tibial plateau. This causes the usage of a higher inlay

The clinical outcome after revision of UKA to TKA versus primary TKA was compared at a follow-up time of 8–17 years in a comparative study showing more dissatisfaction and less range of motion in the revision group [17]. A similar study was performed in our institution [18]. Thicker polyethylene liner, lower range of motion, and inferior knee and function score according to KSS were seen in the revision group after almost 5 years of follow-up. However, revision of UKA to TKA shows better outcome than revision of primary TKA.

Overstuffing of the medial compartment should be avoided in order to prevent overloading of the lateral compartment [19]. It occurs frequently when insufficient resection at the medial tibial plateau causes joint line elevation and valgus alignment (Fig. 43.7a, b).

Malalignment might be caused when the medial collateral ligament is damaged. Mobile bearing UKA is contraindicated in this case because of the significant hypercorrection into valgus and subluxation at the femorotibial joint. When correct balancing is not achievable, TKA should be considered (Fig. 43.8a, b).

The 90-day perioperative complication and mortality rates were analyzed in 828 patients after UKA [20]. There was a total complication rate of 12%, one deep venous thrombosis (0.1%), three myocardial infarctions (0.31%), one congestive heart failure (0.1%), one angina (0.1%), and three arrhythmias (0.31%). Secondary proce-

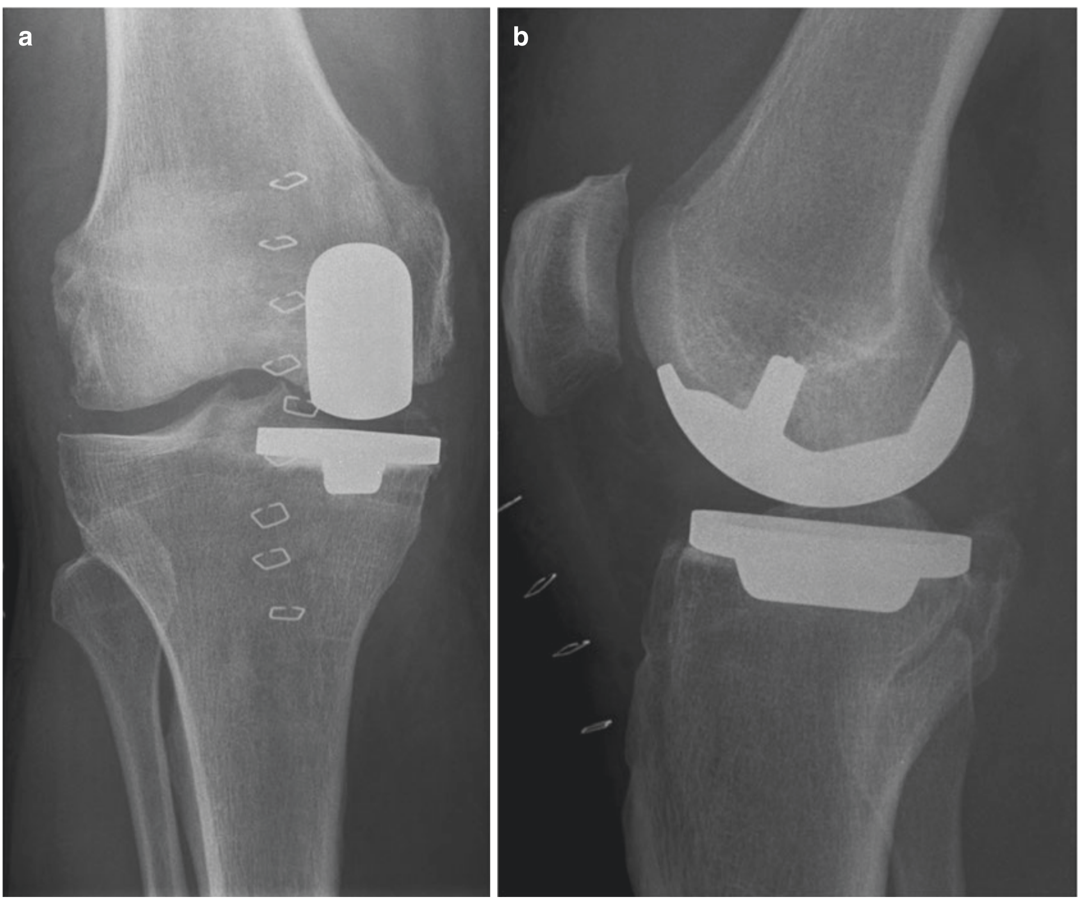

Fig. 43.7 (**a**, **b**) Anteroposterior and lateral view after UKA. Overstuffing due to insufficient bone resection at the tibial side, which caused joint line elevation and hypervalgus

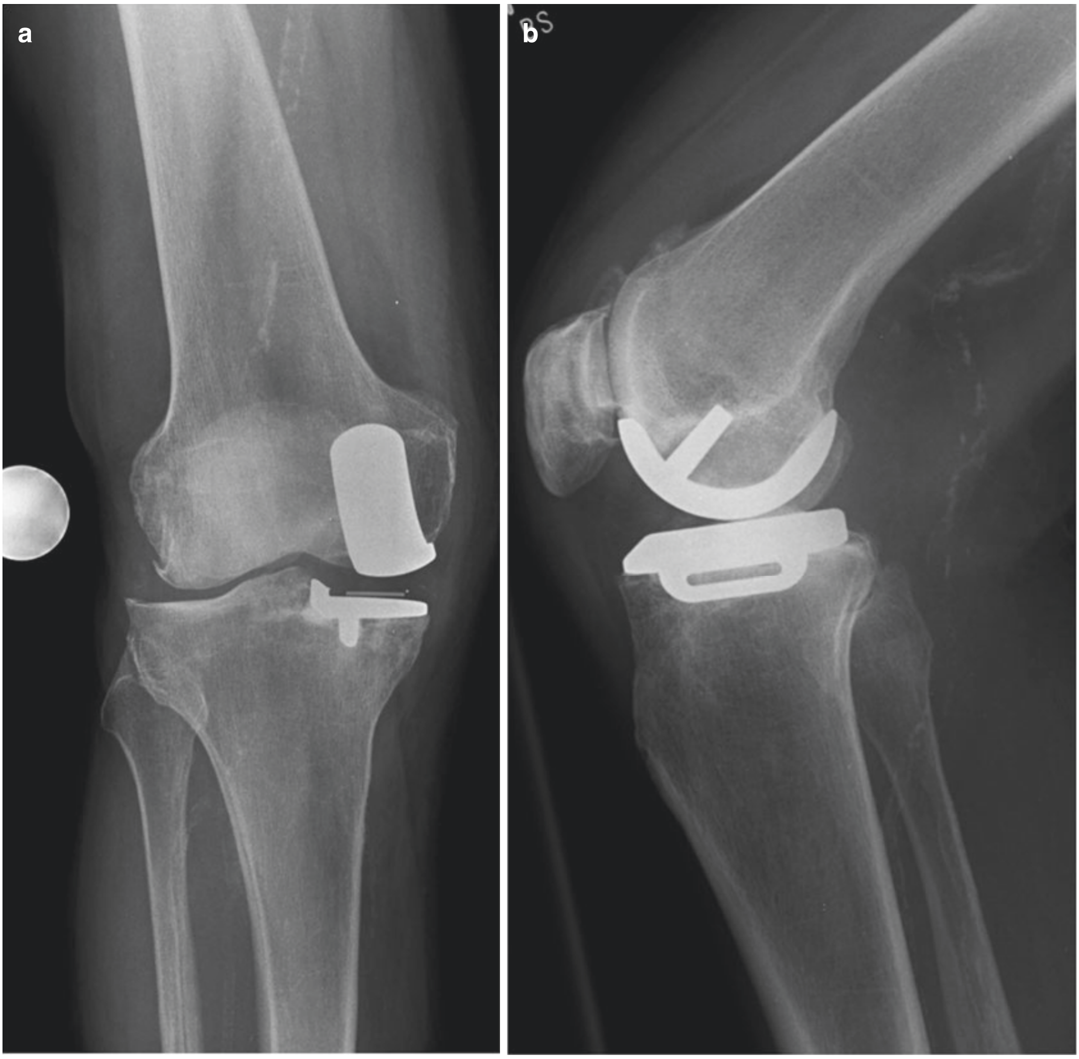

Fig. 43.8 (**a**, **b**) Anteroposterior and lateral view after mobile bearing UKA. The medial collateral ligament seems to be insufficient and a bigger mobile bearing was inserted, causing a valgus alignment and subluxation of the femorotibial compartment

dures were necessary in 15 patients; six of them required manipulation under anesthesia, one arthroscopic removal of cement and a drain, one secondary wound closure, three irrigation and debridement procedures for hematoma, and one revision for periprosthetic joint infection. These numbers show a significant lower rate of complication when compared with TKA.

43.3 Lateral Unicondylar Knee Arthroplasty

Lateral unicondylar knee arthroplasty is significantly less frequently performed, but patients do very well. The most frequent complications of up to 15% was seen due to luxation of the bearing in mobile bearing UKA [21]. The increased risk of bearing luxation is caused due to the higher natural laxity and mobility of the lateral compartment. Therefore a domed tibial component was developed for UKA to increase stability of the bearing due to the biconvex shape. After four years of follow-up, the reoperation rate was 4.9% of which 1.5% were bearing dislocation [22]. Other studies reported no dislocation when a domed tibial design was used [23].

Fixed bearing lateral UKA shows a survival rate of 94.4% after 10 years and 91.4% after 15 years [24]. No progression of osteoarthritis in the contralateral compartment was seen in these patients [25]

While some authors have reported better quality of life after medial UKA versus lateral UKA, a systematic review of the literature showed no difference in survival rate between the medial and lateral UKA [26, 27].

Care should be taken when the tibial cut is performed, which should be very conservative because most often the bone defect is on the femoral site. Due to the screw-home mechanism care needs to be taken in femoral component positioning in order to avoid impinging at the tibial eminence. Therefore, the femoral component should be positioned as lateral as possible on the condyle in knee flexion. A perfectly placed femoral component in 90° of knee flexion may show internal rotation in extension.

Side Summary
Avoid overcutting of the tibial plateau in lateral UKA. Be careful when positioning the femoral component in order to avoid impingement.

43.4 Patellofemoral Arthroplasty

The indication for isolated patellofemoral arthroplasty (PFA) is rare. Overstuffing of the patellofemoral compartment seems to be the most common complication. Revision of PFA is significant, more frequently than after TKA [28]. The weighted rate for revision of patients after PFA and TKA was 6.34 and 0.11, respectively. Clinical and functional outcomes after PFA and TKA were assessed in a matched pair study at a mean follow-up time of 9.2 years [29]. While there was no significant difference in clinical outcome Oxford Knee Score or Short Form-12, the survival rate after 10 years of the PFA and TKA was 92.3% and 100%, respectively. A large series of the Avon®-PFA showed a survival rate of 77.3% and 67.4% at 10 and 15 years of follow-up time [30]. There were 105 revisions out of 483 implants, of which 58% was due to progression of osteoarthritis. Interestingly, all documented revisions were revised to primary TKA without using any augmentations.

Data were analyzed from the Australian Joint Replacement Registry including 3251 PFAs. Revision was required in 14.8% due to progress of osteoarthritis (56%), loosening (17%), and pain (12%) [31].

Side Summary
Patellofemoral arthroplasty shows higher revision rate than after medial or lateral UKA.

Complications After Surgery Early and late complications are infection, polyethylene wear, and pain due to alteration of the bone metabolism of the affected tibial plateau.

The infection rate is significantly lower than after TKA and ranges from 0% to 1% [32, 33]. The management of periarticular joint infection is similar to TKA and includes irrigation, debridement, and change of the bearing at the early stage. However, there is a potential risk of accelerated progression of OA in the remaining compartment caused by the infection.

Polyethylene wear is rather infrequent representing up to 12% of the revisions after more than 5 years [34]. Several factors influence polyethylene wear such as life time of the polyethylene and varus or valgus malalignment which increases stress on the bearing and potentially increase of wear. Component reduction of up to 70% has been reported when the femoral component was positioned between −5° and +25° of varus in regard to the tibia [35]. A minimum thickness of 6 mm is recommended [36].

Increase in congruency was the rational for introduction of the mobile bearing concept in UKA. Due to the increase in congruency it was thought that less wear will occur. In fact, the mobile bearing design (10.7 mg per 10^6 cycles) shows an increase in wear when comparing to fixed bearing design (7.5 mg per 10^6) [37]. Significant difference in terms of number of particles was seen as well. The total number of particles was one-third higher in the mobile bearing design. However, the wear pattern and particle size are different between fixed and mobile bearing UKA.

There is a number of patients with unexplained pain after UKA. Unexplained pain was the reason for revision in 23% of all failed UKA according to the National Joint Registry of England and Wales. This number is significantly higher than after TKA. Finite element analysis has shown increase in strain after UKA of 43% [38]. These patients are a difficult group to treat. Patients who received revision UKA to total knee arthroplasty were divided into a group of patients with unexplained pain and a second group for specific reason [39]. Patients with unexplained pain showed significant lower results according to Oxford Knee Score and VSA after revision surgery. 3D scintigraphy (SPECT) combined with CT is a helpful imaging tool especially in these patients [40]. It provides intensity values about bone tracer uptake and component placement. Different uptake pattern may help to identify the cause of persistent pain [41].

Take Home Message

- The joint line should be preserved.
- There is a potential risk of medial tibial plateau fracture when the trough is made too deep or has weakened the cortical bone.
- The pin hole used for the fixation of the tibial cutting block may act as a stress riser and weakens the medial tibial plateau. It may increase the risk for fracture. The pins should be placed as close as possible to the tibial plateau.
- In case of revision of UKA to another UKA be careful with the indication. Significant increase of re-revision has been shown. In case of any doubt one should rather change to TKA.
- There are a number of patients with unexplained pain after medial UKA, which might be caused due to increased stress within the medial compartment.
- Overstuffing of the medial compartment after medial UKA or vice versa will cause progression of OA in the contralateral compartment due to overloading.

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44 How to Handle Complications During TKA?

Stephanie Kirschbaum, Philipp von Roth, and Carsten Perka

Keynotes

1. To avoid critical perfusion, the skin incision should be anterior and longitudinal.
2. If there are multiple scars due to previous surgeries, use the most lateral scar.
3. Make sure that there is a sufficient exposure of the knee joint. In contract or stiff knees, think about, for example, a rectus snip or an osteotomy of the tibial tubercle to avoid damage to the extensor mechanism.
4. Use retractor for better exposure and preparation as well as for protection of the ligaments and popliteal vessels while sawing.
5. Severe valgus deformity (≥15°) in total knee arthroplasty (TKA) often goes along with lateral soft tissue release and is a risk factor for the development of peroneal nerve palsy. If it occurs, immediately therapy is considered.
6. In case of intraoperative ligament injury, use a prosthesis with higher condylar constraint.
7. The risk of a periprosthetic fracture is especially high if the cut surfaces have not been cleanly prepared, there is a severe sclerosis or during preparation of the PS box.
8. A relevant arteriosclerosis or peripheral arterial occlusive disease must be ruled out before tourniquet use.

44.1 Introduction

Various complications can occur during total knee arthroplasty, considering the skin, capsule, ligaments and bone (TKA). Even though serious complications such as vascular injuries are rare, they require prompt and careful treatment. Damage of the popliteal artery requires interdisciplinary collaboration with vascular surgeons, angiologist or interventional radiologists. In addition, nerve injuries can present a major challenge for the surgeon as most of them are detected only post-operatively. In contrast, ligamentous injuries are more common. They need to be detected early and require adequate treatment to avoid subsequent instability.

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In this chapter, the main intraoperative complications occurring during TKA are described and management strategies are presented.

44.2 Intraoperative Complications

44.2.1 Surgical Approach

The vascular supply of the anterior skin and capsular structures of the knee are primarily provided by arteries from the medial aspect of the joint, coming from branches of the femoral artery [1]. A medial approach to the knee joint can result in malperfusion of the skin lateral to the incision. In addition, a very medial skin incision creates a large skin flap laterally, which is often stretched during exposure and can be damaged by this mechanical stress [2]. The consequences range from wound-healing problems to a full skin necrosis (Fig. 44.1). To avoid critical perfusion, the skin incision should be anterior and longitudinally. If there are multiple scars due to previous surgeries, the most lateral scar should always be used. If crossing an existing scar is unavoidable, the angle of incision should be greater than 60° to reduce the risk of skin necrosis and wound-healing problems.

Fig. 44.1 A complete skin necrosis after total knee arthroplasty. The surgeon used an untypical approach due to the pre-existing scars after open resection of the medial meniscus 1973. The necrosis was treated by using a gastrocnemius flap

Side Summary
Main blood supply of the anterior soft tissue of the knee is provided from medially.

In case of very complex scar formations, Wyles et al. reported on intraoperative laser-assisted indocyanine green angiography (LA-ICGA) visualising the actual perfusion [3]. This may help choosing the optimal approach in complex soft tissue situations and helps to prevent wound-healing problems.

The risk of skin complications during primary surgery is low and has to be distinguished from deep wound infection (incidence 0.6–3%) [4–6]. Wound complications during surgery are very rare. Extreme tension on skin especially during minimal invasive surgery may cause skin damage. If so, early debridement of the skin should be performed.

During preparation of the subcutaneous tissue, the joint capsule and the aponeurosis of the quadriceps femoris muscle should be sufficiently exposed to achieve a good exposure to the knee. This might be difficult in contract and stiff knees.

The most commonly used approach in TKA is the medial parapatellar approach. It allows a good exposure of the knee joint but could lead to injury or malperfusion of the extensor mechanism. The blood supply to the extensor mecha-

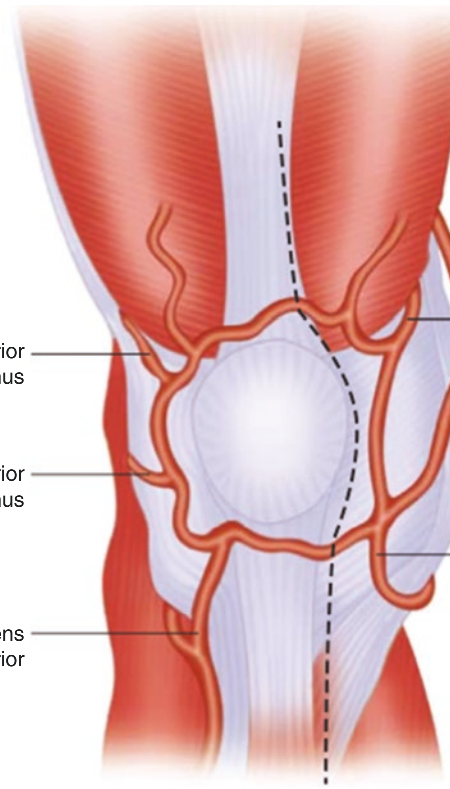

Fig. 44.2 The blood supply to the extensor mechanism comes from the descending genicular artery, medially and laterally from the superior and inferior genicular arteries, and also from the anterior tibial recurrent artery

nism arises from the descending genicular artery, medially and laterally from the superior and inferior genicular arteries, and also from the anterior tibial recurrent artery (Fig. 44.2). A medial parapatellar approach impairs the medial blood supply of the skin and also to the extensor mechanism or even cut it off completely, depending on the especially proximal extension [6–9]. Clearly, this might increase the risk for a post-operative rupture of the extensor mechanism.

The proximal medial blood supply might be preserved using a minimally invasive subvastus or midvastus approach as especially the subvastus approach seems to less affect the bloody supply of the superomedial genicular artery. Up to now, there is no evidence for this assumption. However, both approaches come along with a more limited exposure of the knee joint and are more difficult to extend. Hence, they should only be used in non-obese patients with mobile soft tissues. Previous scars, obesity or severe deformities are relative contraindications [10].

Side Summary
The minimal invasive subvastus or midvastus approach may protect the superomedial genicular artery. However, both approaches may give limited exposure to the knee.

With a subvastus approach, the medial perforating vessels are in danger. This might lead to a severe haematoma. The midvastus approach might result in an atrophy of the distal part of the vastus medialis muscle, if the motoric nerve is injured during the approach [11].

In stiff knees, there is a considerable risk of a rupture of the patella tendon. Careful detachment of the patellar tendon proximally and medially to the tibial tubercle is described for such situations [12]. However, the detachment can weaken the mechanical properties of the extensor mechanism, increasing the risk of post-operative rupture. A ‘rectus-snip’ might help to avoid such devastating complication when dealing with a very stiff knee or patella baja. It is easy to perform, and there is no need for modifying the post-operative rehabilitation procedure. In case of an additional patella baja, an osteotomy of the tibial tubercle might be an option for extension of the approach. The osteotomy should have a length of at least 7–8 cm and a thickness of 1 cm for prevention of a fracture of the flap [13, 14]. In order to avoid secondary displacement of the flap, at least two screws should be used for refixation. As the tibial stem may impede a correct position of the screws, there is the possibility to use cerclage wires as they are easier to place and provide solid static fixation [15].

44.2.2 Exposure of the Knee Joint

The patella tendon is at risk not only during the arthrotomy but also during the entire surgical procedure. The lateral dislocation of the patella during the exposure might result in an injury of the patellar tendon. In an attempt to gain more exposure, for example, by inserting lateral retractors, the patellar tendon might be avulsed from the tibia. Ruptures of the quadriceps or patellar tendon are rare (1–12% incidence). However, these represent a serious complication in TKA. If untreated, these result in loss of extensor function [16].

A complete excision of the infrapatellar fat pad facilitates the exposure and preparation of the tibia, but might also compromise the blood supply to the patellar tendon due to cutting of the anterior tibial recurrent artery. In addition, it might represent a direct injury to the patellar tendon itself. Caution is required if there has been a previous lateral meniscus resection. In such cases, the previous lateral approach might lead to a malperfusion of the extensor mechanism as the lateral inferior genicular artery had been injured. An excessive lateral release might also reduce the blood supply of the extensor mechanism through the lateral superior genicular artery [16].

Depending on the site of injury and quality of the tissue, a suturing attempt or reconstruction of the patellar tendon may be possible. If a suture is performed, it should be supported by performing a McLaughlin cerclage using a cable wire, FibreWire or PDS suture (Fig. 44.3). The augmentation of a patellar tendon using autologous hamstring grafts provides higher primary stability than suture repair alone and allows an early post-operative mobilisation [17]. However, if tendon quality is poor, a suturing attempt is rarely successful [18]. Various techniques using autograft, allograft or synthetic material have been published, with mixed results [19]. Reconstruction using a polypropylene mesh appears to be promising, especially in cases of pre-existing chronic injuries and extensor mechanism insufficiency, and shows good results in short- and mid-term follow-up for both ruptures of the patellar and quadriceps tendon [16, 20].

Side Summary
In case of patellar ligament rupture, primary repair and cerclage might be sufficient. In case of poor ligament quality, augmentation with autograft or allograft should be considered.

44.3 Femoral and Tibial Preparation

44.3.1 Vascular Injuries

Even though very rare, an injury to the popliteal artery is a serious complication in TKA. The reported incidence is 0.11–0.17% [21, 22]. The main cause is a direct injury to the popliteal artery with a saw, a chisel or retractors (61%). Indirect injuries can be caused by excessive hyperflexion, hyperextension or twisting of the knee joint (17%), in particular in patients with arteriosclerosis [23].

The use of a retractor can protect the popliteal structures from direct trauma during sawing and furthermore facilitates exposure and preparation of the tibia. It is crucial to place the retractor centro-medial, close to the posterior margin of

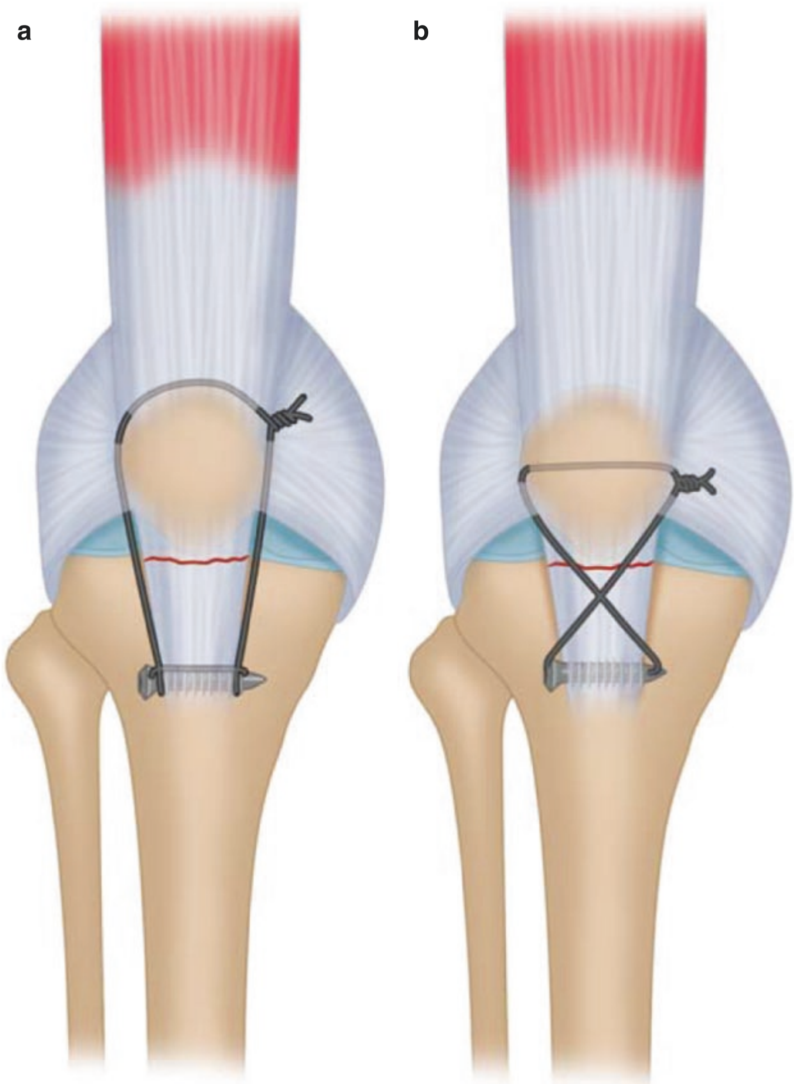

Fig. 44.3 Scheme of McLaughlin Technique Type 0 (**a**) and 8 (**b**) to support the patella tendon suture

the tibia, next to the posterior cruciate ligament (PCL) insertion in order to avoid injury of the popliteal artery. In flexion, the artery can be identified 1 cm posteriorly and 1 cm laterally to the knee joint centre [24].

> **Side Summary**
> The popliteal artery runs 1 cm laterally and 1 cm posteriorly to the centre of the knee in 90° of flexion.

Another potential source of haemorrhage may be encountered during resection of the lateral meniscus for better exposure of the tibial plateau. Bleeding from the lateral inferior genicular artery may occur. During resection of the PCL, in preparation for a posterior-stabilised prosthesis, arterial bleeding may occur from terminal branches of the medial genicular artery.

If bleeding complications occur during surgery, the first step should be exploration and identification of the source of bleeding. Regarding the management of bleeding complications, a distinction must be made between injury to minor vessels and injury to the popliteal artery. Minor sources of bleeding can generally be treated by ligatures, sutures or cauterisation of the vessel. Injury to the popliteal artery accompanied by severe bleeding often requires an interdisciplinary approach. The anaesthetist should be informed first so that an imminent hypovolaemia can be avoided and, if necessary, transfusion of erythrocyte concentrates, coagulation factors and tranexamic acid can be initiated [25]. At the same time, the tourniquet should be used to avoid further blood loss. Depending on the pattern of injury, a vascular suture, patch or arterial bypass may be necessary. Alternatively, the vessel can be repaired using endovascular stenting with interventional radiology. Bleeding from minor vessels can be stopped by coagulation, coiling or endoluminal application of thrombin [22]. Of note, a radiological intervention can be frustrating or more difficult with a prosthesis in situ. There is currently no consensus on the superiority of one method. Both procedures are used, depending on the pattern of injury and the available infrastructure [22, 23, 26]. Once the vascular injury has been treated successfully, implantation of TKA can be completed. Besides the vascular complications described earlier, other complications may occur during femoral and tibial resection or preparation such as neuronal injuries.

44.3.2 Nerve Injuries

When talking about nerve injuries, one must differentiate between cutaneous nerves and mixed motoric or sensoric or purely motoric nerve injuries. Using the medial approach, the inferior ramus of the saphenous nerve is often injured, leading to hypaesthesia of the lateral skin from the proximal tibia down to the diaphysis of the lower leg. There is a risk of neuroma formation, which may cause persistent pain after surgery. Sometimes, revision surgery or removal of the neuroma is required [27]. Very few studies have investigated the incidence of this hypaesthesia. Black et al. observed an incidence of 27% when using the medial skin incision [28]. Therefore, it is important to discuss this common complication preoperatively with the patient.

Side Summary
Damage of the inferior branch of the saphenous nerve may occur during the standard medial approach and cause neuroma formation.

Severe nerve injuries during TKA are a serious but rare complication. The incidence reported in the literature ranges from 0% to 9.5% [29]. Risk factors include flexion contractures and severe valgus deformities with an extent of more than 15°. In particular, the peroneal nerve is prone to injury during a lateral release in case of severe valgus deformity [30]. The peroneal nerve contains fibres from lumbar segments L4-S2. The common peroneal nerve winds around the fibular head before dividing into the deep and superficial peroneal nerves, and, due to this exposed position, it is therefore susceptible to pressure. It often lies directly behind the tendon of the popliteus muscle, around 6–11 mm from the tibial margin [31]. Peroneal nerve injury can lead to loss of function of the tibialis anterior muscle, extensor digitorum muscle, extensor hallucis longus muscle and peroneus muscles. Consequently, the patient can no longer dorsiflex the foot postoperatively and complains of numbness on the lateral aspect of the foot. If the tibial nerve is affected, loss of function of the tibialis posterior muscle occurs, accompanied by limited plantar flexion of the foot. The hypaesthesia in this case is plantar. Correction of severe valgus alignment might increase tension on the lateral soft tissues and peroneal nerve. This might result in postoperative traction-related nerve injuries [32].

Side Summary
Correction of severe valgus deformity or lateral release may damage the peroneus nerve.

In most cases, an injury to nerve structures can hardly be evaluated during surgery and becomes only apparent post-operatively. Sensitivity and motor function should therefore be tested immediately after surgery, before connecting any pain catheters, to rule out a lesion of the abovementioned structures. A very rarely used possibility of evaluating nerve function especially in severe valgus deformation during surgery is neuromonitoring [33]. If paraesthesia or paresis occurs post-operatively after initially intact sensitivity and motor function, compartment syndrome must be excluded urgently and conservative treatment initiated. This involves placing the affected knee in approximately 45° flexion (Fig. 44.4), taking measures to reduce swelling and loosening circular bandages [29]. Further diagnostics should be also initiated. Besides conventional radiographs in two planes to rule out a mechanical conflict, sonography should be performed as a dynamic examination, accompanied by CT or MRI to detect nerve compression due to a haematoma. If a haematoma is identified as a cause of compression, it should be treated immediately. In theory, nerve compression can also be caused by a protruding tibial component. However, there is very little literature at present which discusses this phenomenon.

If no cause of the sensory disturbance or paralysis can be identified, conservative treatment should be initiated and a peroneal splint applied. According to a study by Park et al., up to 75% of patients with incomplete nerve palsy showed a complete recovery [34]. Another study recommends surgical decompression depending on the EMG findings if there is no improvement within the first three months [35]. This approach is contested in the literature, as other studies have shown that a complete recovery can take up to two years [34].

Fig. 44.4 Recommended position of knee in case of post-operative peroneal nerve palsy

44.3.3 Ligament Injuries During Preparation of Femur and Tibia

During tibial and femoral resection, there is also a risk of accidental injury to the collateral ligaments. The retractors should be placed so that the ligament structures are protected from the saw blade (Fig. 44.5). Overall, the preparation of femur and tibia holds the greatest potential for collateral ligament injury. The incidence is reported between 1.2% and 2.7% [36, 37].

The treatment of medial collateral ligament (MCL) injury during TKA remains a subject of controversy. The MCL is in contrast to the lateral collateral ligament well vascularised and shows a good intrinsic healing capability. In principle, there is the option of an intraoperative suture, reconstruction of the collateral ligaments or of using a more constrained prosthesis. However, higher constrained results in increased shear forces acting on the prosthesis-cement interface, which might lead to a reduced survival rate [38]. Bony avulsions of the ligament insertion can be reattached using bone anchors or screws. Alternatively, a reconstruction of the collateral

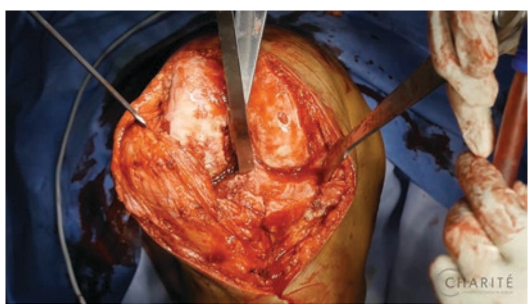

Fig. 44.5 Recommended position of the retractors to avoid intraoperative ligament injury while sawing, a chisel preserving the PCL from the saw blade

ligaments using the gracilis or semitendinosus tendon has been described [39]. In mid-term follow-up, reliable suture and reconstruction show no disadvantage compared with groups without MCL injury [36, 40]. In general, these reconstructions require more careful post-operative treatment, which includes wearing of a knee brace for about 6–8 weeks and partial weight bearing of the operated leg. This quite frequently results in a flexion deficit in short-term follow-up and therefore a longer and more intensive rehabilitation [36]. Especially in obese patients, the use of such a brace remains difficult as it is often only poorly fitted. In such cases, the surgeon might prefer using a prosthesis with higher condylar constraint. As discussed earlier, the increased degree of constraint results in higher shear forces on the prosthesis-cement interface, so these implants may have a comparatively inferior survival rates [38]. The choice of procedure should therefore be made dependent from the constitution, age and functional requirements of the patient.

During preparation of the tibial plateau, the patellar tendon must also be protected against accidental injury caused by the saw blade. In addition, a forced dislocation of the patella with inadequate exposure and preparation of the tibia can lead to a rupture of the patellar tendon. If there is a limited view of the surgical site, the exposure should be improved appropriately before continuing preparation of the tibia. During tibial resection, the PCL may be injured or the bony attachment may be accidentally cut. The latter can be avoided by inserting a chisel anterior to the bony attachment. In the event of PCL injury or insufficiency, a switch should be made to a posterior-stabilised prosthesis.

44.3.4 Periprosthetic Fractures

The reported rate of intraoperative periprosthetic fractures is 0.4% [41]. The incidence of intraoperative periprosthetic fractures of the femur is significantly higher for cementless prosthesis systems (5.4%) than for cemented components (0.1–1%) due to the greater impacting force required. Another risk factor for periprosthetic fractures is a severe sclerosis [42]. Depending on location, bone quality and fragment size, a periprosthetic fracture can be treated using screws or a plate osteosynthesis, or by a stemmed prosthesis [41].

Different classification systems exist for periprosthetic fractures of the knee joint. A widely used system is that developed by Rorabeck for the femoral site (Table 44.1) and by Felix for the tibial site (Figs. 44.6 and 44.7) [43, 44]. Since 2014, the Unified Classification System (UCS) according to Duncan and Haddad has been established (Table 44.2, Fig. 44.8), which has shown good inter-observer reliability [45, 46].

Periprosthetic fractures occur most commonly during exposure and preparation of the surgical site (39%).

A fracture of the medial femoral condyle can occur during preparation of the PS box in posterior-stabilised implants, especially in small and osteoporotic knees. This is because the size of the PS box is uniform in most prosthesis models and is often independent of the size of the femoral component. In small femoral components, the design leads to a relative increase of the dimensions of the PS box. In contrast to larger components, the femoral preparation of the PS box of small femoral components is substantially larger at the expense of the condyles, which increases the risk of fracture. However, sometimes poor preparation of the box leaving remnants of cortical bone at the posterior condyle may also cause fracture.

Side Summary
Periprosthetic fracture occurs most commonly during knee preparation at the femoral side.

Table 44.1 Classification of the periprosthetic fractures by Rorabeck et al. [43]

Class	Prosthesis	Fracture
Type 1	Fixed	Not dislocated
Type 2	Fixed	Dislocated
Type 3	Loose	Dislocated or not dislocated

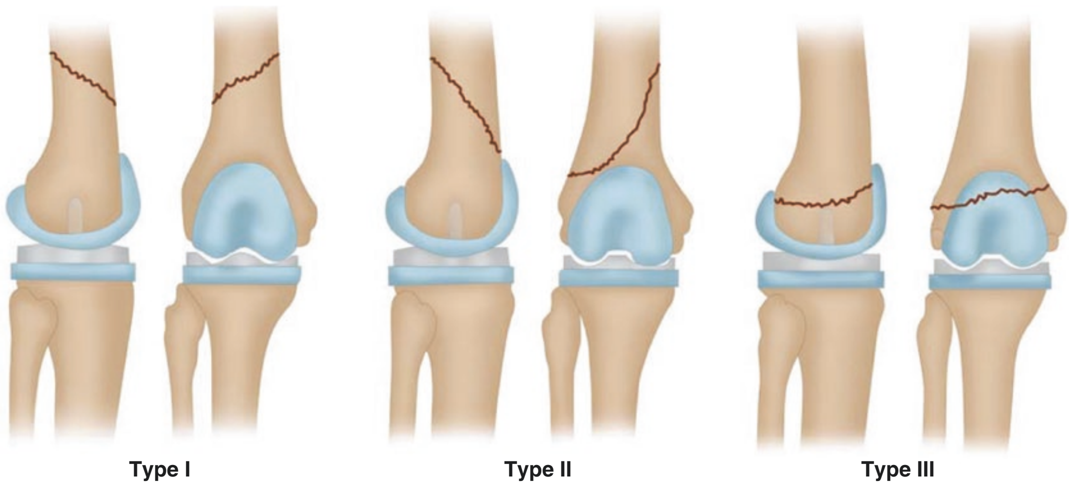

Fig. 44.6 Classification of femoral periprosthetic fractures by Rorabeck [43]

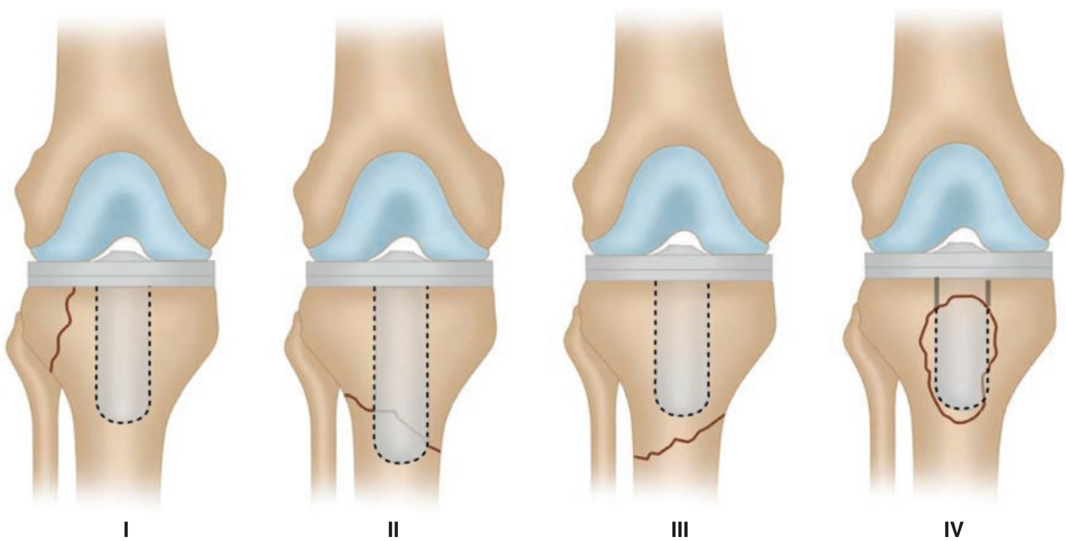

Fig. 44.7 Classification of tibial periprosthetic fractures by Felix [44]

The second-highest rate of periprosthetic fractures (33%) is found during insertion of trial components. Significantly fewer fractures (19%) occur during cementing of the final implants [41]. Trial components are often made of metal and are therefore extremely rigid. This can lead to periprosthetic fractures during placement of the metal trial component. Trial components made of plastic offer an advantage [47]. The cementing and insertion of the final implants also carries a risk of fracture (Fig. 44.9). However, the risk of a periprosthetic fracture is especially high if, as mentioned earlier, the cut surfaces have not been cleanly prepared or if there is a severe sclerosis.

Side Summary

Second-highest rate of periprosthetic fracture occurs during insertion of the tibial component.

Table 44.2 Unified classification system by Duncan and Haddad [45]

Class	Description		Prosthesis	Fracture
Type A	Fracture of an apophysis or protuberance of bone		Fixed	Dislocated or not dislocated
Type B	Fracture involves the bed supporting or adjacent to an implant	1	Fixed	
		2	Loose	
		3 (poor quality of bone)	Loose	
Type C	Fracture which is in the bone containing the implant, but distant from the bed of the implant		Fixed	Dislocated or not dislocated
Type D	Interprosthetic fracture—affecting one bone which supports two replacements		Fixed or loose	Dislocated or not dislocated
Type E	Fracture of two bones supporting one replacement		Fixed or loose	Dislocated or not dislocated
Type F	Fracture of a native surface articulating with a prosthesis		Fixed	

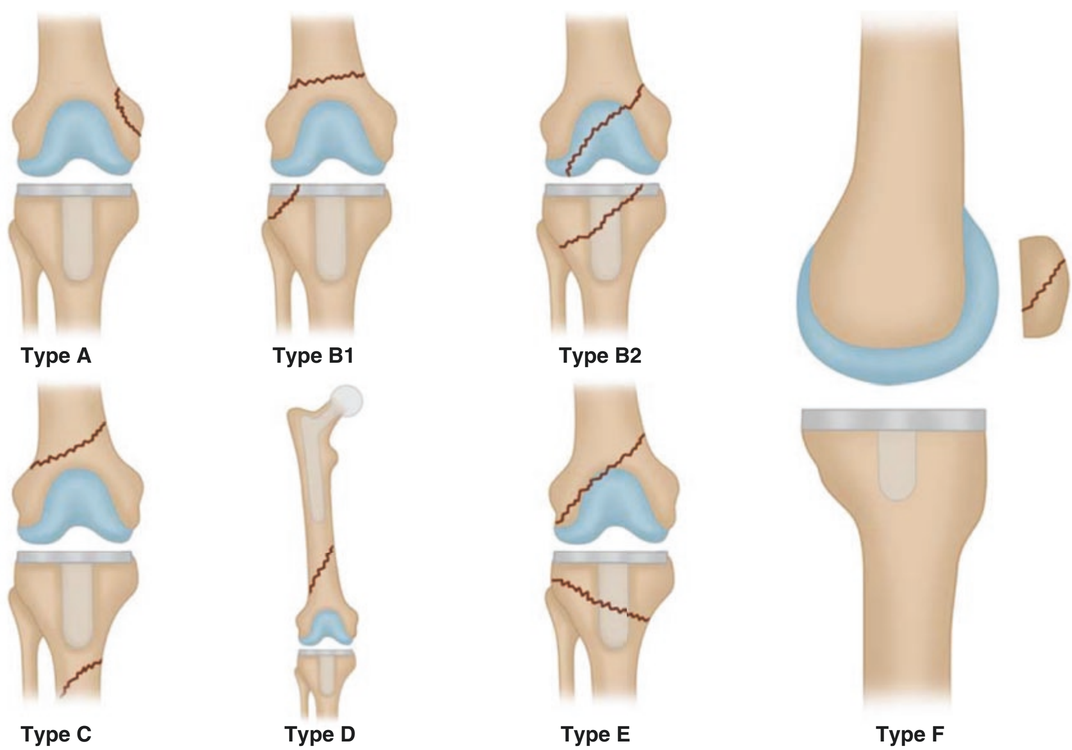

Fig. 44.8 UCS classification by Duncan and Haddad [45]

There are different ways of treating periprosthetic fractures. Treating a periprosthetic facture is always challenging and universal solution cannot be given. The treatment depends on the kind and localisation of the fracture and furthermore requires a critical judgement of the age, constitution and functional demand of the patient. A loose prosthesis should always be revised. If the implant is still well fixed, it can be treated by performing an additional osteosynthesis. However, there are some exceptions. If the fracture is located near the top of the stem or if the bone quality is very poor, there might be a revision of the fixed prosthesis necessary in order to improve the biomechanical requirements for the healing of the fracture. In rare

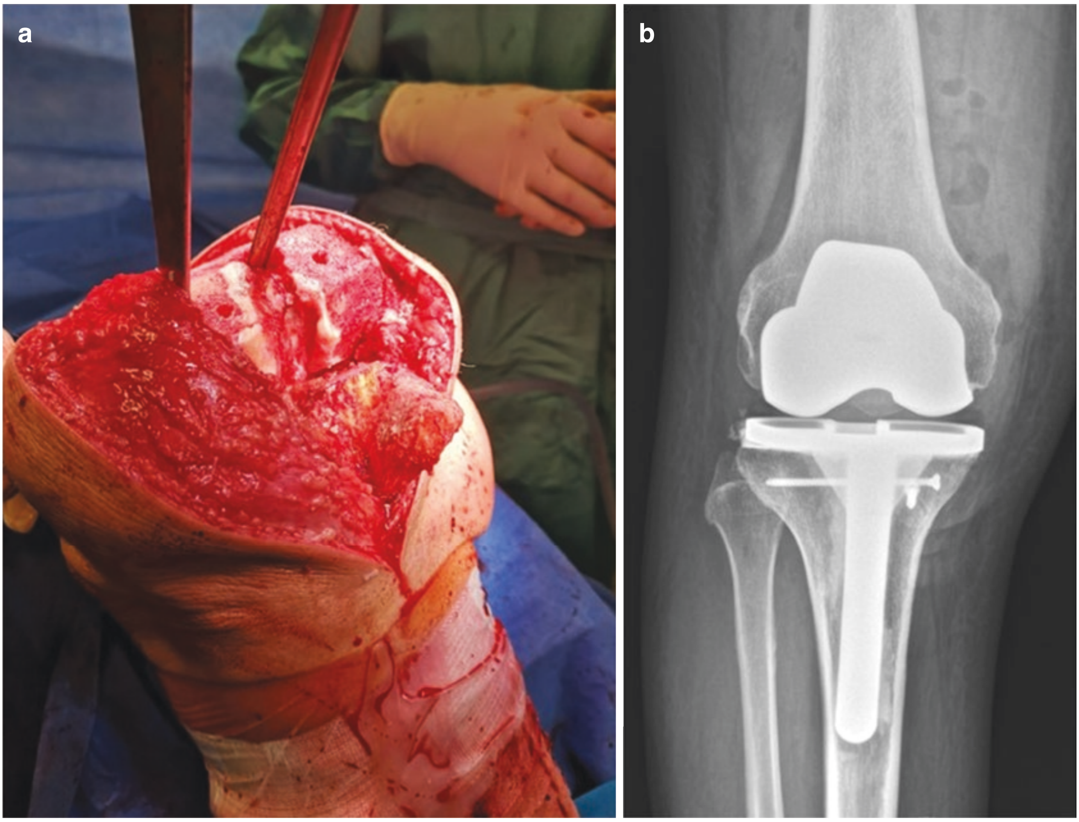

Fig. 44.9 Intraoperative fracture of the anterior tibia when impacting the tibial component (**a**), radiographic follow-up showing the refixation of the fragment by using a screw (**b**)

cases, an osteosynthesis with screws is impossible as the stem of the prosthesis fills the intramedullary canal, while a very thin cortical bone is present. If there are fractures on both sides or the patient is—for other physical or mental reasons—not able to realise a partial weight bearing, performing an osteosynthesis might also not be successful and a revision should be performed.

A further potential complication during preparation of the femur is the 'notching' of the anterior femoral cortex. Biomechanical studies have found this to be a risk factor for supracondylar femoral fractures [48, 49]. Biomechanical studies have shown that notching of over 3 mm is required before significant weakness of the bone should be considered [50]. However, these data have not yet been confirmed in clinical studies [51]. Irrespective of the clinical relevance, notching indicates that the prosthesis was inserted in too much extension or implanted too far posteriorly, which can alter the biomechanics of the prosthesis.

44.4 Insertion of Implants and Wound Closure

44.4.1 Cementing with Use of a Tourniquet

The insertion of the final implants can also produce complications. Tourniquet use improves the surgeon's view and should therefore allow a shorter operating time. In addition, the reduced blood circulation improves the adhesion of the cement, which should extend the prosthesis survival time [52]. For these reasons, some surgeons use a tourniquet for the entire course of the procedure. Whether this can significantly reduce the intraoperative and post-operative blood loss remains disputed. However, most studies have found delayed mobilisation and rehabilitation due to severe pain in the thigh [52]. Tourniquet use while cementation also improves cementing quality, reduces total blood loss and shows significantly faster rehabilitation immediately post-surgery due to the reduced pain symptoms [52, 53]. Very few studies have investigated the influence of tourniquet use on the occurrence of post-operative deep-vein thrombosis (DVT). In a meta-analysis, Yi et al. observed a higher incidence of DVT following tourniquet application (risk ratio 2.63), but there was no statistical significance [54]. Nevertheless, a relevant arteriosclerosis (Fig. 44.10) or peripheral arterial

Fig. 44.10 In case of marked vascular calcification on the preoperative radiograph, there might be a circulatory disorder of the lower limb. In such cases, an angiologist or vascular surgeon should be consulted before surgery and a tourniquet should not be used

occlusive disease must be ruled out before tourniquet use; otherwise damage to the sclerotic vessels or embolic occlusions of the arteries may occur [55]. If a vascular bypass, a circulatory disorder or a severe arteriosclerosis is known, and a tourniquet should not be used. If necessary, an angiologist or vascular surgeon should be consulted before TKA.

44.4.2 The Final Steps

Before wound closure, a final critical examination of the flexion and extension gap is conducted and minor corrections are made if necessary by a medial or lateral release. However, it should be noted here that the tourniquet fixes the quadriceps and vastus lateralis muscles, which can give the impression of an insufficient balancing [56]. Therefore, the soft tissue balancing and the checking of patellar tracking should be carried out with trial components in situ before applying the tourniquet. Otherwise, the altered vastus lateralis compression may give the impression of poor patellar tracking, leading to an excessive lateral release [57, 58]. When the tourniquet is released, the lateral release can lead to instability and persistent pain.

Once the cement has hardened and the knee joint has been flushed, the layered wound closure takes place. Various studies have found that wound closure performed in flexion shows a significantly better range of motion and greatly reduced anterior knee pain in follow-up for up to three months post-operatively [59]. However, other studies have not confirmed this observation [60].

During wound closure, tranexamic acid can be applied intraarticular after capsule suturing to reduce blood loss. In addition, tranexamic acid is often administered intravenously in the context of anaesthesia. As the licensing of tranexamic acid differs from country to country, it is hard to give a general recommendation here. However, combined application (intravenous and intra-articular) showed significantly less post-operative bleeding compared to the control group, a correspondingly lower drop in haemoglobin level, and hence a lower rate of post-operative blood transfusion [61]. This is of major importance, as blood loss in primary TKA can be up to 1.8 L, possibly requiring a blood transfusion [62]. Some studies have shown that the administration of allogenic blood is associated with an increased risk of periprosthetic infection [63]. However, it remains debatable whether the higher infection rate can be attributed solely to the allogenic blood transfusion. In general, it is patients with pre-existing cardiac conditions and multiple comorbidities who require a post-operative transfusion. Increased body mass index, diabetes mellitus and immunosuppression associated with rheumatoid arthritis are also regarded as risk factors for a periprosthetic infection [63].

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45 Deformity Correction in Total Knee Arthroplasty

Arun Mullaji and Taufiq Panjwani

Keynotes

1. Severe varus and valgus deformity make TKA surgery challenging.
2. The goal is to correct the malalignment and to achieve equal extension and flexion gaps.
3. Extra-articular deformity is to be distinguished from intra-articular deformity. The surgical approach differs between the two deformities.
4. Extra-articular deformities may require osteotomy and correction of the femoral or tibial bony alignment.
5. Flexion contraction is in general solved due to resection of all osteophytes and release of the posterior capsule.
6. Care should be taken of the medial soft tissue in valgus knees. Distal femoral and proximal tibial resection should be sparse.
7. The author provides a classification about types of valgus knee based on the amount of deformity and the degree of correction.

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45.1 Introduction

The goals of total knee arthroplasty, besides durability, include accurate restoration of limb alignment, optimal soft-tissue balancing, and good range of motion (ROM). The importance of preoperative planning cannot be overemphasized. Appropriate patient selection and a thorough physical examination and imaging are important parts of preoperative planning [1].

In this chapter we focus on the principles of correcting knee deformity based on our experience of nearly 16,000 TKAs over the last 25 years [2].

45.2 Surgical Planning

Patients being considered for TKA need to be investigated primarily using plain radiographs (either conventional or digital). The authors prescribe weight-bearing full-length hip-to-ankle radiograph, weight-bearing antero-posterior view, and lateral and skyline views of the knee in all the cases. These radiographs help in assessing the type and extent of knee deformity, the degree of joint space loss and bone loss, the amount of lateral or medial laxity, the distribution and size of osteophytes, the presence of loose bodies, the presence of extra-articular deformities or pathologies, the sequelae of prior surgeries, and the general bone quality in the patient. Preoperative

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radiographs are also invaluable in planning the procedure, implant size and special requirements, and determining the technical difficulty that the surgeon may encounter.

This is probably the most common radiograph for diagnosis of knee arthritis and planning of TKA. It is important that the radiographs are obtained while the patient is weight bearing as a supine view may underestimate the degree of arthritis, deformity, and instability (Fig. 45.1). Assess the extent of medial femoral and tibial osteophytes, bone defects, the relative amounts of medial and lateral tibial and femoral resections, and the center of the putative tibial tray, which can also be planned on the weight-bearing knee AP view.

The lateral view gives a fair estimate of posterior osteophytes and tibial slope (Fig. 45.2). The position of the patella in respect to joint line can also be assessed. In post-HTO cases specifically, patellar infera is often seen and tibial slope and/or joint line may be altered.

The authors obtain a weight-bearing long hip-to-ankle radiograph in all cases for TKA routinely. It helps in accurate estimation of preoperative knee deformity measured as the hip-knee-ankle (HKA) angle, which may be grossly underestimated by the standard knee AP radiograph (Fig. 45.3). HKA axis is defined as the angle between the mechanical axis of the femur (center of the femoral head to the center of the knee) and mechanical axis of the tibia (center of the knee to the center of the tibial plafond).

Fig. 45.1 Anteroposterior full weight-bearing view for assessment of the lower limb alignment

Fig. 45.2 The lateral view provides information about the tibial slope, position of the patella based on the Insall-Salvati-Index, posterior osteophytes, and loose bodies

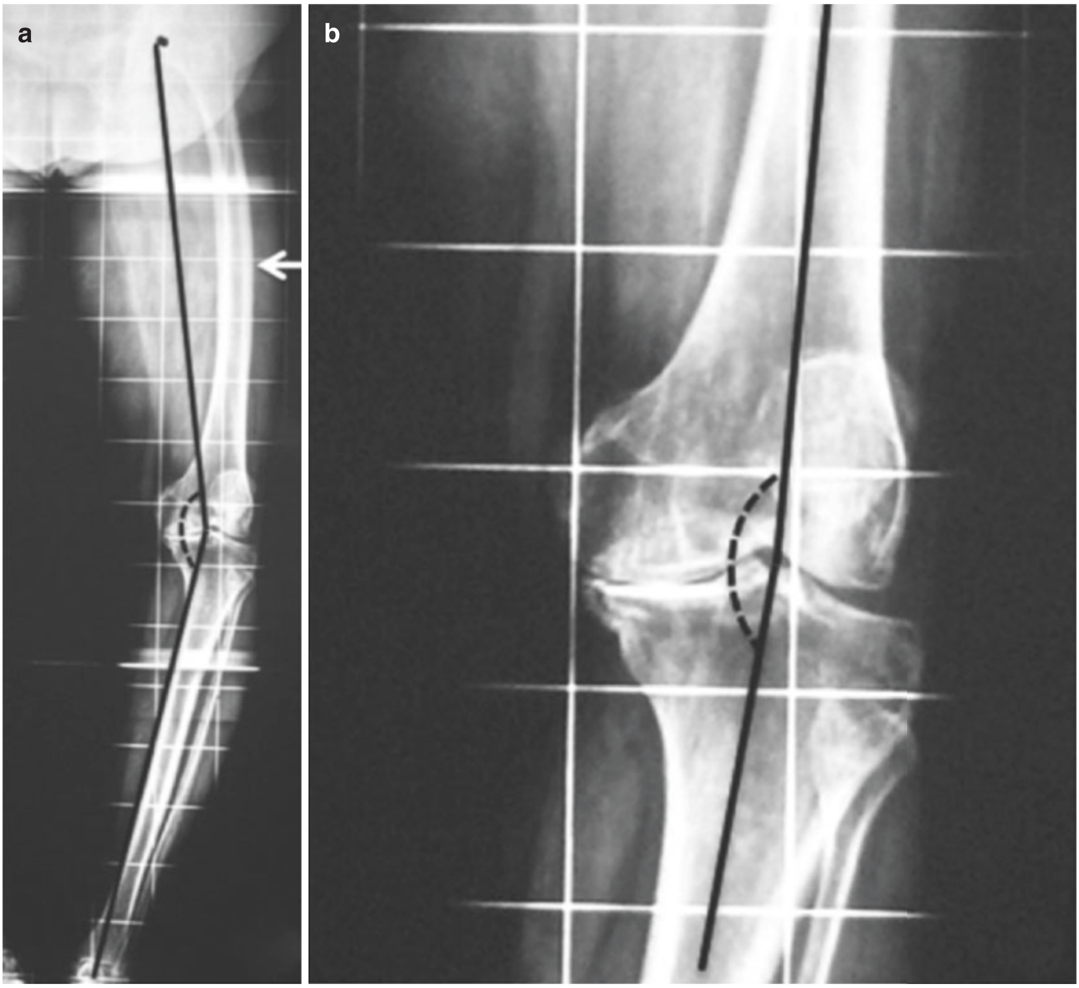

Fig. 45.3 (**a**, **b**) The long leg weight-bearing view shows a deformity of approximately 20° when calculated using the mechanical axes (hip–knee–ankle (HKA) angle). Note the extra-articular deformity due to severe coronal bowing of the femur (*arrow*) (**a**). The short film to the right is a standing anteroposterior knee radiograph which however shows only a 4° varus deformity of the knee when calculated using the anatomic axes (femorotibial angle or FTA) (**b**)

The assessment of the weight-bearing long hip-to-ankle radiograph includes:

- Degree of limb malalignment or deformity based on hip-knee-ankle (HKA) angle.
- Distal femoral valgus correction angle (VCA)—this determines the valgus angle at which the distal femur must be cut in the coronal plane to align the femoral component perpendicular to the mechanical axis (Fig. 45.4). Also, the greater the VCA, the greater the need for an extensive soft-tissue release with or without an osteotomy [3].
- Evaluation of extra-articular deformity in the femur or tibia and the need for osteotomy.
- Stress fractures, prior trauma.
- Hip pathology or condition after hip arthroplasty.

Fig. 45.4 Distal femoral valgus correction angle (VCA) is calculated as the angle ABC between the mechanical axis of the femur (line AB) and the distal anatomic axis of the femur (line CB)

The authors believe that weight bearing long HKA radiographs give indispensable information in the planning of TKA. We therefore recommend it as a routine before all our cases.

CT scans are rarely indicated in routine planning of TKA. It may be required when seeking information about torsional deformities in the femur or tibia. MRI scans are also rarely indicated; they may be useful to confirm stress fractures [4].

The surgeon is well prepared with a better understanding of the deformity and the potential challenges in surgery only after a complete physical examination and critical assessment of radiographs.

45.3 Varus Deformity

It is the most commonly encountered deformity in patients undergoing TKA [5] and is associated with HKA angle of less than 180 degrees. Medial osteophytes cause tethering and functional shortening of the medial soft-tissue structures in a varus deformity; the superficial MCL does not contract and hence need not be released. Posterior osteophytes too exert the same effect and tent the posterior capsule leading to flexion contracture and obstruction to deep flexion. There may also be associated lengthening and attenuation of the lateral soft-tissue structures especially in severe varus deformities.

The challenges in performing TKA in a varus arthritic knee include restoration of limb alignment, balancing the medial and lateral soft-tissue tension, equalizing flexion and extension gaps, and restoring medial bone loss. Severe varus deformity may be associated with extra-articular deformities as well as malrotation of the femur and tibia which makes TKA technically challenging.

Stability and function of the knee joint involve a dynamic interplay of various soft-tissue structures around the knee joint. A sound knowledge of the pathoanatomy of these structures is important to achieve optimum alignment, balance and kinematics after TKA.

The three principal clinical features of varus deformity on clinical examination (under anesthesia) which need to be noted are (1) correctability of the deformity (rigid, partially correctible, fully correctible, or unstable) with knee in maximum extension, (2) associated sagittal plane deformity (fixed flexion or hyperextension), and (3) extent of lateral side soft-tissue laxity (mild, moderate, or severe) (Fig. 45.5a–c). The degree of correctability of deformity will decide the amount of soft-tissue release required medially in order to achieve correction and bal-

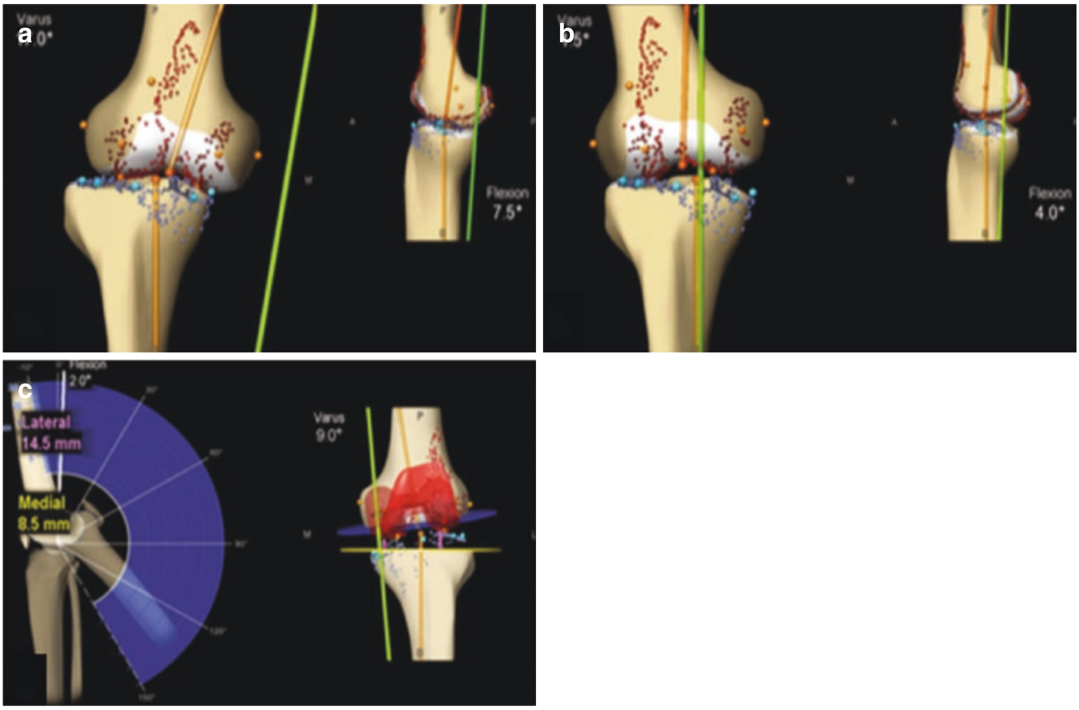

Fig. 45.5 The three principal clinical features of varus arthritic deformity which needs to be noted during TKA (shown here using computer navigation screen shot images). Maximum varus deformity (using a varus stress at the knee joint in maximum extension) and maximum knee deformity in the sagittal plane (flexion) (**a**). Maximum correctability of varus deformity (using a valgus stress at the knee joint in maximum extension) (**b**). Maximum lateral soft-tissue laxity (using a varus stress at the knee joint in maximum extension) (**c**)

ance. Similarly, amount of soft-tissue laxity on the lateral side of the knee in a varus deformity decides the extent of medial soft-tissue release required in order to equalize the medial and lateral soft-tissue gaps. Any associated sagittal plane deformity will require titrating the amount of tibial and distal femoral bony resection and posterior soft-tissue release to achieve deformity correction and flexion-extension gap balance.

Preoperative radiographic features usually help in predicting the difficulty of TKA. The five radiographic features of varus arthritic knees which should be assessed carefully [6]

1. Degree of deformity (as measured on full-length hip-to-ankle radiographs)
2. Amount of lateral laxity (based on joint divergence angle and lateral translation of tibia)
3. Presence of extra-articular deformity (coronal femoral bowing based on valgus correction angle, tibia vara based on tibial plateau angle)
4. Medial bone loss (mild, moderate, severe)
5. Presence of osteophytes (minimal, moderate, severe)

Based on the severity of arthritic involvement and the degree of knee deformity some or all of these features may be present.

45.3.1 Surgical Technique for Varus Deformity

The two basic techniques commonly used in TKA are the measured resection and the gap-balancing technique. The authors have used the gap-balancing technique with cruciate-substituting prosthesis in all their cases. The surgical technique is as follows and is tailored to each individual knee based on the presence or absence of the above-mentioned clinical and radiological features. The varus arthritic knee is treated with a stepwise systematic technique to achieve full correction of deformity and to achieve soft-tissue balance. However, releases of medial soft-tissue structures need to be controlled and measured to avoid overcorrection or instability [7, 8].

The first step to achieve these goals is to remove all osteophytes around the joint, which will not only free the tethered soft-tissue structures but also help avoid unnecessary soft-tissue release. Following this principal step, the surgeon can accurately assess in full extension how much residual deformity and soft-tissue tightness persists and which may require a formal soft-tissue release. Based on whether the deformity is fully correctible, partially correctible, rigid, or unstable, further soft-tissue release may be required in order to correct the deformity. Most partially correctible deformities get fully corrected with removal of osteophytes and the preliminary soft-tissue release (deep MCL) performed for exposure of the joint and anterior dislocation of tibia. However, the medial release may require extensive release of the attachment of the posteromedial capsule to proximal tibia and segmental excision of the posteromedial capsule in cases with rigid deformities or knees with severe medio-lateral soft-tissue imbalance. Sometime an osteotomy might be considered and may require performing a reduction osteotomy [9] of the tibia with or without undersizing the tibial component. In contrast, soft-tissue releases should be restricted and controlled in knees that are unstable in coronal and/or sagittal planes.

The next step after achieving deformity correction is to assess how lax the lateral soft-tissue structures are vis-à-vis the medial structures. This is best done by giving a varus stress with a spacer block placed in the extension gap to determine how much the LCL is elongated. Although a varus deformity may appear to be fully corrected with medial soft-tissue release as evidenced by correct alignment being achieved with a spacer block in extension with a *valgus* stress being applied, medio-lateral soft-tissue balance may still prove to be elusive due to excessive lateral soft-tissue laxity, which may manifest only with a *varus* stress. Similarly, in the presence of an extra-articular deformity, achieving optimum deformity correction and soft-tissue balance may not be possible despite extensive medial release. Both these scenarios may warrant performing either a sliding medial condylar osteotomy [10] or a corrective osteotomy of the extra-articular deformity.

45.3.2 Knee Deformity of Less Than 10°

Typically, knees with mild deformities (<10° varus or HKA angle >170–180°) have minimal or no osteophytes, medial bone loss or extra-articular deformities, and no associated sagittal plane deformities. Such knees are easily correctible merely with exposure and a preliminary medial release of the deep MCL, just enough to facilitate anterior subluxation of the tibia and circumferential exposure of the proximal tibia, followed by standard bone cuts. However, these deformities may occasionally be associated with mild to moderate lateral laxity or an associated sagittal plane deformity. Excessive lateral laxity may be dealt with by posteromedial capsular release. An associated fixed flexion deformity may get corrected by a thorough posterior clearance (osteophyte excision and capsular release) and as a last resort resecting additional distal femoral bone. However, when an associated hyperextension deformity is present, conservative tibial and distal femoral bone resection should be performed and posterior soft-tissue release avoided.

45.3.3 Knee Deformity Between 10° and 20°

Such varus deformities are commonly associated with mild to moderate degree of lateral laxity, medial bone loss, sagittal plane deformity, or extra-articular deformity. The amount of osteophytes present may vary from mild to moderate. Again, although most of these deformities can be easily tackled using the standard procedure, an associated extra-articular deformity either in the femur (excessive coronal bowing) or the tibia (proximal tibia vara) may make deformity correction and soft-tissue balancing a challenge. The presence of such extra-articular deformity will require more than the usual medial soft-tissue release to achieve limb realignment and gap balance: resection of the posteromedial capsule, a further reduction osteotomy, or sometimes semimembranosus release from its tibial attachment. Rarely, when even extensive measures fail to achieve the surgical goals (due to extra-articular deformity or excessive lateral laxity with or without excessive medial tightness), a sliding medial condylar osteotomy (SMCO) may be required. The need for SMCO in such cases can usually be predicted on preoperative radiographs by the presence of an extra-articular deformity confounding the lesser degree of intra-articular knee deformity, often in combination with the presence of excessive lateral laxity of the knee joint (lateral divergence angle), lateral translation of the tibia, and lack of osteophytes, excision of which would otherwise have contributed to deformity correction without the need for excessive medial release.

45.3.4 Knee Deformity of over 20°

Severe varus deformities pose several challenges during TKA including severe extra-articular deformity, severe lateral laxity, medial bone loss, and associated moderate to severe sagittal plane deformities. The degree of soft-tissue release is governed by the amount of soft-tissue tightness assessed using a tensioning device. An extensive, graded, stepwise soft-tissue release (subperiosteal elevation of the deep medial collateral ligament (MCL), posteromedial capsule and semimembranosus) is performed as per the technique previously described by the authors. Excision of osteophytes along the posteromedial tibia and medial femoral condyle is initially performed. Tibial resection is restricted at approximately 6–7 mm of bone with respect to the lateral tibial condyle when the deformity is associated with excessive lateral laxity or an associated hyperextension deformity. In the presence of a medial tibial bone defect, this cut usually passes some distance above it and not through its base. An additional 1–2 mm is resected if it reduces the size of the bone defect. By lowering the tibial surface with this additional resection, a smaller tibial component could be used, which in turn helps in increasing the amount of reduction osteotomy which can be performed for deformity correction and/or medio-lateral soft-tissue balancing.

The distal femur is cut at a valgus correction angle (VCA) determined on preoperative long hip-to-ankle radiographs for each individual limb since this may show wide variation among individuals. The thickness of the distal cut is determined by the extent of medial femoral condylar bone defect and the severity of the flexion contracture. The thickness must be reduced if the medial condyle shows significant bone loss or in the presence of an associated hyperextension deformity or severe instability. Additional bone may have to be resected from the distal femur in the presence of a significant flexion deformity which has not improved with removal of posterior osteophytes and release of posterior capsular adhesions. In the presence of excessive coronal bowing of the femur, a short intramedullary guide rod should be used to avoid malposition of the distal cutting block with respect to the mechanical axis of the femur, or computer navigation should be used to accurately align the cutting block and to bypass the extra-articular deformity in the femur.

The medio-lateral gap balance in knee extension is assessed with a spacer block, and any discrepancy is addressed with additional soft-tissue release and reduction osteotomy. Usually the flexion gap may be larger than the extension gap (due to extensive soft-tissue release), and the femoral component may have to be upsized, flexed 2–5°, and translated posteriorly to achieve balance. If the flexion gap is still larger than the extension gap, additional resection of distal femur is needed to accommodate a thicker spacer.

Despite associated femoral and tibial extra-articular deformities and excessive lateral laxity, the above technique of bone resection and soft-tissue release results in well-aligned and balanced knees in majority of limbs with severe

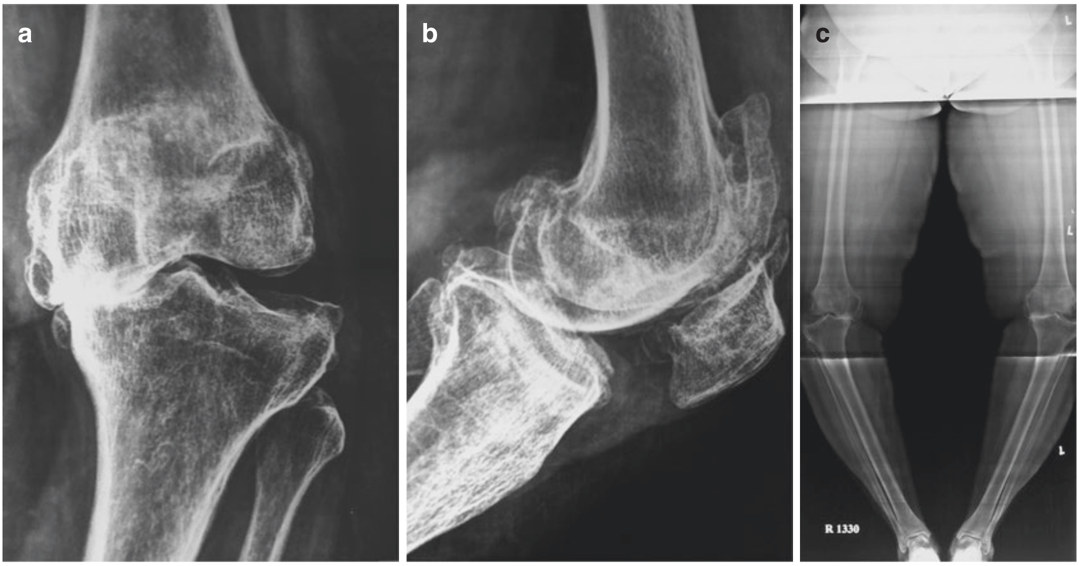

Fig. 45.6 AP view shows a severe varus deformity. There are severe osteophytes on the medial side and significant bone deficiency of the medial tibial plateau (**a**). The lateral view shows severe patellofemoral osteophytes (**b**). The long leg weight-bearing radiographs show the severe varus deformity and significant opening of the lateral joint space. Femorotibial subluxation in more advanced on the right side (**c**)

varus deformity undergoing TKA. However, in a few cases of rigid deformities, medial tightness may persist even after extensive medial soft-tissue and posterior capsular release, and a sliding medial condylar osteotomy (SMCO) may be required (Fig. 45.6a–c). This involves distalizing and fixing the medial femoral condylar fragment using cancellous screws after the implant has been cemented. Rarely, in cases with persistent and severe lateral side soft-tissue laxity and severe instability, a constrained implant may have to be used [2].

Medial tibial bone defects may be significant even after the tibial cut has been performed. Bone defects are dealt with based on their size and position. Usually, uncontained medial tibial bone defects less than 5–10 mm in depth are filled with bone cement, whereas defects ≥10 mm are filled with autologous bone graft (typically using bone from the resected notch area). The bone defect should be first gently fashioned into a step-cut defect using a saw and then the bone block shaped to match the defect. The graft is usually punched into position or fixed into place using 2-mm K-wires or cancellous screw if the size of the graft is large (Fig. 45.7). These should be directed parallel to the tibial surface to avoid the peg or stem of the tibial component. A tibial stem extender is usually used in cases with large medial bone defects of >10 mm. Rarely, significant medial femoral bone defects may require the use of metal augments supplemented with a femoral stem.

45.4 Valgus Deformity

A valgus knee is less commonly encountered in arthritic knees undergoing TKA [11] and its incidence is less than 10% in the senior author's series. It involves a distinctly different set of pathoanatomic structural changes and surgical challenges when compared to a varus knee. Restoration of optimal limb alignment and gap balance after TKA in valgus knees can be a formidable challenge because of several reasons. First, the surgeon may be less familiar with the technique and soft-tissue releases as there is paucity of soft-tissue structures to release on the lateral side as compared to the medial side. Second, there is a higher risk of common peroneal nerve palsy after correction, especially in long-standing

Fig. 45.7 Sever varus deformity with partial loss of the medial tibial plateau (**a**). The medial plateau has been bone-grafted and fixed with a screw. The intramedullary stem serves for additional stability (**b**)

valgus knees associated with flexion deformity. Finally, hypoplastic lateral femoral condyle, external rotation deformity of femur and tibia, and patellar maltracking are commonly encountered in a valgus knee.

Valgus arthritic deformities commonly present with tightness of lateral soft-tissue structures, which may be associated with varying degrees of laxity of the medial structures. Contracture of the iliotibial (IT) band, posterolateral capsule, and popliteo-fibular ligament may be encountered in these knees (Fig. 45.8). We do not believe that the lateral collateral ligament (LCL) undergoes contracture and shortening. The surgeon should be aware which soft-tissue structures are tight in different positions of knee flexion and extension so that a calibrated, stepwise approach is followed during release and imbalance or instability avoided. Essentially, the LCL and popliteus tendon are tight in both flexion and extension, the IT

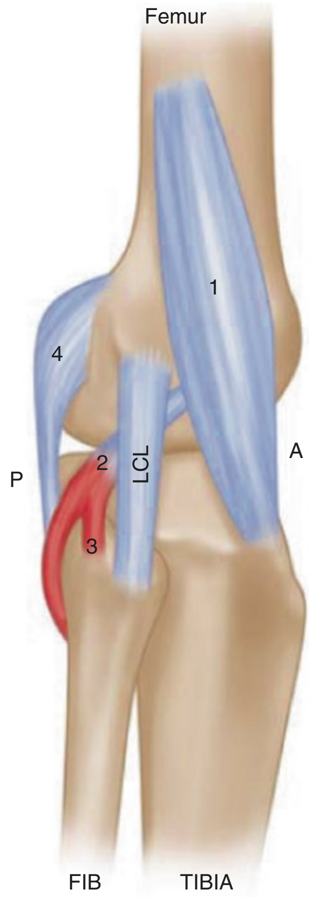

Fig. 45.8 Soft-tissue structures on the lateral and postero-lateral aspect of the knee joint which may require release during TKA in a valgus arthritic knee. *1* Iliotibial band, *2* popliteus tendon, *3* popliteofibular ligament, *4* posterolateral capsule. *A* anterior, *P* posterior, *LCL* lateral collateral ligament

Fig. 45.9 Severe bilateral valgus deformity in conjunction with flexion contracture. The flat feet cause significant pronation and for compensation the lower limbs are positioned in external rotation

band and posterolateral capsule are tight only in extension, and the popliteo-fibular ligament is taut only in flexion.

In valgus knees, there may be asymmetric wear or hypoplasia of the lateral femoral condyle posteriorly (and also distally) with excessive wear of the posterolateral condyle of the femur and/or tibia. Using the posterior condyles as reference to place the AP cutting block may cause excessive resection from the posterior femoral condyle laterally, thereby resulting in excessive internal rotation of the femoral component and patellar maltracking. Using the AP axis is also fraught with risk, especially if there is patellar maltracking and wear of lateral trochelar groove. Hence, the transepicondylar axis (TEA) is preferred by the authors in severe valgus deformities as a landmark for determining femoral rotation. Patellar maltracking, external rotational deformity of tibia, and hind foot valgus (flat feet) are commonly associated with valgus deformity (Fig. 45.9).

Valgus knees form a spectrum of deformities with important differences which impact surgical technique. The senior author has classified valgus knees to include six types based on (1) severity and degree of correction of valgus deformity, (2) associated flexion, hyperextension, or extra-articular deformity, and (3) status of the medial collateral ligament (MCL).

Type 1	Correctable valgus, no associated deformity, MCL intact
Type 2	Rigid valgus, no associated deformity, MCL intact
Type 3	Valgus with hyperextension deformity, MCL intact
Type 4	Valgus with flexion deformity, MCL intact
Type 5	Severe valgus with incompetent MCL
Type 6	Valgus with extra-articular deformity

Fig. 45.10 Type 2 valgus deformity. Clinical photograph showing maximum valgus deformity with a valgus stress applied with patient under anesthesia followed by a varus stress showing partial correctability of valgus deformity. The pre- and postoperative radiographs showing the valgus deformity with restoration of knee alignment with a cruciate-substituting design and a lateral epicondylar osteotomy (*LEO*)

Fig. 45.11 Lack of full extension in a severe valgus deformed knee (type 4)

Fig. 45.12 Significant hyperextension of the knee prior to TKA (type 3)

The majority of valgus knees are correctible under anesthesia with a varus stress. These are typical knees where the valgus deformity present in extension disappears on flexing the knee (type 1).

Type 2 knees are those in which the valgus deformity is rigid in both extension and flexion and are most likely to be associated with a hypoplastic lateral femoral condyle (Fig. 45.10). In type 3 knees, there is hyperextension deformity, while in type 4 there may be a trapezoidal flexion gap due to contracture of posterolateral structures (Figs. 45.11 and 45.12). Any long-standing valgus deformity which is severe may develop attenuation of the MCL (type 5).

45.4.1 Surgical Technique for Valgus Knees

The authors follow an algorithmic approach for management of valgus knees during TKA based on their classification.

The classic medial parapatellar approach is done in the majority of valgus knees with mild to moderate deformity. In severe cases with patellar maltracking, lateral parapatellar approach provides greater access to lateral soft tissue structures. Occasionally, the difficulty in accessing the medial aspect of the knee may sometimes necessitate the need for a tibial tubercle osteotomy, which carries the risk of patellar tendon failure and non-union.

The knee should be subluxated anteriorly after excision of the cruciate ligaments without or minimal release only on the medial side. Any release will cause additional laxity of medial soft-tissue structures and will make medio-lateral soft-tissue balancing even more difficult. Prior to any lateral soft-tissue release, all osteophytes from the lateral and posterolateral aspect of tibia and femur should be removed. This helps in reducing the tethering of posterolateral capsule. In severe valgus deformities with a fixed flexion contracture, a subperiosteal excision of the fibular head helps in significantly reducing the tenting of LCL and also reduces the risk of stretching of the common peroneal nerve after the deformity has been fully corrected.

After excision of the PCL, an initial release of the IT band with the knee in full knee extension helps in reducing lateral tightness. The IT band is typically released from Gerdy's tubercle but can also be lengthened using multiple small incisions (piecrusting) at the level of the knee joint with the knee placed in full extension with a varus stress to feel the taut IT band. Lateral tightness in full extension can be further reduced by releasing the posterolateral capsule. Lateral tightness in flexion is reduced by freeing the popliteus tendon from surrounding fibrous tissue and releasing the popliteofibular ligament. The popliteofibular ligament is a thin structure which runs from the inferior margin of the popliteus ligament to the head of the fibula. This structure is released by running the tip of the electrocautery below the inferior border of the popliteus tendon along the posterolateral corner of the knee joint.

Minimal amount of bone needs to be resected in both severe valgus deformities and in knees with associated instability or hyperextension. There is a wide variation in valgus correction angle (VCA) for distal femoral resection in valgus knees and therefore it must be individualized for each case based on preoperative full-length hip-to-ankle radiographs. Very rarely, when substantial soft-tissue release laterally fails to correct deformity or achieve medial-lateral soft-tissue balance, a sliding lateral epicondylar osteotomy (LEO) may be indicated.

An alternative for dealing with excessive laxity medially in a valgus knee is to shorten the medial soft-tissue structure by MCL advancement from tibial side, MCL mid-substance imbrication, or a medial epicondylar osteotomy. The authors perform a sliding lateral epicondylar osteotomy (LEO) in a valgus knee whenever necessary, preferably under computer navigation [12]. However, these procedures are rarely indicated and only deployed in the most severe and rigid valgus knees. Under certain rare circumstances when the MCL is too incompetent and is a cause of significant instability, a constrained prosthesis (with a taller post and deeper box) may be needed. However, every attempt must be made to balance the soft tissues so as not to excessively load the post leading to post wear and fracture.

Severe valgus knees with associated flexion deformity carry a high risk of postoperative common peroneal nerve palsy. Although this may be transient due to stretching of the nerve on full correction of the valgus and flexion deformities, it may cause considerable disability and distress in the patient causing delay in postoperative recovery. In knees with profound valgus deformity with associated significant fixed flexion deformity ($\geq 20°$), the authors undercorrect the flexion deformity to approximately less than 10°, keep the knee in flexion over a pillow for the first 48 h postoperatively to avoid undue stretching of the nerve, and gradually correct it postoperatively using physiotherapy and occasionally a push-knee splint.

45.5 Flexion Deformity

Flexion deformities in arthritic knees may result from intercondylar notch osteophytes which act as a mechanical block preventing full extension, whereas posterior osteophytes cause tenting of the posterior capsule which can enhance this deformity. In long-standing cases, these osteophytes are associated with secondary contracture and shortening of soft-tissue structures such as the posterior capsule, posterior oblique ligament, semimembranosus (in varus knee), and popliteofibular ligament (in valgus knee) which add to the deformity. In severe cases, the hamstrings and gastrocnemius may also be affected. Rarely in patients with inflammatory arthritis, neuromuscular disorders, hemophilia, or long-standing immobility, flexion deformity is primarily the result of isolated soft-tissue contractures, and minimal osteophytes may be present.

The first step, after exposure, to deal with flexion deformity is to remove all osteophytes. The medial and posteromedial tibial and medial femoral osteophytes need to be excised first followed by posterior femoral osteophytes. When the posterior osteophytes are too large, these can be better accessed and removed only after the tibial cut has been performed or by performing a preliminary freehand resection of the posterior femoral condyle. Removal of the posterior osteophytes prior to performing the distal femoral resection is important; it reduces the need for excess distal femoral resection and obviates or minimizes the need for soft-tissue release thereby reducing the likelihood of mid-flexion instability. Any retained posterior osteophytes will result in an underestimation of the extension gap.

Rarely, if the flexion deformity persists despite complete posterior clearance, a posterior soft-tissue (posterior capsule, medial and lateral head of gastrocnemius) release is required. The authors perform this using a broad gouge which is applied flush to the femoral condyles and the soft tissues are gently stripped from their femoral attachment.

Subsequent assessment of the flexion gap usually shows that the extension gap previously achieved is much smaller than the flexion gap. This mismatch is addressed by adjusting the size and position of the femoral component. Upsizing, posteriorly shifting and slightly flexing the femoral component usually help in closing the large flexion gap and equalizing it to the extension gap.

Rarely, slight flexion deformity may persist despite all the above measures when the limb is assessed using trial components. We address this by resecting 2–3 mm from the distal femur. However, this should be performed cautiously as excessive resection from the distal femur may cause elevation of the joint line and mid-flexion instability.

Postoperative management is based on the degree of correction achieved and the amount of residual flexion contracture at the end of the procedure. A postoperative residual flexion contracture of <5° can be managed with routine physiotherapy. However, any correctible residual contracture between 5° and 10° at the end of the procedure, especially in patients where the flexion deformity was long-standing or exceeding 15–20°, will require application of an above-knee plaster splint for 48 h postoperatively in order to maintain the knee in maximum correction. These patients may subsequently require a push-knee splint or a long knee brace while walking in order to maintain correction of the flexion contracture. These patients need careful surveillance during the postoperative rehabilitation period for signs of recurrence of flexion contracture.

Another common feature in patients with long-standing flexion contracture is an associated significant quadriceps weakness. This is usually not obvious preoperatively and gets unmasked postoperatively after the flexion contracture has been corrected. This may require prolonged physiotherapy in order to strengthen the quadriceps. Most patients with >20° of FFD preoperatively are given a push-knee splint for 30 min three times a day and while walking in the initial 2–4 weeks along with electrical stimulation of the quadriceps to strengthen them.

45.6 Hyperextension Deformity

Hyperextension deformity is rather uncommon in arthritic knees undergoing total knee arthroplasty, occurring in less than 5% of patients (Fig. 45.12). In a publication by the senior author [13], the incidence of hyperextension in knees undergoing TKA was 3.9%. Hyperextension sometimes is seen with valgus deformities and ligamentous laxity, in rheumatoid arthritis (RA), after high tibial osteotomy (HTO) and in neuromuscular disorders such as poliomyelitis. Our study showed that 78% of our patients with hyperextending knees had primary osteoarthritis. An associated varus deformity was evident in 58% of the limbs while 42% showed a valgus deformity. Challenges encountered with hyperextension include associated coronal plane deformities (varus or valgus), bony abnormalities such as reverse sloping of the tibial plateau, and mediolateral instability. These may lead to difficulty in achieving a stable, well-balanced knee. Moreover, there is a possibility of recurrence of the deformity postoperatively. Numerous surgical techniques have been suggested to deal with hyperextension during TKA: posterior capsular plication, proximal and posterior transfer of collateral ligaments, using thicker inserts to balance the extension gap, resecting a lesser amount of distal femoral and proximal tibial bone, under-sizing the femoral component, deploying distal femoral augmentation blocks, and resorting to a constrained prosthesis. Most times, however, after under-resection of tibia and femur, using a smaller femoral size and a thicker insert usually, one can achieve a stable and well-balanced knee.

45.6.1 Pathoanatomy

Hyperextending knees have certain characteristic features which need to be considered while performing a TKA: the posterior capsule is overstretched, the cruciate and collateral ligaments are attenuated, and the posterior soft tissue structures resemble a “hammock” which needs to be made taut by pulling the ends apart. The iliotibial band may be contracted in knees with associated valgus deformities and if anteriorly displaced may enhance the hyperextension deformity. Attenuation of posterior soft tissue structures results in a larger extension gap than the flexion gap. As a consequence, resecting a standard thickness of proximal tibia and distal femur will further enlarge this extension gap, resulting in severe mismatch of the extension and flexion gap. The disproportionately larger extension gap would necessitate a very thick insert. Hence, one key tenet of correcting hyperextension deformity during TKA is to resect minimal bone from proximal tibia and in particular from the distal femur with strictly care being taken to desist from any release of posterior soft-tissue structures whatsoever. Hyperextension may be accentuated by bony factors such as a reduced posterior slope or even a reverse anterior slope of the tibia, significant wear or bone loss on the anterolateral or medial aspect of the tibial plateau and distal femur. A prior, poorly executed high tibial osteotomy may also result in an anterior slope. In these situations, the surgeon should to be aware of avoiding a neutral slope.

Patients with hyperextension with associated bony deformities and muscular degeneration as in neuromuscular disorders such as poliomyelitis should be excluded. Patients with neuromuscular deficit run a higher risk for a poorer result after TKA with recurrence of hyperextension and instability if a standard cruciate-substituting prosthesis or one with varus-valgus constraint is used. These patients may be better served by use of a hinged device. Most of our patients, often obese, had hyperextension owing to weak quadriceps causing them to overextend their knee by throwing their body weight anteriorly in order to lock it.

45.6.2 Surgical Technique

The amount of bony resection that needs to be performed is inversely proportional to the severity of the deformity: the greater the recurvatum, the less should be the resection. The mean thickness of proximal tibial and distal femoral bone resection was approximately 6.5 mm on the less affected side in the authors’ study. We usually do not resect more than 6 mm from the tibia and femur initially. The pins that secure the cutting block are left in position to facilitate further resection if the thinnest spacer cannot be inserted in the extension space. Generally, these knees are quite lax—hence releases have to be performed in a very guarded fashion. Medial release for varus knees and lateral release for valgus knees may be required to restore the mechanical axis to 180°. No capsular release whatsoever is performed posteriorly. After the distal femoral and proximal tibial cuts a spacer block is used to assess medio-lateral soft-tissue stability in full extension. The coronal alignment is also checked. The AP cutting block (non-slotted) is placed on the distal femur and the flexion gap is assessed with the spacer block of identical thickness in order to achieve a well-balanced knee in flexion and extension. Rotational alignment of the block is assessed from standard landmarks. A stylus or "angel wing" is used to check for anterior notching and appropriate adjustments are to avoid the complication. If the flexion gap equals the extension gap, the size of the AP block is determined. If 1–2 mm disparity exists in the gaps (provided that notching will not occur) minor changes are made in the position of the block. Larger disparities will need upsizing the femoral component or, more likely, downsizing the AP block/femoral component. Once gaps are balanced, the AP cuts are completed; limb alignment and flexion extension gap balancing are rechecked with the knee in full extension and 90° flexion using trial components. By following these basic principles, the vast majority of hyperextending knees can be managed with a regular cruciate-substituting implant without the need for a constrained prosthesis.

From our data of 45 TKAs, we ended up using inserts of thickness 12.5 mm or less in 92% of and inserts of thickness 15 mm in the remaining 8%. We did not use inserts greater than 15 mm thickness nor did we require constrained prostheses. We aimed to achieve slight extension deficits of 2°–5° at the end of the surgical procedure. The thickness of proximal tibial and distal femoral resection, the extent of soft-tissue release, femoral sizing, and the need for additional procedures (such as epicondylar osteotomy) were based on the severity of recurvatum deformity and the type of associated varus and valgus deformity. Postoperatively, the patient was allowed full weight-bearing walking and active knee flexion on the first postoperative day. Patients were encouraged to keep a pillow below the knee for 2 weeks to allow tightening of the posterior soft-tissue structures. In cases with severe preoperative recurvatum where the recurvatum at the end of surgery was closer to 0°, a long-leg knee brace was used while walking for 2 weeks. Immobilization was in general not required after surgery. Hence, key factors in correcting such knees include resecting less bone from the proximal tibia and distal femur and refraining from performing a posterior release.

45.6.3 Computer-Assisted and Robotic-Assisted Technique

CAS [14, 15] enable the surgeon to recognize even the slightest degree of hyperextension and forewarn the surgeon to desist from routine resection and releases, which should both be performed incrementally. It is preferable to revisiting a cut rather than taking off too much bone. Computer-assisted navigation system accurately quantifies the amount of bone resection and, by demonstrating that the coronal and sagittal alignment have been achieved, can limit soft-tissue release during TKA. The femoral component planning feature of the software is particularly valuable in determining femoral component size and position to equalize gaps, as is the ability to assess and visualise the soft-tissue balance [16].

Take Home Message

- A long leg weight-bearing and lateral radiographs are essential for planning the correction of deformities. In case of torsional deformities CT is required in addition.
- The long leg radiograph provides the information about the site of deformity, which is either intra-articular or extra-articular. Extra-articular deformities

might be corrected by osteotomy first. Intra-articular deformities can be corrected during TKA surgery.

- Care has to be taken in valgus knees. Under-resection of the distal femoral and proximal tibial is recommended in order to achieve correct mediolateral balance, and will prevent a thick liner and elevation of the joint line.
- In patients with severe hyperextension neuromuscular disorders should be ruled out first. These patients may require a hinged knee in order to gain stability.

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46 Total Knee Arthroplasty for Fracture Treatment

Roland Becker

Keynotes

1. Fracture at the distal femur and proximal tibia are rare, but devastating especially in elderly patients.
2. Distal femoral or proximal tibial fracture of type B or C are indications for total knee arthroplasty.
3. Geriatic patients show a high mortality rate within 1 year.
4. Especially in elderly patients primary total knee arthroplasty (TKA) might be considered in order to achieve early mobilization without restriction.
5. The approach differs in regard to younger patients where open reduction and internal fixation should be the first choice of treatment.
6. There are three different zones for component fixation at both femur and tibia.
7. There is an increased risk for complication after primary or secondary TKA.
8. The clinical outcome after TKA in fracture around the knee shows promising results.

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46.1 Introduction

The average life expectation increases, and fracture treatment of patients at an age over 80 years becomes more common. The treatment of geriatric patients is challenging due to poor bone quality, comorbidities, and mental status. Early mobilization under full weight bearing is essential for this group of patients. However, in comminuted fractures, early mobilization goes often along with none or partial weight bearing. Especially geriatric patients are often incapable to accept any restrictions in weight bearing.

Four hundred thousand fractures in elderly patients are treated in Germany annually. The most common fractures are fracture of the neck of femur, humerus, and radius. Fracture of the tibial head accounts 1% but increased to 8% in geriatric patients [1, 2]. The analysis of 5953 fractures showed an incidence for distal femur and proximal tibia fractures of 0.4% of 1.2%, respectively [3]. Distal femoral fractures are more frequently in female and proximal tibial fracture in male patients. These fractures are due to high energy trauma and characteristically caused by axial loading coupled with varus or valgus force.

Special certified geriatric trauma centers have been established in Germany over the last decade in order to improve the quality of patients care. These centers provide a special infrastructure in the hospital, and a team consisting of trauma sur-

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geon, geriatric specialist, physiotherapist, psychologist and specially trained staff provide optimal care especially prior, during, and after surgery. When geriatric patients are well prepared for surgery the peri- and postsurgical phase will be more successful. It has been shown that the 30 days and one-year mortality rate after surgery can be reduced by 25% [4].

Side Summary
Geriatric trauma centers should treat complex fracture in elderly patients because these patients require care of a team of orthopedic surgeon, geriatric specialist, psychologist, and specially trained staff and physiotherapists.

A one-year mortality rate of 13.4% was reported after distal femoral fracture in elderly patients [5]. The delay in surgery of 2 days showed already an increase in the mortality rate. Older age and immobilization also increase significantly the risk of deep vein thrombosis.

The chapter will discuss the pros and cons of TKA in patients with fractures around the knee.

46.2 AO-Classification

The AO (Arbeitsgemeinschaft für Ostheosynthese)-classification is one of the most commonly used classifications for fractures and was introduced by Maurice Müller from Switzerland in 1958 and consists of a four part alpha-numerical code. The purpose of the classification is a well defined documentation of the type and location of the fracture. Each bone is numbered according to the Orthopaedic Trauma Association and divided into three segments: proximal, diaphyseal, and distal (https://classification.aoeducation.org) [6]. The morphology of the end segment is divided into extra-articular (Type A), partial articular (Type B), and complete intra-articular (Type C) fractures. Type B3 and C fractures of the tibial head occur in 34% and 17%, respectively (Fig. 46.1a, b).

46.3 Indication for Total Knee Arthroplasty

Tibial plateau fracture shows a higher incidence in early osteoarthritis (OA). OA develops in 98% of the patients after 10 years, and there is a 3.5–5.3 times higher risk of receiving TKA in comparison to age and gender matched people [7–9].

Negative prognostic factors for early OA after tibial plateau fracture are valgus and varus deformities of more than 5° and 4° respectively and compression of the joint surface of more than 2 mm [10]. Taking these numbers into consideration, it is difficult to restore the joint line exactly by open reduction and internal fixation (ORIF). Fractures are in general repositioned using an imaging intensifier but dislocation of <5 mm is recognized in 37–83% only [11]. The usage of 3D-computer tomography becomes popular in order to reduce the fragments more correctly.

Side Summary
Early osteoarthritis occurs in varus and valgus deformities of 4° and 5° respectively and joint compression of more than 2 mm

Biomechanical loading analysis of the lower limb have shown femorotibial loading of 240% BW during level walking, of 360% during stair descending and up to 260% when stair rising [12]. Osteosynthesis after complex fracture does not provide such stability in order to allow immediate joint loading. Angle stable plates provide superior strength and due to their elasticity better bone healing [13]. However, unloading is required for 9–12 weeks. In some cases, TKA might be considered in order to allow early full weight bearing.

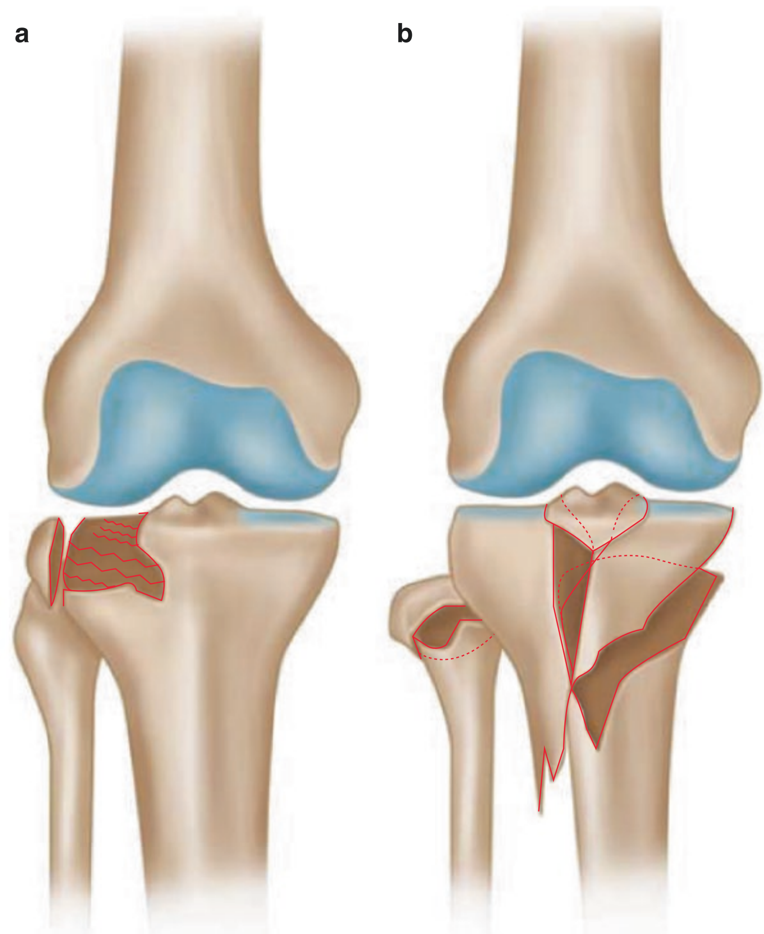

Fig. 46.1 AO-classification of the distal tibial fracture (AO 43 B (**a**) and C (**b**))

Table 46.1 Pros and cons of fracture treatment in elderly patients either with osteosynthesis or TKA

	Osteosynthese	Prothese
Mobilization after surgery	Non-weight bearing for 12 weeks	Immediately
Revision surgery	Yes, secondary osteoarthrits	Yes, septic or aseptic loosening
Approach	Medial and/or lateral approach	Median skin incision, Payr approach
Risk for infection	Low	High
Revision	Total knee arthroplasty	Difficult to treat failed arthroplasty

The main indications for total knee arthroplasty for fracture treatment around the knee are:

- Elderly patients
- Advanced osteoarthritis of the knee
- Lack of compliance
- Multiple comorbidities (e.g., dementia, osteoporosis)
- Comminuted intra-articular fracture
- Compound fracture
- Knee instability

There are numerous pros and cons for the indication of ORIF or TKA, and decision should be made on an individual basis (Table 46.1).

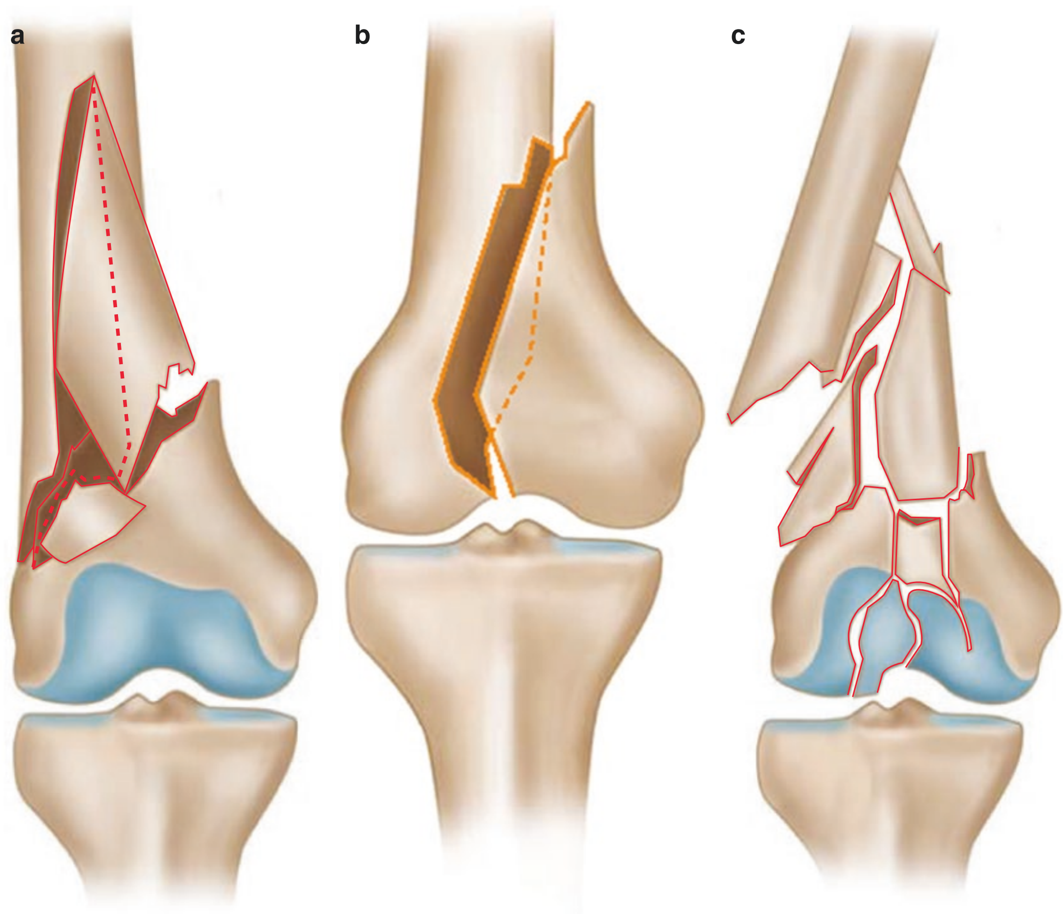

Fig. 46.2 (**a**–**c**) AO-classification of the proximal femoral fracture (AO 42A,B,C)

46.4 Distal Femoral Fracture

Extra-articular and intra-articular distal femoral fractures (AO 33.3A–C) are difficult to restore the anatomical joint surface (Fig. 46.2) [14]. These fractures can be treated by either angle stable plates or total knee arthroplasty. Unloading will be required for at least 9–12 weeks after ORIF using the angle stable plate. Biomechanical studies looked at the stability provided by angle stable plates [15]. Plate deformity, breakage, and proximal or distal cut out of the screws are the major complications (Fig. 46.3). These failures frequently occur in geriatric patients due to the incapability of unloading during walk.

When total knee arthroplasty is considered, revision implants including the option for using stems, spacer, sleeves, and cones need to be taken into account. In some cases, a complete distal femoral component might be required (Case report Figs. 46.4, 46.5, 46.6, 46.7, 46.8).

There are three zones of femoral and tibial component fixation: intra-articular, metaphyseal, and diaphyseal fixation (Fig. 46.9) [16]. Two of the three zones should be used for fixation. Cones or sleeves may help for improving stability; however, fractures of type B or C do not provide the bone stock for using these implants. Primary stability will be achieved due to diaphyseal fixation.

Side Summary
There are three zones providing component fixation: intra-articular and epiphyseal, metaphyseal, and diaphyseal.

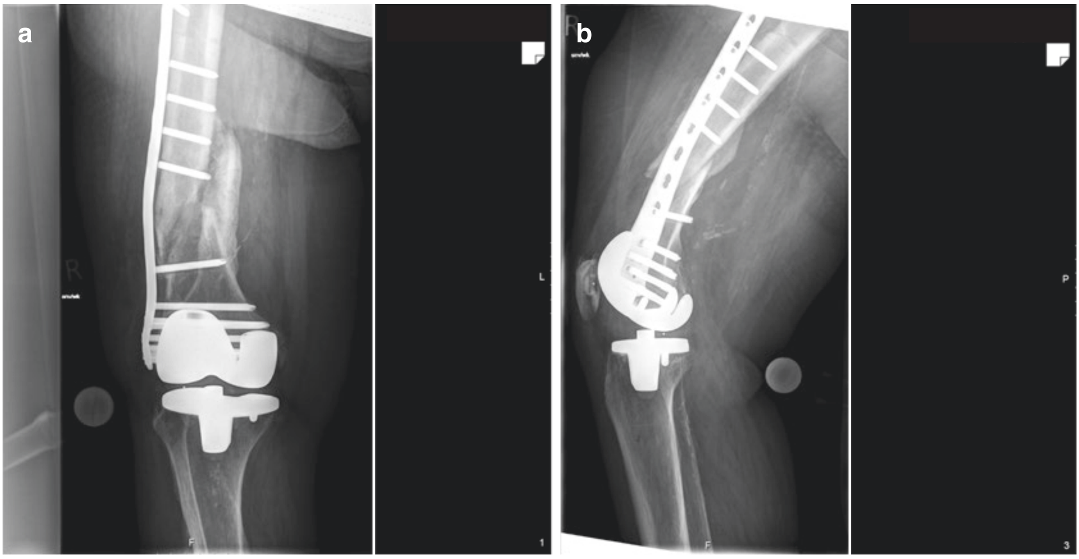

Fig. 46.3 (**a**, **b**) Anteroposterior and lateral view shows a failed angle stable plate osteosynthesis of a distal femoral fracture above the knee prosthesis

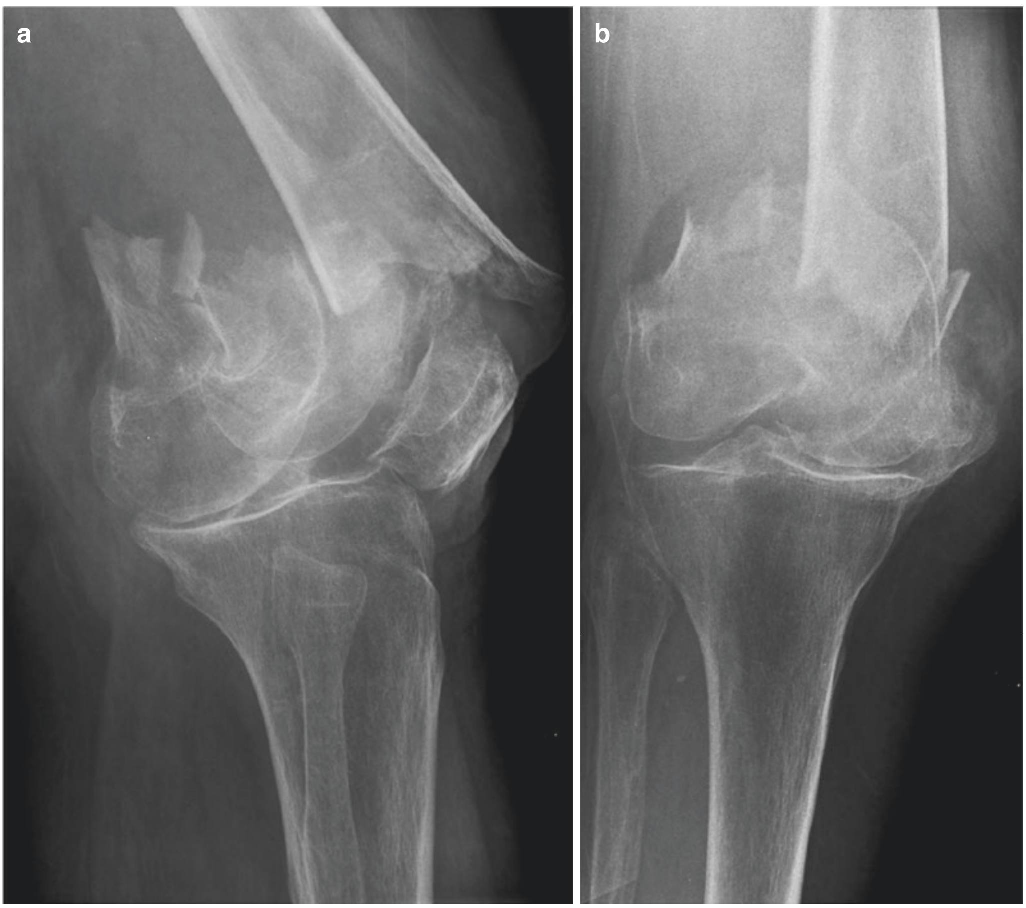

Fig. 46.4 (**a**, **b**) Anteroposterior and lateral view of a 43C3 fracture of an 88-year-old lady

Fig. 46.5 Intraoperative view shows the severe fracture of the distal femur

Case 1: A 75-year-old lady sustained a distal femoral fracture classified as AO-43C. Total knee arthroplasty was performed indicated due to the significant osteoporosis, a comminuted fracture, which involved the metaphysis and the age of the lady. Femoral fixation was solely via the diaphysis. A complete replacement of the distal femur was preferred. A rotating hinged knee was implanted. The commonly used bony landmarks are missing in this type of fracture. The level of the joint line can be calculated by measuring the length of the opposite femur (Fig. 46.10). The position of the patella in regard to the joint line is the second important landmark and crucial with respect to good knee function. Joint line elevation increases the patellofemoral force [17]. Based on a literature review a significant correlation was reported between increase in joint line elevation and lower outcome [18]. Joint line elevation should not exceed 4 mm according to the review.

Correct component placement in the axial plane can be achieved by using the flattened dorsal cortical bone of the distal femur (Fig. 46.11).

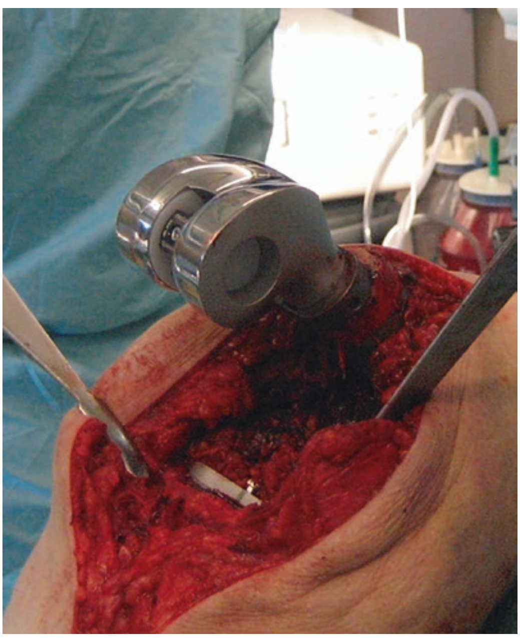

Fig. 46.6 Rotating hinged knee. A distal femoral component is used for reconstruction of the knee. The tibial component is already in place, and the two components will be connected to each other. No ligaments are required

46.5 Proximal Tibial Fracture

Proximal tibial fracture may affect either the medial, lateral, or both compartments.

For fracture of a single femorotibial compartment, primary total knee arthroplasty may be considered. Spacer and stems are required on the tibial site using a stemless primary implant on the femoral side (Fig. 46.12A–D). The collateral ligaments are in general intact and unconstrained implants can be used. In smaller defects and especially in younger patients, unicondylar replacement might be considered (Case 2).

Case 2: A 54-year-old lady fell of the bike and fractured the lateral tibial plateau (AO 41.B2). The fracture extends into the metaphysis of the tibia (Fig. 46.13). The fracture was initially treated by osteosynthesis using an angle stable plate (Fig. 46.14a, b). Significant impression of the lateral tibial plateau pain and instability during walking cause revision to unicondylar knee replacement (UKA). Lateral UKA is considered as a successful option in posttraumatic osteoar-

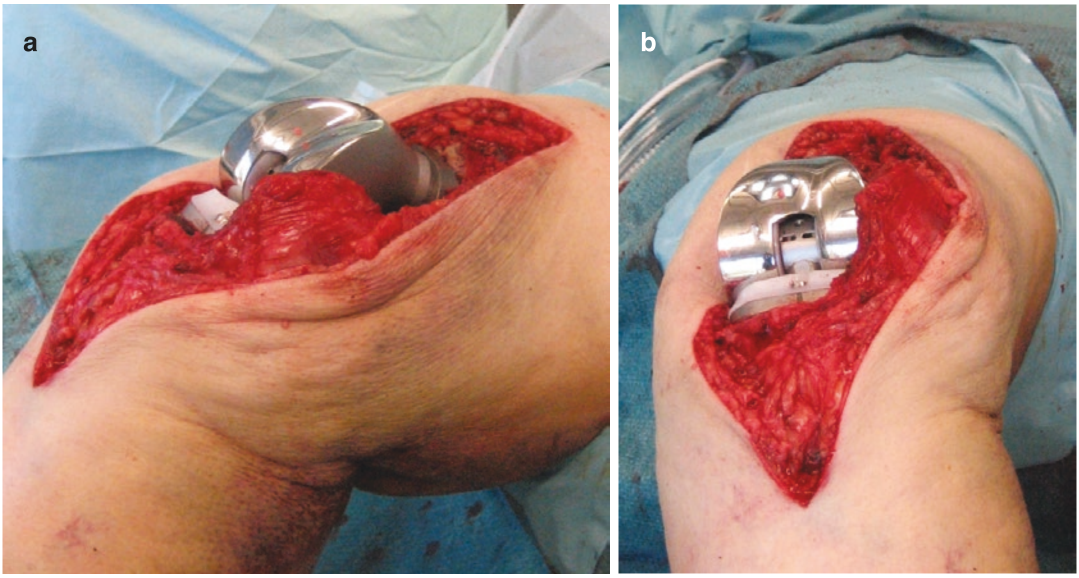

Fig. 46.7 (**a**, **b**) Anteroposterior and lateral view of the rotating hinged knee

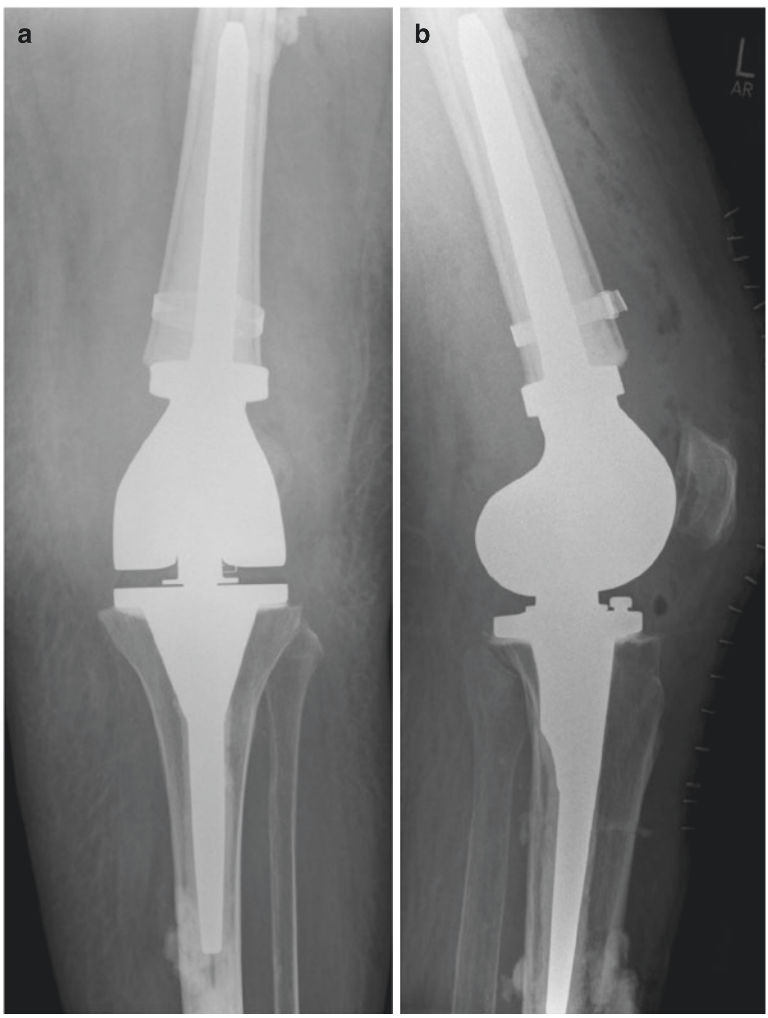

Fig. 46.8 (**a**, **b**) Postoperative radiography after TKA implantation

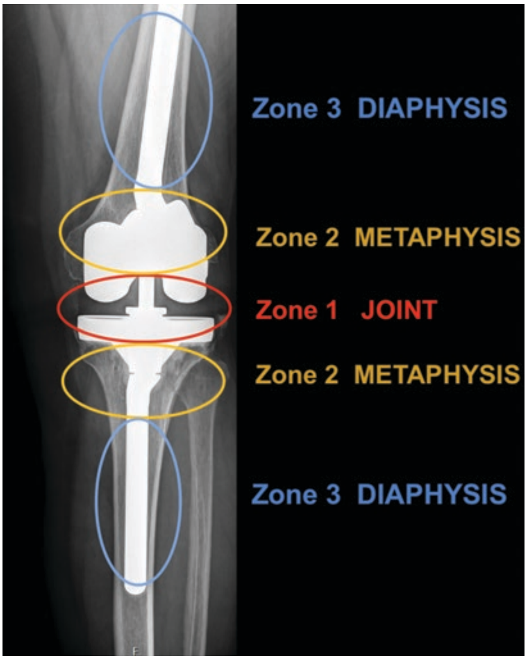

Fig. 46.9 Three zones for femoral and tibial component fixation: diaphyseal zone—metaphyseal zone—epiphyseal zone/intra-articular zone

thritis [19]. The indication should be very restrictive because of the increased risk of aseptic loosening.

More severe tibial plateau fracture are very demanding when reconstruction of the joint line is considered. In elderly patients TKA might be the first choice in order to allow early mobilization. The fixation of the tibial component is the challenging part of the procedure. However, the primary goal should be to preserve as much bone as possible as shown in Case 3.

Case 3: A 78-year-old gentleman fell off a ladder and sustained a proximal comminuted fracture of the tibia (AO 41.C3) (Fig. 46.15a, b). Initially an external fixator was applied for stabilizing the fracture (Fig. 46.16). A rotating hinged knee was used. The proximal tibial fragments were anatomically positioned as much as possible and stabilized with four cancellous screws in order to gain metaphyseal support for the tibial component. The tibial tuberosity was

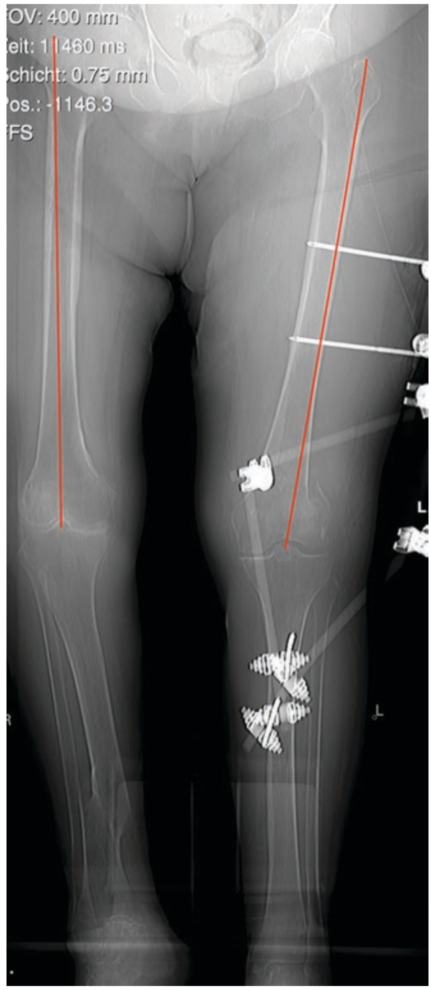

Fig. 46.10 CT scout can be used for surgical planning. The correct leg length can be calculated from the opposite limb

not fractured and the entire extensor mechanism preserved. For correct joint line position the distance between the medial malleolus served as reference. The final position of the joint line was determined by referencing according to the position of the patella. The Caton-Deschamps Index which is defined as the patella facet length of the patella and the length between the lower pole of the fact and the anterior tibial plateau, which in TKA will be the liner (normal index 1.06) [20]. Finally, the femoral and tibial components were cemented, and the components were connected to each other. Full weight bearing on crutches for 9 weeks was recommended (Figs. 46.17a–e and 46.18a,b).

The alternative might be a complete proximal tibial component; however, the extensor mechanism would have been detached and reattached to the prosthesis and increased risk of extensor mechanism insufficiency.

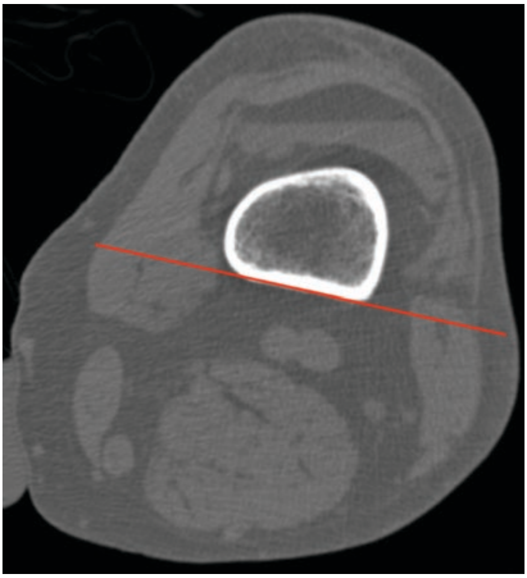

Fig. 46.11 Dorsal cortical bone 11 cm above the joint line may serve as a reference for correct femoral rotation

Fig. 46.13 Lateral tibial plateau fracture of a 54-year-old lady. Compression of the plateau of 12 mm. Osteosynthesis was performed using an angle stable plate

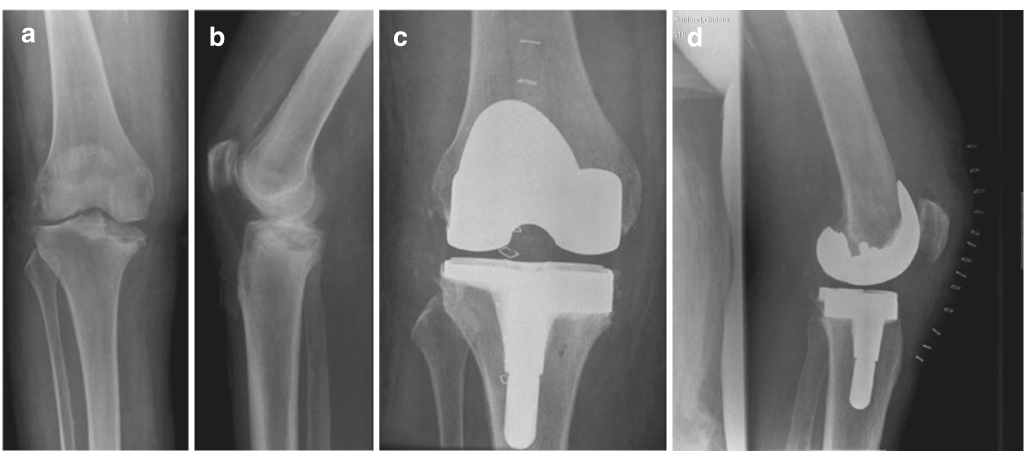

Fig. 46.12 (**a**–**d**) Anteroposterior (**a**) and lateral view (**b**) of the medial tibial plateau fracture. TKA was performed for revision using a primary femoral component (**c**) and a revision component with 10 mm medial spacer and short intramedullary stem (**d**)

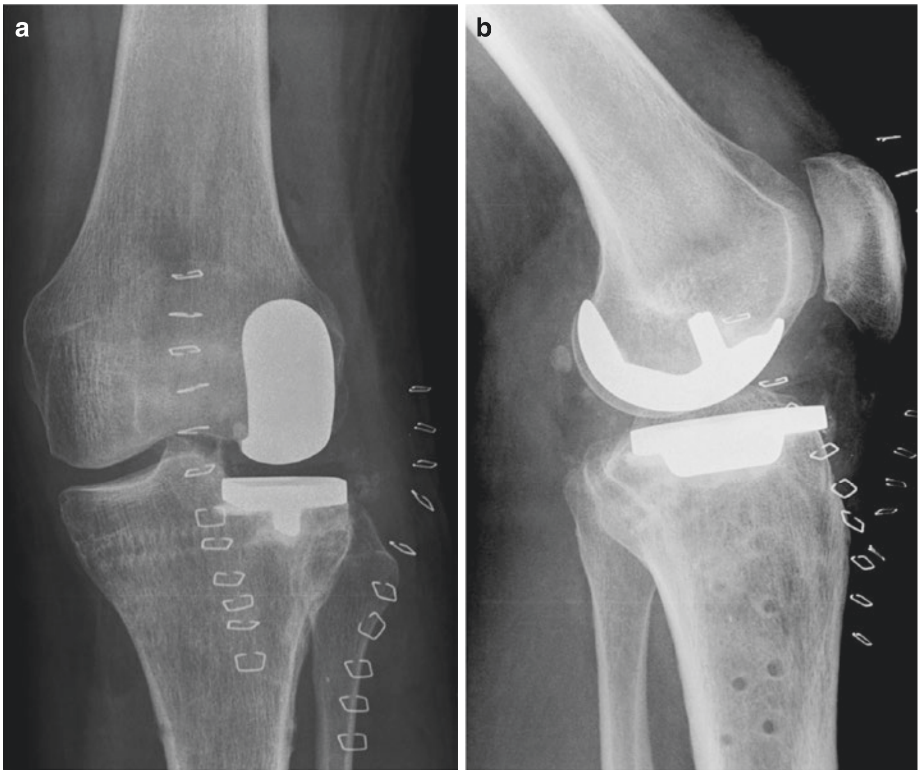

Fig. 46.14 (**a**, **b**) Anteroposterior and lateral view after revision using a lateral UKA

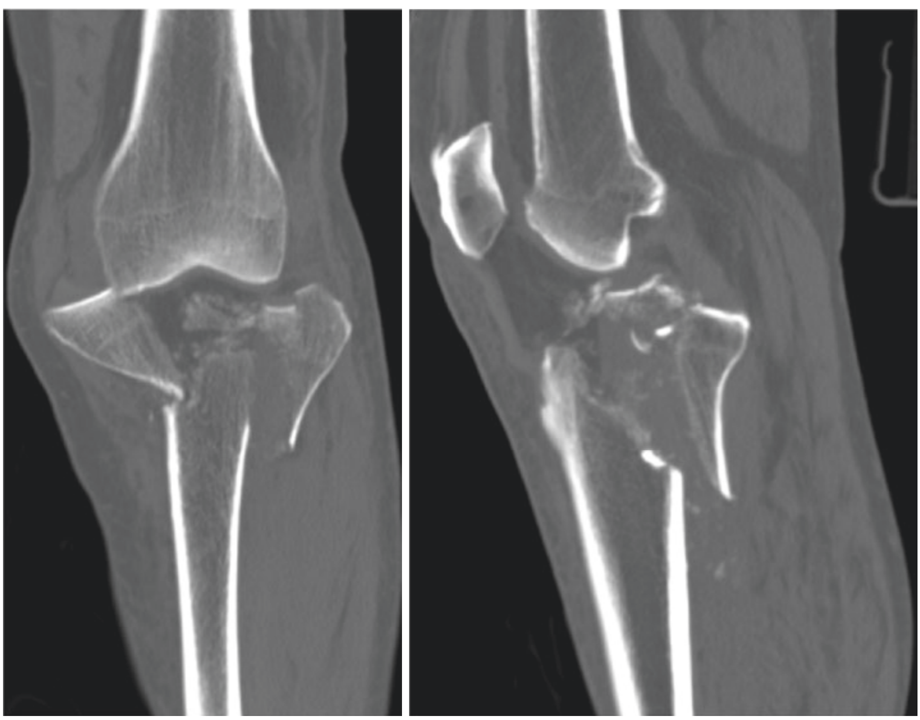

Fig. 46.15 (**a**, **b**) Coronal and sagittal plane of the CT scan showing a comminuted tibial plateau fracture (AO 41.C3)

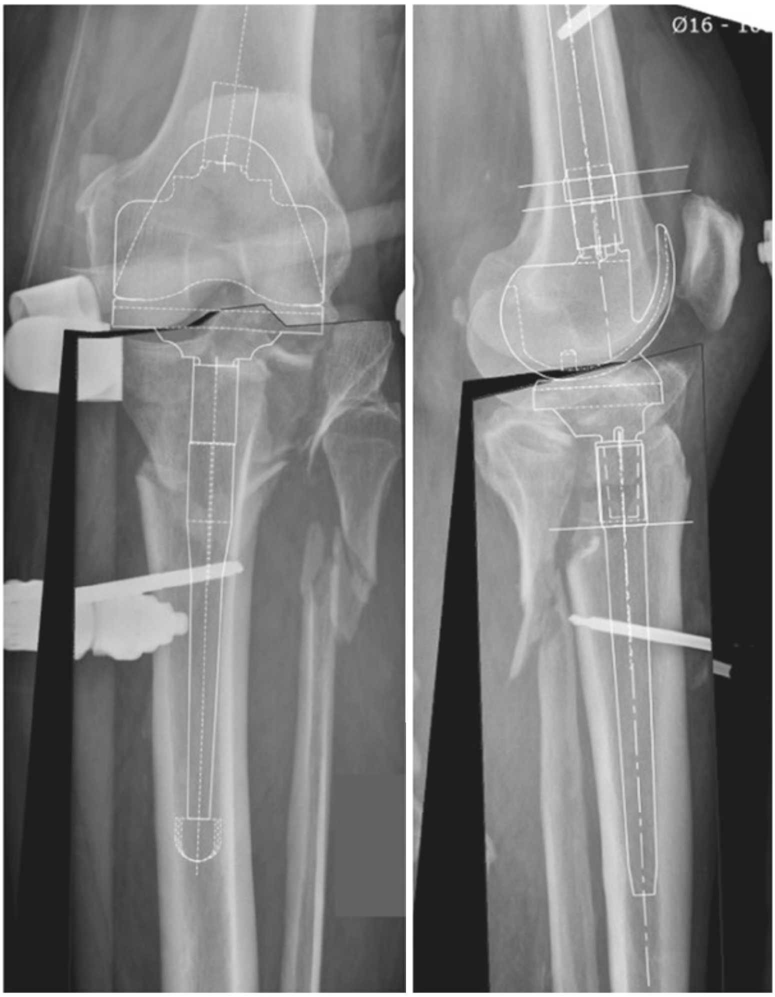

Fig. 46.16 Anteroposterior and lateral view of the left knee after temporarily fixation using an external fixator

46.6 Outcome

TKA after fracture around the knee may have a significant higher complication rate during surgery, but no difference in patient reported outcome was reported in comparison to primary TKA [21]. The overall complication rate is higher in TKA after tibial plateau fracture, and the revision rate occurs predominantly within the first 2 years [22]. Implants, which are well fixed, showed similar results to primary TKA after a follow-up of 15 years.

A review of outcome after TKA for distal femoral fractures in osteoporotic bone showed a mortality rate at 30 days and 18 months of 3.34 and 18.4%, respectively [23]. The mean time for mobilization was 3.9 days and time until discharge 16.6 days.

Patients after TKA seem to perform better than after ORIF in terms of range of motion and return to independent ambulation [24]. Hart et al. did not find difference in revision or deep infection between TKA and ORIF in patients with 70 years and older. However, ORIF had an 18% rate of nonunion. All patients were ambulatory after TKA but one in four showed wheel-chair dependency after ORIF.

Patients after ORIF complained about persistent pain in 40% and development of osteoarthritis after 1 year in 40.6% [25, 26]. Loss of reduction after ORIF has been reported in 30–79% of the cases.

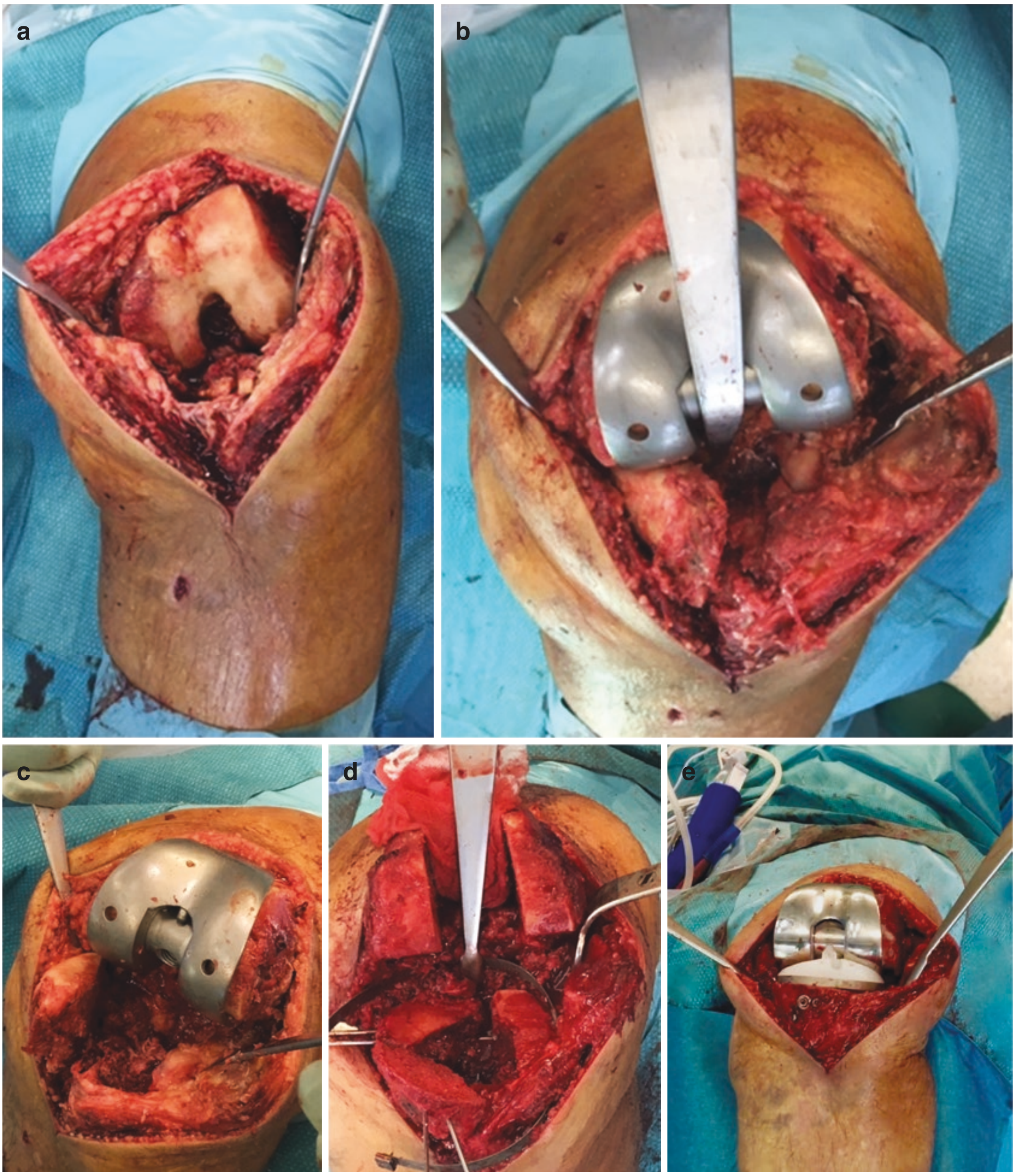

Fig. 46.17 (**a**–**e**) Intraoperative images showing the surgical sites after opening the knee (**a**). The femoral component was placed (**b**) on the bone and the tibial plateaus prepared for component placement (**c**). Osteosynthesis of the tibial plateau was performed using k-wires and later cannulates 4 mm screws (**d**). Final sites after the hinged prosthesis was implanted

In case of metaphyseal instability cone-shaped augments may provide additional fixation [27]. No aseptic loosening has been reported in a series of 15 cases at 24 months of follow–up, and the mean knee and function score was 73.2 ± 20.2 and 68.3 ± 20.2, respectively. All patients were mobilized on day one with full weight bearing.

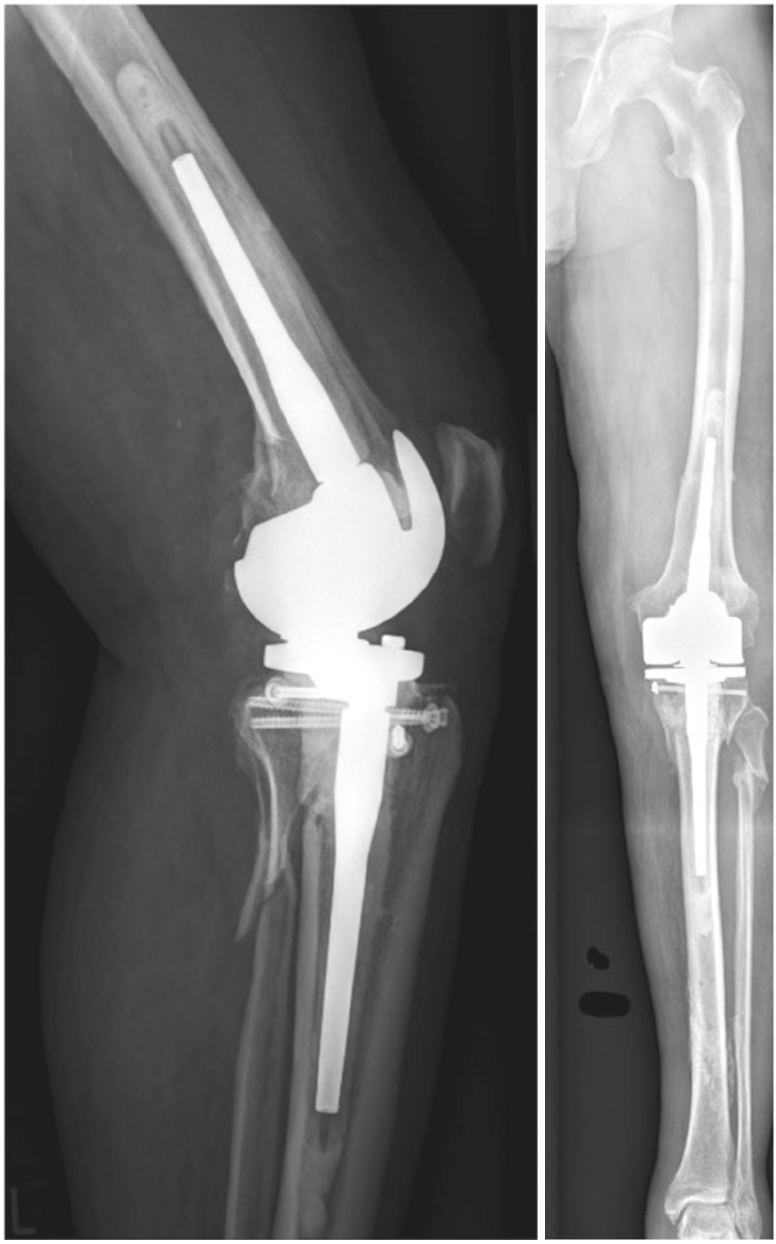

Fig. 46.18 Anteroposterior and lateral view of the radiography showing the rotating hinged TKA

> **Side Summary**
> Early mobilization under full weight bearing can be achieved after primary TKA in fracture around the knee.

A series of 54 patients with a mean age 82 years (55–98) and follow-up time was studied. The length of stay was 15 days and the median survival after surgery was 1.7 years [28].

The one-year mortality rate showed 13.4% after distal femoral fracture in 283 patients with an average age of 76 ± 9.8 years [5].

Take Home Message

- Total knee arthroplasty is appropriate in type B and C fractures around the knee. Surgery should be performed in centers of geriatric traumatology where orthopedic surgeon, geriatric specialist, and specially trained nurses and physiotherapists work in one team.
- Careful planning is important, and the contralateral leg taken via a scan serves as the reference, because the commonly used anatomical landmarks are missing.
- Higher constraint implants, augments, sleeves or cones have to be available for surger.
- The goal should be early mobilization of the geriatric patients with full weight bearing in order to minimize complications such as deep vein thrombosis or pulmonary disorders.

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47 Thromboembolic Prophylaxis After Partial or Total Knee Arthroplasty

Murat Bozkurt and Alper Deveci

Keynotes

1. Pulmonary embolism (PE) is the most common preventable cause of hospital mortality.
2. In the absence of VTE prophylaxis after TKA, the incidence of DVT is reported as 47% and TKA is in the highest risk group.
3. UKA has lower risk of DVT than TKA.
4. The most important advantage of mechanical VTE prophylaxis is that there is no risk of bleeding.
5. When VPF-regulated below-the-knee compression and aspirin were used together, the incidence of asymptomatic DVT in USG was reported to be 0%.
6. Warfarin may cause transient hypercoagulability due to protein C inhibition.
7. LMWH does not increase the risk of bleeding in both short-term treatment and prolonged prophylaxis.
8. AAOS and ACCP have recommended the use of aspirin for the prophylaxis of VTE after TKA. The recommended dose is 325 mg twice daily for 6 weeks after surgery.
9. Rivaroxaban has a lower incidence of overall VTE than aspirin, but no difference is observed in symptomatic VTE.
10. Apixaban is more effective than enoxaparin in reducing VTE after TKA.

47.1 Introduction

Venous thromboembolic disease includes a wide spectrum of asymptomatic deep venous thrombosis (DVT) to severe pulmonary embolism (PE). PE is the most common preventable cause of hospital mortality. The comprehensive protocols of VTE (venous thromboembolism) prophylaxis after knee arthroplasty significantly reduced the incidence of symptomatic PE. The incidence of PE associated with VTE following knee arthroplasty is now reported as 0.4% [1, 2]. Due to these lethal problems of thromboembolism, routine thromboprophylaxis is recommended after total knee arthroplasty (TKA) [3–5]. However, the most appropriate procedure for VTE prophylaxis is still controversial. In the absence of VTE prophylaxis after TKA, the incidence of DVT is

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reported as 47%. In this case, TKA is in the highest risk group [6].

> **Side Summary**
> In the absence of venous thromboembolism prophylaxis after TKA, the incidence of deep vein thrombosis is reported as 47%.

There is not enough data on the incidence of DVT and PE after unicondylar knee arthroplasty (UKA). However, it is reported that UKA has lower risk of DVT than TKA. Schmidt-Brekling et al. reported an incidence of asymptomatic DVT as 0.9%. They have not encountered symptomatic deep vein thrombosis [7]. Another study reported symptomatic thromboembolic events in 1.0% of the TKA patients and 0.64% of the UKA patients [8]. The incidence of thromboembolic events following UKA is very low.

When compared to UKA and TKA, the UKA has a faster recovery time. In addition, UKA is a more minimally invasive surgery. For these reasons, the incidence of thromboembolic events following UKA is very low.

Current VTE prophylaxis protocols generally include early mobilization, the use of mechanical compression devices, and chemoprophylaxis. Bleeding, wound problems, and surgical site infections are risk factors, even if the incidence of VTE is significantly reduced, especially with chemoprophylaxis. Therefore, the balance between bleeding and thrombosis is important.

47.2 Mechanical VTE Prophylaxis

Both the American Academy of Orthopaedic Surgeons (AAOS) and the American College of Chest Physicians (ACCP) recommend the use of mechanical compressive devices for VTE prophylaxis in patients undergoing total joint arthroplasty [9–11]. The most important advantage of this method is that there is no risk of bleeding. However, skin and wound problems are important disadvantages. It is also reported that its efficacy is lower than that of chemoprophylaxis.

Mechanical compression prophylaxis includes different techniques [12] such as compression stockings, foot pumps, below-the-knee sequential compression devices, below-the-knee asymmetrical devices, above-the-knee symmetrical devices, and below-the-knee venous phasic flow (VPF)-regulated devices. Among these methods, VPF-regulated below-the-knee compression device is the most suitable method for this application. When VPF-regulated below-the-knee-compression and aspirin were used together, the incidence of asymptomatic DVT in USG was reported to be 0%. The patients received aspirin with inpatient-only compression prophylaxis. The asymptomatic DVT rate was found 23% [12]. Current evidence-based data suggest the long-term administration of VPF below-the-knee compression devices in addition to chemoprophylaxis. Also, the duration of use of these devices for VTE prophylaxis in TKA is still unclear.

> **Side Summary**
> Mechanical VTE prophylaxis can be done using compression stockings, foot pumps, below-the-knee sequential compression devices, below-the-knee asymmetrical devices, above-the-knee symmetrical devices, and below-the-knee venous phasic flow (VPF)-regulated devices.

47.3 Pharmacologic VTE Prophylaxis

47.3.1 Warfarin

Warfarin acts by inhibiting the hepatic synthesis of vitamin K-dependent coagulation factors (factors II, VII, IX, and X). Warfarin is an anticoagulant with extensive clinical experience in TKA. When used for VTE prophylaxis after TKA, the VTE ratio was reported to be 1.12%. In fact, warfarin-related surgical site infection, wound problems, and bleeding complications are not high. But there are a few other important issues with the use of warfarin. First, the process of reaching an INR level at the therapeutic level is long. This time is approximately 24–36 h. Second, it may cause transient hypercoagulability due to protein C inhibition. Third, it requires routine dose monitoring to maintain INR at the therapeutic level. Additionally, it can have drug-drug and drug-food interactions resulting in unpredictable pharmacokinetics that can adversely affect both the therapeutic range and the bleeding risk profile. Today, due to these disadvantages, its use is very low in VTE prophylaxis after TKA. In terms of efficacy and reliability, the therapeutic window is rather narrow.

Side Summary
Warfarin acts by inhibiting the hepatic synthesis of vitamin K-dependent coagulation factors (factors II, VII, IX, and X). Warfarin is an anticoagulant with extensive clinical experience in TKA. When used for VTE prophylaxis after TKA, the VTE ratio was reported to be 1.12%.

INR levels after TJA frequently are not within the predetermined target range [13]. Studies have also shown that patients with an INR above the target range are more prone to developing a periprosthetic joint infection (PJI) [14]. A recent study has also suggested a rapid rise in the INR after warfarin initiation in total joint arthroplasty patients is associated with increased risk of symptomatic venous thromboembolism [15]. The risks associated with warfarin as a VTE prophylaxis may outweigh the potential benefits, especially with contemporary surgical techniques, mechanical VTE prophylaxis, early mobilization, and alternate chemoprophylaxis [1].

47.3.2 Low-Molecular-Weight Heparin

LMWH is a molecule with 4000–5000 Da obtained by chemical and enzymatic depolarization of heparin. Like heparin, the main effect of LMWH is antithrombin-3 activation. Thus, it inhibits factor IIa, IXa, Xa. The dose-response relationship of LMWH is more predictable and safer than heparin. The risk of heparin-induced thrombocytopenia decreased with LMWH. A potentially serious complication of heparin therapy that can lead to platelet aggregation and risk for venous and arterial thrombosis is reduced by using LMWH. LMWHs are suitable for extended thromboprophylaxis outside the hospital setting [16].

Side Summary
LMWH is a molecule with 4000–5000 Da obtained by chemical and enzymatic depolarization of heparin. Like heparin, the main effect of LMWH is antithrombin-3 activation. Thus, it inhibits factor IIa, IXa, Xa.

It has been shown that it does not increase the risk of bleeding in both short-term treatment and prolonged prophylaxis. There are a large number of data available in the literature about use of LMWH in total joint arthroplasty patient population. LMHH is an effective agent for prophylaxis of VTE. However, there are contradictory reports of surgical wound and bleeding complications. Surgical site bleeding is suggested to be greater when compared to aspirin use alone in patients following TKA [17]. In comparison with warfarin, it is reported that the efficacy is higher and the risk of DVT is lower. In patients following TKA, when enoxaparin (40 mg/day) used for 10–14 days, VTE and PE are, respectively, 1.3% and 1%. Besides, the risk of symptomatic DVT was found to be 1.8%. These rates are further reduced in extended prophylaxis (27–35 days).

47.3.3 Aspirin

It irreversibly binds and inactivates cyclooxygenase on platelets. The use of aspirin alone has been controversial in terms of chemoprophylaxis [18]. Aspirin is preferred because of its low surgical field problem, low bleeding rate, and cost-effectiveness. The data demonstrated DVT and PE rates of 0.6% and 1.2%, respectively. The major bleeding rate was 0.3% [19].

Aspirin 325 mg twice daily is the most commonly used dosing regimen. The efficacies of lower dose of aspirin have recently been studied. Parvizi et al. conducted a prospective crossover study comparing aspirin 325 mg twice daily and aspirin 81 mg twice daily in standard risk patients. They reported that the lower dose regimen was not inferior to the higher dose regimen for VTE prophylaxis [20]. Although, in theory, the low-dose aspirin regimen should confer reduced risk of GI discomfort and potential bleeding complications, the rate of GI bleeding events was not different from the high-dose group [21]. In addition to its efficacy and safety for VTE prevention, aspirin has been shown to reduce the healthcare utilization costs [9].

Side Summary
Aspirin irreversibly binds and inactivates cyclooxygenase on platelets. Aspirin is preferred because of its low surgical field problem, low bleeding rate, and cost-effectiveness. The data demonstrated DVT and PE rates of 0.6% and 1.2%, respectively. The major bleeding rate was 0.3%.

Aspirin has also been reported to be associated with a lower rate of periprosthetic joint infection compared with adjusted-dose warfarin, further supporting the cost-effectiveness [22].

Aspirin has been reported to have similar efficacy and complication rates in many publications in terms of efficacy and possible local complications when compared with new-generation oral anticoagulants. In a randomized controlled study by Colleoni et al., there were no significant differences between the 300 mg aspirin group and the 10 mg rivaroxaban group in terms of complications and efficacy. Both methods were reported to be successful [23]. In terms of risk of bleeding, aspirin and enoxaparin confer similar bleeding risks, and both exhibit less bleeding than patients who received rivaroxaban [24].

As a result, accumulating literature has demonstrated that aspirin is not inferior to other agents for the prevention of VTEs. The main problem with the use of aspirin in prophylaxis is how much daily dose should be. In general, it is suggested that there is no difference in efficacy and complications between low-dose (81 mg/day) and high-dose (325 mg/day) aspirin applications [20, 25].

Side Summary
Aspirin has been reported to have similar efficacy and complication rates in many publications in terms of efficacy and possible local complications when compared with new generation oral anticoagulants. The recommended dose is 325 mg twice daily for 6 weeks after surgery.

Another problem is the duration of prophylaxis. The American Association of Orthopaedic Surgeons (AAOS) and the American College of Chest Physicians (ACCP) have recommended the use of aspirin for the prophylaxis of VTE after TKA. The recommended dose is 325 mg twice daily for 6 weeks after surgery [10, 26].

47.3.4 Rivaroxaban

Rivaroxaban is an oral factor Xa inhibitor and a well-tolerated drug. When evaluated in terms of pharmacokinetic and pharmacodynamic properties, the dosage range is quite wide (5–80 mg). Rivaroxaban has a low potential for drug-drug interactions. No routine monitoring is necessary. It is recommended to use 10 mg/day for 15 days following total knee arthroplasty. Rivaroxaban has a lower incidence of overall VTE than aspirin, but no difference is observed in symptomatic VTE [27].

Side Summary
Rivaroxaban is an oral factor Xa inhibitor and a well-tolerated drug. It is recommended to use 10 mg/day for 15 days following total knee arthroplasty.

47.3.5 Dabigatran

Dabigatran is an oral direct thrombin inhibitor. It is recommended to use 150 mg/day (12–15 days) for prophylaxis of DVT and PE after TKA. It only has approval for nonsurgical use in USA. The use of VTE prophylaxis after arthroplasty in other parts of the world is considered safe. Dabigatran has minimal drug-drug interactions and has predictable pharmacokinetics and pharmacodynamics. No routine monitoring is necessary [10].

Side Summary
Dabigatran is an oral direct thrombin inhibitor. It is recommended to use 150 mg/day (12–15 days) for prophylaxis of DVT and PE after TKA.

47.3.6 Apixaban

Apixaban is also an oral factor Xa inhibitor. It is recommended to use a daily dose of 2.5 mg and 12–15 days for VTE prophylaxis following TKA. Apixaban 2.5 mg twice daily was compared with enoxaparin 30 mg twice daily in the ADVANCE-1 study for VTE prevention in patients who underwent TKA. The VTED event rates for the primary efficacy endpoint were similar for apixaban and enoxaparin (8.99 vs. 8.85%, respectively) [28]. In a second study, the ADVANCE-2 trial, apixaban 2.5 mg twice daily was compared with enoxaparin 40 mg once daily for the prevention of VTE after TKA. The results demonstrated that apixaban was more effective than enoxaparin in reducing VTE after TKA [29].

Side Summary
Apixaban is also an oral factor Xa inhibitor. It is recommended to use a daily dose of 2.5 mg and 12–15 days for VTE prophylaxis following TKA.

Take Home Message

- Both the AACP and the AAOS guidelines recommend combined mechanical and pharmacological prophylaxis. There has been increasing clinical evidence of the efficacy and the safety of using aspirin as pharmacological prophylaxis in patients with standard risk stratification. The direct factor Xa and direct thrombin inhibitors are effective in reducing VTE, however may be associated with an increased bleeding and wound complication rates.
- Although guidelines (such as those of the American College of Chest Physicians [ACCP] and the American Academy of Orthopaedic Surgeons [AAOS]) for thromboprophylaxis are available, a substantial proportion of orthopedic patient still do not receive adequate prophylaxis. With the convenience of oral dosing and the potential for simplified postoperative management of patients, it is possible that these new agents will replace the more conventional anticoagulants currently used in clinical practice.
- A safe and effective VTE prophylaxis algorithm requires a thorough understanding of the AAOS and ACCP guidelines. VTE prophylaxis should be individualized to balance safety and efficacy. An understanding of VTE risk factors and knowledge of the various VTE prophylaxis options are paramount for the development of a safe and effective VTE prophylaxis algorithm for the surgeon's practice [30] (Tables 47.1 and 47.2).

Table 47.1 AAOS 2011 Guidelines

No.	Recommendations	Grade
1	We recommend against routine postoperative duplex ultrasonography screening of patients who undergo elective hip or knee arthroplasty	Strong
2	Patients undergoing elective hip or knee arthroplasty are already at high risk for venous thromboembolism. The practitioner might further assess the risk of venous thromboembolism by determining whether these patients had a previous venous thromboembolism	Limited
	Current evidence is not clear about whether factors other than a history of previous venous thromboembolism I increase the risk of venous thromboembolism in patients undergoing elective hip or knee arthroplasty, and therefore, we cannot recommend for or against routinely assessing these patients for these factors	Inconclusive
3	Patients undergoing elective hip or knee arthroplasty are at risk for bleeding and bleeding-associated complications. In the absence of reliable evidence, it is the opinion of this work group that patients be assessed for known bleeding disorders like hemophilia and for the presence of active liver disease which further increase risk for bleeding and bleeding-associated complications	Consensus
	Current evidence is not clear about whether factors other than the presence of a known bleeding disorder or I active liver disease increase the chance of bleeding in these patients, and therefore, we are unable to recommend for or against using them to assess a patient's risk of bleeding	Inconclusive
4	We suggest that patients discontinue antiplatelet agents (e.g., aspirin, clopidogrel) before undergoing elective hip or knee arthroplasty	Moderate
5	We suggest the use of pharmacologic agents and/or mechanical compressive devices for the prevention of venous thromboembolism in patients undergoing elective hip or knee arthroplasty, and who are not at elevated risk beyond that of the surgery itself for venous thromboembolism or bleeding	Moderate
	Current evidence is unclear about which prophylactic strategy (or strategies) is/are optimal or suboptimal. Therefore, we are unable to recommend for or against specific prophylactics in these patients	Inconclusive
6	In the absence of reliable evidence, it is the opinion of this work group that patients undergoing elective hip or knee arthroplasty, and who have also had a previous venous thromboembolism, receive pharmacologic prophylaxis and mechanical compressive devices	Consensus
7	In the absence of reliable evidence, it is the opinion of this work group that patients undergoing elective hip or knee arthroplasty, and who also have a known bleeding disorder (e.g., hemophilia) and/or active liver disease, use mechanical compressive devices for preventing venous thromboembolism	Consensus
8	In the absence of reliable evidence, it is the opinion of this work group that patients undergo early mobilization following elective hip and knee arthroplasty. Early mobilization is of low cost, minimal risk to the patient, and consistent with current practice	Consensus
9	We suggest the use of neuraxial (such as intrathecal, epidural, and spinal) anesthesia for patients undergoing elective hip or knee arthroplasty to help limit blood loss, even though evidence suggests that neuraxial anesthesia does not affect the occurrence of venous thromboembolic disease	Moderate
10	Current evidence does not provide clear guidance about whether inferior vena cava (IVC) filters prevent pulmonary embolism in patients undergoing elective hip and knee arthroplasty who also have a contraindication to chemoprophylaxis and/or known residual venous thromboembolic disease. Therefore, we are unable to recommend for or against the use of such filters	Inconclusive

Table 47.2 American College of Chest Physicians 2012 Guidelines (ninth edition)

Recommendation	Grade
In patients undergoing THA or TKA, one of the following agents should be used for a minimum of 10–14 d, rather than providing no antithrombotic prophylaxis	
LMWH	1B
Fondaparinux	1B
Apixaban	1B
Dabigatran	1B
Rivaroxaban	1B
LDUH	1B
Adjusted-dose VKA	1B
Aspirin	1B
IPCD	1C
In patients undergoing major orthopedic surgery (THA, TKA, or hip fracture surgery) and receiving LMWH as thromboprophylaxis, the agent should be started either $12 h preoperatively or $12 h postoperatively rather than #4 h preoperatively or #4 h postoperatively	1B
In patients undergoing THA or TKA, regardless of IPCD use or the length of treatment, LMWH should be used in preference to other alternative agents, including the following:	
Fondaparinux	2B
Apixaban	2B
Dabigatran	2B
Rivaroxaban	2B
LDUH	2B
Adjusted-dose VKA	2C
Aspirin	2C
In patients undergoing major orthopedic surgery, thromboprophylaxis should be extended in the outpatient 2B period for up to 35 days from the day of surgery rather than for only 10–14 days	2B
In patients undergoing major orthopedic surgery, dual prophylaxis with an antithrombotic agent and an IPCD during the hospital stay is recommended	2C
In patients undergoing major orthopedic surgery with an increased risk of bleeding, an IPCD or no prophylaxis is recommended over pharmacologic treatment	2C
In patients undergoing major orthopedic surgery and who decline or are uncooperative with injections or an IPCD, apixaban or dabigatran (if unavailable, rivaroxaban or adjusted-dose VKA) should be used rather than alternative forms of prophylaxis	1B
In patients undergoing major orthopedic surgery, using an IVC filter is not recommended for primary prevention over no thromboprophylaxis in patients with an increased bleeding risk or contraindications to both pharmacologic and mechanical thromboprophylaxis	2C
Following major orthopedic surgery, asymptomatic patients do not need a Doppler ultrasound test or DUS screening before hospital discharge	1B

1B Strong recommendation, moderate-quality evidence, *1C* Strong recommendation, low-quality evidence, *2B* Weak recommendation, moderate-quality evidence, *2C* Weak recommendation, low-quality evidence, *DUS* Duplex ultrasound screening, *IPCD* Intermittent pneumatic compression device, *IVC* Inferior vena cava, *LDUH* Low-dose unfractionated heparin, *LMWH* Low-molecular-weight heparin, *THA* Total hip arthroplasty, *TKA* Total knee arthroplasty, *VKA* Vitamin K antagonist

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48 How to Avoid Typical Complications After Total Knee Arthroplasty?

James F. Fraser and Antonia F. Chen

Keynotes

1. Arthrofibrosis is a common complication following total knee arthroplasty.
2. Postoperative stiffness can be minimized with appropriate surgical technique.
3. Manipulation under anesthesia should be performed within 6–12 weeks of surgery.
4. Open or arthroscopic surgery may be required in severe cases of arthrofibrosis.
5. Neurovascular injuries are rare but serious events following TKA.
6. Patients with preoperative valgus deformity are at increased risk for nerve palsy.
7. Nerve palsies are managed with supportive care.
8. Vascular injuries require early detection and intervention for optimal outcomes.

48.1 Introduction

Total knee arthroplasty (TKA) is generally a safe operation with high patient satisfaction rates, but orthopedic surgeons must be cognizant of a myriad of potential problems. Certain complications, such as periprosthetic joint infection and deep vein thromboses, are covered in other chapters. Knee stiffness is one of the most common complications after TKA due to arthrofibrosis, over-constraining the patellofemoral or femorotibial compartment during surgery, or lack of compliance.

Arthrofibrosis and neurovascular injuries may occur in the early postoperative period and often require timely detection and intervention to ensure favorable patient outcomes.

This chapter will review the incidence, diagnosis, and management of arthrofibrosis and neurovascular injuries following TKA.

48.2 Arthrofibrosis

Arthrofibrosis following TKA is a relatively common and potentially debilitating complication. While an exact clinical definition of arthrofibrosis is not widely accepted, most studies on the topic describe it as an arc of total motion <60°, flexion <75°, or a flexion contracture >15° [1]. This stiffness can make routine activities of daily living a challenge for patients, as a minimum amount of flexion is necessary for navigating stairs (83° flex-

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ion), sitting in a chair without hands (93°), and tying shoelaces while seated (106°) [2].

Side Summary
Arthrofibrosis is described as an arc of total motion <60°, flexion <75°, or a flexion contracture >15°. It can make routine activities of daily living a challenge for patients, as a minimum amount of flexion is necessary for navigating stairs (83° flexion), sitting in a chair without hands (93°), and tying shoelaces while seated (106°).

In the modern literature, arthrofibrosis requiring intervention is seen in 1–7% of patients following primary TKA [3–6]. The cause of arthrofibrosis following TKA can be difficult to determine and is often multifactorial.

The best predictor of postoperative range of motion (ROM), however, is preoperative ROM [1, 3, 6, 7]. Patients who are stiff before surgery must be warned that they are at a higher risk for postoperative stiffness. Most authors feel that there is an individualized biological predisposition for postoperative stiffness [1]. Other patient factors that have been associated with arthrofibrosis include complex regional pain syndrome, diabetes, Caucasian race, and smoking [1, 3, 7]. Surgical factors can also result in postoperative stiffness and include component malrotation or oversized implants [5].

Side Summary
The best predictor of postoperative range of motion is preoperative range of motion.

Specifically, full extension is essential in order to allow proper pain-free mobilization. Lack of extension causes an increase in patellofemoral contact pressure and may become symptomatic.

To avoid postoperative stiffness, removal of osteophytes and appropriate soft tissue releases should be performed at the time of surgery [1]. Components should be appropriately sized and placed during the index procedure.

Continuous passive motion (CPM) machines are not effective at preventing or treating stiffness after TKA, and should not be used according to 24 randomized trials including 1445 patients [8]. More recent meta-analyses have also concluded that CPM machines offer no improvement in ultimate ROM or outcome following TKA, and the use of these devices has fallen out of favor in many centers as a result [9]. However, aggressive physical therapy and motion should be performed in the immediate postoperative period to avoid stiffness [10, 11].

Side Summary
Continuous passive motion (CPM) machines are not effective at preventing or treating stiffness after TKA.

Orthopedic surgeons must carefully monitor patients for arthrofibrosis in the weeks following TKA. While the decision to intervene must be individualized to each patient, most surgeons agree that flexion less than 90° at 6 weeks should raise concern for clinically significant stiffness [6]. At a minimum, these patients require close observation and formal physical therapy [12]. If these less-invasive interventions do not achieve flexion >90° or a total arc of motion >60° between 6 and 12 weeks after surgery, more aggressive treatment is often indicated [1, 6, 13, 14].

Side Summary
Knee surgeons must carefully monitor patients for arthrofibrosis in the weeks following TKA. While the decision to intervene must be individualized to each patient, most surgeons agree that flexion less than 90° at 6 weeks should raise concern for clinically significant stiffness. The most common intervention for arthrofibrosis is a manipulation under anesthesia (MUA).

The most common intervention for arthrofibrosis is a manipulation under anesthesia (MUA). MUAs have been shown to be both safe and effective, if performed in the following manner (see Figs. 48.1, 48.2, 48.3 and 48.4). After appropriate anesthesia has been administered, the patient is placed in the supine position. The surgeon first ranges the knee to check passive ROM. Next, gentle pressure is applied to the proximal tibia with both hands or the weight of the surgeon's chest to force the knee into flexion beyond the initial degree of passive ROM. As the soft tissue contractures break apart, audible or palpable crepitation may be noted within the knee. The surgeon must keep in mind an expected goal range of motion with the MUA (typically based on preoperative ROM) and be cautious not to push a knee beyond this point. Some surgeons advocate directing the flexion force at the proximal one-third of the tibial shaft, to avoid a long lever arm that could result in fractures of the femoral condyle. While limited gains are often made in extension, a similar technique may be utilized to break up adhesions that may be causing a flexion contracture. It is critical that the surgeon accurately documents post-manipulation ROM, and pre- and post-MUA photographs are often useful to counsel the patient and their physical therapists on the surgeon's expectations following the procedure.

Fig. 48.1 Lack of extension prior to manipulation

Fig. 48.2 Flexion deficit prior to manipulation

Fig. 48.3 Extension after manipulation

Fig. 48.4 Flexion after manipulation

On average, patients regain 30–35° of their total arc of motion following an MUA (Table 48.1) [6, 13, 14]. MUAs have proven to be more effective at increasing flexion relative to extension, with one study reporting average flexion gains of 36°, compared to improvements of only 6° in extension [15].

Early detection of arthrofibrosis is key, as MUAs performed within 12 weeks of surgery have been shown to have improved gains in ROM and higher Knee Society Scores (KSS) compared to MUAs performed after 12 weeks [16]. Later MUAs should still be considered, however, as another study reported good outcomes following MUA performed more than 12 weeks after TKA [6]. Aggressive multimodal physical therapy is

Table 48.1 Average range of motion (ROM) in cases of arthrofibrosis [6]

Time period	ROM (°)
Before TKA (active ROM)	102
During TKA after closure (passive ROM)	111
After TKA before MUA (active ROM)	70
During MUA (Passive ROM)	110
Immediately After MUA (active ROM)	94
6 months after MUA (active ROM)	97
12 months after MUA (active ROM)	101
60 months after MUA (active ROM)	105

encouraged following an MUA [10]. A rare but serious potential complication with MUA is an iatrogenic periprosthetic fracture (0.2% of cases); this can be avoided with the careful technique described above [13]. While the majority of patients have a successful outcome after MUA, up to 17% of patients require a repeat MUA for recurrent stiffness with a subsequent success rate of only 59% [7]. The remaining 41% of patients that failed a second MUA required surgical intervention [7].

Patients who come into surgery with fixed flexion or extension contractures can achieve optimal outcomes and range of motion with careful surgical technique and aggressive postoperative therapy. Patients with lack of flexion entering surgery may gain increased range of motion through careful removal of posterior osteophytes, which may block deep flexion. Preoperative flexion contractures may be improved by increasing the amount of bone resected from the distal femur or performing a posterior capsular release from the back of the femur during surgery [17]. While some surgeons advocate for dynamic splinting to achieve full extension for postoperative flexion contractures [18], a paucity of literature exists to guide the surgeon in the decision to treat flexion contractures with aggressive physical therapy or splinting.

A multitude of adjuvant treatments at the time of and immediately following an MUA has been proposed. These adjuvant strategies typically attempt to decrease scar tissue formation, either by blunting the inflammatory response or by directly inhibiting collagen formation. In targeting inflammation, different reports have supported the use of non-steroidal anti-inflammatory drugs, intra-articular cortisone injections, or systemic steroid use [11, 19, 20]. One recent comparative study showed no difference with or without an intra-articular cortisone injection following an MUA [21]. No other comparative studies exist to support the use of one anti-inflammatory strategy over another [11, 21]. A recent study demonstrated that disruption of extracellular collagen formation may prevent excessive scar tissue and improve range of motion following traumatic injury to a joint [22]. Other novel adjuvant therapies that have been reported with limited literature support include Botulinum toxin injections [23], indwelling epidural catheters [24], radiation therapy [25], and interleukin-1 antagonists [26].

Surgical interventions for refractory cases of arthrofibrosis include arthroscopic or open lysis of adhesions and/or revision surgery. Recent studies have reported average arc of motion gains of 36° (range 18–60°) following arthroscopic lysis of adhesions [14, 27]. Similar gains were reported following an open lysis of adhesions with improvements ranging from 19° to 43° [14, 27]. Typically reserved for stiff knees that have not responded to other interventions, or when correctable component malrotation or implant oversizing is identified, revision TKA has been shown to have average gains of only 25° [27]. In severe cases of arthrofibrosis, where contracted collateral ligaments are involved, one study has recently reported mean gains of 57° in total arc of motion and a reduction in the flexion contracture of 28° with a revision to a rotating hinge followed by low-dose irradiation [25].

Side Summary

In cases of arthrofibrosis that do not respond to therapy alone, average gains of 30–35 degrees can be expected with a manipulation under anesthesia. In refractory cases that require arthroscopic or open lysis of adhesions, similar average gains of 36 degrees can be expected.

Despite generally good outcomes with most interventions for postoperative stiffness, orthopedic surgeons must be aware of pre- and intraoperative factors that can be associated with arthrofibrosis. If stiffness becomes a problem in the postoperative period, early detection and intervention can typically result in a satisfactory patient outcome. While recurrent cases of arthrofibrosis may be treated successfully with surgical intervention, every effort must be made to avoid this extreme and potentially morbid option.

48.3 Nerve Injuries

Fortunately, nerve injuries are rare complications reported in only 0.3–1.3% of primary TKAs (Table 48.2) [28–32]. The most frequent nerve deficit is a common peroneal nerve palsy (CPNP) [33]. Risk factors for nerve palsy following TKA include preoperative valgus deformity, flexion contracture (≥20°), younger age, and higher body mass index (BMI) [28, 33]. Rheumatoid arthritis has also been associated with nerve palsies after TKA, with rates as high as 17% [34]. A clinical history of prior or existing nerve palsy or nerve injury may also predispose patients to a CPNP following TKA, because of the “double-crush” phenomenon [28, 35]. This theory suggests that a peripheral nerve that is compressed or damaged at one point along its track may be more sensitive to injury from a second insult, even if the second insult may not cause any nerve injury in isolation [35]. A classic example would be compression of a nerve root exiting the spine with contemporaneous compression of the same nerve fibers in a peripheral nerve in the arm or leg. Iatrogenic causes of nerve palsy following TKA may include epidural analgesia, constrictive dressings, and prolonged or high-pressure tourniquet use [28, 29, 31, 36]. Generally, tourniquet pressures above 300 mmHg and durations beyond 120 min should be avoided [36].

Table 48.2 Incidence of peroneal nerve palsy following total knee arthroplasty

Study	Number of TKAs	Incidence of nerve palsy (%)
Rose (JBJS 1982) [30]	2626	0.9
Asp (CORR 1990) [32]	8998	0.3
Idusuyi (JBJS 1996) [31]	10361	0.3
Schinsky (JOA 2001) [37]	1476	1.3
Park (JOA 2013) [33]	7405	0.5

Side Summary
Nerve injuries are rare complications reported in only 0.3–1.3% of primary TKAs, with the most frequent nerve deficit being a common peroneal nerve palsy.

As with arthrofibrosis, early detection and management of postoperative nerve palsies are important for optimizing patient outcomes. The vast majority of nerve palsies are detected in the immediate postoperative period with a careful neurological exam [29]. Orthopedic surgeons must make detailed neurological checks part of their routine following TKA, especially after the epidural/spinal anesthetic has worn off. In cases of severe valgus deformity or flexion contracture, the index of suspicion must be higher and patients should be forewarned of this potential complication during their preoperative visit [28].

Side Summary
Patients with severe valgus deformity are at increased risk for postoperative common peroneal nerve palsy and should be made aware of this risk prior to surgery.

Once a nerve deficit has been identified, early management should include removal of any compressive dressings and cessation of epidural analgesia [33]. The knee should immediately be flexed to reduce tension on the common peroneal nerve. If a foot drop is detected, an ankle–foot orthosis (AFO) is essential to aid with ambulation and to prevent equinus contracture [33]. Outside of these early interventions, the basic management strategy for a postoperative nerve palsy, as with most nerve palsies, is simply observation. A baseline electromyography (EMG) and/or nerve conduction study (NCS) may be useful to assess the extent of the injury and monitor nerve recovery over time, although controversy exists regarding the utility and timing of these studies in the setting of peripheral nerve injury [38].

Side Summary
Once identified, peroneal nerve palsies should be treated with removal of compressive dressings, an ankle–foot orthotic to prevent equinus contracture, and observation.

A full recovery can usually be expected in 50% or more of the cases of nerve palsy (Table 48.3) [30–33, 37]. The best predictor of ultimate nerve recovery is the extent of the initial injury. When the initial injury is incomplete, there is a 75% chance for a full recovery [33]. When the initial injury is complete (i.e., no motor or sensory function in the nerve distribution), full recovery has been observed in only 20% of cases [33]. Fortunately, the vast majority (86%) of palsies are incomplete [33]. Maximal recovery usually occurs in the 6–12 months following injury, but improvement in nerve function can continue for more than 2 years [37]. Finally, it should be noted that even patients without complete nerve recovery reported Knee Society Scores (KSS) similar to those without palsies [30]. Persistent foot drop lasting more than 2–3 years after surgery may be managed with tendon transfers.

Nerve injury following TKA is a rare complication that can typically be managed with observation and supportive care. Despite the low incidence of this complication, orthopedic surgeons must understand risk factors for nerve palsies and identify nerve dysfunction in the early postoperative period. With the appropriate management, partial or total recovery can be expected in most cases.

Side Summary
The timing and extent of nerve recovery depend on the severity of the initial injury. While 75% of patients with partial nerve palsies have a full recovery, complete injuries only demonstrate full recovery in 20% of cases.

Table 48.3 Full recovery following peroneal nerve palsy after total knee arthroplasty

Study	Cases with full recovery (%)	Mean length of follow-up (range) (years)
Rose (JBJS 1982) [30]	9	(0.5–7)
Asp (CORR 1990) [32]	50	5.1
Idusuyi (JBJS 1996) [31]	50	3.9
Schinsky (JOA 2001) [37]	68	1.5
Park (JOA 2013) [33]	68	2.5

48.4 Vascular Injuries

Vascular injuries are even less common than nerve injuries following TKA, occurring in only 0.03–0.17% of cases (Table 48.4) [39–43]. While direct laceration of vessels at the popliteal region has been reported and can be directly repaired intraoperatively, the vast majority of vascular injuries after TKA involve pseudoaneurysms [44]. These pseudoaneurysms form as a result of arterial wall injury, potentially from subluxation of the tibia during TKA, that can lead to localized pulsatile vascular engorgement and subsequent thrombus formation [45]. These can potentially lead to blood flow occlusion to the distal extremity. Pseudoaneurysms are typically located in the popliteal artery, but they have also been reported in the geniculate vessels [46].

Side Summary
Vascular injuries following TKA are exceedingly rare, occurring in 0.03–0.17% of cases.

Table 48.4 Incidence of vascular injury following total knee arthroplasty

Study	Number of TKAs	Incidence of vascular injury (%)
Rand (JOA 1987) [39]	9022	0.03
Calligaro (JVS 2003) [42]	13618	0.17
Geertsema (JOA 2012) [40]	2026	0.15
Troutman (JVS 2013) [43]	26374	0.14
Ammori (JOA 2016) [41]	7937	0.09

Orthopedic surgeons must be aware of risk factors for vascular injury following TKA. Extensive flexion contracture, pre-existing peripheral vascular disease, and weak or absent pulses on preoperative exam are all risk factors for acute limb ischemia after TKA [39, 42]. Debate exists regarding the appropriate screening and management for patients undergoing TKA, but a vascular consult should be considered preoperatively if distal pulses are absent [42]. The vascular surgery literature reports that patients with ankle–brachial indices (ABIs) <0.40 warrant advanced vascular imaging and/or angiography [42]. Controversy exists regarding the importance of vascular calcifications identified on preoperative radiographs, which have been documented in more than 30% of TKA patients in some series [47]. While one study showed no increase in perioperative ischemic complications in patients with calcified vessels on preoperative radiographs [48], a newer study refuted those findings and reported an increased risk of arterial thrombosis and delayed wound healing in patients with vascular calcifications on pre-op X-rays [47]. Recent literature suggests tourniquet use does not significantly alter the risk of wound healing problems or venous thromboembolism in this population [48].

While rare, vascular injuries following TKA are potentially devastating and can result in nerve palsies, compartment syndrome, amputation, and death [41–44]. In order to avoid these complications, early detection and intervention is crucial. Vascular injuries may present with signs of ischemia, hemorrhage, or both [43]. Fortunately, most cases of vascular injuries are identified immediately following surgery with a careful pulse exam [41, 44]. Vascular consultation and advanced imaging, such as a duplex ultrasound, computed tomography (CT) angiogram, or angiography, can then be performed to confirm the diagnosis [41]. In one large series, 57% of cases were diagnosed immediately following surgery, 37% were detected between postoperative day (POD) 1 and 5, and the remaining 6% were diagnosed between POD 6 and 30 [43]. Delayed diagnoses have also been reported in other studies, with poorer outcomes associated with delay in detection and treatment [41].

Side Summary

While rare, vascular injuries following TKA are potentially devastating and can result in nerve palsies, compartment syndrome, amputation, and death. In order to avoid these complications, early detection and intervention is crucial.

Management options for acute limb ischemia following TKA include open or endovascular operations. Minor injuries have been managed non-operatively with success, but most cases require angioplasty, thrombectomy, or a bypass graft [44]. Traditionally, open surgeries have been the gold standard for acute revascularization [42, 43]. More recently, successful outcomes have been achieved with less-invasive endovascular approaches [43, 49].

Assuming early detection and intervention, most patients will make a full recovery following vascular injury (Table 48.5) [39–44]. Compartment syndromes requiring fasciotomies have been reported in 22–43% of cases [41, 42, 44]. Simultaneous nerve palsies, most commonly foot drop, have been documented in 12–22% of cases [42, 43]. While rare, amputation has been performed in approximately 7% of cases [39, 41, 44].

Vascular injuries are exceedingly rare complications following TKA. Unfortunately, it is a

Table 48.5 Outcome following vascular injury after TKA

Study	No. of cases	Full recovery	Complications/amputation
Rand (JOA 1987) [39]	3	1	2/2
Calligaro (JVS 2003) [42]	18	12	6/0
Parvizi (JOA 2008) [44]	11	8	3/1
Geertsema (JOA 2012) [40]	3	3	0/0
Troutman (JVS 2013) [43]	37	33	4/0
Ammori (JOA 2016) [41]	7	3	3/1

potentially severe complication that can result in loss of limb if detected in a delayed fashion or managed improperly. Up to 50% of cases have resulted in litigation against the operative surgeon [44]. In order to avoid these poor outcomes, orthopedic surgeons must be awtare of this potential complication and monitor patients closely for any signs of vascular compromise in the acute postoperative period.

Take Home Message

Avoiding complications after TKA requires an understanding of arthrofibrosis and neurovascular injuries. Surgery should be performed with properly placed implants, appropriate soft tissue releases, minimal tourniquet time, and careful subluxation of the tibia relative to the femur to avoid these complications in the first place. With the proper clinical suspicion and patient monitoring, these complications can be detected and addressed in the hours or weeks following surgery. Early detection and treatment often results in full recovery and high patient satisfaction. Delayed diagnosis and improper management can result in poor outcomes, including permanent disability and loss of limb and/or life.

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Infection Prophylaxis in TKA

49

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Keynotes

1. Surgical site infection (SSI) and periprosthetic joint infection (PJI) are serious and feared complications following total knee arthroplasty (TKA), leading to significant morbidity and repeat surgical procedures.
2. Despite all efforts at infection reduction, the rate of PJI is around 0.5–1.9% in primary TKAs and 8–10% in revision TKAs. PJI in total joint arthroplasty (TJA) is projected to cost the healthcare system over $1.62 billion US dollars by 2020.
3. Modifiable preoperative risk factors of infection include diabetes mellitus, nutritional deficiencies, obesity, smoking, inflammatory arthritis, and methicillin-susceptible *Staphylococcus aureus* (MSSA), and methicillin-resistant *S. aureus* (MRSA) colonization.
4. Intraoperative techniques utilized to mitigate infection risk include skin preparation and draping, surgical gowns and gloves, antimicrobials, operating room (OR) traffic, wound irrigation, wound closure and dressings, and length of surgery.
5. Postoperative factors that contribute to infection risk include indwelling catheters, wound drains, blood transfusions, and dental procedures.
6. Surgeons should be mindful of modifiable risk factors that can be utilized to minimize the risk of PJI.

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49.1 Preoperative Risk Factors

There are several risk factors that can be modified for infection prophylaxis in TKA. These include diabetes mellitus, nutritional deficiencies, obesity, smoking, inflammatory arthritis, and MSSA/MRSA colonization.

49.1.1 Diabetes Mellitus

Patients diagnosed with diabetes mellitus have a significantly higher risk for PJI after TJA compared to nondiabetic patients [1], since dia-

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betes mellitus impairs both the innate and adaptive immune systems and affects phagocytosis [2]. A prospective review of 1214 TKA patients found an increased rate of deep infection in those with diabetes mellitus [3].

There are multiple metrics used to diagnose diabetes mellitus, of which glucose and hemoglobin A1c are the most common. Many orthopedic surgeons utilize hemoglobin A1c levels, or glycosylated hemoglobin, to stratify infection risk in patients with diabetes mellitus. It is known that the risk of infection increases as perioperative hemoglobin A1c increases [4]. Several studies have attempted to establish a hemoglobin A1c threshold associated with increased PJI, with cutoffs ranging from 7 to 8% [2, 3, 5]. A multicenter retrospective study of 1645 diabetic patients with an average hemoglobin A1c level of 6.6% found a hemoglobin A1c threshold of 7.7% to be predictive of PJI [6].

Perioperative glucose levels have also been identified as a modifiable risk factor. Preoperative glucose levels greater than 194 mg/dL lead to increased postoperative maximum glucose levels and increased average perioperative glucose levels, which were correlated with an increased risk of PJI [7]. Increased glucose variability, assessed using a coefficient of variation, is also associated with increased rates of SSI and PJI infections [8]. The relationship between postoperative blood glucose levels and PJI increased linearly, with an optimal cutoff of 137 mg/dL, suggesting that postoperative glycemic control is critical [9].

More recently, other markers of hyperglycemia have been investigated to evaluate the risk of PJI. Serum fructosamine levels greater than 292 umol/L preoperatively had a significantly higher risk for deep infection in TJA [10]. Postoperative hyperglycemia can be safely controlled in both diabetic and nondiabetic patients using a subcutaneous insulin protocol. Insulin was started when finger-stick glucose levels >140 mg/dL when fasting or >180 mg/dL after meals [11].

Efforts should be made to decrease preoperative hemoglobin A1c and fructosamine levels, and control perioperative glucose levels and variability for patients undergoing elective TKA.

Side Summary
Preoperative hemoglobin A1c thresholds ranging from 7 to 8% have been associated with PJI. Preoperative glucose levels greater than 194 mg/dL, serum fructosamine levels greater than 292 umol/L, and increased postoperative glucose variability are associated with increased risk of PJI. Postoperative glucose values and PJI increased linearly with an optimal cutoff of 137 mg/dL. Postoperative hyperglycemia can be safely controlled with subcutaneous insulin protocols.

49.1.2 Nutritional Deficiencies

Nutritional status has become increasingly important for optimizing surgical outcomes and preventing postoperative infections. Nutritional markers and values corresponding with malnutrition are shown in Table 49.1. Wound complications and infections are higher in TKA patients who are below the normal range of albumin, prealbumin, and transferrin when compared with patients who were in the normal range [12]. Vitamin D deficiency has also been associated with a higher rate of infection in a retrospective review of 6593 patients [13]. Patients with a total lymphocyte count <1500 cell/mm^3 had five times greater risk for developing a major wound complication following TJA [14]. Hypoalbuminemia appears to be the most validated marker [13–15] with one institution performing malnutrition screening with albumin and prealbumin levels [16].

Simple laboratory tests can help identify patients who are malnourished, and the appropri-

Table 49.1 Markers of malnutrition

Albumin	<3.5 g/dL
Prealbumin	<18 mg/dL
Total protein	<6.0 g/dL
Total lymphocyte count	<1500 cells/mm^3
Iron	<45 ug/dL
Serum transferrin	<200 mg/dL
25-OH vitamin D	<30 ng/mL

ate treatment or referral to a dietician can be made at that time. One institution's nutritional intervention plan is shown in Table 49.2, with follow-up laboratory studies obtained 6–12 weeks post-intervention [17].

Side Summary
Wound complications and infections are higher in malnourished TKA patients. Markers of malnutrition should be evaluated preoperatively, and low values should be supplemented.

49.1.3 Obesity

The prevalence of obesity is rising and is an increasingly burdensome healthcare issue. Obesity can be classified as severely obese (body mass index [BMI] >35 kg/m^2), morbidly obese (BMI >40 kg/m^2), and super obese (BMI >50 kg/m^2). Multiple studies have correlated increasing BMI with increased rates of wound infection in TKA [18–20]. Proposed mechanisms include increased dead space and impaired wound healing [21]. Obese, morbidly obese, and super obese patients had higher rates of infection than non-obese patients undergoing TKA with super obese patients having a significantly higher risk of infection when compared to all groups [22]. In one study of 8494 TJA, patients with a BMI greater than 50 kg/m^2 had an increased odds ratio of infection of 21.3 when compared to those with a BMI less than 50 kg/m^2 [23]. Morbid obesity (BMI >40 kg/m^2) has been associated with an increased rate of PJI when compared to a normal weight (BMI <25 kg/m^2) [24].

Table 49.2 Supplementation for malnourished patients

Protein supplements	1 gm/kg/daily for 10–14 days
Iron supplementation	324 mg PO TID for 3–4 weeks
Vitamin D	800 IU daily unless deficient. If <20 ng/dL, 50,000 IU weekly for 8 weeks. If 20–30 ng/dL, 5000 IU daily for 3–6 months
Vitamin C	500 mg daily for 2 weeks
Zinc sulfate	220 mg daily

The American Association of Hip and Knee Surgeon (AAHKS) has recommended that consideration should be given to delaying TJA in patients with BMI >40 kg/m^2. Initiating treatment, such as referral to a dietician for a structured weight loss program, can result in weight loss and improved physical health scores [25]. In addition, referral to a bariatric surgeon prior to arthroplasty should be considered, although surgical intervention for weight loss may not significantly reduce complication rates or improve clinical outcomes [26].

Side Summary
Severely obese, morbidly obese, and super obese patients have higher rates of infection than non-obese patients. AAHKS recommends considering delaying TKA in patients with BMI >40 kg/m^2.

49.1.4 Smoking

Smoking and nicotine have been associated with microvascular disease and decreased tissue oxygenation. Nicotine increases carboxyhemoglobin levels, leading to decreased tissue oxygenation. Nicotine also increases catecholamines leading to poor tissue epithelization. Cigarette smoke has been found to alter mesenchymal cells and fibroblasts, reduce growth factors, and increase free radicals. A retrospective review of nearly 80,000 TJA patients revealed that current smokers have an increased risk of wound complications and deep wound infection when compared to former smokers and non-smokers [27]. Current smokers are significantly more likely than non-smokers to undergo reoperation for infection [28]. Both current and former tobacco users are at increased risk of wound complications and PJI; however, former tobacco users had a significantly lower risk of wound complications and PJI compared to current tobacco users [29].

Nicotine is extensively metabolized by the liver into several metabolites. Cotinine has been identified as the most important metabolite since 70–80% of nicotine is converted to it. Cotinine

Table 49.3 Serum cotinine levels by smoking status

Non-smoker	<3 ng/mL
Passive tobacco exposure	3–8 ng/mL
Active tobacco use (cutoff)	>8 ng/mL
Active tobacco use (peak)	200–800 ng/mL

can be measured in the blood, urine, saliva, or hair [30]. Smoking cessation can be confirmed via the serum cotinine assay with values shown in Table 49.3. Cotinine testing improves the self-reported quit rates of smokers before surgery and helps identify those who are still smoking [31]. Patients should quit 4–6 weeks prior to surgery to normalize immune function. Smoking cessation programs have been shown to increase the value of care prior to TJA and remain an important public health issue where orthopedic surgeons can promote life-changing habits [32].

Side Summary
Both current and former tobacco users have an increased risk of PJI, with former tobacco users having a significantly lower risk when compared to current tobacco users. Cotinine can be measured preoperatively to ensure smoking cessation.

49.1.5 Inflammatory Arthritis

Patients with inflammatory arthritis have an increased risk of postoperative infection following TKA relative to those with OA [33]. Many of these patients are on complex drug regimens that affect wound healing and can predispose patients to infections including disease-modifying antirheumatic drugs (DMARDs), biologic agents such as TNF-alpha inhibitors, and glucocorticoids. The American College of Rheumatology and AAHKS have provided recommendations in which medications should be stopped prior to TJA and for how long they should be withheld [34]. Traditional DMARDs and severe lupus-specific medications, as shown in Table 49.4, should be continued at their current dose prior to surgery. Biological agents should be withheld one dosing cycle prior to surgery, and the surgery should be planned at the end of the dosing cycle for that specific medication. Tofacitinib should be withheld at least 7 days prior to surgery. Biological agents are typically restarted after the sutures/staples are out, and there is no clinical evidence of SSI, which is often at 14 days. Glucocorticoids should be continued at their current daily dose if adult patients are taking <15 mg glucocorticoids per day. Otherwise, patients should receive stress doses of glucocorticoids if taking >15 mg per day.

Table 49.4 DMARDs and lupus-specific medications that should be continued prior to surgery

DMARDs
Methotrexate
Sulfasalazine
Hydroxychloroquine
Leflunomide
Doxycycline
Severe lupus-specific medications
Mycophenolate mofetil
Azathioprine
Cyclosporine
Tacrolimus

Communication with the patient's rheumatologist regarding the perioperative management of these medications is essential to help provide the best outcome.

Side Summary
Patients with inflammatory arthritis undergoing TKA are at increased risk of PJI. Recommendations on medication usage perioperatively are provided based on the American College of Rheumatology and AAKHS, with continued administration of methotrexate and no need for stress dose steroids if taking less than 15 mg per day.

49.1.6 MSSA and MRSA Colonization

S. aureus (*S. aureus*) is the leading healthcare-associated pathogen in hospitals worldwide and is a significant cause of morbidity and mortality. In the general population, MSSA nasal colonization is believed to be 20–36.4%, while MRSA nasal colonization is 0.6–6% [35]. The most common pathogens in PJI after TJA are *S. aureus* and coagulase-negative *Staphylococci*, accounting for over 50% of organisms [36]. Several studies have shown that *S. aureus* nasal colonization is associated with SSIs and that preoperative treatment can reduce infection rates [37, 38]. Risk factors for increased *S. aureus* colonization include diabetes, renal insufficiency, and immunosuppression [39].

Screening techniques, such as nasal swab rapid polymerase chain reaction, identify MSSA and MRSA carriers, and allow for targeted prophylactic antibiotic administration of vancomycin in MRSA-positive patients. Implementing institution-wide screening and decolonization programs have resulted in significant reductions in postoperative SSIs [40]. Treatment includes 5 days of twice-daily intranasal mupirocin to both nares. Alternatively, some institutions administer a universal decolonization protocol versus a screening and decolonization method, with reports of 85% patient compliance [41, 42]. A study in a single institution found significant decreases in the overall SSI rate for TJA patients and SSIs caused by *S. aureus* organisms with decreased hospital costs when implementing a universal decolonization protocol [43]. However, utilizing mupirocin may result in resistance, which has been shown to be as high as 3.3% in one study [44]. Another treatment alternative that may result in less antibiotic resistance is the use of 5% povidone–iodine nasal swabs in both nares twice a day for 5 days prior to surgery, which was found to significantly reduce both MSSA and MRSA colonizations and could serve as a less costly alternative to mupirocin [35].

> **Side Summary**
> *S. aureus* should be screened preoperatively in patients undergoing TKA and treated with intranasal mupirocin if positive.

49.2 Intraoperative Prevention of Infection

Intraoperative techniques can also be utilized to decrease the risk of infection when performing TKA. These include skin preparation and draping, surgical gowns and gloves, antimicrobials, OR traffic, wound irrigation, wound closure and dressings, and length of surgery.

49.2.1 Skin Preparation and Draping

Skin preparation reduces bacterial skin counts before surgery. Hair removal, if necessary, should be performed as close to surgery as possible in the preoperative area with electric clippers, not razor blades as razors can cause skin irritation. Preoperative cleansing of the patient's skin with chlorhexidine–alcohol was shown to be superior to cleansing with povidone–iodine alone for preventing both superficial and deep infections in TJA patients (Video 49.1) [45, 46]. Dual preparation of the skin should be considered, as contamination may occur while draping. One study found a significant reduction in the incidence of superficial SSI after reapplication of the surgical preparation solution after draping when compared to the group that did not receive the second preparation [47]. Elective arthroplasty should not be performed in patients with active ulceration of the skin in the vicinity of the surgical site [48].

Drapes impregnated with bacteriostatic agents, such as iodine, have been shown to reduce bacterial proliferation during surgery [49]. Iodophor-impregnated adhesive incise drapes significantly reduced bacterial colonization of the surgical site when compared to patients without adhesive drapes [50].

> **Side Summary**
> Hair removal should take place as close to surgery as possible using electric clippers, and chlorhexidine–alcohol can be used as a surgical preparation solution to reduce the likelihood of TKA infections. Iodophor-impregnated adhesive drapes can reduce bacterial colonization at the surgical site and should be utilized.

49.2.2 Surgical Gloves and Gowns

Surgical gloves can be a source of wound contamination. One study that included 1226 primary TKAs found the risk of superficial SSI to be higher after visible glove perforation [51]. Changing gloves at regular intervals is an effective way to decrease both the incidence of glove perforation and bacterial contamination [52]. Consideration should be given to changing gloves after draping or when the case is prolonged to help decrease bacterial contamination [53].

Surgical exhaust suits are often used when performing TKA, although the evidence supporting decreased infection risk is debatable (Fig. 49.1). The number of colony-forming units (CFUs) significantly decreased when exhaust gowns were used in comparison to regular occlusive gowns; however, evidence of wound contamination was seen in 64% of cases when exhaust gowns were used and in 60% when standard occlusive gowns were used [54]. A systematic review found that body exhaust suits reduced operative contamination and deep infection rates, while modern surgical helmet systems did not reduce contamination of deep SSIs during TJA [55].

Side Summary
Hair removal should take place as close to surgery as possible using electric clippers, and chlorhexidine–alcohol can be used as a surgical preparation solution to reduce the likelihood of TKA infections. Iodophor-impregnated adhesive drapes can reduce bacterial colonization at the surgical site and should be utilized.

49.2.3 Antimicrobials

Administration of preoperative antibiotic prophylaxis is effective for reducing SSI rates. Routine prophylactic antibiotics should include a weight-based dose of the first-generation cephalosporin, such as cefazolin. Vancomycin or clindamycin may be used if a beta-lactam allergy is present. Vancomycin should be considered in patients who are current MRSA carriers, and clindamycin use should be limited as it can lead to *C. difficile* colitis. The Centers for Disease Control and Prevention (CDC) recommends that the timing of prophylactic antibiotics be administered such that a bactericidal concentration of the agent is established in the serum and tissues when the incision is made. Guidelines indicate that most antibiotics should be administered within 1 h of surgery and within 2 h for vancomycin and fluoroquinolones. Preoperative antibiotics should be based on weight and should be weight-adjusted. Antibiotics should also be re-dosed intraoperatively after two half-lives of the prophylactic agent (after 4 h), if there is a large blood volume loss (>2000 cc) and if there is large fluid resuscitation (>2000 cc) [18]. Postoperative antibiotics should not be administered for greater than 24 h after surgery, and in clean cases, the CDC recommends that patients only receive one preoperative dose of antibiotics, which is controversial [56].

Antibiotic-impregnated polymethylmethacrylate cement (ABX-PMMA) has been used to help reduce the risk of PJI. However, there is no conclusive evidence to demonstrate that the routine use of ABX-PMMA in primary TKA reduces the risk of subsequent PJI. A systematic review of 8 articles, and nearly 35,000 patients showed that ABX-PMMA did not reduce the prevalence of PJI and resulted in an additional cost of $155,000–$310,000 per year at a center that performs approximately 1000 TKAs per year [57]. The benefits of ABX-PMMA may outweigh the cost and other adverse effects of antibiotic administration, such as nephrotoxicity, in high-risk patients, such as those with immunosuppressive diseases like diabetes, rheumatoid arthritis, systematic lupus erythematosus, or with a history of previous PJI [58, 59].

The use of local antibiotics, such as topical vancomycin powder, has been utilized to reduce PJI (Fig. 49.2). One retrospective study of 744 cases found that the administration of 2 g of vancomycin powder in the surgical wound prior to capsule closure prevented PJI in primary TKA patients and trended toward prevention in primary total hip arthroplasty (THA) and revision TKA and THA patients [60].

Side Summary
Preoperative antibiotic prophylaxis is effective in reducing SSI rates, and a first-generation cephalosporin such as cefazolin is recommended, which should be administered within 1 h of incision. Postoperative antibiotics should not be continued greater than 24 h after surgery. There is no clear evidence that ABX-PMMA reduces the prevalence of PJI, and the benefits and risks should be considered. Application of vancomycin powder to the surgical wound prior to capsule closure can be considered to reduce the risk of infection.

49.2.4 Operating Room Traffic

OR traffic and door openings during TJA correlate with the number of airborne particles in the OR, potentially predisposing patients to increased risk of PJI [61]. One study of 124 surgical procedures showed that the levels of CFUs significantly correlated with the number of people present and the number of door openings. Of the 6717 door openings, 77% were considered unnecessary [62]. Door openings led to increased contamination rates by two mechanisms: (1) it was linked to the number of staff in the OR during operations, and (2) it created air turbulence disrupting the positive laminar flow in the

Fig. 49.1 Body exhaust suit from the (**a**) anterior and (**b**) lateral viewpoints

Fig. 49.2 Vancomycin powder being applied intraarticularly to a total knee arthroplasty wound prior to closure

OR. Data collection during 30 orthopedic procedures demonstrated a significantly positive correlation between traffic flow rates and number of people present in the OR with bacterial counts [63]. Traffic flow, number of people present, and duration of surgery explained 68% of the variance in bacterial counts [53].

Numerous strategies have been proposed to reduce OR traffic, including limiting the number of people present (Fig. 49.3), proper education of OR personnel regarding OR traffic and infection risk, and minimization of staff rotation during TJA [64, 65]. OR traffic should be kept to a minimum to decrease the risk of airborne contamination and PJIs.

Side Summary
OR traffic and door openings correlate with the number of airborne particles and should be kept to a minimum to decrease the risk of PJI.

49.2.5 Wound Irrigation

Intraoperative irrigation during TJA is used to reduce bacterial burden and subsequent SSIs. The CDC and World Health Organization recommend intraoperative irrigation with dilute povidone–iodine before closure [66]. A meta-analysis of seven randomized controlled trials consisting of general surgery and orthopedic surgery procedures demonstrated a significant SSI reduction when performing incisional wound irrigation with an aqueous povidone–iodine solution in clean and clean-contaminated surgeries [46]. A retrospective study found a significant reduction in acute postoperative deep infections when comparing 688 primary TJA cases that utilized 0.35% povidone–iodine lavage to 1862 primary TJA historical controls that did not use the same betadine lavage protocol [67]. The pressure in which wound irrigation is performed (high-pressure pulse lavage vs. low-pressure) has not been shown to make a difference in infection risk, although most studies have been conducted in traumatic open wounds [68, 69]. The addition of antibiotics to irrigation, such as polymyxin or bacitracin, is controversial and does not appear to make a significant difference [66]. The CDC concluded that antibiotic irrigation of the wound results in no benefits or harms for reducing SSIs when compared with no irrigation or saline irrigation [56]. Given the current data and current concerns of antimicrobial resistance, costs, and hypersensitivity, antibiotic irrigation is not recommended in TKA [66].

Side Summary
Incisional wound irrigation with an aqueous povidone–iodine irrigation has been shown to reduce the rate of PJI, the pressure at which irrigation is performed and the addition of antibiotics does not seem to make a significant difference in infection prevention.

Fig. 49.3 Operating room traffic

49.2.6 Wound Closure and Dressings

Surgical wound closure and postoperative dressings may affect infection rate. Staples, sutures, and adhesives are used for closure of TJA; however, one method has not been shown to consistently reduce the risk of PJI [70–72]. In a blinded, prospective randomized control trial of 187 TJAs closed with either skin staples, subcuticular 3.0 monocryl suture, or 2-octylcyanoacrylate (OCA), there was no difference in infection rates between groups [73]. Closure with OCA was associated with less wound drainage in the first 24 h, although there was a trend for prolonged wound drainage in TKA. Closure with staples was significantly faster than with OCA or suture.

The use of prophylactic negative pressure wound therapy (NPWT), such as an incisional wound vac, has demonstrated no significant difference in deep infection rates when compared with standard surgical dressings after routine primary TJA [74]. A prospective analysis of 33 TKAs found no improvement in wound healing or cost with an insignificant improvement in wound leakage in NPWT compared to conventional dry dressings [75]. Occlusive or silver-impregnated dressings have been shown to reduce the rates of wound complications, SSIs, and PJI compared with standard gauze dressings and should be used routinely [76]. A prospective, randomized controlled trial of 240 TKA patients found that using a silver-impregnated dressing was independently associated with SSI reduction when controlling for confounding variables compared to an antimicrobial dressing (Sofra-Tulle) and gauze with tape [77]. Dressings that remain dry should remain in place for a minimum of 48 h and are often left on for 1 week. Minimizing unnecessary dressing changes decreases repeated exposure to pathogens in the surrounding air and allows for maximum wound healing [70].

Side Summary
There is no wound closure method that consistently reduces the risk of PJI when evaluating staples versus sutures versus adhesives. The use of NPWT has not demonstrated a significant reduction in PJI. Occlusive or silver-impregnated dressings have been shown to reduce the rate of wound complications and PJI and should be utilized.

49.2.7 Longer Surgical Time

Increased operative times have been correlated with increased SSIs and PJIs in TKA. One review of 11,840 primary TKAs found that SSI rates and PJI rates were significantly higher in cases >121 min compared to those <85 min [78]. Cases complicated by PJIs had longer mean operative times (135 min) compared to non-infected cases (105 min), and multivariate analyses revealed an 18% PJI increase and an 11% SSI increase for every 15 min increase in operative time. A review of 905 patients found that the mean operative duration for TKA with SSI was significantly longer compared to TKA without SSI [79]. Prolonged operative times may be a result of the complexity of surgery; however, efforts should be coordinated to reduce OR time without compromising the procedure being performed [80].

Side Summary
Efforts should be made to reduce OR time, as longer OR times have been associated with increased rates of PJI.

49.3 Postoperative Risk Factors

Differences in postoperative management have been demonstrated to influence perioperative infection rates. These include the use of indwelling catheters, wound drains, blood transfusions, and dental procedures.

49.3.1 Indwelling Catheters

The perioperative use of indwelling foley catheters is a controversial, yet it is a routine practice for some individuals. Theoretically, the prolonged use of indwelling foley catheters may place patients at increased risk of developing urinary tract infections and subsequent hematogenous spread of pathogens to prosthetic implants [81, 82]. However, sub-optimal postoperative bladder management can lead to postoperative urinary retention (POUR). Zhang et al. performed a randomized controlled trial comparing the rates of urinary tract infection (UTI) and POUR in lower extremity TJA patients comparing the use of indwelling foley catheterization versus intermittent straight catheterization (ISC). This study demonstrated that indwelling foley catheterization removed less than 48 h postoperatively was superior to ISC in the prevention of POUR without demonstrating an increase in the rate of UTI [83]. Wald et al. retrospectively reviewed 35,904 patients undergoing a variety of surgical procedures and found that retention of the indwelling catheter beyond 48 hours was associated with a doubling in the rate of UTI [84]. However, patients who had arthroplasty performed with spinal anesthesia might not benefit from foley catheterization at all. Miller et al. demonstrated that in patients undergoing THA under spinal anesthesia, there was no statistical difference in urinary retention, UTI, or length of stay between the catheterized versus control group [85]. Although it is unclear if increased rates of UTI correspond to increased PJI, prolonged catheterization can contribute to increased cost and length of hospitalization [86]. Thus, if foley catheters are used, they should be removed as soon as possible after surgery.

Side Summary
Retention of postoperative indwelling urinary catheters greater than 48 h is associated with increased rates of UTI. Patients undergoing joint replacement under spinal anesthesia might not benefit from catheterization at all.

49.3.2 Closed Suction Drains

The use of postoperative closed suction drains persists despite mounting controversy. The theoretical advantages of closed suction drains include improved pain control and hematoma reduction. However, drains increase exposure to contamination, as bacterial colonization of the drain tip is known to occur within the first 24 h, although there is no clear evidence that culture-positive drain tips lead to early PJI [87–91]. Parker et al. performed a meta-analysis review of 3495 patients undergoing TKA managed with and without placement of a wound drain. They found no difference in infection rate, wound hematoma, or wound complications; however, there was a significantly greater need for transfusion in wounds managed with drains [92]. Additionally, no difference was seen with respect to limb swelling, venous thrombosis, or hospital stay. Parker et al. performed a Cochrane database systematic review on the use of drains in orthopedic surgery [93]. They pooled data from 36 studies including 5464 patients undergoing a variety of orthopedic surgery, including THA, TKA, shoulder surgery, and hip fracture surgery, among others. They found no statistical difference in the incidence of wound infection, hematoma, dehiscence, or reoperation between wounds with and without closed drain suction. They similarly found that blood transfusion was required more frequently in patients with drains, whereas increased dressing changes and bruising were more common in the group without drains.

Side Summary
Drain use after TKA does not demonstrate any difference in infection rate, wound hematoma, or wound complication. There is a significantly greater need for transfusion when using postoperative drains.

49.3.3 Blood Transfusions

The use of blood transfusions in patients undergoing TJA was historically widespread, with up to 70% of patients undergoing transfusion after TJA [94–96]. Allogeneic blood transfusions have been associated with postoperative infection, although many studies have been inconclusive due to being underpowered [97]. Friedman et al. performed a pooled analysis of 12,000 patients who received allogeneic transfusion, autologous transfusions, and no transfusions after TJA with an endpoint of postoperative infections. They found no significant difference in postoperative infection rates between the no-transfusion group and the autologous transfusion group. Those who received allogeneic transfusion had increased rates of upper and lower respiratory tract infections, lung infections, and wound inflammation/infections (9.9%) versus the autologous and no-transfusion group (7.9%). There was no significant difference in the rate of bone and joint infections, UTIs, or other infections between the two groups [98]. Innerhofer et al. similarly demonstrated that infection rates were higher (12%) in TJA patients who received allogeneic blood transfusions versus those who only received autologous blood (1.2%) [99].

Using multivariate analysis, Newman et al. demonstrated that the total number of allogeneic transfusions used and an American Society of Anesthesiologist score >2 significantly predicted postoperative infection, whereas allogeneic blood exposure alone was not indicative of postoperative infection [100]. Although certain postoperative patients may require transfusion, it is important to minimize exposure to autologous blood in postoperative patients by keeping low transfusion thresholds. Hebert et al. performed a randomized, controlled clinical trial of transfusion requirements in critical care (TRICC) patients to determine whether liberal and restrictive strategies of blood transfusion in critically ill patients yielded equivalent mortality rates [101]. In the restrictive strategy, patients underwent transfusion when hemoglobin concentration was <7.0 g/d, with a desired range of 7.0–9.0 g/d. Patients treated with a liberal transfusion strategy underwent transfusion when the hemoglobin concentration was <10 g/d, with a desired range of 10.0–12.0 g/d. In this study, patients who were less acutely ill and those who were less than

55 years of age had significantly lower mortality rates with the restrictive transfusions strategy. Furthermore, the restrictive strategy reduced the number of red-cell units transfused by 54%. There was no difference in mortality observed in patients with significant cardiac disease. The conclusion of the TRICC trial was to administer blood products to maintain hemoglobin between 7.0 and 9.0 g/d. Although this trial focused on critically ill patients, it may be reasonable to apply a similarly restrictive strategy to orthopedic patients who are typically less comorbid than this study population.

Side Summary
Restrictive blood transfusion strategies (target hemoglobin 7.0–9.0 g/d) demonstrate lower mortality rates than liberal transfusion strategies (target hemoglobin 10.0–12.0 g/d).

49.3.4 Dental Procedures

Transient bacteremia associated with dental procedures may pose a risk of PJI via hematogenous seeding. Bacteremia from routine dental maintenance is common. The frequency of bacteremia may be as high as 44% after tooth brushing, 41% after flossing, and 17% after chewing [102–105]. However, the magnitude of bacteremia caused by these bacteria is quite low (1–32 CFU/mL), and the magnitude of bacteremia required to cause clinically important bacteremia is unknown [106, 107].

Berbari et al. performed a prospective case-controlled study on 339 patients with periprosthetic hip and knee infections and 339 patients without infection; their study found that dental procedures within 6 months to 2 years after the index procedure was not associated with an increased risk of PJI [108]. The second case-controlled series using Medicare Current Beneficiary Data demonstrated similar results, with no association between dental procedures and increased risk of PJI [109]. However, anecdotal evidence of PJI following dental procedure persists. As such, the American Academy of Orthopedic Surgeons (AAOS) and American Dental Association (ADA) developed appropriate use criteria for the management of patients undergoing dental procedures, categorizing vignettes as "rarely appropriate (R)," "may be appropriate (M)," or "appropriate (A)." The 2016 iteration determined that routine prophylactic antibiotic usage is rarely appropriate. According to these guidelines, antibiotic usage in patients with immunocompromised status, hemoglobin A1c >8%, and a history of PJI undergoing dental procedures that involve gingival manipulations is generally appropriate or may be appropriate [110, 111].

Side Summary
Transient bacteremia after dental procedures is common, but the clinic significance is unclear. Routine antibiotic prophylaxis after routine dental procedures is not recommended by AAOS or the ADA.

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50 Rehabilitation After Total Knee Arthroplasty

Robert Prill, Robert Schulz, Gesine Seeber, and Roland Becker

Keynotes

1. There is a lack of consensus regarding the rehabilitation after TKA.
2. Evidence for prehabilitation programs is currently weak. Neither short programs nor very long programs are useful.
3. Postoperative physical therapy should start immediately after TKA surgery using multi-modal interventions.
4. Active interventions are promising in order to decrease the rehabilitation times but with better outcome.
5. There is limited evidence for the usefulness of continuous passive motion (CPM), cryotherapy, and ergometer cycling after TKA.
6. Neuromuscular electrical stimulation should be combined with active exercises.
7. Manual lymphatic drainage rather helps for increasing range of motion than reducing swelling.

50.1 Introduction

50.1.1 Patients' Individual Goals After TKA

The work of the physical therapists (PTs) starts long time before the patient will receive total knee arthroplasty (TKA). The kind of treatment depends on a few main factors, such as the general health status of the patient, motivation, and the level of activity. Patient rehabilitation might be performed in an inpatient or outpatient setting

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or at home, which depends mainly on patients' social and general health status and again motivation. Educational programs for instructing the patient might be additional instruments besides physical therapy. When physical therapy is successful, surgery can be delayed or may even become unnecessary.

Patients with end-stage knee osteoarthritis (OA) show a wide range in terms of age, weight, comorbidities, and physical and psychological conditions. Each patient presents individual factors related to the level of activity, being decisive for the rehabilitation program. The proper judgment of a successful treatment outcome is not easy. Patients' expectation is a very important aspect to take into consideration.

While some patients may feel satisfied when they suffer less pain and regain the ability to perform simple activities of daily living, others may expect full recovery and reintegration into their daily life.

50.1.2 Treatment Evaluation

Patient assessment is important. There are many different scores available; however, important domains should be evaluated. According to the Outcome Measures in Rheumatology (OMERACT), all studies which evaluate patients prior to and after TKA should mandatorily include the domains *pain*, *function*, *satisfaction, revision, adverse effects,* and *death*. Moreover, *economical aspects/costs, everyday participation,* and, if possible, *knee range of motion* should be reported [1]. Some of the aforementioned domains may have minor relevance for PTs in acute hospital settings as other professionals are responsible for their documentation and reporting. However, even though reporting of all domains is not mandatory for daily clinical practice in physical therapy, those domains still influence the therapeutic management strategy. There is a lack of consensus between surgeons and PTs concerning the core domains and frequently used outcome measures [2]. The core domains such as *pain* and *function* and partly *satisfaction* are usually those with special interest for PTs. Patient satisfaction is usually reported with standardized patient self-reported outcome measurements (PROMs), like the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Oxford Knee Score (OKS), and Knee Injury and Osteoarthritis Outcome Score (KOOS). Pain is mostly evaluated and reported by the use of a Visual/Verbal Analog Scale (VAS) or Numeric Pain Rating Scale (NRS) [3, 4]. The most relevant parameters being important for assessing knee and general physical function are currently widely discussed. Some evaluate function by the use of questionnaires including subdomains of *physical functioning*, while others report results of physical examination. With regard to the latter, walking ability and aspects of symmetry like strength of the lower extremity and loading while standing or transferring from sit to stand seem to be promising outcome parameters of physical function.

50.2 Preoperative Treatments and Exercises

The concept of prehabilitation has received increasing acceptance over the last years [5]. The aim is to enhance functional capacity and performance to fulfill the optimal prerequisites prior to surgery in order to cope with stress-related factors during surgery and the early rehabilitation period. The idea of this concept is shown in Fig. 50.1 [6].

Side Summary
Prehabilitation is important in order to improve patients' preparation for surgery and the early postoperative period.

In general, prehabilitation programs should focus on those physical parameters that show low improvement in function and quality of life after TKA. Prehabilitation can be done either at home after initial supervision by a physical therapist or in an outpatient setting under constant physical therapeutic supervision with a major focus on muscle strengthening [7]. In particular, often core

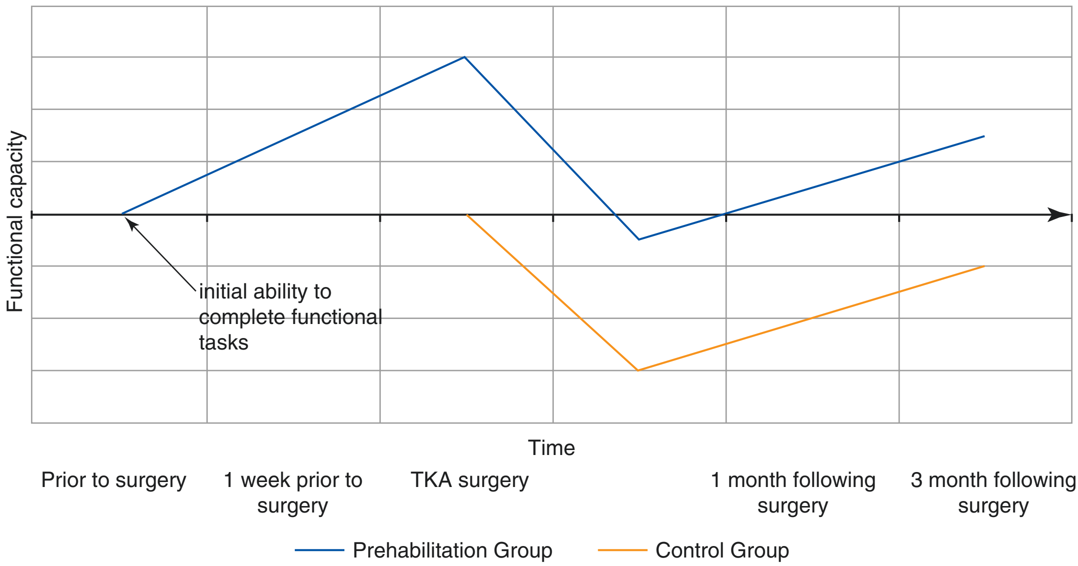

Fig. 50.1 Concept of prehabilitation

stability training, lower extremity strengthening and stretching, strengthening of the upper limb in preparation for walking with crutches, gait and stair training using crutches, lower limb stretching, step training, aerobic training, and proprioceptive training take place.

> **Side Summary**
> Prehabilitation should focus on functional and quality of life parameters, which show slow improvement after TKA only.

However, there is no evidence in the current literature that prehabilitation programs will improve clinical and functional outcomes [5, 6, 8–10]. The same seems to be true for preoperative patient education [11]. The lack of evidence is most likely due to insufficient therapeutic validity and minor methodological quality of currently existing studies [12, 13]. A 12-week prehabilitation program prior to TKA was evaluated, and no improvement was found in the prehabilitation group compared to a control group after 3 and 6 months [14]. Interestingly, twenty percent of the participants in the intervention group canceled their surgery and, as a consequence, were excluded from statistical comparison. Probably, the cancelations were due to improvements of participants' knee-related problems, being a successful outcome for a physical intervention. But this aspect is more interesting for the treatment of end-stage OA than for prehabilitation.

> **Side Summary**
> There is still a lack of approval of using prehabilitation. However, one reason could be inappropriate designs of previous studies.

With regard to prehabilitation programs, it seems rational to use similar types of exercises that are used in the rehabilitation process to restore quadriceps strength, knee range of motion, gait, and stair-climbing capacity. Indeed, most TKA prehabilitation programs comprise lower extremity strengthening, stretching, and stair training [6].

As there is some evidence that hip strengthening is useful in end-stage knee osteoarthritis as well as after TKA, the implementation of prehabilitation program exercises that predominantly target gluteus medius and maximus muscle appears to be promising [15, 16]. In particular, exercises should be performed in an appropriate intensity and duration. Prehabilitation programs of less than 4 weeks seem to lack effectiveness, whereas programs with a longer duration than 8 weeks increasingly lack adherence of the participants [6, 17].

Side Summary
Gluteal muscle strengthening is useful in end-stage OA but also after TKA.

In summary, even though the concept of prehabilitation sounds reasonable, as single trials achieved promising results with prehabilitation especially for the outcome domains *pain* and *function* [18], the current state of evidence does not yet provide justification of its broad application into the clinical routine [19]. Future studies of good methodological quality and better therapeutic validity are warranted before final conclusions regarding the benefit or uselessness of prehabilitation can be drawn.

50.3 Postoperative Treatment and Exercises

Postoperative physical therapy should start immediately after TKA surgery. The exact management strategy, and therefore the associated type and amount of treatment, depends on the clinical setting and the average length of postoperative hospitalization, which differs significantly between hospitals and countries [20]. In addition, individual patient-related and surgery-related factors must be considered. Once the patient is discharged from hospital, different types of rehabilitation programs and settings, including inpatient- or outpatient-based rehabilitation as well as home-based programs, are available. There is an increasing tendency of outpatient rehabilitation programs over the last years.

Side Summary
There are different rehabilitation concepts after discharge from hospitals such as inpatient or outpatient rehabilitation.

50.3.1 Multimodal Rehabilitation Programs

Evidence is given for early multimodal rehabilitation in inpatient settings [21]. Programs only focused on interventions do not cover all aspects of rehabilitation. For example, walking capacity is a fixed relevant outcome after TKA. An isolated walking-skill program leads to better 6-min-walk-test results, being more promising than other physical therapy interventions for this special outcome. However, such gait training program does not affect stairclimbing tests, timed stands, figure-of-eight test, muscle function index, active knee range of motion, or the KOOS [22]. Some of those results are, however, of high interest for an overall positive rehabilitation outcome.

Multimodal rehabilitation programs lead to a more rapid achievement of functional milestones, fewer complications, shorter hospital stays, and reduced costs within the first months, but more research regarding optimal intensity, frequency, and duration of rehabilitation is necessary [21]. Due to the lack of consistency in rehabilitation programs, high variation exists between practice-reported pre- and postoperative care [23]. Supervised physical therapy seems to be more effective than standardized home programs [24]. In the following section, benefits from different types of common treatment components are described in alphabetical order (Figs. 50.2 and 50.3).

50.3.2 Active Physical Therapy Programs

Active programs will decrease the length of rehabilitation while improving the outcome at the


Figs. 50.2 and 50.3 Multimodal treatment approaches including combinations of hands-on and hands-off techniques are generally recommended

same time. Systematic reviews and meta-analyses have shown evidence for muscle strengthening of the lower limb after intensive land-based or aquatic functional exercises in the outpatient setting [25, 26]. Henderson et al. performed a systematic review on active physical therapy measures during inpatient rehabilitation with a focus on decreasing pain, improving activity and range of motion, and reducing hospital length of stay [27]. Active physical therapy programs have been shown to reduce hospital length of stay. Moreover, pain, physical activity, and range of motion were beneficially affected by active intervention programs [27]. Proprioceptive neuromuscular facilitation with its passive, active, and resistive components also seem to positively influence TKA patients, especially on several gait parameters (Figs. 50.4 and 50.5) [28].

Side Summary
Active physical therapy programs such as improving range of motion and muscle function are important. Patients should be mobilized on day 0.

50.3.3 Continuous Passive Motion

A common method intended for preventing venous thromboembolism and knee arthrofibrosis while improving knee range of motion and reducing pain after TKA is continuous passive motion (CPM). However, there is no evidence for any preventive effect of CPM for venous thromboembolism based on a Cochrane review including meta-analyses [29]. In addition, Harvey evaluated the existing literature regarding short-term CPM use but also found no clinically important short-term effects on active knee flexion, pain, function, quality of life, or number of adverse effects [30]. Thus, it can be concluded that there is no need for implementing continuous passive motion in standardized TKA management programs.

Side Summary
There is no evidence that continuous passive motion shows benefit for outcome after TKA.


Figs. 50.4 and 50.5 Gait training as well as stair climbing is fundamental to every active physiotherapeutic treatment approach and can be varied with the use of different levels of aid

50.3.4 Cryotherapy

Cryotherapy is applied during the first days after surgery, aiming to reduce pain, blood loss, and swelling, and to enhance early functional improvements. Less blood loss and a beneficial short-term effect in pain reduction according to visual analog scale were shown within the first 48 h after surgery, while no effect was found at 24 or 72 h [31]. Intensity and duration of ice application are discussable and mainly rely on individual perceptions. There is some evidence for using cryotherapy only (i.e., using moderate cooling temperature of 17 °C) in combination with exercise programs like walking. Michel et al. showed that walking combined with cryotherapy improves walking duration by about 67% and also improves stride length by 57% compared to a control group [32]. In addition, moderate cooling showed statistically significant reduction of pain levels during walking. It remains questionable whether changes in pain levels of 1,2 points on a numeric rating scale of 1–10 is clinically meaningful. However, there is some more evidence for the use of computer-assisted cryotherapy. A long application of 4 to 6 h daily seems to be promising inpatient care. Computer-assisted cryotherapy after TKA seems to be most effective for reduction of opiate use, while the effect on ROM remains questionable [33, 34].

Side Summary
Moderate cooling temperature of 17 °C is recommended for cryotherapy.

50.3.5 Ergometer Cycling

Ergometer-based cycling is a common treatment for patients with knee pathologies. In a randomized controlled trial of 159 patients after TKA, it was found that low resistance ergometer-based cycling, three times a week for 3 weeks, starting 2 weeks after surgery, showed no effect on patients' satisfaction in terms of the rehabilitation process [35]. However, more studies might be required in order to analyze the effect of ergometer cycling on clinical outcome after TKA.

Side Summary
The effect of ergometer cycling remains still unclear for postoperative rehabilitation after TKA.

50.3.6 Manual Lymphatic Drainage

Following TKA surgery, many patients experience severe knee swelling due to excess interstitial fluid resulting from the body's physiologic inflammatory response to the significant tissue trauma caused during surgery [36]. As the fluid load exceeds beyond the lymphatic system's transport capacities, protein remains within the interstitial space, leading to remaining edema, local ischemia, and thus increased pain and functional limitations [36, 37]. In case of severe edema, manual lymphatic drainage may be beneficial as it manually enhances functional transport capacity of the lymphatic system. The current literature for manual lymphatic drainage after TKA surgery is sparse. Two recent randomized controlled trials investigated the effects of manual lymphatic drainage after TKA surgery. Pichonnaz et al. found no significant effects of manual lymphatic drainage for edema reduction [37]. However, these authors found greater passive knee range of motion after 3 months in the intervention group. These findings are in concordance with others, who also found no reduction in knee swelling but an increase in passive knee flexion 4 days after surgery [36]. These findings are important as increased range of motion is associated with a positive effect on pain, functional outcome, perceived satisfaction, and quality of life. However, the impact of manual lymphatic drainage on the long results remains currently entirely unclear [36, 37].

Side Summary
Lymph drainage shows some positive impact on swelling but also on range of motion (Fig. 50.6).

50.3.7 Neuromuscular Electrical Stimulation

Quadriceps femoris muscle weakness and reduction in muscle function are commonly reported after knee surgery. Neuromuscular

Fig. 50.6 Manual lymphatic drainage techniques could be indicated in case of severe edema and may help to regain range of motion earlier

Figs. 50.7 and 50.8 When using NMES, a combination with high-intensity functional tasks appears to be promising

electrical stimulation (NMES) is an additional method for improving strength and reducing pain. Evidence for this method is of low quality. No significant advantages are reported for maximum voluntary isometric torque or endurance between NMES group and controls [38]. There seems to be a short-term benefit of NMES when combining with high-intensity exercise [39]. The exercise and neuromuscular stimulation group shows significantly better quadriceps muscle activation at 6 weeks but not at 12 weeks after NMES and training intervention. Both studies carried high risk of bias [40]. There is more research needed on parameters like duration, frequency, intensity, and adverse events before generally implementing NMES in combination with high-intensity training postsurgery (Figs. 50.7 and 50.8).

50.4 Additional Measures

The role of Vitamin D is not limited to calcium metabolism but also influences inflammatory processes and musculoskeletal function [41]. A cut-off value of a 25(OH)D3 level <40 nmol/L is considered for Vitamin D deficiency [23]. A prevalence of 24% of Vitamin D deficiency was found in a cohort of elderly patients presenting with advanced knee osteoarthritis [42]. The preoperative functional knee scores were significantly lower in patients with Vitamin D deficiency. It has been hypothesized also: Low Vitamin D intake and decreased 25(OH)D3 blood levels may be associated with greater risk of OA and progression of OA [42]. It may also be in part responsible for inferior functional recovery after TKA [41]. Thus, Vitamin D sup-

Table 50.1 Standard rehabilitation program

	Day 1	Day 2	Day 4	Day 8–10
Mobilization in bed	– Respiratory and cardiac exercises – Manual lymph drainage – Isometric exercises	Passive/active ROM (goal for inpatient setting: 0/0/90), assisted exercises	ROM, Strengthening: low ROM squats, Abductor muscle Training, NMES in open kinetic chain	
Get up	Transfer and short walks	Weight-bearing exercises for symmetry		Balancing exercises
Intense physical therapy (30 min)	The accentuation of the therapy components is based on the condition of the patient			
Gait training		3× of maximum walking capacity (time or distance)	Increase walking distance	Increase walking speed
		If possible combined with cryotherapy		
Climbing stairs			Technique	Increasing load
Discharge from hospital				Yes, depending on patients' condition
After discharge rehabilitation				If organizable directly after hospital discharge

plementation prior to surgery and/or during the postoperative TKA rehabilitation process may be considered in patients presenting with Vitamin D deficiency.

50.5 Rehabilitation Programs

50.5.1 Standard Rehabilitation Program

Table 50.1 summarizes the early rehabilitation program during hospitalization starting on day 1. However, especially in conjunction with rapid recovery programs for rehabilitation, mobilization should even start on the day of surgery. Active motion will improve blood circulation and thus reducing the risk of swelling and deep vein thrombosis (DVT). Nevertheless, in many hospitals there is a lack of appropriate physical therapy due to time and staff constrain. There is also few research on standard inpatient rehabilitation programs available so far, especially when considering the combination of different treatment modalities.

50.5.2 Fast-Track Program

Den Hertog and team performed a randomized controlled trial on the Joint Care® (Biomed Europe BV) fast-track program [43]. They showed promising results, based on the following PROMs: American Knee Society Score, WOMAC, and length of stay (LOS). The program focuses on individual patients' abilities and an early standardized mobilization (Table 50.2). A positive and competitive attitude such as "Yes, you can" was implemented in the program showing a stimulating effect for enhancing physical activity of patients. Starting mobilization and class-type group therapy on the day of surgery, two hours of standard intensive physical therapy with a focus on Activities of Daily Living (ADL) and individual case management, this program impresses quite progressive. The two hours of intense physical therapy included walking exercises, improvement in passive range of motion, lower limb muscle strengthening, and respiratory training. Patients received this intense program for another 18 days after discharge. Discharge was scheduled for postoperative day 6.

Table 50.2 Fast-track rehabilitation program

	Day 0	Day 2	Day 6	Day 24
Getting up	Yes			
Group therapy	Yes			
Intense physiotherapy (2 h)	Yes			
Climbing stairs		Yes		
Discharge from hospital			Yes	
Post-discharge rehabilitation			Yes	Stop

CAVE: Even if there is some evidence for the benefit of fast-track programs, it is not finally clarified if disadvantages will be detected in long-term follow-ups.

Take Home Message

- The type, duration, and intensity of rehabilitation are still debatable. Prehabilitation might be a concept to pay more attention to patients' conditions prior to surgery in order to identify and to treat functional deficits better, which are not improving significantly after surgery. However, it needs to be proven in further research.
- Inpatient or outpatient rehabilitation can be performed; however, outpatient programs have become more favorable during recent years. Early mobilization of the patients after TKA is very important. Lymph drainage may help in reduction of swelling and improving range of motion. The positive effect of CPM and cooling therapy on clinical outcome is still not proven yet. However, good scientific studies are scarce. Numerous rehabilitation programs are used and especially fast-track programs gain increasing interest.

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51 How to Assess Outcome After Partial or Total Knee Arthroplasty—Measuring Results that Really Matter!

Cornelia Lützner, Toni Lange, and Jörg Lützner

51.1 Health Outcome Measurement

Health outcome measurement is the basis of clinical practice and medical research [17]. To identify, quantify, and qualify a patient's health status and its alterations is crucial in clinical diagnostics, therapeutic processes, and prognostic issues. At the beginning of a medical treatment or an intervention, the focus lies on health outcomes, meaning changes in the health of an individual, or a group of people, or a population, which can be attributed to the applied procedure [91]. It is important to understand that outcomes are an indicator of changes and typically require repeated measurements before and after an intervention [71]. An outcome covers the outcome domain (*what* is being measured), the measurement instrument (*how* a particular domain is being measured), and the time point of measurement [13]. In the context of knee arthroplasty, for instance, a commonly reported outcome is pain (domain), measured on a Likert scale (measurement instrument) at 1 year postoperatively (time point).

> **Side Summary**
> An outcome covers the outcome domain (what is being measured), the measurement instrument (how a particular domain is being measured), and the time point of measurement.

Before starting the outcome measurement, the domain should be defined clearly, and subsequently, the most appropriate measurement instrument should be selected.

Osteoarthritis (OA) of the knee is a chronic disease, which causes pain, decline in knee function, deformity, and has a significant impact on the patient's life. Knee arthroplasty is an elective surgical procedure for reconstruction of the joint and alleviation of these symptoms [42, 34]. For decades, outcome measurement after knee arthroplasty has focused heavily on clinician-based assessments, such as impaired physical function, and on physical measures, such as range of motion (ROM) and joint stability [44, 21]. These are outcomes that are simply defined by the patient's obvious disorders and their improve-

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ment. In order to assess the effectiveness of the surgery, procedural and technical results are of further interest, such as complications, adverse events, re-operations, revisions, mortality, and prosthesis survivorship [85, 71, 42, 29]. Meanwhile, the focus has shifted toward a more patient-centered approach. More than 20 years ago, Kantz et al. [44] argued for assessment of outcomes that capture the unique perspective of those most affected by the illness and treatment—the patients themselves. Nowadays, patient-centered outcomes, above all other health-related quality of life (HRQoL) outcomes, are widely reported and an integral part of outcome measurement.

51.2 Outcomes of Interest

The main goals of knee arthroplasty are relief of pain and improvement in physical function [20, 38, 85]. Beyond the aforementioned traditional outcomes, there are more variables of concern. The conceptual model of Wilson, Cleary [92] illustrates how various aspects of health status are inter-related [17]. This model consists of health-related variables and contextual factors (environmental and individual characteristics), which range from biological and physiological variables to the impact of health or disease on individuals in their environment and on their quality of life (QoL) (Fig. 51.1) [17].

In applying this model to knee OA, the following considerations might lead to possible outcomes in the context of knee arthroplasty. In patients with knee OA, the cartilage gradually wears away, leading to inflammation, effusion, osteophytes, and damage to the bone stock (biological and physiological variables). The patient's primary symptoms are pain, swelling, and stiffness (symptom status). In the later phases of OA, everyday activities, such as walking, stair climbing, or rising from a chair, are affected negatively (functional status). Patients are less active, they may lose the ability to participate in sport or recreational activities, travel, do the shopping, and take care of themselves,

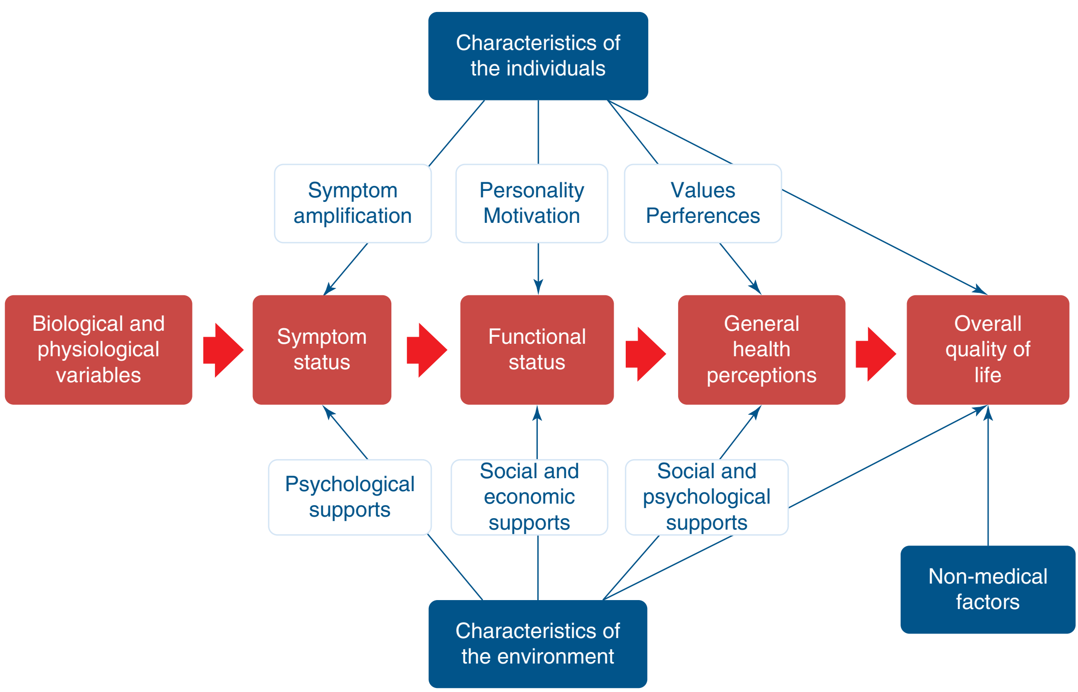


Fig. 51.1 Relations between measures of patient outcome (according to Wilson, Cleary [92])

and furthermore, they might lose social contacts or become reliant on assistance. All of these are causes of increased susceptibility to mental illnesses, like depression. The severity of OA affects patient's knee function, but apart from that, the personality of the patient (coping behavior) and environmental characteristics (support of family or friends, adaptability of work, or residential environments) are important. In appraisal of all these variables, patients achieve an estimation of their HRQoL.

HRQoL is defined as a multidimensional construct of personal health status, representing the individual's perception of how illness and its treatment affect the physical, mental, and social aspects of his or her life [17]. This in turn influences the extent to which personal satisfaction with life circumstances can be achieved [26]. To gain a meaningful evaluation of HRQoL, multiple domains (also called dimensions) need to be assessed. The question of which domains under which circumstances are important remains unclear [28]. Finally, non-medical factors, such as the patient's financial situation or the country of residence, also play a role in the patient's overall QoL. The model of Wilson, Cleary [92] illustrates many possible outcomes, but without any prioritization.

Nevertheless, appropriate outcome selection is one of the most challenging decisions in health outcome measurement. The two main questions are

1. Which domains are the most important?
2. Which measurement instruments are available and appropriate to measure them?

Nowadays, the evidence-based approach of medical thinking and practice emphasizes the patient's predicaments, rights, and preferences, to derive a "shared decision" on an intervention or treatment [74]. This process evoked a shift in measuring outcomes from the clinician's perspective to that of the patient [38], and this revealed not only a myriad of possible outcomes, but also a plethora of measurement instruments to accompany them [52, 85, 88].

Side Summary
Osteoarthritis of the knee affects various health-related variables and contextual factors. Knee arthroplasty leads to a change in all of them. In order to reflect these changes properly, the domains of interest and the most appropriate measurement instrument should be thoroughly selected.

51.3 Current Strategies for Standardization

51.3.1 Core Outcome Set (COS)

In an effort toward international harmonization of measurement procedures in clinical trials, the Outcome Measures in Rheumatoid Arthritis Clinical Trials (OMERACT) reached a consensus on a minimum of required outcomes for knee OA [6]. This so-called core outcome set (COS) defines *what* to measure. It is an agreed standardized set of outcome domains that should be measured and reported in all clinical trials. Hereby, these domains are not intended to be the only possible endpoints of trials [60, 75], but rather serve as a reliable, fixed set of reported outcomes, which guarantees compatibility for the combination of studies and generalized results. The four outcome domains, pain, physical function, patient global assessment, and joint imaging (for studies of 1 year or longer) were identified as core outcomes for treatment of knee OA [6, 38]. Unfortunately, this COS has not been used widely in orthopedic research. In a systematic review of clinical trials and TKA, Lange et al. [52] found that only 4% of the studies investigated reported all four domains. Recently, a preliminary new COS has been published by OMERACT, including the following domains: joint pain, function or functional ability, patient satisfaction, revision surgery, adverse events, and death [79]. Once again, these domains serve as a minimum of outcomes for assessment, but every other outcome of interest or outcomes of future importance may be additionally assessed.

The identification of core domains does not solve the problem of the heterogeneous application of instruments. Lange et al. [52] found that in 100 recent studies on TKA, a total of 111 different measurement instruments were used, which makes comparison of studies very difficult if not impossible. Until now, there has been no consensus on any measurement instruments. The integration of an explicitly defined measurement instrument set into the existing COS will be the next challenge.

51.3.2 ICHOM Standard Set

Whereas OMERACT deals with the harmonization of outcomes in clinical trials, the International Consortium for Health Outcomes Measurement (ICHOM), a non-profit organization, intends to transform healthcare systems worldwide by measuring and reporting patient outcomes in routine care in a standardized manner. In order to achieve a global standard, they are developing so-called "standard sets" for, currently, 21 diseases or population groups. ICHOM does not confine itself to *what* should be measured, but also recommend measurement instruments, time points, and associated risk factors, and the recommendations for a standard set for hip and knee OA are not treatment specific.

The ICHOM standard set consists of

- Baseline data (e.g., age, gender, physical activity, comorbidities)
- Disease control (treatment progression, need for surgery, orthopedic procedure)
- Acute complications of the treatment (mortality, admission within 30 days, re-operations)
- Patient-reported health status (pain, function, work status, HRQoL, satisfaction with result)

The recommended measurement instrument for the assessment of pain is the numeric pain rating scale; for assessment of physical function, the Knee Injury and Osteoarthritis Outcome Score–Physical Function Short Form (KOOS-PS) is recommended, and for assessment of HRQoL the EuroQol is used, including five dimensions and ratings on three levels (EQ-5D-3L) or the Short Form 12 Health Survey (SF-12). The recommended follow-ups should proceed annually for as many years as feasible. Like COS, the ICHOM standard set should serve as a minimum of assessable outcomes, but on closer inspection it is clear that some useful outcomes concerning physical examination or imaging are missing.

51.3.3 What Outcomes Should Be Considered?

When considering outcome measurement, it is helpful to distinguish between different approaches (Fig. 51.2):

- Clinicians' ratings of patients' health status, including measures of physiological parameters and imaging
- Patient-reported outcomes
- Patient-reported experience
- Performance-based outcomes
- Routine collection of outcome-related indicators by healthcare organizations (to assess the organization's performance) [8, 91]

This last approach assesses the quality, safety, and effectiveness of health care and is not discussed further in this article.

Patient-reported experience (PRE) is an approach aimed at capturing the patient's perspective on process issues, such as time spent waiting, involvement in decision-making, knowledge of the care plan and pathways, or quality of communication [86]. PRE primarily evaluates information in order to initiate improvements in quality; however, these experiences might also influence the patient's satisfaction with treatment or intervention, physical health, or even HRQoL, and should therefore be considered a useful complement to other outcome assessments (Fig. 51.3) [8, 86].

The question of which outcomes should be considered in the context of unicondylar or total knee arthroplasty (UKA, TKA) is difficult, and there is no satisfactory, and certainly no holistic, answer. Comparison of the recommended domains of OMERACT and ICHOM shows that there is agreement on the assess-

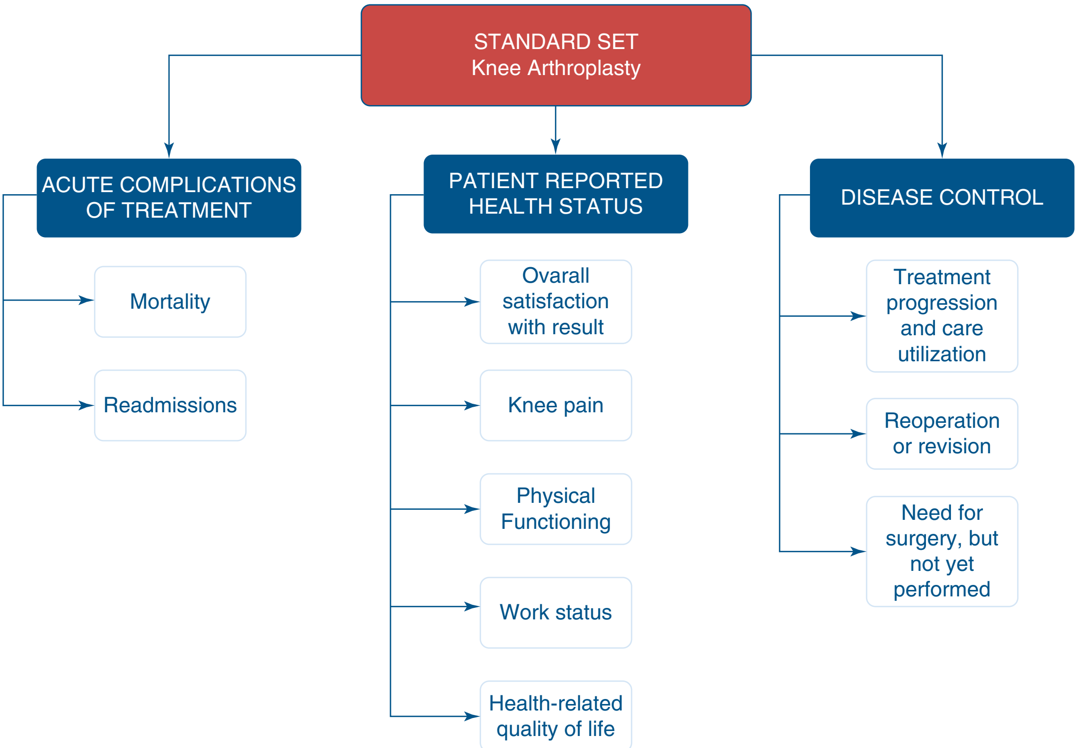
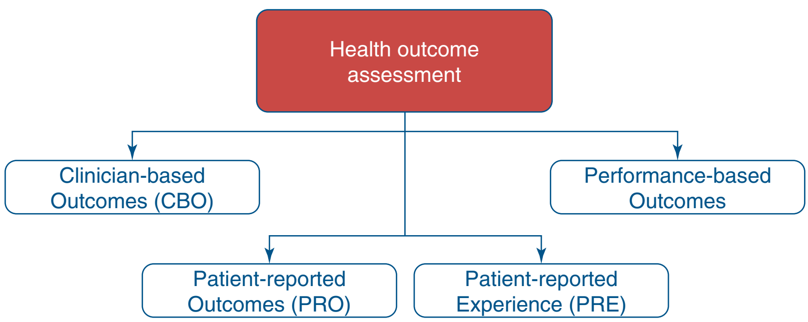


Fig. 51.2 Standard set outcome measurement (according to ICHOM [39])

Fig. 51.3 Overview of health outcome assessment



ment of pain, physical function, and patient global assessment/overall satisfaction. Additionally, there are numerous domains to be considered for HRQoL and numerous subdomains for physical function, including physical examination, as well as various factors influencing these outcomes. Ultimately, the patient's expectations should be fulfilled, and this has a significant impact on the main goal, patient satisfaction with the intervention (Fig. 51.4) [36, 57, 64].

Side Summary
Clinician-based outcomes (ROM, joint stability, adverse events, mortality, prosthesis survivorship) have been the main focus of assessment for a long time. Meanwhile, an extensive variety of patient-reported outcomes have become an integral part of internationally recommended standardized measurements.

Fig. 51.4 CBO, PRO, and satisfaction can be largely discrepant: radiograph, ROM, and WOMAC reveal a disappointing result but the patient is highly satisfied

51.3.4 Traditional Outcomes

For many years, mainly traditional outcomes such as revisions and prosthesis survivorship have been reported for knee arthroplasty. Adverse events (AE), including surgical and non-surgical AE, have been reported less frequently. These outcomes can be captured in selected patient groups in studies or in unselected groups in regions or nationwide in arthroplasty registries. The Swedish Knee Arthroplasty Register was the first nationwide registry to collect data and has done so since 1975. Nowadays, arthroplasty registries can be found around the world, and these constitute an important source of knowledge regarding survivorship and the reasons for revisions. Due to the large number of patients and the long periods of observation, many questions can be answered by these registries; however, most of them can only provide basic data (e.g., whether a prosthesis is revised or not) without information on the functional status or patient-reported outcomes (PROs). In a recently performed survey of patient-reported outcome measures in arthroplasty registries, the International Society of Arthroplasty Registries (ISAR) discovered that only two national registries (the National Joint Registry of England and Wales, and the Dutch Registry) and another six regional registries collect PROs for all patients [71]. In many registries, the performance of implants is presented without consideration of other factors, besides the implant, which may account for survival, such as the surgeon and the patient themselves. This is a possible source of bias, particularly in smaller registries and for less frequently used implants, and hence, these data must be interpreted with caution.

51.3.5 Clinician-Based Outcomes

Physicians evaluate a patient's health status by utilizing several clinical parameters measuring attributes believed to be associated with well-being [83, 91]. Knee stability, ROM, muscle strength, leg alignment, and imaging measures, like leg axis or implant position, are reported outcomes in patients with OA. In assessing these outcomes, clinicians rely on an array of tests and measures—all of them observed and judged from the clinician's perspective—the so-called clinician-based outcome (CBO) [83]. Most of CBOs evaluate parameters directly and for a long time and were therefore considered to be objective. The objectivity of an outcome, however, is not determined by who applies the measure, but by reliability and many studies have reported substantial variability in CBOs. Furthermore, CBOs are not necessarily correlated with the outcomes that matter to patients. Satisfaction with TKA, for example, depends mainly on fulfillment of patient expectations and not only on the achievement of specific objective thresholds, such as the ability to bend the knee more than 90° [64]. Hence, CBOs alone are not sufficient to assess the success of an intervention and should be accompanied by measurement of the patient's perspective [38, 47].

51.4 Range of Motion (ROM)

Improved ROM is an important aim for most patients after knee arthroplasty. To perform the activities of daily living (ADLs), a knee range between 0° and 105° is necessary; approximately, 65° are required for ambulation, 80° for stair walking, or 105° to rise from a sitting position with ease [42, 73]. Measuring flexion and extension of the knee with a goniometer is a gold standard; however, intra- and inter-rater reliability have been reported to vary substantially, with high [11, 23, 33, 90] to low correlation coefficients [43, 77]. When using a navigation system during surgery, ROM can be measured more precisely intraoperatively; however, the ROM ultimately achieved is often less. Hence, these measurements can be used to compare technical aspects of implants, but not for outcome evaluation. There are trends to measure ROM with a smartphone app. Accuracy and precision of such apps need to be evaluated before general use can be recommended.

51.5 Joint Stability

Knee stability is another aspect of importance for patients after knee arthroplasty. This needs to be divided into passive stability, which is mainly determined by the status of the collateral and cruciate ligaments, and active stability, which is mainly determined by the extensor mechanism and the strength of the quadriceps. Laxity can be tested manually by the clinician but is not very precise, or by use of instruments. While there is a well-accepted standard for anteroposterior laxity (KT1000), there is no such instrument for mediolateral laxity, but this can be measured by performing stress radiographs. However, mediolateral laxity depends on the knee flexion degree (e.g., midflexion instability) and is different between individuals, and it is therefore very difficult to define a standard. Furthermore, the perception of stability or instability is different between patients and depends not only on ligament laxity but also on the extensor mechanism. Therefore, despite being part of the frequently used knee society score, reported laxity measurements are subjective and need to be interpreted with caution. Finally, patients tend to rate a loose knee better after TKA, which makes it even more difficult to define a standard [22].

51.6 Imaging

Radiographs are the basic diagnostic tool for assessing OA and for analyzing component placement and leg alignment after UKA and TKA. Preoperative planning based on radiographs is essential and to assess the accuracy of the surgery thereafter. The following parameters should be assessed: leg axis, position of the femoral and tibial component (varus–valgus position, tibial slope, femoral flexion, femoral posterior offset, and joint line), under- or oversizing of the femoral or tibial components, patella position (patella height, tilt, and alignment), and position of a patellar resurfacing. These parameters should be compared with the preoperative planning, and, during later examinations, radiographies should be analyzed with respect to signs of loosening (change of implant position, radiolucent lines), polyethylene wear, and osteolysis. There are no conclusive recommendations on which time points X-rays should be performed. If the initial implant position and fixation are correct and the patient has no complaints, it seems appropriate to perform the next examination 5 years after surgery, but if complaints arise, imaging should be performed earlier.

Side Summary

Range of motion, joint stability, and radiographs are clinician-based outcomes (CBOs) and standard evaluations after knee arthroplasty. CBOs are not necessarily correlated with outcomes that matter most to patients and should therefore be accompanied by patient-reported outcomes (PROs).

51.7 Patient-Reported Outcomes

In 2006, the US Food and Drug Administration introduced a guidance paper for how patient-reported outcomes (PRO) should be used in medical product development. PROs are defined as outcomes, which are directly reported by the patient without interpretation of the patient's response by a clinician or anyone else and pertains to the patient's health, quality of life, or functional status associated with health care or treatment [91]. The relevance of these outcomes is driven by the view that patients are the best, and in many cases, the only judges of their own well-being [86, 87]. The application of PROs complementary to CBOs provides additional information on treatment effects and patient perceptions and achieves an integrated view of the patient's health status [35, 38, 47]. Patient-reported outcome measures (PROMs) are the instruments used to assess PRO, and Table 51.1 presents details of frequently applied PROMs in

Table 51.1 Overview of widely reported and/or recommended Patient-Reported Outcome Measures (PROMs)

Name of instrument	Type	No. of items and domains	Domains
Knee Society clinical rating system (KSS) [40][a]	Disease-specific, multidimensional composite scale	12 items, 5 domains	Pain, ROM, joint stability, imaging, function
The 2011 Knee Society Knee Scoring System (KSS, 2011 version) [63, 76]	Disease-specific, multidimensional composite scale	34 items, 8 domains	Pain, ROM, joint stability, imaging, satisfaction, expectation, function, physical activity
Western Ontario and McMasters Universities Osteoarthritis Index (WOMAC) [5][a,b]	Disease-specific, multidimensional composite scale	24 items, 3 domains	Pain, stiffness, function
Oxford Knee Score (OKS) [16][a,b]	Disease-specific, multidimensional composite scale	12 items, 2 domains	Pain, function
Oxford Knee Score–Activity and Participation Questionnaire (OKS-APQ) [15]	Disease-specific, unidimensional composite scale	8 items, 1 domain	Higher level of activity and participation
Knee Injury and Osteoarthritis Outcomes Score (KOOS) [72][b]	Disease-specific, multidimensional composite scale	42 items, 5 domains	Pain, stiffness, function, sport/ recreation function, knee-related QoL
Knee Injury and Osteoarthritis Outcome Physical function Short form (KOOS-PS) [65][c]	Disease-specific, unidimensional composite scale	7 items, 1 domain	Function
University of California at Los Angeles (UCLA) activity rating scale [2][a,b]	Generic, unidimensional single-item	1 item, 1 domain	Physical activity
Euroqol (EQ-5D) [27][b,c]	Generic multidimensional composite scale	5 items, 5 domains	Mobility, self-care, usual activity, pain/ distress, depression/anxiety
EQ VAS [27][b,c]	Generic unidimensional single item	1 item, 1 domain	General health
Short Form 36 health survey (SF-36) [89][a,b]	Generic multidimensional composite scale	36 items, 8 domains	Physical function, physical role, bodily pain, general health, vitality, social functioning, emotional role, mental health
Short Form 12 health survey (SF-12) [31][b,c]	Generic multidimensional composite scale	12 items 8 domains	Physical function, physical role, bodily pain, general health, vitality, social functioning, emotional role, mental health

[a]Recently reported as most widely used/recommended measurement instruments [1, 4, 10, 20, 34, 52, 85, 78]
[b]Measurement instruments used by 15 national/local registries [71]
[c]Measurement instruments recommended by ICHOM

the context of UKA and TKA. The choice of the described instruments was based on the ICHOM recommendations and recent literature reviews of PROMs in clinical trials and registries. PROMs are classified primarily into generic and disease-specific instruments, and further into unidimensional single-item measures (one domain measured by one item), unidimensional composite scale measures (one domain measured by several items), and multidimensional composite scale measures (several domains measured by several items). The challenge for these instruments is to guarantee valid, reliable, and comparable outcomes. Hence, PROMs should provide a necessary level of (methodological) quality, and they should be tested for reliability, validity, and responsiveness to change [10].

Side Summary
Patients are the best judges of their own well-being. Patient-reported outcome measures (PROMs) record patient evaluations on various aspects that cannot be evaluated directly by another person. PROMs are divided into generic and disease-specific instruments.

51.7.1 Generic PROMs

Generic instruments are expected to be sensitive to any condition affecting health status. The advantage of generic instruments is the possibility of comparing the effect of treatments across different diseases. However, generic instruments do not directly display functional changes, but only their impact on general health status and should be supplemented with disease-specific measures [44]. Frequently used instruments in the context of knee arthroplasty include the Short Form 36 (SF-36), Short Form 12 (SF-12), and EuroQol (EQ-5D) questionnaires.

51.7.2 Short Form 36 Health Survey (SF-36)

The SF-36 is the most widely applied instrument for assessment of HRQoL [32]. It consists of 36 items, which measure health using the following eight multi-item domains: physical function, physical role, bodily pain, general health, vitality, social functioning, emotional role, and mental health. Completion of the SF-36 takes about five minutes, and the answers are evaluated to determine a score according to the eight respective scales, and which can be combined into two summary scores: Physical Component Score (PCS) and Mental Component Score (MCS). The calculation of these two scores is rather complex and uses norm scores of general population. The SF-36 has been translated into many languages and evaluated on measurement properties.

51.7.3 Short Form 12 Health Survey (SF-12)

The SF-12 is the shortened version of SF-36, and the purpose of its development was to reproduce the SF-36 PCS and MCS with fewer items. It contains a subset of 12 items from the SF-36, including one or two items from each of the eight SF-36 scales [31].

51.7.4 European Quality of Life (EuroQoL EQ-5D)

The EQ-5D was developed by the EuroQoL Group in order to provide a simple, generic measure of health status. EQ-5D 3 level version (EQ-5D-3L) was introduced in 1990, and consists of two elements: the EQ-5D-3L descriptive system and the EQ visual analog scale (EQ VAS) [27]. The EQ-5D descriptive system covers five domains (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression), which are rated on three levels (no problems, some problems, and extreme problems). The answers can be converted into a single summary index ranging from 0 (worst general health) to 1 (best general health). EQ VAS reflects the patient's self-rated health status on a vertical, visual analog scale. EQ-5D has been translated into different languages and psychometrically tested.

Side Summary
Generic PROMs measure several domains of health status to evaluate the impact of a disease, a condition, or a treatment on general health. They are comparable across different diseases and conditions. The instruments differ largely in scope of items and domains being measured (e.g., 36 items (SF-36) vs. five items (EQ-5D)).

51.7.5 Disease-Specific PROM

Numerous specific measurement instruments for patients with knee OA, UKA, or TKA are available [70, 30]. The most commonly applied and recommended instruments are the Western Ontario and McMasters Universities Osteoarthritis Index (WOMAC), the Knee Society Score (KSS), the Oxford Knee Score (OKS), the Knee Injury and Osteoarthritis Outcome Score (KOOS), and the University of California Los Angeles (UCLA) activity rating scale [1, 4, 10, 20, 34, 52, 69, 85, 78].

51.7.6 Western Ontario and McMasters Universities Osteoarthritis Index (WOMAC)

The WOMAC was the first widely used PROM assessing various aspects of treatment outcomes after hip and knee replacement [4]. It measures 3 domains via 24 items: 5 questions concerning pain, 2 questions on joint stiffness, and 17 questions on ADL. The original WOMAC is available with two response options, a visual analog scale (10 cm) and a Likert scale with five possible answers (none, mild, moderate, severe, extreme). The WOMAC has been translated into different languages and tested on measurement properties.

51.7.7 Oxford Knee Score (OKS)

The OKS has been widely used in the context of knee OA and knee arthroplasty. It consists of 12 items concerning pain and physical function, which are scored on a five-point scale. The OKS is commonly reported as a summary score, but the distinction between pain (OKS pain component) and function (OKS functional component) has recently been introduced [37]. OKS is available in different languages and has been extensively tested on measurement properties.

51.7.8 Knee Injury and Osteoarthritis Outcome Score (KOOS)

The KOOS was developed and published in 1998 as an instrument to assess the patient's opinion about their knee and associated problems [72]. It consists of 42 items which covers the five domains of pain (9 items), symptoms (7 items), ADL (17 items), sport and recreation function (5 items), and knee-related QoL (4 items). In order to ensure content validity, the questions from the WOMAC were included in their full and original form [72], and therefore, the WOMAC score can be calculated from the KOOS. Answers are given using a five-point Likert scale. KOOS has been validated and translated into different languages.

51.7.9 Knee Society Clinical Rating System (KSS)

The KSS was developed by the American Knee Society as a dual-rating system of clinician-based and patient-reported outcomes [40]. It is subdivided into a knee and a function score. The Knee Society Knee Score (KS-KS) is calculated from patient-reported pain, and clinician-based ROM, joint stability, and malalignment, with a maximum of 100 points. The Knee Society Function Score (KS-FS) is comprised of walking distance, stair climbing, and walking aids, with a maximum of 100 points. The KSS can also be reported as a summary score with a maximum of 200 points.

51.7.10 University of California at Los Angeles (UCLA) Activity Rating Scale

The UCLA activity rating scale is a single-item measure, which was developed for the evaluation of treatment effects of joint replacements [2]. It classifies physical activity levels from one (wholly inactive) to ten (regularly participating in impact sports) and can be assessed on a clinician-based or patient-reported basis. The UCLA activity rating scale is widely used in joint replacement studies and allows comparison between times (before and after surgery) and studies [84].

51.8 Single-Item Satisfaction Outcome Measure

The assessment of global satisfaction after knee arthroplasty is recommended by the Osteoarthritis Research Society International (OARSI), ICHOM, and ISAR. A single-item questionnaire to assess the outcome is very attractive because it is easy to apply and analyze [70]. ISAR recommends the wording, "How satisfied are you with the results of your right/left knee replacement?" with five response options (very dissatisfied, dissatisfied, neutral, satisfied, and very satisfied) [70].

51.9 Expectations and Their Fulfillment

Fulfillment of expectations has been demonstrated to be a key indicator of satisfaction with the results of knee arthroplasty [36, 57, 64]. Patients' perspectives are determined by many factors, for example, patient-reported function, the importance of symptoms to patients, or their concerns about different treatment options [58]. With the goal of systematically measuring patients' expectations with a self-administered instrument, Mancuso et al. [58] introduced The Hospital for Special Surgery Knee Surgery Expectation Survey (TKR Survey) [55, 58], a patient-reported scale composed of 19 items addressing symptoms, walking distance, daily function, employment, and psychologic well-being. For assessment of expectations preoperatively, two response formats were developed; patients can either indicate the importance of an expectation (very, somewhat, a little, not important, not applicable) [58] or rate the degree of expectation (complete, a lot, a moderate, a little improvement, not applicable) [55]. In order to measure fulfillment of expectations after surgery, Mancuso et al. [56] suggested asking patients to compare their preoperatively rated expectations with their perceived fulfillment (completely, somewhat, not at all) [56]. The importance of measuring the fulfillment of expectations has also been acknowledged in novel or revised PROMs [38, 51, 76].

51.10 New Developments

Critics of health outcome assessment in the context of UKA and TKA are concerned with the increased proportion of younger patients undergoing knee replacements and their expectations for work, sports, and recreational activities [18, 38, 93]. These demands are not in line with current outcome assessments and have made the development of novel PROMs and adjustments to established PROMs necessary. Examples of these developments are the OKS-activity participation questionnaire (OKS-APQ), which includes items assessing higher activity level, and the new Knee Society Knee Scoring System, which includes items assessing fulfillment of expectations and satisfaction [63, 76]. Table 51.1 presents further details of these PROMs.

Side Summary
Disease-specific instruments reflect on specific issues of knee OA and knee arthroplasty, like walking ability, stability, and activities of daily life. The most commonly used knee-specific instruments are Knee Society Score (KSS), Knee Injury and Osteoarthritis Outcomes Score (KOOS), and Oxford Knee Score (OKS). There are great variations in the scope of these instruments (e.g., 12 items and 1 summary score (OKS) vs. 42 items and 5 sub-scores (KOOS)).

51.11 Performance-Based Outcomes

Performance-based outcomes are an alternative outcome measure, which provide an objective measure of the true functional capability of patients [82]. Whereas PROs rather reflect the patient's own perception of their functional abilities, performance-based outcomes assess the patient's ability to complete directly observed tasks, like walking, stair climbing, or rising from a chair [48]. These outcome measures are observer-assessed, standardized, and quantify the results on the basis of timing, counting, or distance. In evaluating a physical activity under defined circumstances, the true performance of a patient emerges and results guarantee comparison between patients and times. Performance-based outcomes are complementary to clinician-based or patient-reported assessments [19, 38]. It has been proposed that a combination of PRO and performance-based outcome is necessary to fully characterize the change in physical function of patients after knee arthroplasty [59]. The disadvantages of these tests are the focus on a single physical function in a non-natural environment and the time-consuming execution [9]. In the context of UKA and TKA, reported performance-based tests are walking tests, sit-to-stand tests, stair negotiation tests, hop tests, and several multi-activity measures [48]. In 2013, OARSI published a consensus-derived set of performance-based tests for use in people diagnosed with hip or knee OA or following joint replacement [19]. The five recommended tests are the 30-s chair-stand test, the 40-m fast-paced walk test, a stair-climbing test, the timed up-and-go test (TUG), and the six-minute walk test (6MWT).

51.11.1 The 30-s Chair-Stand Test (30s CST)

This test represents the sit-to-stand activity and requires leg strength, dynamic power, and endurance. Patients are asked to rise from a chair (standardized seat height of approximately 43 cm, without armrests) with their hands crossed in front of their chest, for the duration of 30 s in which the number of times a full standing position is achieved is counted. Minimal reporting standards should include the seat height, the use of any adaptation (e.g., armrests, use of hands), and assistive devices (e.g., walking aids).

51.11.2 The 40-m Fast-Paced Walk Test (40m FPWT)

This test assesses the ability for fast walking and changing direction during walking. Patients walk a distance of 4 × 10 m as quickly as possible without running, and the time taken to complete the trial is recorded. Minimal reporting standards should include the use of any assistive devices (e.g., walking aids).

51.11.3 Stair-Climbing Test (x-step SCT)

The test of stair negotiation activity is recommended by OARSI but without any specifications [19]. This test assesses the ability of ascending and descending stairs and requires leg strength, dynamic power, and endurance. Patients are asked to climb a flight of stairs (a number of steps are not defined), and the time taken is measured. Minimal reporting standards should include number of stairs, step height, use of handrail, and walking aids.

51.11.4 The Six-Minute Walk Test (6MWT)

This test is one of the most widely used performance-based outcome measures [82] and tests leg strength, dynamic balance, aerobic capacity, and long-distance walking activity. Patients are asked to walk for six minutes on a flat walking area as quickly as possible without running. Minimal reporting standards should include assistive devices and the duration of necessary rests. The 6MWT has an excellent test–retest reliability and is responsive to change after TKA [81].

51.11.5 The Timed Up-and-Go Test (TUG)

This test incorporates multiple activities, including sit-to-stand activity, walking short distances, changing direction during walking, and the transitions between these activities [19]. Patients are asked to rise from a chair (standardized seat height of approximately 46 cm, with armrests), walk 3 m, turn around, walk back to the chair, and sit down, and the time taken to complete this trial is measured. Minimal reporting standards should include assistive devices (e.g., walking sticks). The TUG has excellent inter- and intrarater reliability and is also responsive to change after TKA [45, 68].

Side Summary
Performance-based outcomes are directly observed tasks, like walking, stair climbing, or rising from a chair. They are observer-assessed, standardized, and quantify the results on the basis of timing, counting, or distance, which guarantees comparison between patients and times.

51.12 Activity Measurement

With the acknowledgment of younger patients undergoing knee replacements and their expectations concerning physical activity, and in the context of the promotion of healthy, active lifestyles to prevent comorbidities, the measurement of physical activity became a major outcome after surgery. There are different methods to measure physical activity, which can be classified into subjective and objective instruments. PROMs, such as the UCLA activity rating scale, are considered to be subjective, whereas objective instruments are physical activity monitors, such as pedometers and accelerometers. A wide variety of these monitors are commercially available, and various studies have been conducted to validate and compare their performance. Nowadays, most smartphones can be used for activity measurements. Possible outcome variables of these monitors are steps per day, stride frequency (strides/min), time walking (h/d), time upright (h/d), time lying (h/d), sit-to-stand-movements, accelerometer activity counts, or metabolic equivalent [3]. Although the use of activity monitors is demanding, more expensive, and requires greater patient compliance, it should be preferred if objective and reliable data are favored (Fig. 51.5).

51.13 Measurement Properties and Practical Issues

51.13.1 Consensus-Based Measurement Properties

Comparability of results in medical research and health care is indispensable for evidence-based medicine; hence, outcomes (what should be measured) and their instruments (how outcomes should be measured) have to be consistent in definition, use, and reporting. The methodological quality of measurement instruments influences the comparability of results and is why special requirements should be fulfilled. COSMIN (Consensus-based Standards for the selection of health Measurement Instruments) is

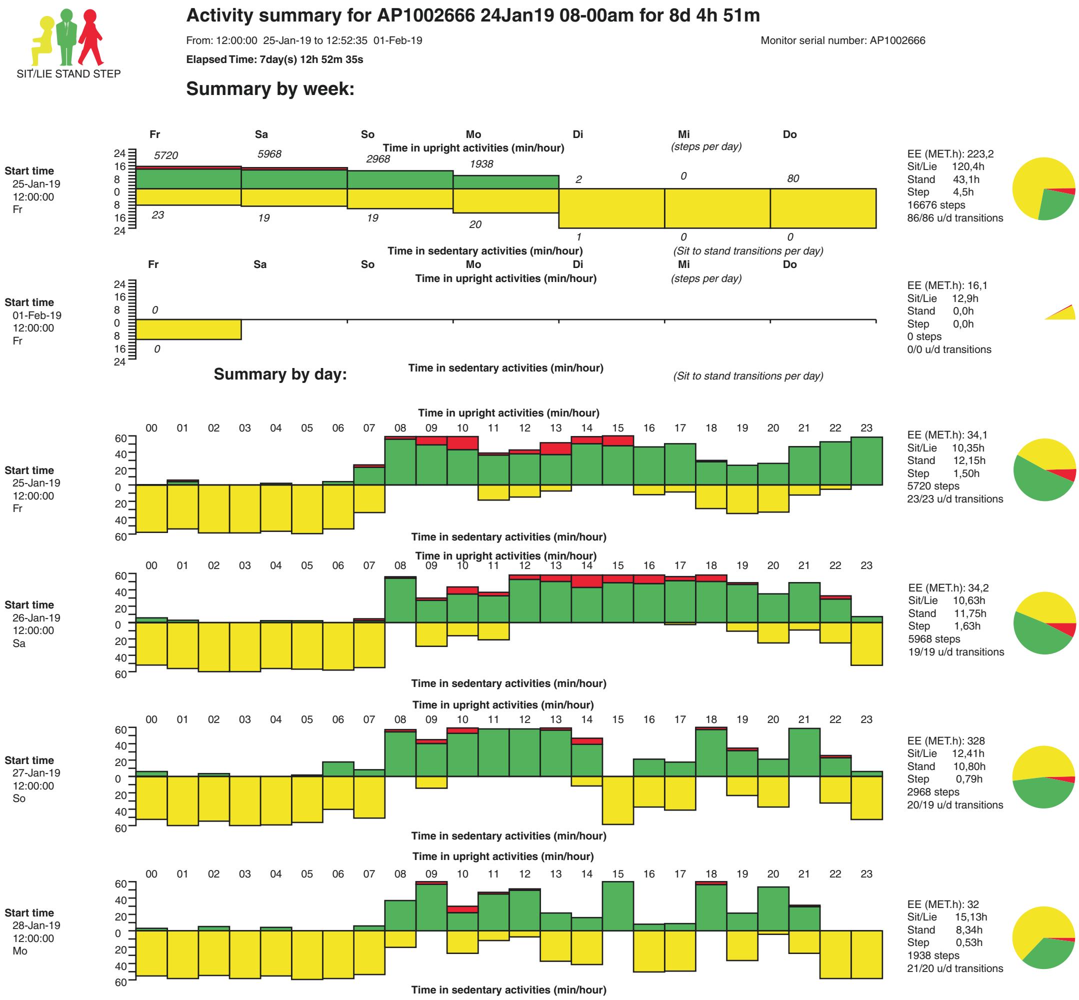


Fig. 51.5 Activity chart of the activPAL™ monitor

an initiative which provides taxonomy, terminology, and definitions of measurement properties based on a consensus reached by an international, multidisciplinary panel of experts [60, 61]. Within this consensus process, three measurement properties were determined: reliability, validity, and responsiveness (Fig. 51.6).

A measurement instrument should measure the domain for which it is intended (validity) [60, 61]. Validity can be divided into content validity, construct validity, and criterion validity. Content validity is the degree to which a measurement instrument reflects the domains it is supposed to measure [60]. For instance, if a PROM evaluates the domain ADL, it should evaluate impairments of representative daily activities for the target population.

Criterion validity is the extent to which a measurement instrument conforms to a gold standard and is only applicable if a gold standard for the outcome exists. If there is no gold standard available, the construct validity reflects the relationship of the measurement instrument and other instruments measuring the same domain [17]. If this correlation is low, the construct validity will also be low.

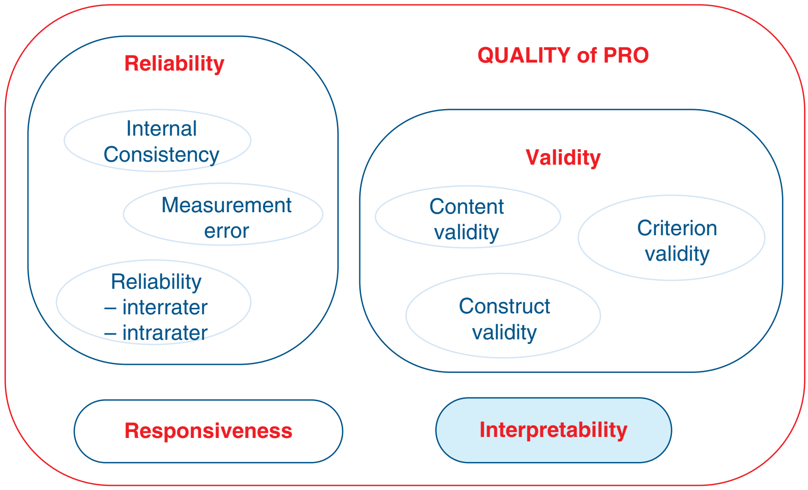


Fig. 51.6 Measurement properties of instruments (according to Mokkink et al. [60])

Furthermore, measurements performed by different observers and/or at different time points should produce similar results (reliability). Reliability summarizes inter- and intra-rater reliability, as well as internal consistency [62]. Inter-rater reliability refers to the reproducibility of measurements by two or more observers, whereas intra-rater reliability refers to the agreement between two or more measurements by the same observer at different times [50]. The internal consistency describes the degree of correlation of different items for the same domain. Furthermore, a systematic and random error in a patient's score, which is not attributable to true changes—the measurement error—has to be considered [62].

Finally, a measurement instrument should be able to detect relevant changes over time in the outcome (responsiveness) [62]. A high level of responsiveness is present if the minimal important difference is higher than the smallest detectable change and the measurement error. This means that a relevant change can be detected using this instrument and that this change is not caused by measurement error.

Further requirements may be needed with regard to practical issues (practicability, interpretability, feasibility, and acceptance) [49].

51.13.2 Practical Issues

When choosing domains and the corresponding measurement instruments, practical issues also need to be considered, besides methodological quality and comparability to other studies. While PROs can be assessed by postal survey, CBOs and performance-based outcomes require direct patient contact and therefore, more clinical resources. When choosing PROMs, the complexity of the questionnaire and the number of questions need to be considered. HRQoL can be measured using the complex SF-36 with 36 questions or using the EQ-5D questionnaire with only five questions. Knee function can be assessed with the use of the KOOS with 42 questions or the OKS with only 12 questions. All the scores mentioned are validated, have been frequently used for knee replacement outcome measurement, and have been tested for different measurement properties. It should be taken into consideration that the acceptance of a questionnaire partly depends on its scope, especially when combining different PROMs.

As it takes time to recover after knee replacement, the timing of outcome measurement is important, as most of the improvement occurs within the first 6 months after surgery [12]. There is only minimal difference between outcomes assessed at 12 months compared with later time points; however, some journals require a minimum of 2 years of follow-up for publications.

Side Summary
Clinician-based outcomes, such as ROM, joint stability, and imaging, are still essential outcomes after knee arthroplasty. They should be accompanied by patient-reported outcomes concerning knee-specific issues (pain, symptoms, ADL, sports) and generic (HRQoL) questions. Furthermore, performance-based outcomes and objectively measured physical activity can generate a holistic picture of the abilities of the patient. Finally, the satisfaction with the results of the intervention should be assessed.

51.14 Interpretation of Outcomes

Any interpretation of measurement depends on the surgeons' and patients' definition of a successful knee replacement. Success is multidimensional and, in the context of UKA and TKA recovery without complications, comprises pain relief, restoration of physical function, long prosthesis survivorship, improvement in HRQoL, and fulfillment of expectations, which finally summates in the degree of satisfaction with the results of the surgery [69]. Furthermore, healthcare providers want to know if an intervention is not only successful but also cost-effective and was applied appropriately [10], and there are several concepts for the interpretation of outcomes.

For some instruments, thresholds have been established to translate the result of a measurement into categories of success (e.g., "excellent," "good," "fair," or "poor"). Thresholds can also be used to detect patients, who are satisfied with surgery or have experienced functional improvement [66]. For the Oxford Knee Score, for instance, several thresholds coupled with the patient's postoperative satisfaction outcome have been evaluated [46, 66]. Greater age, lower BMI, severe preoperative symptoms, and the expectation of no postoperative pain have been shown to increase the requirement for greater improvement to reach satisfactory results after knee replacement [46].

Another approach to translating measurements into clinically meaningful outcomes is the minimally clinically important difference (MCID). MCID is defined as "…the smallest differences in a construct to be measured between patients that is considered important…" [61]. In the context of TKA, MCID has been evaluated for OKS [14], KSS [53], KOOS [7], WOMAC [24, 80], SF-12 [14], and SF-36 [24]. For instance, the MCID of OKS has been described to be 5 points [14], and the MCID of the sub-scores of the KSS has been reported to be between 6.1 and 6.4 for KS-FS and between 5.3 and 5.9 for KS-KS [53].

Another concept for interpretation of outcome measures is the categorization into responder and non-responder groups. In 2004, the OMERACT-OARSI initiative provided a set of criteria allowing the change of symptoms after a treatment to be transferred to a single variable [67]. These so-called responder criteria discriminate between responders and non-responders, which means patients with or without a satisfactory response to an applied treatment [25, 67]. For the domains of pain, function, and the patient's global assessment, a response by a relative and an absolute change was defined. This set can be applied to the WOMAC as follows: responders are patients with more than 50% improvement and absolute change of more than 20 points in pain and function sub-scores [67]. The responder criteria have been applied in many studies in the context of hip and knee OA.

For comparison of different treatments with regard to their benefit to health status, the estimation of quality-adjusted life-years (QALYs) is a common approach. QALYs quantify the benefit gained by an intervention by measuring the change in HRQoL with time [41]. One QALY equals 1 year with the best possible health status, whereas death is considered to be equivalent to zero. Furthermore, for the assessment of cost-effectiveness, the cost per QALY can be estimated. To calculate QALYs, only instruments that result in a single score can be used, and typically the EQ index has been applied. Studies have shown that TKR is among the most cost-effective interventions performed [41]. Depending on the healthcare system, costs vary greatly; therefore, costs per QALY have been reported to be between € 1650 in Germany and about US$ 6600 in the USA [54]. A recent study from the UK estimated the cost per QALY at about £ 2100, which is far below the threshold of £ 20,000 to £ 30,000 per QALY, above which drugs or treatments are not recommended by the National Institute for Health and Care Excellence [41].

Side Summary

A successful knee arthroplasty is usually determined by the absence of complications and re-operations, by pain relief, improvement of physical function and HRQoL, fulfillment of expectations, and long prosthesis survivorship. There are several approaches to translate measures into meaningful outcomes such as thresholds, minimally clinically important difference (MCID), identification of responder and non-responder, or quality-adjusted life-years (QALYs).

Take Home Message

- The main goals of knee replacement surgery are pain relief and improvement of physical function as well as the long survivorship of the prosthesis. Traditionally, these outcomes were only evaluated by physicians through examinations, tests, and imaging. Nowadays, a variety of outcomes are of further interest and measurement shifted from the clinician's perspective to that of the patient.
- Outcome measurement distinguishes between clinician-based outcomes (CBOs), patient-reported outcomes (PROs), patient-reported experience, and performance-based outcomes. Range of motion, joint stability, and radiographs are the standard CBOs before and after knee arthroplasty. CBOs alone are not sufficient and should be accompanied by PROs.
- PROs in the context of knee arthroplasty reflect on pain, walking ability, activities of daily living, physical activity, satisfaction, expectations, and their fulfillment and health-related quality of life. PROs are measured via generic or disease-specific instruments.
- The most frequently used generic instruments are Short Form 36 (SF-36), Short Form 12 (SF-12), and EuroQol (EQ-5D); often used disease-specific instruments are Western Ontario and McMasters Universities Osteoarthritis Index (WOMAC), the Knee Society Score (KSS), the Oxford Knee Score (OKS), the Knee Injury and Osteoarthritis Outcomes Score (KOOS), and the University of California Los Angeles (UCLA) activity rating scale.
- When deciding on an outcome (what, how, and at which time points is it measured), practical issues need to be considered. CBOs require direct patient contact, and PROs can be assessed by postal or online survey. Shorter questionnaires enhance the acceptance by the patients but reduce the possibilities for analysis. The used measurement instruments should fulfill a minimum of methodological quality to ensure comparability to other studies. The time points of measurement should be sufficient in answering the research question (survivorship of prosthesis at long-term follow-up).

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Function After Unicondylar Knee Arthroplasty—What Could You Expect?

52

Michael C. Liebensteiner

Keynotes

1. The theoretical and conceptual advantages of unicondylar knee arthroplasty (UKA) are preservation of bone stock, preservation of both cruciate ligaments, and in most cases also a less invasive surgical approach when compared to total knee arthroplasty (TKA).
2. The evidence is controversial whether UKA also provides better short- or long-term function as compared to TKA regarding range of motion and patient-reported outcomes.
3. On the basis of two publications, it can be cautiously concluded that return to sports and sports participation may be better in UKA patients than in TKA patients.

52.1 Introduction

Unicondylar knee arthroplasty (UKA) means preservation of bone stock, preservation of both cruciate ligaments, and in most cases also a less invasive surgical approach compared to total knee arthroplasty (TKA). It may be asked whether these theoretical and conceptual advantages of UKA also provide superior knee function in comparison to TKA.

This chapter is based on a thorough analysis of the literature and the author's research. Out of the 183 research results, 19 articles provided relevant information about functional outcome after UKA [1–19].

52.2 Range of Motion

Six studies investigated the range of motion after UKA with follow-up periods between two and nine years [3, 6, 11, 14, 18, 19]. While five of these publications compared UKA and TKA, one study compared UKA and high tibial osteotomy with regard to range of motion. Those studies that compared UKA and TKA reported conflicting results. Three articles found superior range of motion in patients treated with UKA [3, 14, 18] and two articles reported no such benefits [6, 11]. Among those that reported superior range of motion of UKA, the superiority of UKA ranged from 4 degrees [3] to 20 degrees [18].

When compared with high tibial osteotomy, UKA patients showed equal outcome regarding range of motion [19]. In synopsis of the above-mentioned studies, range of motion appears to be good after UKA. However, there is no consensus in the literature on whether UKA gives better

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range of motion than the typical competitors TKA and high tibial osteotomy.

Side Summary
There is no consensus in the literature on the question whether UKA gives better range of motion than TKA and high tibial osteotomy.

52.3 Return to Sports

Others investigated the functional outcome of UKA in terms of return to sports [4, 5]. Hopper et al. reported a return to sports rate of 96.7% in the UKA group and 63.6% in the TKA group. Both publications found that after UKA, patients returned to sports more quickly than after TKA with golfing, bowling, and swimming being the most popular activities in UKA patients.

Side Summary
UKA patients returned to sports more quickly than TKA patients.

52.4 Patient-Reported Outcome

Many researchers used patient-reported outcome measurements to verify function after UKA. Three publications [13, 15, 17] used the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) that comprises the subscales WOMAC pain, WOMAC stiffness, and WOMAC function. The latter two subscales should provide sufficient information on function following UKA. Also, the total WOMAC score should suffice because the aforementioned two subscales constitute the vast majority of the total points. Lyons et al. compared the pre- and postoperative changes in the WOMAC total and subscales and reported no differences between 5606 TKAs and 279 UKAs. The pre- to postoperative changes were 22 vs. 19 points for WOMAC total score for TKA and UKA patients, respectively. In both populations, WOMAC function improved by 25 points [13]. Sweeney et al. [17] also investigated the pre- and postoperative changes in the WOMAC score (317 UKAs vs. 425 TKAs) and reported no differences between the groups, although stratified for age and sex. Conflicting data were published by Noticewala et al. [15], who tested 128 TKA and 70 UKA. The authors reported that UKA patients showed significantly more improvement in WOMAC function than did those who underwent TKA (34 vs. 26 points change).

Six research groups applied the Oxford Knee Score (OKS) to determine the outcome of UKA as compared to TKA [2, 7, 8, 10, 17, 18]. The OKS is a 12-item patient-reported outcome measurement that mainly comprises questions on knee function. Four of the six publications stated that UKA showed no benefits over TKA in terms of OKS change from preoperative to different postoperative points in time [2, 7, 8, 17]. For example, Sweeney et al. [17] reported that after adjusting for age and sex, prosthesis type (TKA/UKA) was not a statistically significant predictor of 6-month postsurgery OKS ($p = 0.8$). Comparing the baseline and postoperative assessment of UKA and TKA patients based on Oxford Knee Society Score, changes were reported from 23.3 to 38.2 points and from 21.4 to 35.5, respectively. There was no significant difference between the UKA and the TKA groups ($p = 0.22$).

The remaining two studies reported greater OKS improvement in UKA patients than in TKA patients [10, 18]. However, Walker et al. [18] solely dealt with lateral UKA, which makes comparability difficult. In the latter study, the postoperative mean OKS was 43 for UKA and 37 for TKA, respectively ($p = 0.023$).

In synopsis of the abovementioned studies on patient-reported functional outcome of UKA (WOMAC, OKS), it appears that the majority of publications reported no superiority of UKA over TKA (six vs. two publications).

Side Summary
Patients who underwent UKA did not show superior patient-reported functional outcomes (WOMAC, OKS) when compared to patients who underwent TKA.

The patient-reported Tegner Activity Score was used by others to investigate UKA outcome [9, 19]. Krych et al. compared 183 medial UKA to 57 high tibial osteotomies and reported superior Tegner scores among UKA patients within a 5-year follow-up period [9]. Conflicting evidence comes from Yim et al., who investigated 50 medial UKA vs. 55 high tibial osteotomies and reported no differences between groups three years postoperatively [19]. No publications were identified that applied the Tegner score to compare UKA and TKA.

52.5 Gait Analysis

Jones et al. investigated gait parameters to determine function following UKA [8]. One year postoperative they found more physiologic gait pattern (several aspects of ground reaction force) and higher top walking speed in UKA patients than in TKA patients.

52.6 Limitations

When conducting a literature analysis regarding functional outcome of UKA (vs. TKA), one encounters several potential limitations. First, the indication for medial UKA is typically isolated osteoarthritis of the medial compartment—with or without patellofemoral osteoarthritis. However, not all articles precisely stated whether the indications for their TKA patients were also medial compartment osteoarthritis or lateral compartment osteoarthritis or both. This could imply a relevant confounder for some of the articles that compared UKA and TKA. Second, many articles do not precisely state whether all the UKA cases were medial UKA. It can be assumed that also some lateral UKA cases were included. Thirdly, other confounders like baseline differences in BMI, age, or physical activity might be present in some of those articles.

52.7 Author's Investigations

A study project of our own prospectively compared gait characteristics and knee extensor strength following medial UKA vs. TKA has given the same standardized surgical approach in both groups [20]. A 3D gait analysis was done preoperatively and eight weeks after the procedure with a 3D motion analysis system (VICON, Oxford, UK, and AMTI, Watertown, MA, USA), using a 4-segment lower-body marker model (Fig. 52.1).

We also performed extensor torque measurements preoperatively and eight weeks postoperatively with an isokinetic dynamometer (Con-Trex® MJ; CMV AG, Zurich, Switzerland) (Fig. 52.2).

Ultimately, full datasets were available for 15 medial UKA patients and 17 TKA patients. The groups showed no baseline differences regarding age, BMI, sex, side treated, or stage of osteoar-

Fig. 52.1 A 4-segment marker model was applied to capture gait data during level walking at self-selected speed

Fig. 52.2 The dynamometer used for torque assessment in UKA and TKA patients

thritis. Preoperative peak extensor torque of the operated leg was 52.75 Nm and 56.46 Nm for TKA and UKA, respectively. Eight weeks postoperatively, peak extensor torque was 39.60 Nm and 41.13 Nm, respectively. The changes over time were statistically significant ($p = 0.004$), but statistical significance was not determined for the factor group or for time × group interactions. For (a) temporospatial parameters, (b) sagittal knee kinematics, and (c) frontal knee kinematics, we did not observe a significant influence of the surgical group. Nor were there any time × group interactions.

Our study suffered from the limitation that gait analysis was performed on only two occasions. Further postoperative measurement would have added additional information. Moreover, it would have been beneficial to also test at different walking speeds and/or inclinations (e.g., treadmill).

Unpublished data from our institution compared functional outcomes of UKA and TKA based on the function scale (Hypothesis 1), the total scale of the WOMAC (Hypothesis 2), and range of motion (Hypothesis 3). Data available from the federal state's Arthroplasty Registry (WOMAC score) and from clinical routine (ROM) were analyzed. Regarding Hypotheses 1 and 2, the amount of improvement in WOMAC scales was not influenced by the surgical group ($p = 0.608$ and 0.392). Regarding Hypothesis 3, we found no significant group × time interaction for the ROM data ($p = 0.731$). In conclusion, knee osteoarthritis treated either with UKA or TKA had no difference in terms of improvement of ROM and WOMAC subscales.

Take Home Message

Good functional outcome for UKA can be expected. However, the evidence is controversial whether UKA provides *better* short- or long-term function as compared to TKA regarding range of motion and patient-reported outcomes. With respect to other UKA competitors (e.g., osteotomies), the evidence is even more rare or conflicting. On the basis of two publications, it can be cautiously concluded that return to sports and sports participation may be better after UKA than after TKA.

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53 Outcome After Total Knee Arthroplasty—What Can Be Expected?

José M. H. Smolders and Gijs G. van Hellemondt

Keynotes

1. The measurement and prediction of dissatisfaction through patient-reported outcome measurements (PROMs) are still very limited.
2. The most common reasons for a patient to be dissatisfied after TKA are residual pain and limited function.
3. Other predictors for dissatisfaction are pre-operative pain, unmet expectations and less chronic disease prior to arthroplasty.
4. The tools to improve satisfaction (and improve the outcome of the knee replacement) are a proper surgical technique, addressing pre- and post-operative pain and pre-operative counselling of expectations through a shared decision-making process.

53.1 Introduction

In the early years of joint arthroplasty, relief of the crippling pain of arthritic disease was the primary goal, and in this respect, arthroplasty in general has been an overwhelming success [1]. More specific, total knee arthroplasty (TKA) has proved to be a reliable treatment to reduce pain and improve quality of life in 90% of the patients. It is an overall very successful, relatively low-risk surgery with an excellent long-term outcome: 96.9% survival at ten years for all primary cemented total knee replacements [2, 3]. However, 44% of patients report pain of any severity three to four years post-operatively [4], and only 42.9% of TKAs are considered always forgotten in all everyday activities [5]. Furthermore, about one in five patients is not satisfied with the outcome of their primary TKA [6–10]. 7.4% of the patients had another surgery on their primary TKA, 18% had planned another surgery and 27% had problems with their knee [6].

This underlines the controversy between an overall successful treatment and high percentage of dissatisfaction. The most common reasons for patient dissatisfaction after TKA are residual pain and limited function; however, there is still no clear definition in literature on what is considered a 'successful' TKA.

Side Summary

The most common reasons for patient dissatisfaction after TKA are residual pain and limited function. Forty-four percent of patients report pain of any severity three to

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four years post-operatively. Only 42.9% of TKAs are considered always forgotten in all everyday activities. 7.4% of the patients had another surgery on their primary TKA, 18% had planned another surgery and 27% had problems with their knee.

53.2 How to Define a 'Successful' TKA?

There are several ways to define a successful TKA, depending on which factors are weighed. It appears that often surgeons are more satisfied than patients after a TKA. Most studies are surgeon reported, and it is known that the concerns and priorities of patients and surgeons differ [8].

Side Summary
Often surgeons are more satisfied than patients after a TKA. Global knee scores such as KSS or OKS have a ceiling effect and do not capture the presence of difficulty or dissatisfaction with specific activities important to patients.

Registries data report mainly on revision rates, with few outcome measures used. If patient-reported outcomes (PROM) are measured, how heavily does fulfilment of expectations and satisfaction count in the overall definition of outcome and success?

Global knee scores (KSS, OKS) have a ceiling effect and do not capture the presence of difficulty or dissatisfaction with specific activities important to patients. Despite several scoring systems, there is no globally accepted outcome score for post-operative knee surgery assessment. It is known that the fulfilment of the expectations of the patients is associated with a better absolute clinical outcome and greater improvement in clinical scores following surgery. How can we measure this as, for example, the impact of meeting pre-operative expectations with regard to walking ability or leisure-time activities does not influence the post-operative KOOS scores [11]? Maximum knee flexion is widely used as an outcome measure after knee arthroplasty. Obtaining higher post-operative flexion beyond the average range leads to a more normal feeling, but not to higher satisfaction. The Knee Society Score failed to detect any change in patient's functional outcome with the achievement of high flexion [1]. Of the patients with a perfect outcome on the Knee Society Score (KSS = 100), 66.1% met the features of a forgotten knee [12]. Furthermore, Robertsson et al. found that patients report being very satisfied with poor scores on

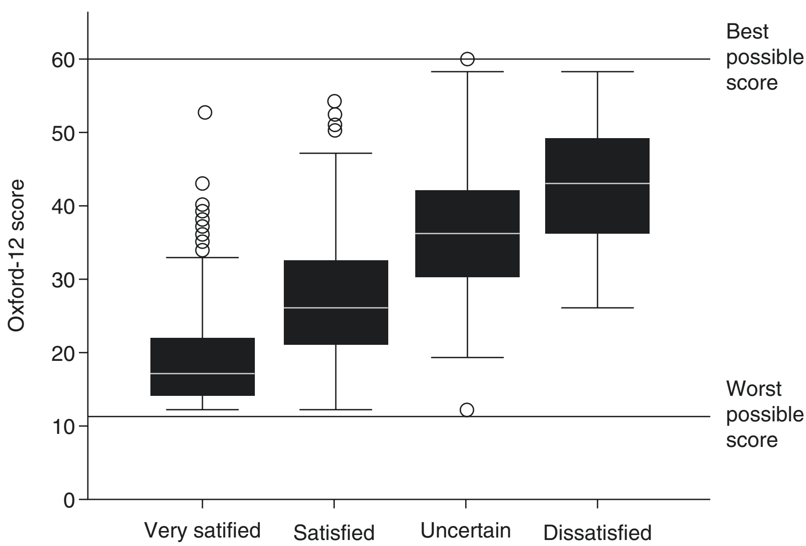

Fig. 53.1 For patients having expressed the same level of satisfaction, the range of their Oxford-12 Item Knee Score is expressed as a box plot showing the median (white line), interquartile range (block box representing 25% of scores on each side of the median), fences (horizontal lines between which 95% of the score lie) and outliers (circles). Solid horizontal lines represent the best (maximum) and worst (minimum) possible scores [13]

Oxford-12 and vice versa (Fig. 53.1). This illustrates the limited utility of health outcome questionnaires, urging caution regarding the use of standard instruments to assess satisfaction [14].

53.3 Relation Between Functional Abilities and Expectations After Knee Replacement?

Several studies utilizing self-reported outcomes indicate that patients perceive themselves to be more physically active after TKA than they were before surgery [15]. When these self-reporting outcomes are compared to objective accelerometer-based outcomes, the latter fall short. The physical activity level recovers only to pre-operative levels at 6 months after TKA, which means they still exhibited the same level of limitation that they did prior to surgery [15, 16]. When compared to healthy adults, one year after TKA an increased timed up-and-go (TUG) times, 18% slower walking speed, a 51% slower stair-climbing speed and deficits of nearly 40% in quadriceps strength are reported [17, 18]. One year after TKA, patients report having greater difficulty with kneeling, squatting, moving laterally, turning, cutting, carrying loads, stretching, performing lower extremity strengthening exercises, playing tennis, dancing, gardening and participating in sexual activity, when compared to healthy adults [19]. On the other hand, when looking at the older patient population in general, many of the limitations reported by patients after total knee arthroplasties are shared by individuals with no previous knee disorders. Approximately 40% of the functional deficit found after a total knee arthroplasty could to be attributable to the normal physiologic effects of ageing [19].

Side Summary

At one year after TKA, many patients still complain about difficulty with kneeling, squatting, moving laterally, turning, cutting, carrying loads, stretching, performing lower extremity strengthening exercises, playing tennis, dancing, gardening and participating in sexual activity, when compared to healthy adults. Approximately 40% of the functional deficit found after a TKA could to be attributable to the normal physiologic effects of ageing.

53.4 Are 'Young' Patients a Specific Group When Managing Expectations?

There is no consensus in literature on the definition of a young age (cut-off point below 55 or 60? biological or chronological age?) and the influence of age on patient satisfaction. In contrast to anecdotal belief, both Culliford et al. and Goudie et al. challenge the perception that surgeons now perform TKA on increasingly younger patients, since the mean age (and the 95% confidence intervals) for TKA has not changed [20, 21]. However, as the incidence of knee replacements is rising, the absolute number of young patients with a knee replacement is increasing. Generally speaking, 13–14% of the patients receiving a TKA are under 60 years of age [22]. When looking into this younger population, the outcomes seem to be worst. Registry data show inferior implant survivorship in the under 55-year age group, with a ten-year cumulative risk of revision of 9–11% (National Joint Registry 2016). The pain relief in this group is comparable to the whole population, with 91% satisfied 2.6 years post-operatively [23]. The overall dissatisfaction (or unsure) one year post-operative was 25% of the patients under 55 years [24]. The authors identified the pre-operative OKS, poor improvement of OKS and knee stiffness after surgery as significant predictors in that age group. A normal feeling of the knee is only found in 66%, absence of a limp in 47% and 50% is able to participate in their most preferred sport or other physical activity. Other reported symptoms were difficulty climbing up and down stairs (54%), stiffness (41%), difficulty in getting in and out of a car (38%), some degree of pain, swelling/tightness and grinding/noises (all 33%), and difficulty getting up and down from a chair (31%) [23].

Side Summary
About 13–14% of the patients receiving a TKA are under 60 years of age. Registry data show inferior implant survivorship in the under 55-year age group, with a ten-year cumulative risk of revision of 9–11%. Only 50% are able to participate in their preferred sports afterwards.

53.5 Defining the Reasons for Dissatisfaction

Rates of dissatisfaction as reported in three registry studies from three different countries were remarkably consistent at approximately 18%. The most important reasons for dissatisfaction are residual pain and limited function [6, 14]. Pain at rest prior to surgery is a risk factor for dissatisfaction and should elicit a more detailed history regarding chronicity of pain as well as types and amounts of medication [7].

Side Summary
Pain at rest prior to TKA is an important risk factor for dissatisfaction and should elicit a more detailed history regarding chronicity of pain as well as types and amounts of medication.

More patients are satisfied with their pain relief (87%) than with their improvement in physical function (80%) [11]. It is also related to pre-operative pain, physical function and perceived health. It is suggested that pre-operative patient-specific factors (such as level of disability, depression and anxiety) were much more significant factors in outcome than any surgical variable (such as implant type, bearing, patellar resurfacing and minimally invasive approach). 'Catastrophizing' can lead to worse subjective outcomes and may be manageable with appropriate psychological counselling [13]. Another apparent relationship is the chronicity of disease prior to surgery, with those suffering the longest having the highest satisfaction rates, whereas post-traumatic or osteonecrosis patients were the least satisfied (Fig. 53.2) [11, 14]. On the contrary, Baker et al. found in their

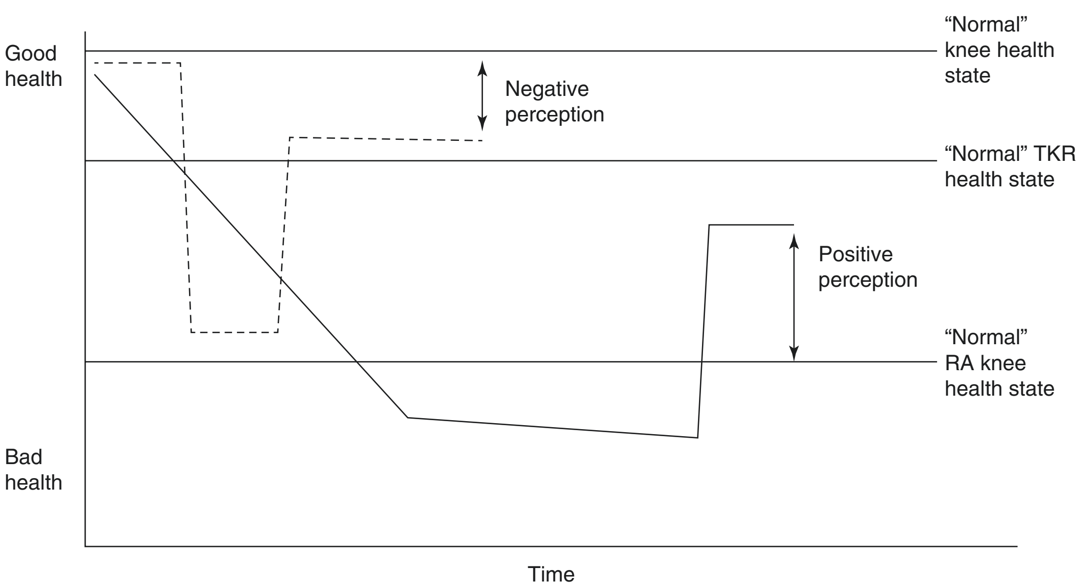

Fig. 53.2 Satisfaction is related to perceived level of health. The graph shows that chronic disease states, such as rheumatoid arthritis (RA) black line, reset the patient's concept of 'normal' health such that their TKA results in a perceived positive gain in health. Patients with a more recent onset of pathology, such as avascular necrosis, dashed line, compare their TKA outcome to a normal health state that results in a negative perception [13]

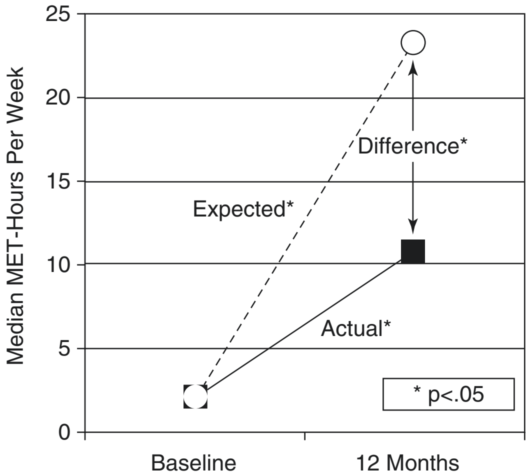

Fig. 53.3 Expected and actual median total leisure activity in metabolic equivalent of task (MET) before and 12 months after total knee arthroplasty [25]

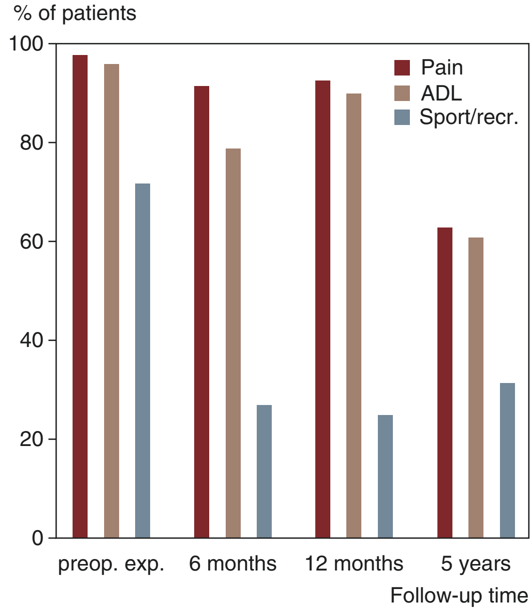

Fig. 53.4 Percentages of patients (n = 80) with pre-operatively high expectations ((much) less pain; (much) better activities of daily living (ADL), (much) better sport and recreational function (sport/rec)) and the percentages of patients reporting fulfilled expectations at three different follow-up times [27]

registry study that a diagnosis of primary osteoarthritis was associated with lower rates of satisfaction than any other diagnosis.

Furthermore, the patients' expectations regarding their post-surgical health state and the inability to meet them are a very significant risk factor for dissatisfaction [11]. This is represented by the risk ratio of 10.8 for unmet expectations after the surgery. In comparison, a complication requiring readmission to hospital carried a risk ratio for dissatisfaction post-operatively of 1.9, and pain at rest prior to surgery had a risk ratio of 2.5 [7]. Patients have in general (too) high expectations of a knee replacement (Fig. 53.3) [25, 26]. For example, 41% expected to be able to perform activities such as golfing and dancing while only 14% were capable of these activities at 5 years (Fig. 53.4) [27]. Despite the risk ratio of 10.8 for unmet expectations, unmet expectations do not automatically lead to dissatisfaction. And to make the matter even more complex, fulfilled expectations do not necessary lead to satisfaction.

53.6 Indication Criteria for Surgery?

There are no absolute indications for surgery concerning pain or stage of osteoarthritis on pre-operative radiographs [28]. Although several guidelines [29–34] on indication criteria are available, the cut-off values or ranges at which the best post-operative outcome is achieved are unknown [35]. It is known that there is a positive correlation between the pre-operative and post-operative PROM scores [36–40]. Furthermore, pain and disability depend as much on depression and isolation as it does on the severity of the joint damage [41]. There is limited evidence what seems to be the 'ideal' moment to perform a TKA based on pre-operative criteria related to post-operative outcome. This makes the current available guidelines less helpful in our daily practice to improve outcome on an individual basis.

Side Summary

There are no absolute indications for TKA concerning pain or stage of osteoarthritis on pre-operative radiographs. Several guidelines are available but fail to give an equivocal answer to this pertinent question of optimal indication and timing.

53.7 How to Increase Patient Expectations and Improve Outcome?

Addressing the pre-operative expectations start with offering a balanced review of conservative (pain medication, physical therapy, weight loss, group counselling) and invasive treatment options, including the option of observation only. Only 10% of the osteoarthritis patients in the orthopaedic practices receive counselling for all non-surgical treatment options, which means that 90% of the patients might be undertreated conservatively before proceeding to surgery [42].

Side Summary
Only a paucity of patients suffering from osteoarthritis in the orthopaedic practices receive counselling for all non-surgical treatment options. Although this is dependent from the individual healthcare system, a considerable number of patients might be undertreated conservatively before proceeding to TKA.

Patients should be encouraged to list examples of their expectations and goals to do after their TKA, with respect to pain, sport, leisure activities and work. Surgeons must appropriately address the relative probability that they would be able to accomplish their stated goals. In the case of a mismatch between patients' expectations and surgeons' accomplishments, the surgeon should explain how realistic the patients' hopes are [13].

In younger patients, it is far from obvious that with a TKA, patients could continue their physical job in, for example, construction or farming. Ask for patient expectations is an essential component of patient counselling and is a part of shared decision-making (SDM). The process of SDM helps to move beyond passive informed consent to more collaborative, patient-focused experiences. By offering a balanced review of conservative and invasive treatment options, including the option of observation only, SDM provides patients an opportunity to express their personal values and goals in the context of health decisions [43]. To effectively use a patient-focused approach, like SDM, it is important to understand the factors involved.

Side Summary
Patients should be encouraged to list examples of their expectations and goals to do after their TKA, with respect to pain, sport, leisure activities and work. Surgeons must appropriately address the relative probability that they would be able to accomplish their stated goals.

The factors that influence the decision of a patient into knee arthroplasty are the following: the relationship with the physician; fear of surgery (including anaesthesia), recovery, outcome and pain; functional ability post-operative; psychological aspects including frustration, fear, letting others down and self-image; and the social network, for information and perceived pressure. With the help of decision aids, the decisional conflict of the patient can be reduced.

Since optimistic patients do better after surgery [44], the mental status of the patient and the timing of surgery may play a role in SDM. A recent prospective study [45] showed that pre-operative anxiety and depression correlate with dissatisfaction after TKA. There are several strategies to reduce the impact of mental aspects in the outcome of TKA and improve the degree of satisfaction. Among others, these strategies include psychological assessment and treatment, improve patients' self-efficacy and manage pain with more than only narcotics. A new prediction model for patient satisfaction as described by van Onsem et al. might also be a beneficial tool for both surgeon and patients to evaluate the risks and benefits of surgery [10]. After validation, this tool will be helpful in selecting, on an individual basis, the patient who is likely to benefit from knee replacement surgery.

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Check for updates

54 Function After Small Knee Implants

Bert Boonen and Nanne P. Kort

Keynotes

- Unicompartmental knee arthroplasty (UKA), bicompartmental knee arthroplasty (BKA), and patellofemoral arthroplasty (PFA) all have their very precise indications. When surgeons adhere to these indications, all procedures result in good to excellent functional outcome.
- Concerning data presentation of functional outcome, there is no clear consensus on what patient-reported outcome measures and/or functional tests to use.
- Functional outcome after medial UKA is better than after TKA, continues to improve beyond 6 months and up to 2 years, and is sustainable in the long term.
- There is no difference in survival or functional outcome in mobile bearing compared to fixed-bearing medial UKA.
- Best survival rates in medial UKA are with strict adherence to "safe zones" for component alignment. An overhang of tibial component >3 mm and joint space elevation >2 mm lead to inferior functional results.
- A high BMI, presence of chondrocalcinosis, or deviant patellar height are no contraindications for medial UKA. Partial thickness cartilage loss and a fixed flexion deformity >10° are contraindications.
- For lateral UKA, best functional results are obtained with post-op valgus alignment of 3°–7°. In general, patients receiving a medial UKA are more satisfied than patients receiving a lateral UKA, but survival rates are similar.
- PFA results in good clinical outcome when strictly adhered to indications for this type of surgery.
- Functional results and survival figures of unlinked BKA are better than those of monolithic femoral component BKA.
- Evidence on functional results of BKA compared to TKA is conflicting.

54.1 Introduction

This chapter describes the knee function in patients after small knee implants. More specifically, it describes what to expect with regard to knee function following unicompartmental knee

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arthroplasty (UKA), bicompartmental knee arthroplasty (BKA), and patellofemoral arthroplasty (PFA).

54.2 Unicompartmental Knee Arthroplasty

UKA is a joint-resurfacing procedure in which the affected degenerative compartment is treated with a prosthesis, and the non-affected compartments are preserved. The most common indication for UKA is anteromedial osteoarthritis (OA) of the medial femorotibial compartment. A significant advantage of UKA over total knee arthroplasty (TKA) is that joint kinematics and knee stability more closely resemble natural knee joint kinematics because of the preservation of the anterior cruciate ligament (ACL) [2, 3].

> **Side Summary**
> UKA closely resembles natural knee kinematics.

At surgery, these knees mostly demonstrate functionally healthy cruciate ligaments, though the ACL may have suffered some damage. Also, the articular cartilage on the tibia is eroded, and eburnated bone is exposed, in an area that extends from the anteromedial margin of the medial plateau for a variable distance posteriorly but never as far as the posterior margin. An area of full-thickness cartilage is always present, preserved at the back of the plateau. Similarly, the cartilage on the distal articular surface of the medial femoral condyle is eroded, and eburnated bone is exposed. The posterior surface of the femoral condyle retains its full-thickness cartilage. The articular cartilage of the lateral compartment, although often fibrillated, preserves its full thickness. The MCL is of normal length, and the posterior capsule is shortened.

Most research that resulted in the criteria mentioned above was done by the Oxford group who developed the Oxford UKA. These criteria, although widely accepted, are therefore mainly applicable to the Oxford UKA philosophy: congruent, freely mobile meniscal bearing that is free to slide and rotate between the congruent surfaces of the spherical femur and flat tibia. This congruency is maintained in all positions throughout the range of movement of the knee joint. Generalization of all these indications for any other design of UKA may not be possible, but high quality evidence on this topic is lacking.

54.3 Patellofemoral Arthroplasty

The use of patellofemoral arthroplasty (PFA) in the knee with severe OA of the patellofemoral joint has been reported since 1979 [4]. Severe, isolated patellofemoral OA is the typical indication for PFA. More recent evidence indicates that PFA should be restricted to patients with trochlear dysplasia, in whom arthritis was triggered by patellar instability and maltracking rather than degenerative or age-related diseases [11].

Until recently, available PFA prostheses were not reliable enough to be used on a regular basis when compared to outcomes from TKA. Observed shortcomings in design features were perceived as a common problem. However, in recent years, new devices with designs, that attempt to mimic more accurately normal knee anatomy in an attempt to reproduce patellofemoral joint function, have been introduced. This has resulted in better survival rates. One of the reasons for revising a PFA is the progression of osteoarthritis in the tibiofemoral joint. Vandenneucker et al. found that isolated patellofemoral arthroplasty alters the natural tibiofemoral kinematics [49]. The effects become more pronounced in case of increased patellar thickness. They recommend a slight over-resection of patellar bone if sufficient bone stock is available to prevent overstuffing in order to increase longevity of the implant.

When comparing onlay to inlay design of the trochlear component, the theoretical advantages of an inlay design appear not to result in better clinical outcome scores [13]. In the same study, a progression of tibiofemoral OA was found to occur significantly less common in patients with an inlay trochlear component and the authors therefore concluded that this implant design might improve long-term results and survival rates after isolated PFA. Furthermore, in-debt analysis of these survival rates and possible failure mechanisms is beyond the scope of this chapter.

Side Summary
There are online and inline designs available. The superiority of one or the other remains unclear.

54.4 Bicompartmental Knee Arthroplasty

Bicompartmental knee arthroplasty (BKA) involves the replacement of the patellofemoral joint compartment and either the medial or the lateral tibiofemoral joint compartment. The purpose of this procedure is to restore natural knee kinematics and to preserve bone stock, especially in younger patients [15, 43]. This type of surgery is proposed to bridge the gap between UKA and TKA [40]. Historically two types of femoral design have been used in bicompartmental arthroplasty; the older monolithic architecture with a fixed position of tibiofemoral and patellofemoral components, or the more recent modular unlinked design where the two parts are split and placed independently [43, 57, 60]. The implant of monolithic femoral component forces the surgeon to compromise the final placement on the coronal plane to best resurface medial and patellofemoral compartments. Poor results are recorded with this design [33, 36].

Side Summary
Poor results have been reported when using component out of the shelf in bicompartmental arthroplasty.

Even with more recently introduced PSI techniques, the positioning of this component rest challenging, given a 20% rotational malalignment [46]. In this respect, unlinked modular designs are better suited to recreate the patient's individual morphology [31]. In general, clear indications for this type of surgery exist: minimum of 90° flexion arc and less than 5° of flexion contracture, angular deformity of no more than 10° of varus and 15° of valgus and intact anterior cruciate ligament [25].

Side Summary
There is still a 20% of malrotation of the femoral component when patient-specific arthroplasty is used.

54.5 What is the Functional Outcome?

The goal of joint replacement surgery, in general, is to relieve pain and to restore function. Therefore, it is reasonable to assess these parameters following arthroplasty. There is a considerable debate, however, concerning the optimal way to gain insight into these parameters and concerning the optimal way of presenting results. Clinicians are struggling with questions as, for example, what aspects of the pain (e.g., activity-related pain, night pain, or resting pain) and types of function (e.g., stair climbing, shopping, getting on a bus, or playing golf) should be assessed. Also, these often depend on issues such as culture and context.

The basic problem is that outcome measures are an artificial construct, as everyone's life and health change continuously and well-being is influenced by many factors other than a specific illness or its treatment.

Not surprisingly, therefore, in the current literature, several ways of assessing function are used. They can be classified according to who makes the judgment: a clinician, the patient alone, a "significant other," or a mixture of two or more groups. In early studies, adverse events such as infection and prosthesis survival were the main issues of concern [58]. As prosthesis design and the control of adverse events improved, these issues became less important and attention turned toward clinician-administered tools and more recently toward patient-reported outcome measures (PROMs). Clinician-administered tools have been widely criticized because of the recognized discordance between views of patients and clinicians [28]. Therefore, more recent research studies in joint replacement frequently use PROMs assessing different domains. Patients rate their pain, function, health-related quality of life (HR-QoL), social participation, mental health, and satisfaction with the outcome of health-care interventions. Drawbacks of PROMs are that they reflect only a patient's perception, thus represent subjective measures which are regularly influenced by socioeconomic and psychological factors [51]. Moreover, there is increasing evidence to suggest that pain is the primary determinant of outcome for many PROMs as patients are unable to discriminate between pain and functional disability [18]. Last, PROMs suffer from a ceiling effect, which limits their capability of determining the true functional abilities in different categories of patients [54].

Routinely used PROMs for patients following joint replacement are the Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Knee Society Clinical Rating System (KSS), EuroQol EQ-5D, Knee injury and Osteoarthritis Outcome Score (KOOS).

Side Summary
The most commonly used PROMs are Oxford Knee Score, Western Ontario and McMaster Universities Osteoarthritis Index, Knee Society Clinical Rating System, EuroQol EQ-5D, and Osteoarthritis Outcome Score.

In addition to the classification, according to who makes the judgment, outcome measures may be general or joint specific. General outcome measures reflect overall pain, function, and well-being. Joint-specific measures are used to assess the effectiveness of an intervention targeting a joint (e.g., joint replacement).

The WHO (World Health Organization) introduced in 2001 the International Classification of Functioning, Disability and Health. The International Classification of Functioning, Disability and Health provides a theoretical framework on which to base the assessment of function. This framework splits function into three separate domains: impairment, activities' limitations, and participation restrictions. Research has shown that the relationship between the impairment, activities' limitations, and participation restriction domains of the International Classification of Functioning, Disability and Health (ICF) is not simple. With other factors such as self-efficacy and comorbidities acting as independent determinants of the relationships between these variables [42].

More recently, attention has also shifted toward performance-based tests (PBT). Various measurement tools for performance-based assessment of physical function following joint replacement are available, ranging from high-end optical motion capture systems to wearable motion sensors [5, 50].

Side Summary
Performance-based test may be critical for patients' assessment in the future.

While PROMs relate to the patient's belief and experience of their functional ability during activities in the ICF model, performance-based measures of such activities prove what a patient can do rather than what the patient perceives he/she can do. They capture a different construct of physical function than PROMs alone. Therefore, performance-based measures and PROMs provide distinct information, and the two methods are considered to be complementary rather than competing. Ideally, as such, the outcome should be assessed using a combination of outcome measures. To date, however, no clear consensus exists on what these measures, both PROMs and PBT, should be in specific patient categories.

54.6 Functional Outcome After UKA

In the current literature, functional outcome after UKA is mostly assessed and reported using PROMs. This section is divided into seven subsections.

General functional outcome following UKA will be discussed in the first section. The influence of implant type, of the alignment of the components, patient factors, and the rehabilitation type on the functional outcome will be discussed in separate sections. UKA patients are generally younger than TKA patients. In the last section, the functional outcome following lateral UKA will be briefly evaluated. The literature has been summarized in Tables 54.1 and 54.2.

Short-term functional outcome, as measured by PROMs, in patients after UKA is better than in patients after TKA. A total of 3519 UKA patients were matched to 10 557 TKAs using data from the national joint registry (NJR). The mean 6-month PROMs favored UKA and UKA patients were more likely to achieve excellent results and to be highly satisfied, and were less likely to report complications than those who had undergone TKA [29].

Functional recovery after UKA continues beyond 6 months and even up to 2 years [23]. As discussed before, more challenging tests are needed that can discriminate improvement beyond a point where questionnaires cease to improve. In this study by Kleijn et al., an accelerometer-based system (DynaPort Knee system) that objectively measures functional aspects of gait during various tasks of daily life was used [23]. The test consists of five small movement sensors that are fixed to the patient's

Table 54.1 Short-term functional outcome (FO), long-term FO, component alignment and FO after unicompartmental knee arthroplasty (UKA)

	Short-term FO	Long-term FO	Component alignment and FO
Liddle et al. [29]	3519 UKA patients matched to 10 557 TKAs: OKS 37.7 (95% CI 37.4–38.0) for UKA; 36.1 (95% CI 35.9–36.3) for TKA UKA more likely to achieve excellent results (OR 1.59, 95% CI 1.47–1.72, $p < 0.001$) and to be highly satisfied (OR 1.27, 95% CI 1.17–1.39, $p < 0.001$)		
Friesenbichler et al. [14]	Quadriceps strength of TKA, but not of UKA patients, lower than that of controls ($P < 0.05$). UKA better gait function than TKA ($P < 0.01$), better self-reported pain ($P < 0.05$), function ($P < 0.01$), and stiffness ($P < 0.05$)		
Pandit et al. [37]		1000 UKAs, at 10 years: mean OKS 40 (SD 9; 2–48): 79% excellent or good outcome	
Winnock de Grave et al. [56]		Mean OKS 43.3 (7–48), with 94.6% patients showing excellent or good outcomes at mean follow-up of 5.5 years	

(continued)

Table 54.1 (continued)

	Short-term FO	Long-term FO	Component alignment and FO
Walker et al. [53]		Clinical outcome good to excellent with OKS of 39.9 at 11 years, a KSS of 89.3, and a mean range of motion of 122°	
Kim et al. [22]			Series of 246 cases at 5-year follow-up: no significant relationship between tibiofemoral angle and knee score, function score, and ROM ($p > 0.05$)
Gulati et al. [16]			No significant difference in OKS between outer alignment ranges for femur varus-valgus −10° to −7.5° and 7.5° to 10° ($p = 0.242$), femur flexion-extension −10° to −7.5° and 7.5° to 10° ($p = 0.445$), tibia varus-valgus −5° to −2.5° and 2.5° to 5° ($p = 0.327$) and tibia slope −5° to − 2.5° and 2.5° to 5° ($p = 0.777$) compared to inner ranges of alignment.
Chau et al. [7]			Five years after surgery, patients with major overhang (>3 mm) had significantly worse OKS ($p = 0.001$) and pain scores ($p = 0.001$)
Kamenaga et al. [21]			Rotation angles of tibial components' significant negative correlations with recovery of the OKS 2Y following UKA
Chatellard et al. [6]			559 medial UKAs, several failure modes. The only factor associated with worse functional scores, however, was a joint space elevation by more than 2 mm

OKS Oxford Knee Score, *TKA* Total Knee Arthroplasty, *UKA* Unicondylar Knee Arthroplasty, *KSS* Knee Society Score

thorax, pelvis, left thigh, and beneath both knees. These sensors measure the accelerations related to the orientation and movement patterns of the body and the trunk while the patient performs a set of 29 test items. An algorithm calculates four cluster scores, locomotion, transfer, lift and move, rise and descend, and automatically relates the cluster scores to control of healthy subjects. The scores are weighted and combined into one overall DynaPort Knee Test score that ranges from 0 to 100. Functional tests like this can provide more detailed information on function following joint arthroplasty.

Functional results at long-term follow-up after UKA are satisfying, with 79% of knees reporting an excellent or good outcome at 10-year follow-up of the largest available follow-up study (1000 minimally invasive Phase 3 Oxford medial UKAs) [37].

A critical remark when discussing clinical outcome following UKA surgery is that most research is done using the Oxford medial UKA prosthesis. Moreover, long-term functional outcome is generally reported by the Oxford group itself, and although research is generally of sufficient quality, there may be an inherent risk of bias due to conflicts of interest.

Table 54.2 Mobile versus fixed bearing, patient factors and functional outcome (FO), and rehabilitation and FO

	Mobile versus fixed bearing	Patient factors and FO	Rehabilitation and FO
Sebilo et al. [44]	720 cases, mean follow-up 62 months: KSS score improvement not significantly different between fixed and mobile implants (30.7 and 30.5 points, respectively). Active range of flexion was 118.3° and 114° in these two groups (n.s)		
Parratte et al. [39]	Minimum follow-up of 15 years. No difference in KSS 82 (SD 2, range: 55–100) versus 81 (SD 2, range: 66–100), $P = 0.84$. Mean active knee flexion improved from 120° ± 7° (range, 100°–150°) preoperatively to 129° ± 4° (range, 115°–150°) at final follow-up in the fixed-bearing group and from 115° ± 8° (range, 105°–145°) to 127° ± 6° (range, 110°–145°) in the mobile bearing ($p = 0.85$)		
Murray et al. [34] Plate et al. [41]		2438 UKAs: BMI <25 ($n = 378$), BMI 25 to <30 ($n = 856$), BMI 30 to <35 ($n = 712$), BMI 35 to <40 ($n = 286$), and BMI 40 to <45 ($n = 126$) and BMI ≥ 45 ($n = 80$). At mean follow-up of 5 years (range 1–12 years): no significant difference in KSS between groups 746 UKAs: Mean postoperative OKS was 37 (SD 11) without correlation with BMI (n.s.).	
Hamilton et al. [17]		Significantly lower OKS and KSS in patients with partial thickness cartilage loss at 1-year, 2-year, and 5-year follow-up in 94 UKAs	
Kumar et al. [26]		No significant difference in OKS and OKS change between patients with (87 cases) or without (996 cases) radiological signs of chondrocalcinosis at 10-year follow-up	
Ali et al. [1]		In a series of 1000 UKAs, mean follow-up 6.1 years: final OKS and KSS-F were significantly better in the high activity group compared to the low-activity group (OKS 45v40, KSS-F 95v78), there was no difference in the change in OKS or KSS	

(continued)

Table 54.2 (continued)

	Mobile versus fixed bearing	Patient factors and FO	Rehabilitation and FO
Chen et al. [8]		803 UKAs, 2-year follow-up: 26 patients (3%) with severe fixed flexion deformity (FFD). The Knee Society Function Score and Knee Score in the severe FFD group were 10 ± 4 and 10 ± 2 points lower than in the control group, respectively ($P = 0.017$ and $P = 0.001$). Oxford Knee Score and Physical Component Score in the severe FFD group were 5 ± 1 and 7 ± 2 points lower than in the control group, respectively ($P = 0.033$ and $P < 0.001$).	
Jorgensen et al. [20]			Cohort of 55 patients. No difference in leg extension power in progressive resistance training group versus home-based exercises alone group. Walking speed and KOOS scores: no between-group difference (6-min walk test $P = 0.63$, KOOS $P > 0.29$)

KSS Knee Society Score, *OKS* Oxford Knee Score, *UKA* Unicondylar Knee Arthroplasty, *BMI* Body Mass Index, *KOOS* Knee injury and Osteoarthritis Outcome Score

54.6.1 Influence of Type of Implant on Functional Outcome

Concerning the type of implant, a distinction can be made between fixed-bearing and mobile-bearing UKAs. A study of Sebilo et al., comparing UKAs from different manufacturers in 940 patients, found no significant differences between clinical outcomes or prosthesis survival across implant design categories [44]. They used biomechanical features to categorize the implants: condylar cut (455 of 836 cases with available data, 54%) versus condylar resurfacing (381/836, 46%); and all-polyethylene tibial component (356 cases of 910 with available data, 44%) versus metal-backed tibial component (554/910, 56%; 48 fixed and 506 mobile).

In a retrospective study comparing 77 mobile-bearing UKAs to 79 fixed-bearing UKAs, the mean Knee Society function and knee scores were comparable in the two groups. At final follow-up, considering revision for any reason, no difference in survivorship between fixed and mobile bearing was found [39].

Concerning reoperation rate, the overall reoperation rate was similar between mobile-bearing and fixed-bearing UKAs in a study performed by Ko et al. [24]. The overall incidence of complications was also similar for fixed- and mobile-bearing designs in this study.

54.6.2 Influence of Component Alignment on Functional Outcome

When discussing the influence of alignment, a distinction can be made between the alignment of the leg and the alignment of the individual components of the prosthesis. The angle between the anatomical axis of the femur and the tibia (tibiofemoral angle) is often used to describe limb alignment.

Kim et al. reviewed 246 cases of medial UKA, which were followed up for at least 5 years after surgery [22]. They concluded that the tibiofemoral angle after UKA had no significant influence on the midterm clinical scores, but there was a significant relationship between the postoperative tibiofemoral angle and failure rate of the implant. They found best survival rates when the tibiofemoral angle was between 4° and 6° of valgus.

Concerning proper component alignment, research has been done by Gulati et al. on the Oxford UKA prosthesis in 211 cases with a follow-up of 4 years [16]. They concluded that, because of the spherical femoral component, the Oxford UKA is tolerant to femoral malalignment of 10° and tibial malalignment of 5°.

An overhang of the tibial component can cause pain. Chau performed a study on 160 UKAs to determine the maximal acceptable degree of overhang. They concluded that surgeons must avoid tibial component overhang of 3 mm or more, as this severely compromises the outcome [7]. Chatellard et al. studied 559 medial UKAs and concluded that the mean 10-year survival rate was 83.7% [6]. Factors associated with decreased prosthesis survival were higher than 2 mm change in joint space height, a greater than 3° change in tibial component obliquity, a slope value higher than 5° or a change in slope greater than 2°, and more than 6° of divergence between the tibial and femoral components. Residual mechanical varus of 5° or more was also associated with mechanical failure. The only factor associated with worse functional scores, however, was a joint space elevation by more than 2 mm.

54.6.3 Influence of Patient Factors on Functional Outcome

In Table 54.2 evidence is summarized for pre- and postoperative phase. Both phases are discussed seperate below.

54.6.3.1 Patient Characteristics in the Preoperative Period

A high body mass index of patients has been advocated as a contraindication to UKA. More recent studies in large patient cohorts have demonstrated that increasing BMI was not associated with an increasing failure rate. It was also not associated with a decreasing benefit from the operation. Therefore, it has been stated that the classic contraindication of BMI >30 kg/m^2 may not be justified with the use of modern UKA designs or techniques [34, 41].

Patients with partial thickness cartilage loss, on the other hand, had significantly worse functional outcomes at 1, 2, and 5 years postoperatively compared with those with full thickness loss [17]. In this study by Hamilton et al., a quarter of knees with partial thickness loss had a fair or poor result and a fifth failed to achieve a clinically significant improvement in OKS from a baseline of four points or more; double that seen in knees with full thickness loss. While there was no difference in implant survival between the groups, the rate of reoperation in knees with partial thickness loss was three times higher. Also, they found that some patients with partial thickness loss achieve a good result but that it is impossible to identify which these will be and that, in this situation, MRI is unhelpful and misleading.

Chondrocalcinosis does not influence functional outcome or survival following UKA according to a study by Kumar et al. in 88 patients [26]. Preoperative radiological evidence of chondrocalcinosis should, therefore, not be considered as a contraindication to UKA [26].

Patellar height has been hypothesized to influence outcome after UKA. Naal et al. studied this topic in a group of 83 UKAs [35]. After UKA, the patellar height decreased significantly according to the Blackburne-Peel index, but not significantly according to the Insall-Salvati ratio. There were only weak and inconsistent correlations between the patellar height and clinical outcome parameters. Hence, based on their results, the patellar height seems not to be a strict separate patient selection criterion for UKA.

54.6.3.2 Patient Characteristics in the Postoperative Period

High activity does not compromise the outcome of the Oxford UKA and may improve it. The activity should not be restricted nor considered to be a contraindication. This was concluded based on the outcome of 1000 Phase 3 cemented Oxford

UKAs using survival analysis, the OKS, and the KSS. Patients in this study were grouped according to the maximum postoperative Tegner Activity Score [1].

In some patients, a fixed flexion deformity (FFD) can persist after surgery. An FFD of >10° after UKA is associated with significantly poorer functional outcomes [8].

54.7 Influence of Type of Rehabilitation on Functional Outcome

Only a paucity of studies has been conducted on specific rehabilitation protocols following UKA. Jorgensen et al. randomized 40 patients into either progressive resistance training (home-based exercise 5 days/week and progressive resistance training 2 days/week) or control group (home-based exercise 7 days/week). It was concluded that progressive resistance training 2 days/week combined with home-based exercise 5 days/week was not superior to home-based exercise 7 days/week in improving leg extension power of the operated leg [20].

An advantage of UKA over TKA is a greater improvement in range of motion when compared to TKA. A recent meta-analysis on this topic showed an improvement of the joint flexion (effect estimate 11.33; CI 7.92, 14.73; $P < 0.00001$) and total ROM (effect estimate 6.42; CI 1.84, 11.00; $P = 0.006$) for UKA over TKA in a total of over 900 patients [32]. A substantial part of patients, however, reports an inability to kneel after UKA. Jenkins et al. studied this subject to determine whether a single physical therapy intervention would improve patient-reported kneeling ability following UKA in 60 patients. The single factor that predicted patient-reported kneeling ability at 1-year postoperatively was the physical therapy kneeling intervention given at 6 weeks after UKA. The results of this study suggest that advice and instruction in kneeling should form part of a postoperative rehabilitation program after UKA [19].

54.8 Lateral UKA

Lateral UKA is less frequently performed than medial UKA. In a large series of 265 cases in which a domed lateral Oxford UKA with a biconcave bearing was implanted, the mean OKS was 40 of 48 (SD 7.4). Survival at 8 years in these series, with failure defined as any revision, was 92.1% [55].

Concerning limb alignment after lateral UKA, postoperative valgus alignment of 3°–7° was correlated with the best short-term functional outcomes in lateral UKA surgery [47].

A vast majority (98%) of 45 patients returned to sporting and recreational activities following lateral UKA [52]. The return to sports was independent of patient age or gender. Two-thirds of these patients reached a high-activity level. Activities patients were most participating in were of low- or mid-impact, whereas high-impact activities were mostly given up.

When comparing lateral UKA to medial UKA, patients receiving a medial UKA had better mean scores on PROMs compared with patients who had a lateral UKA. Similar implant survival rates were similar for medial (90%) and lateral UKAs (83%) in large series of 558 patients who underwent mobile-bearing UKA [30].

54.9 Functional Outcome After Patellofemoral Arthroplasty

In 2015, van der List et al. published a large meta-analysis including 12 level II studies and 45 level III or IV studies (Table 54.3). They found reasonable survival rates' good functional outcome [48].

In a smaller study in 70 patients (79 knees), Leadbetter et al. investigated the ability of patients to climb stairs and perform daily activities. Seventy-one knees (90%) functioned without pain in daily activity and stair climbing [27].

DeDeugd et al. studied the relationship between the grade of patellofemoral OA and the functional results following PFA. They concluded that caution should be used when consid-

Table 54.3 Revision rates, short-term and long-term functional outcome (FO) and relationship between degree of OA and FO

	Revision rates and long-term FO	Short-term FO	Degree of OA and FO
Van der List et al. [48]	Systematic review: 900 revisions in 9619 PFAs: 5-, 10-, 15-, and 20-year PFA survivorships of 91.7, 83.3%, 74.9%, and 66.6%, respectively. Functional outcomes in 2587 PFAs with an overall score of 82.2% of the maximum score. KSS and Knee Function Score were 87.5% and 81.6%, respectively		
Leadbetter et al. [27]		79 PFAs: mean follow-up of 3 years (range: 2–6 years), 84% of knees had KSS greater than 80 points. 90% of PFA functioned without pain in daily activity and stair climbing	
DeDeugd et al. [10]			75 PFA, mean follow-up of 3 years (range, 2–10). Significantly more improvement in KSS pain ($P = 0.046$), KSS function ($P = 0.02$), University of California at Los Angeles (UCLA) ($P = 0.046$), and Tegner ($P = .008$) scores in the Iwano grade II–IV group versus the Iwano grade I group. Patient-reported pain quality improved significantly more following PFA in the grade II–IV group ($P = 0.04$)

FO Functional outcome, *OA* Osteoarthritis, *PFA* Patellofemoral arthroplasty

ering PFA for patients with minimal radiographic evidence of patellofemoral OA [10].

54.10 Functional Outcome After Bicompartmental Knee Arthroplasty

When discussing the functional outcome, it is important to make a distinction between modular unlinked and monolithic femoral components in bicompartmental knee arthroplasty (BKA). Results in the literature are conflicting, especially when a comparison is made with TKA (Table 54.4).

Thienpont and Price reviewed the literature of all peer-reviewed published articles on BKA and reported that BKA performed with modular components obtains good to excellent results at ±10-year follow-up. Function and biomechanics were superior to TKA. Modern monolithic femoral components, however, were reported to give early failure and high revision rates (17-year survival to revision, radiographic loosening, or disease progression of 54%) and it was advised not to use this kind of implants [40]. Survivorship of BKA in general in the included studies was inferior to TKA [45].

Since publication of the previous mentioned study, several other authors compared BKA to TKA with results that are generally in line with the study of Thienpont et al. In a smaller study of 24 patients (31 knees), Chung and Min found no difference between BKA (medial UKA and patel-

Table 54.4 Functional outcome (FO) of bicompartmental knee arthroplasty (BKA) versus total knee arthroplasty (TKA)

	Thienpont et al. [45]	Chung et al. [9]	Engh et al. [12]	Yeo et al. [59]	Parratte et al. [38]
FO BKA versus TKA	Literature review of all peer-reviewed published articles. Bicompartmental arthroplasty performed with modular components obtains good to excellent results at ±10-year follow-up. Function and biomechanics were superior to TKA	31 knees: 15 modular bicompartmental versus 16 TKA. Knee extensor and flexor torque, hamstring/quadriceps ratio, position sense, and physical performance not significantly different preoperatively, at 6 and 12 months after surgery. Only TKA group showed enhancement in stair climbing test	25 TKA versus 25 monolithic BKA: Both groups achieved equivalent Knee Society scores (2-year mean 93.6 vs. 92.6, $P = 0.43$) and Oxford scores (2-year mean 43 vs. 41, $P = 0.35$)	26 unlinked BKA versus 22 TKA: at 5 years postop no significant difference in outcome scores in the BKA group compared to the TKA group	34 BKA versus 34 TKA: at mean follow-up of 3.8 ± 1.7 years, probability of FJS significantly higher in the BKA group (odds ratio, 4.64; 95% confidence interval, 1.63–13.21; $P = 0.007$, Chi2 test). Mean range of knee flexion significantly greater in the BKA group (130° ± 6° vs. 125° ± 8° after TKA; $P = 0.03$). BKA group had significantly higher mean values for the knee and function KSSs, TUG test, and UCLA score ($P < 0.04$ for all four comparisons)

BKA Bicompartmental Knee Arthroplasty, *TKA* Total Knee Arthroplasty, *FJS* Forgotten Joint Score, *KSS* Knee Society Score, *TUG* Timed Get Up and Go Test, *UCLA* University of California Los Angeles patient activity scale score

lofemoral arthroplasty) and TKA when it came to knee extensor and flexor torque, hamstring/Quadriceps ratio, position sense, and physical performance, at 6 and 12 months after UKA [9].

Engh et al. studied 50 patients receiving either a BKA (monolithic femoral component) or a TKA. Knee Society scores, Oxford questionnaires, radiographs, and functional tests were performed preoperatively, and at 1, 4, 12, and 24 months postoperatively [12]. Functional testing included gait analysis, stair climbing, lunging, and sit-to-stand analysis. Two years postoperatively the BKA and TKA groups achieved equivalent results in clinical scores and functional testing.

Yeo et al. analyzed the results of 48 patients, randomized into either unlinked BKA or TKA, 5 years after surgery [59]. There was no significant difference in outcome scores in the BKA group compared to the TKA group.

Parratte et al., on the other hand, did find that the probability of forgotten knee status (100/100 value of the Forgotten Joint Score (FJS-12) and each of the five KOOS subscales) was significantly higher in the BKA group (34 patients) compared to a matched TKA group [38]. The mean postoperative extension was not significantly different between the groups, whereas the mean range of knee flexion was significantly higher in the BKA group. The BKA group had significantly higher mean values for the knee and function KSSs, Timed Up-and-Go test, and UCLA score.

Take Home Message

- UKA, PFA, and BKA all have their precise indications. When surgeons adhere to these indications, all procedures result in good to excellent functional outcome, although patients experience functional limitations in higher impact activities after their arthroplasty surgery.
- The surgery itself can be technically demanding in some cases. Results presented in the current literature might be overestimated, as most authors are surgeons that vastly believe in the specific type of implant and generally are high-end users.
- When describing functional outcome following small knee implants, there is no clear consensus on which PROMs and functional test should be used.

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55 Sports After Partial or Total Knee Arthroplasty

Caroline Hepperger, Christian Fink, Christian Hoser, Elisabeth Abermann, and Peter Gföller

Keynotes

Sports after knee arthroplasty play an increasingly important role for surgeons and patients. Therefore, physicians are frequently faced with the patient's questions regarding their involvement in sports activities and what sports level will be possible after knee arthroplasty. However, the question of whether participating in sports after a knee arthroplasty is safe or if it has positive effects is highly debated. Several studies about sports after knee arthroplasty have been published, reporting controversial results. Sports activity is possible after UKA and TKA. Patients following UKA present higher return to sports rates and the time to return to sports is faster than in patients following TKA. The participation in sports seems to be more often possible in patients following UKA than TKA.

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55.1 Introduction

Nowadays, sports after knee arthroplasty play an increasingly important role for surgeons and patients. The indications for knee arthroplasty are including younger and more active patients [1]. A patient's desire to return to sports has become more important in the decision to undergo surgery [2–6].

Side Summary

Sports after total knee arthroplasty have increasingly become important in the decision to undergo surgery.

Therefore, physicians are frequently faced with the patient's questions regarding their involvement in sports activities and what sports level will be possible after knee arthroplasty [7, 8]. Most recommendations are based on the surgeon's experience, rather than on evidence [4, 9, 10]. There are many different expectations in patients following knee arthroplasty, but being

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active after knee arthroplasty is a common goal [11]. Furthermore, there is also a controversy regarding sports after partial and total knee arthroplasty among surgeons. The question of whether participating in sports after a knee arthroplasty is safe or if it has positive effects is highly debated. While some studies describe increased wear and loosening of implants due to activity [12–15], other studies indicate that adjusted physical activity reduces wear and loosening [9, 10, 16–19]. However, in general, only few studies report sports activity in patients following knee arthroplasty. The expectations of patients following total knee arthroplasty (TKA) are influenced by personal experience and social environment [20] and are based on geographic differences [21]. Previous studies showed that the type of sports practiced by patients following TKA depends on the region. In alpine regions, skiing and mountain hiking are practiced by TKA patients [9, 22–24], in contrast to studies in the lowlands that found swimming and cycling to predominate [25–27].

Side Summary
The question of whether participating in sports after knee arthroplasty is safe or if it has positive effects is highly debated.

55.2 Sports After Partial Knee Arthroplasty

Several studies dealing with sports after partial knee arthroplasty have been published [24, 27–33]. Most of them are cross-sectional studies comparing pre- to postoperative state.

Fisher et al. investigated 76 patients at a mean follow-up period of 18 months after mobile-bearing unicompartmental knee arthroplasty (UKA). Postoperatively, 39 patients (59%) of the patients practiced sports in comparison to 42 patients (64%) prior to surgery [28]. Ninety-three percent of the patients following UKA returned to their previous sports [28]. Similar results were found by another study showing that 94.8% of patients following UKA returned to such activities. On average, patients participated in three different sports disciplines postoperatively in comparison to five disciplines prior to surgery.

The most popular sports following UKA were hiking, cycling, and swimming [29]. A significant decrease in the participation of high-impact sports, such as jogging and soccer, as well as cross-country and downhill-skiing, was shown. Additionally, swimming, dancing, and hiking decreased.

No change in overall sports frequency was observed. However, there was a decrease in the minimum session length after surgery (66 min prior to surgery vs. 55 min after surgery). Older patients participated in sports more often than younger patients. A possible reason for that is retirement, allowing the older patients to spend more time on sports activities [24]. In contrast, a study in 159 patients following medial UKA demonstrated that younger patients (< 65 years) participated in sports more than older patients. An increase of 10% (74% prior to surgery in comparison to 84% post-operative) in sports participation was observed. Hiking, cycling, and swimming were the most common sports in which participation increased after surgery [29].

Side Summary
Patients following UKA practice sports regularly and return to sports after surgery. Hiking, cycling, and swimming are popular sports in patients following UKA.

A recent study by Walker and colleagues showed that 6 months postoperatively after lateral UKA, 77.8% of patients returned to their activities. At the final follow-up of 35.4 months postoperatively, a return to activity rate of 97.6% was found. A significant decrease in high-impact sports and a significant increase in low-impact sports after the surgery were observed [30]. Hopper and Leach contacted 121 patients following TKA and UKA by postal questionnaire regarding sports participation. Prior to surgery, 30 of 34 patients (88.2%) practiced low-impact sports, compared to 29 of 34 patients (85.3%) postoperatively. No gender- or age-related differences could be observed in this group. On average, patients participated in 1.4 different low-impact sports after surgery. The average frequency of sports sessions increased following surgery (3.2 sessions per week prior to surgery to 3.4 sessions per week postoperative) but was not statistically significant ($p = 0.727$). 24.1% of patients following UKA reported pain during sports activities. On average, patients returned to sports after 3.6 months [27].

Side Summary
In some studies, a decrease in high-impact and an increase in low-impacts sports were observed.

Similar results regarding return to sports and sports participation have been observed by other studies [31, 32]. The return to sports (RTS) rates vary from 80.1% to >100% [28, 31–33]. A more detailed overview is presented in Table 55.1.

Side Summary
The return to sports (RTS) rate varies from 80.1% to 100%.

Table 55.1 Return to sports after partial knee arthroplasty

Study	Study population	RTS (%)	Sports	Pre-op (*n*)	Post-op (*n*)	RTS (%)
Fisher et al. (2006) UK [28]	Patients: 76 Mean Age: 64 y Follow-up: 18 mo	93	Swimming	13	12	92.3
			Golf	10	10	100
			Dancing	6	5	83.3
			Bowls	3	3	100
			Cycling	4	3	75
			Hiking	3	3	100
			Jogging	1	1	100
			Gym	1	1	100
			Squash	1	1	100
Pietschmann et al. (2013) Germany [32]	Patients: 131 Mean Age: 65.3 y Follow-up: 4.2 y	80.1	Cycling	45	44	97.8
			Swimming	17	14	82.4
			Fitness	9	10	>100
			Hiking	13	13	100
			Alpine Climbing	8	3	37.5
			Golf	3	3	100
			Gymnastics	14	12	85.7
			Alpine skiing	17	7	41.2
			Cross-country skiing	2	2	100
			Soccer	4	0	0
			Tennis	3	0	0
			Table tennis	1	1	100
			(Nordic) Walking	4	10	>100
			Others	5	4	80
Walton et al. (2006) Australia [31]	Patients: 150 Mean Age: 71.5 y Follow-up: ≥12 mo		Walking	77	88	>100
			Swimming	23	27	>100
			Golf	21	15	71.4
			Crown green bowls	20	19	95
			Cycling	19	20	>100
			Hiking	18	10	55.5
			Fishing	11	10	90.9
			Tennis	8	3	37.5
			Gym work	7	8	>100

y Years, *mo* Months, *RTS* Return to sports, *pre-op* Preoperative, *post-op* Postoperative, *n* Number of patients

Several studies investigated the Tegner Activity Level in patients following UKA [34–39], but the results were controversial. While most studies found an increase in the Tegner Activity Level from the preoperative to the postoperative state, Yim et al. found a decrease (3.2 preoperatively to 2.6 postoperatively) [34–39].

Side Summary
Results of studies investigating the sport activity level represented by the Tegner Activity level in patients following UKA are controversial.

55.3 Sports After Total Knee Arthroplasty

A considerable number of studies about sports after total knee arthroplasty (TKA) have been published [11, 18, 23, 25–27, 40–49]. Most of these are cross-sectional studies. However, two intervention studies investigate the effects of skiing and hiking on patients following TKA.

Bradbury et al. investigated the athletic activity of 160 patients at a mean follow-up of 5 years. 77% of patients who participated in regular exercises the year before surgery continued to participate in sports postoperatively [25].

A prospective study in 455 patients following TKA by Argenson et al. showed return to sports rates of 86%. The most common postoperative sports were walking, hiking, swimming, cycling, exercising, and golfing [40].

Huch and colleagues evaluated more than 600 patients 5 years after joint replacement. At the 5-year follow-up, 34% of patients engaged in sports following TKA. The reasons for not participating in sports activity following joint replacement were precaution, pain elsewhere in the body, and pain at the replaced site. More than 16% of patients reported pain in the replaced joint [23].

In contrast, a study by Chang et al. showed that the reasons that patients do not participate in sports activities after TKA were not restricted to problems with the replaced knee. Symptoms in spine or other joints, presence of medical comorbidities, and lack of motivation or sports facilities were reasons for not participating in sports after TKA [41].

Münnich et al. demonstrated that following TKA, patients showed an increase of the activity level from 62.5% prior to surgery to 91.5% 2 years after surgery. Furthermore, pain reduction could be determined [42]. An observational study of 396 patients demonstrated that the mean activity level in patients following TKA remained similar than prior to surgery (UCLA (University of California at Los Angeles) 4.5 prior to surgery versus 4.8 after surgery). The frequency of moderate activity levels and the types of physical activities increased [26].

Dahm et al. reviewed 1630 patients at a mean follow-up of 5.7 years [43]. On average, the patients reached a UCLA score of 7.1 points, which is associated with sports activity. Only 11% (145 patients) stated the participation in strenuous sports/manual labor. 16% of patients reported participation in sports "not recommended" by the Knee Society survey.

Side Summary
The most common postoperative sports are walking, swimming, and cycling.

A study by Lützner and co-worker reported that patients improved in physical activity post TKA [44]. One-third of patients following TKA achieved an active lifestyle. The study team reported that the activity level prior to surgery and the patients' characteristics had a relevant influence on postoperative activities. A cross-sectional study with 84 patients and a mean follow-up of 8 years discussed walking and cycling as the most popular sports of their study population. The activity level was measured with the Tegner Score and showed an increase from 1.3 prior to surgery to 3.5 after surgery [45]. Similar results have been found by Hepperger et al. The Tegner Activity Level increased significantly from 3.1 preoperatively to 3.6 24 months postoperatively ($p = 0.005$). Six months after surgery, 43% of the patients returned to the same level, and 35% to a higher Tegner Activity Level, than prior to surgery. Twenty-four months postoperative 83% of patients practiced sports, in comparison to 79% prior to surgery. The study group did not observe a change with regard to patients' preferred sports. Both prior to and after surgery, the patients stated a preference for low-impact, medium-impact, and high-impact sports [46].

A retrospective study in patients following TKA older than 60 years showed an increase in sports frequency of 67% and duration of 60.6% at 6 years postoperatively in comparison to 1 year preoperatively [47]. On average, the patients were practicing sports 3.5 times a week and a total of 5.3 h. The most common sports practiced postoperatively were biking (94%), swimming (76%), and mountain hiking (70%). The patients also participated in high-impact sports such as alpine skiing (25%) and dancing (26%) [47].

Bonnin et al. showed that among patients younger than 75 years, 10% regularly participated in strenuous sports after TKA [48]. Mont and colleagues showed that following TKA, 20% of patients return to high-impact sports including downhill skiing, single tennis, and basketball and have successful clinical and radiographic outcomes at 4 years postoperatively [18].

Lefevre et al. investigated eight black belt judokas older than 60 years in age after TKA. Five of them returned to Judo after TKA [49].

In contrast, other studies report a decrease in sports activity. Hopper and Leach demonstrated that the number of patients participating in low-impact sports following TKA decreased significantly in comparison to prior to surgery ($p = 0.003$). A significant reduction ($p < 0.001$) was also observed regarding the number of sports in which patients were participating in following TKA (1.3 different sports prior to surgery in comparison to 0.7 different sports after TKA). The time for returning to sports activities was 4.1 months in the TKA group. When comparing the preoperative to the postoperative state, a statistically significant decrease in sport session length was seen ($p < 0.001$). 42.9% of patients who returned to sports had pain during sports activities [27]. Chatterji et al. evaluated sports activity in 144 patients at 1 year after surgery. The number of active patients decreased (85% prior to surgery vs. 75% after surgery). Additionally, increased low-impact and decreased high-impact activities in patients following TKA could be observed [11].

Side Summary
Some studies report that patients improved in physical activity post TKA in contrast to other studies reporting a decrease of sports activity.

Similar results have been reported by other studies [8, 22, 31, 50]. The RTS rates vary from 36% to 89.2% [22, 23, 26, 27, 31], depending on which moment the preoperative sports participation was evaluated ("during life" vs. "at time of surgery") [23]. A more detailed overview is summarized in Table 55.2.

Side Summary
The RTS rates vary from 36% to 89.2%, depending on which moment the preoperative sports participation was evaluated ("during life" vs. "at time of surgery")

There is a lack of evidence regarding intervention studies in patients following TKA. However, there are at least two studies investigating the impact of alpine skiing and hiking in patients following TKA [9, 51–55].

Side Summary
Two studies investigating the impact of alpine skiing and hiking in patients following TKA.

The effects of alpine skiing in patients following TKA have been investigated (Fig. 55.1) [51]. A total of 16 patients skied over a 12-week period two to three times a week. Pötzelsberger et al. demonstrated that alpine skiing had beneficial

Table 55.2 Return to sports after total knee arthroplasty

Study	Study population	RTS (%)	Sports	Pre-op (*n*)	Post-op (*n*)	RTS (%)
Chang et al. (2014) Korea [26]	Patients: 369 Mean Age:68.8 y Follow-up: 2 y	76	Walking Swimming Cycling Hiking Stretching Gymnastics Badminton Running Golf Table tennis Gateball Others	177 79 60 34 17 14 9 7 7 5 3 10	221 85 80 22 13 17 6 5 2 3 4 11	>100 >100 >100 64.7 76.5 >100 66.7 71.4 28.6 60 >100 >100
Hopper and Leach (2008) UK [27]	Patients: 76 Mean Age: 62.1 y Follow-up: 21.6 mo	64	Swimming Bowls Golf Dancing Cycling	30 17 17 16 15	23 7 5 11 7	76.7 41.2 29.4 68.8 46.7
Bock et al. (2003) Austria [22]	Patients: 138 Mean Age: 55.3 y Follow-up: 74 mo	89.2	Walking Cycling Swimming Hiking Skiing Cross-Country Skiing Mountain Climbing Tennis Soccer Jogging Stationary biking Aqua Jogging	97 47 43 28 7 4 4 2 3 2 0 0	103 20 38 18 1 2 0 0 0 0 7 1	>100 42.5 88.4 64.3 14.3 50 0 0 0 0 >100 >100
Walton et al. (2006) Australia [31]	Patients: 120 Mean Age: 71.5 y Follow-up: ≥12 mo		Walking Swimming Golf Crown green bowls Cycling Hiking Fishing Tennis Gym work	81 22 15 17 9 8 14 11 9	76 14 6 13 5 1 8 2 7	92.7 63.6 40 76.5 55.5 12.5 57.1 18.2 77.8

y Years, *mo* Months, *RTS* Return to sports, *pre-op* Preoperative, *post-op* Postoperative, *n* Number of patients

effects on gait performance and led to a more balanced load distribution between the legs during daily activities [52]. The skiing intervention led to an increase of the muscle mass. The intervention group showed a gain of 10% in the operated leg and 12% in the non-operated leg regarding the rectus femoris muscle cross-sectional area (RF CSA) [53]. Additionally, the study team showed that skiing was correlated with enhanced well-being [54]. No signs of prosthetic loosening or increased polyethylene wear were observed at the mid-term follow-up. Therefore, the study team concludes that recreational alpine skiing can be safely performed in patients following TKA when they were already sportive prior to surgery [9].

A randomized study evaluated the impact of hiking in patients following TKA (Fig. 55.2) [55]. Forty-eight patients were randomized either to the intervention or the control group. The intervention group went hiking two to three times a week for 3 months, whereas the control group performed activities of daily living. The study group demonstrated that after the 3-month hiking program, the intervention group achieved better

Fig. 55.1 Alpine skiing after total knee arthroplasty

Fig. 55.2 Hiking in the mountains after total knee arthroplasty

results in the stair climb test. The time decreased from 4.3 ± 0.6 s (pretest) to 3.6 ± 0.4 s (posttest) for the stair ascent and from 3.6 ± 0.6 s (pretest) to 3.2 ± 0.5 s (posttest) for the stair descent. Additionally, the intervention group showed a significant improvement on some of the subscales of the Knee Injury and Osteoarthritis Outcome Score (KOOS) from pretest to retention test. Moderate improvement in functional abilities and quality of life aspects of TKA patients who participated in a 3-month guided hiking program in comparison to the control group was demonstrated. Hiking did not have any acute detrimental effects on the TKA patients during the study period. Thus, following TKA, patients should be encouraged to hike to improve their activities in daily life.

Side Summary

Moderate improvement in functional abilities and quality of life aspects of TKA patients who participated in a 3-month guided hiking program in comparison to the control group was demonstrated.

55.4 Comparison Partial Versus Total Knee Arthroplasty

A study by Walton and colleagues compared TKA versus mini-incision UKA with self-assessment questionnaires, showing a higher return to sports rate in the UKA than in the TKA cohort [31]. Postoperatively, in the UKA group, 54% returned to the same level of sports than prior to surgery, whereas 13% of patients increased the sports activity after surgery. In the TKA cohort, 30% returned to the same level of sports than prior to surgery and 14% increased their sports activity after surgery. Patients following UKA were more likely to maintain or increase their preoperative levels than patients following TKA ($p = 0.003$). No significant differences between UKA and TKA were found in regard to the timing of return to sports.

Another study also showed a significantly higher return to sport rate in the UKA group (96.7%) than in the TKA group (63.6%). Furthermore, the average sports frequency decreased in the TKA group in comparison to a small increase in the UKA group. Additionally, more patients (42.9%) of the TKA group reported pain during sports activities after surgery than those in the UKA group (24.1%). Patients in the UKA group returned to sports more quickly than patients in the TKA group [27].

Side Summary
Patients in the UKA group returned to sports more quickly than patients in the TKA group.

55.5 Concerns of Sports Activity in Patients Following UKA/TKA

The highly debated question of whether sports participation after UKA or TKA is safe and also has positive effects has to be investigated and further research is needed.

The recommendations are mostly based on surgeons' experience, rather than on evidence-based results [4, 9, 10]. The impression of the authors is that sports activity in patients following TKA correlates with the sports activity of their physicians. If a physician is personally active in a certain type of sports or in sports generally and/or is very familiar with the benefits and the risk of sports participation, she or he is more likely to encourage patients toward more activity.

For example, a physician who never participated in alpine skiing will not recommend this potentially dangerous activity to her or his patient. A general consensus is that return to low- or medium-impact sports within 3–6 months following knee arthroplasty is possible without any problems [7]. Regarding high-impact sports, there are several studies reporting controversial results. Some studies suggest that patients should be discouraged from participating in high-impact sports, and high-contact sports should be avoided [4, 56–58]. Other studies report that patients may resume high-impact sports following knee arthroplasty and that a successful return to high-impact sports is possible [49, 59]. The intervention studies showed no short-term detrimental side effects on the knee implant [9, 55]. However, long-term effects of high-impact sports on the outcome of TKA need to be determined. Risks of instability, periprosthetic fractures, or early aseptic loosening of implants are only a few concerns regarding the effects of high-impact sports. Data suggest that prosthetic wear is not a function of time, it is a function of use [60]. Lavernia et al. showed that patients with higher activity levels assessed by the UCLA activity scale had larger areas with involvement of creep or deformation and increased severity of involvement than patients with less activity [14]. Another study concluded that the activity level did not appear to be a risk factor for surgical revision. Some studies found higher radiological wear and potential implant failure in sportive patients. Nonetheless, these studies did not demonstrate an increase in surgical revision rates as a result of high-impact sports at a mid-term follow-up [10]. The length of follow-up was not appropriate to make definitive conclusions [61].

Progression of implant technology, new surgical techniques, and survival rates of new types of knee arthroplasty are encouraging for patients with high demands [62].

Side Summary
A general consensus is that return to low- or medium-impact sports within 3–6 months following knee arthroplasty is possible without any problems.

55.6 Recommendations

Based on the literature, it can be concluded that low- and medium-impact sports can be performed following knee arthroplasty without any problems [7]. Additionally, for some patients, certain types of high-impact sports are possible after knee arthroplasty [49, 59]. There is a need for good quality long-term results of patients performing high-impact sports. Kuster et al. suggested that prior sport experience and the way patients perform their sports play an important role with regard to sports participation after TKA [63]. For example, if patients chose an adjusted descent, walk slowly downhill, and use ski poles, the knee joint loads can be reduced by 20%. Therefore, if sports activities such as hiking or skiing were performed on a recreational basis, rather than on a regular endurance basis, they would be less harmful [7]. A summary is displayed in Table 55.3.

Side Summary
There is a need for good quality long-term results of patients performing high-impact sports.

Table 55.3 Sports activity after partial or total knee arthroplasty—comparison of regional differences and recommendations of the Knee Society (adapted from Healy et al, 2008 [4])

Sports	Recommendations Knee Society 2005	Studies UK [27, 28]	Studies CHE, DEU, AUT [22–24, 32]	Studies KOR [26]	Studies AUS [11, 31]
Aerobics			✓		
Basketball	Not recommended		✓		
Bowls	Allowed	✓			✓
Cross-Country Skiing	Allowed with experience		✓		
Cycling	Allowed	✓	✓	✓	✓
Dancing	Allowed	✓	✓		
Downhill skiing	Allowed with experience		✓		
Exercise Walking	Allowed		✓		
Fishing					✓
Golf	Allowed	✓	✓	✓	✓
Gym		✓	✓		
Gymnastics	No consensus		✓	✓	✓
Handball	No consensus		✓		✓
Hiking	Allowed	✓	✓	✓	✓
Ice skating	Allowed with experience				
Inline Skating	No consensus				

(continued)

Table 55.3 (continued)

Sports	Recommendations Knee Society 2005	Studies UK [27, 28]	Studies CHE, DEU, AUT [22–24, 32]	Studies KOR [26]	Studies AUS [11, 31]
Jogging	Not recommended	✓	✓	✓	
Mountain Climbing			✓		
Nordic Walking	Allowed		✓	✓	✓
Normal Walking	Allowed		✓		
Riding	Allowed with experience		✓		
Soccer	Not recommended				
Squash	No consensus	✓			
Stationary Cycling	Allowed				
Swimming	Allowed	✓	✓	✓	✓
Tennis Double tennis Single tennis	Allowed with experience No consensus		✓		✓
Volleyball	Not recommended		✓		

UK United Kingdom, *CHE* Switzerland, *DEU* Germany, *AUT* Austria, *KOR* Korea, *AUS* Australia

Take Home Message

Sports activity is possible after UKA and TKA. Patients following UKA present higher return to sports rates and the time to return to sports is faster than in patients following TKA. The participation in sports seems to be more often possible in patients following UKA than TKA.

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The Immune Response to Metal in Total Knee Arthroplasty

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Simon Donell and Roland Becker

Keynotes

1. Allergic reactions involve Type I hypersensitivity which leads to an acute IgE antibody-mediated response.
2. Metal implants may cause a delayed hypersensitivity (Type IV) which is cell mediated and not an abnormal response to a "harmless" material. Infections may lead to a similar response.
3. There is insufficient evidence to support routine screening by patch or hypersensitivity tests for patients undergoing TKA.
4. There is only anecdotal evidence to support using zirconium, titanium, or ceramic implants for primary TKA in patients with severe dermatitis to metal jewellery exposure.
5. An eczematous rash following TKA without any joint problems can be treated with topical steroids.
6. Painful TKAs with persistent synovitis should have a complete work-up to exclude diagnoses other than metal hypersensitivity. Metal hypersensitivity is a diagnosis of exclusion; dermatitis may not be present.

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56.1 Introduction

Allergy is an emotive word that is used by patients to include food intolerance and hypersensitivity. In patient's mind, allergy is synonymous with anaphylaxis and death. In orthopaedics, the term "implant allergy" is used with the same imprecision and suggests a basic misunderstanding of the immunological basis for how the body handles metal and other foreign bodies. The only true allergy is a Type I hypersensitivity reaction where the dermal or epithelial stimulus of an antigen, for example, nickel, results in a response mediated by the production of IgE and manifests itself with an immediate localised reaction, for example, urticaria ("hives" in colloquial English) [1]. The immune system becomes hypersensitive to a "harmless" substance such as pollen, food, or metal. In its severest form, it can have a systemic response with anaphylaxis and death. Type II and Type III hypersensitivity reactions are also antibody-mediated involving IgG or IgM, where in Type II, the antigen is expressed on the target

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tissue affected by the disease, for example, haemolytic disease of the newborn, and in Type III, the antigen is not associated with the target tissue; the latter being affected at the site of deposition of the immune complexes, for example, rheumatoid arthritis. The most important immune response to metal implants involves delayed type hypersensitivity, known as Type IV. This is cell-mediated and does not involve antibodies. This can be seen in a skin test where the response is not acute (Type I hypersensitivity) but delayed 24–72 h. Unlike the other hypersensitivities, Type IV is not necessarily a response to a harmless material. It can be seen in response to many infections and contributes to protection against pathogens. It is seen in the skin as eczematous dermatitis which can be a result of exposure to metal.

The lack of precision in the use of the term "metal allergy" has led to the confusion about how the metals in implants, such as total knee arthroplasty, can cause adverse reactions and, therefore, the logical way to investigate patients who present with a painful knee following arthroplasty. A further point to make is that a patient may be atopic, but not allergic. In allergy, there is an IgE-mediated hypersensitivity to a particular substance, for example, nickel, whereas an atopic individual can have allergies with a positive skin prick test or an IgE against a specific allergen, but no clinical symptoms.

Side Summary
The most important immune response to metal implants involves delayed type hypersensitivity, known as Type IV, which is cell mediated and does not involve antibodies

56.2 Prevalence of Type I Hypersensitivity to Metals

The prevalence of dermal hypersensitivity to metal is about 10–15%, rising to 25% in patients with metal implants [2, 3]. A significantly higher rate has been found for self-reported hypersensitivity for females (14%) than males (2%) [4]. In a study where patients who had undergone a TKA were compared with controls without implants, 20% of the controls showed hypersensitivity to metal, whilst 48% was noted in a group with the stable asymptomatic TKA, and up to 60% in a group with an unstable implant [5]. Other studies also showed skin hypersensitivity to metals in 25% of patients with well-functioning arthroplasties rising to 60% with poorly functioning arthroplasties [2, 6, 7].

However, only a small number of <0.1% may exhibit symptoms. Nickel is the most common sensitiser in humans [8]. Other sensitisers are chrome, cobalt, beryllium, and components of bone cement including gentamicin. Metal hypersensitivity seems to occur between 2 months and 2 years after operation [9, 10].

Side Summary
The prevalence of dermal hypersensitivity to metal is about 10–15%, rising to 25% in patients with metal implants but <0.1% may exhibit symptoms

The importance of hypersensitivity in joint arthroplasty remains controversial with rigid protocols for managing patients used in the German-speaking world, but much more scepticism in English-speaking countries. As a result, in Germany in 2009, coated implants were used in 4% of TKAs because of positive history of hypersensitivity to metal such as chrome, cobalt, and nickel [11]. In the United Kingdom to the end of 2017, 1.2% of nearly 1 million primary TKAs registered in the National Joint Registry had coated implants; it does not record whether metal hypersensitivity sensitivity was the reason [12]. For medico-legal reasons, it is important to know about metal hypersensitivity, the local protocols for managing it, and when to use coated implants.

56.3 Mechanism of Metal Sensitivity

56.3.1 The Immunological Basis of Allergy

There are three stages to the development of an allergy; sensitisation, mast cell activation when an allergen is encountered, and then the allergic responses [1]. The latter has an early and a late phase. Sensitisation is the production of IgE antibodies in response to an allergen. IgE production occurs when CD4 T cells are converted into T helper 2 (Th2) cells. The latter secrete interleukin-4 (IL-4) which makes B cells specific for the allergen switch to IgE. The IgE binds to mast cells with receptors that are specific for the Fc portion of the IgE antibody. The IgE stays bound to mast cells for many months. The initial exposure does not typically cause any symptoms. With re-exposure to the allergen, this binds to the allergen-specific IgE and ultimately leads to mast cell activation. The mast cells degranulate and release preformed mediators, for example, histamine, and then synthesis of new mediators, for example, leukotrienes and prostaglandins. These mediators cause, for instance, vasodilatation, smooth muscle contraction, and mucus secretion. The exact response depends on the location and occurs within minutes. The activated mast cells secrete TNFα which activates endothelium causing expression of adhesion molecules which promote migration of leucocytes in the blood. Chemotactic factors such as IL-8 are produced with later recruitment of eosinophils, basophils, neutrophils, and T cells. This activation leads to further inflammation, which is seen as the late phase.

56.3.2 The Immunology of Type IV Hypersensitivity

The aims of a delayed hypersensitivity response are to:

1. Recruit monocytes to the affected site
2. Keep monocytes and macrophages at the affected site
3. Activate the monocytes and macrophages which, with infections, kill the intra-cellular organelles of the infecting organism. [1]

Metal particles bind to proteins and form hapten-like complexes of metal peptide. These become identified as antigens by the immune system [13]. T-helper 1 (Th1) lymphocytes are generated from the local draining lymph and differentiate into effector Th1 cells passing into the blood stream. New adhesion molecules are expressed on the effector Th1 cells via cytokines released at the antigen site and then migrate there. The adhesion molecules are activated by macrophages releasing TNFα and IL-1. The new adhesion molecule expression also promotes monocytes from the blood stream. Cytokines then stimulate differentiation of the monocytes. Macrophages are retained at the site by effector Th1 cells secreting a cytokine, macrophage inhibition factor. An amplification loop between the effector Th1 cells and macrophages enhances the delayed hypersensitivity response. The Th cells activate macrophages through interferon γ (IFN-γ). In the presence of IFN-γ, TNFα and IL-2 contribute to macrophage activation. The activated macrophages up-regulate class II Major Histocompatibility Complex (MHC) expression on the cell surface. They are also good antigen processing cells (APC) and present the antigen on their class II MHC to the Th cells. These are then stimulated to secrete more cytokines and further activate the macrophages. Continuous stimulation of Th cells is necessary to continue cytokine production and so helps control the response. This diminishes as the antigen is removed. In infection, the macrophages eliminate bacteria. In metal-induced hypersensitivity, the metal is eliminated through the blood stream and the kidneys.

An increase in the level of interferon (IFN)-γ and interleukin (IL)-6 in metal-sensitive patients after joint arthroplasty has been shown [2, 3]. However, others have found minimal IFN-γ but a significantly elevated level of IL-17 in patients sensitive to nickel with symptomatic joint implants, but not in nickel-sensitive patients with well-functioning joint implants [14, 15].

Aseptic lymphocyte-dominated vasculitis-associated lesions (ALVAL) and pseudotumours seen with metal-on-metal hip implants are also thought to be a Type IV hypersensitivity response [16]. In ALVAL, the inflammatory cells are predominantly lymphocytes and perivascular. Tertiary lymphoid tissue forms, which appears to enhance the local immunological response. Neutrophils may be present and infection has to be considered. A threshold of five neutrophils per high power field is considered diagnostic of infection [17]. It can be speculated that the amount of metal debris present in these circumstances forces an enhanced response. One view is that the periprosthetic cell death is a way of the body walling off the metal debris to stop it circulating in the blood stream.

56.4 Diagnostics

Metal hypersensitivity should be considered in patients presenting with swelling and synovitis of the knee with either a localised or generalised eczematous dermatitis [7]. However, in TKA, all other causes of implant failure should be excluded (infection, aseptic loosening, implant malposition, etc.) before making a diagnosis of metal hypersensitivity [11]. The usefulness of the in vitro lymphocyte tests in TKA is yet to be established [9]. Much further work is needed.

56.4.1 Patch Test

The patch test is the most commonly used and is an in vivo investigation. It has a sensitivity and specificity of 77% and 71%, respectively [18]. The patch test has been modified and a "strip" patch testing has been introduced. The test site should be stripped with an adhesive tape prior the application of the test substance. It will allow to reduce the reaction-induced concentration of the patch test by 30% in comparison to a standard test.

There are several concerns with skin patch testing, such as the immunological response elicited is mediated by intradermal Langerhans cells, whereas the hypersensitivity reaction to metal is mediated by lymphocytes and macrophages. It has been shown that patients presenting with a positive patch test after TKA do not show any symptoms of hypersensitivity to metal. A positive patch test indicates an allergic cutaneous reaction but not a reaction to metal implants [19]. A matched cohort study showed no increased risk of knee arthroplasty failure in patients with positive skin patch testing for metal allergy [20]. No difference in clinical outcome or pain was found after a mean 5-year follow-up.

The skin patch testing is of low value in predicting a hypersensitive reaction to metal implants. It may also induce metal hypersensitivity in patients not previously sensitised. Despite this, Mitchelson et al. [10] recommend that patients with known allergy to a metal used in an implant should be offered an alternative (see below).

Side Summary
The skin patch testing is of low value in predicting a hypersensitive reaction to metal implants

56.4.2 Tests for Metal Hypersensitivity

There are three other tests for hypersensitivity, all in vitro:

- Lymphocyte transformation test (LTT)
- Modified lymphocyte stimulation test (mLST)
- Leucocyte migration inhibition test (LMIT)

56.4.2.1 Lymphocyte Transformation Test

The LTT uses an antigen-induced proliferation of T cells compared to a baseline proliferation of an unstimulated culture. T cells are isolated from whole blood and incubated for 5 days with each metal to be tested. Lymphocyte proliferation is measured by radioisotope because the lymphocytes incorporate the radioactive tracer. The result is a Stimulation Index with a sensitisation detection limit set by the laboratory and is typically SI >3 [21]. This is more suitable for detecting systemic hypersensitivities and differentiates dermal from metal implant-induced hypersensitivity reactions [13]. The test result cannot be taken in isolation of the clinical picture and other diagnostic parameters.

56.4.2.2 Modified Lymphocyte Stimulation Test (mLST)

The mLST is similar to the LTT in that the proliferation is measured upon exposure to a potential antigen [22]. Peripheral blood lymphocytes (PBL) are separated by centrifugation. The PBL are incubated with $NiCl_2$, $CoCl_2$, $CrCl_3$, or $Fe_2(SO_4)_3$ for 72 h. The incorporation of radioactive (^3H) thymidine marker into lymphocytes is measured during the final 6 h of incubation. Based on the uptalk, the stimulation index is calculated with a cut-off of >2.

56.4.2.3 Leucocyte Migration Inhibition Test

"The LMIT uses migration inhibition assays to determine leucocyte activation based on the decreased motility in the presence of known antigens." "Collagen is cast into a tube or layered on to a Petri dish and overlaid with leucocytes incubated in the presence or absence of antigen. Migration is measured either by direct observation of cells within the gel matrix or by scintillographic determinations, using radiolabeled cells." [23].

56.4.2.4 Other Investigations

Receently, Lionberger et al. [24] reported on 32 patients awaiting revision TKA of whom 19 were nickel-sensitised and 13 were not. They undertook cell counts from the synovium and showed that there was activation of both CD4+ and CD8+ T cells. The ratio of CD4+/CD8+ T cells was 1.28 for nickel-sensitive patients compared to 0.76 in the controls. There was no difference between the groups for the CD8+ T cells, but nearly a twofold increase in CD4+ cells in the nickel-sensitive group. This may useful for showing nickel hypersensitivity.

Hypersensitivity may also be caused by bone cement or gentamicin (commonly mixed into the cement) [11, 25]. Hypersensitivity to bone cement components in 113 patients was studied by Thomas et al. [11]. They reported hypersensitivity percentages in the following cement components:

Cement components	No. of patients with reaction	Percentage
Gentamicin	19	16.8
Benzolperoxide	9	8
Hydrochinon	3	2.7
2-Hydroxy-ethyl-methylacrylate	2	1.8
Copper(-II) sulfate	0	
Methylmethacrylat (MMA)	1	0.9
NN-Dimethyl-p-Toluidin	0	
One or more bone cement components	28	24.8
Metal and bone cement components	11	9.7

56.5 Clinical Presentation

If a patient presents with an eczematous rash over the wound following a TKA, metal hypersensitivity should be considered. It is much more common in women than in men (13:2) [26]. Without an associated synovitis and swelling of the knee, a patient with an eczematous rash should be referred to a dermatologist, where topical steroids are likely to be prescribed [9].

In the presence of a persistent effusion and painful synovitis following TKA, then instability, loosening, chronic infection, polyethylene wear, and recurrent haemarthrosis are the more likely diagnoses. A detailed clinical evaluation is required (Fig. 56.1). However, if between 2 months and 2 years following a cobalt-chrome TKA a patient presents with pain from a persistent synovitis, swelling, and, typically, stiffness, and especially if female, and all other diagnoses have been excluded, then metal hypersensitivity needs to be considered. There may or may not be a dermatitis over the knee. The plain radiographs

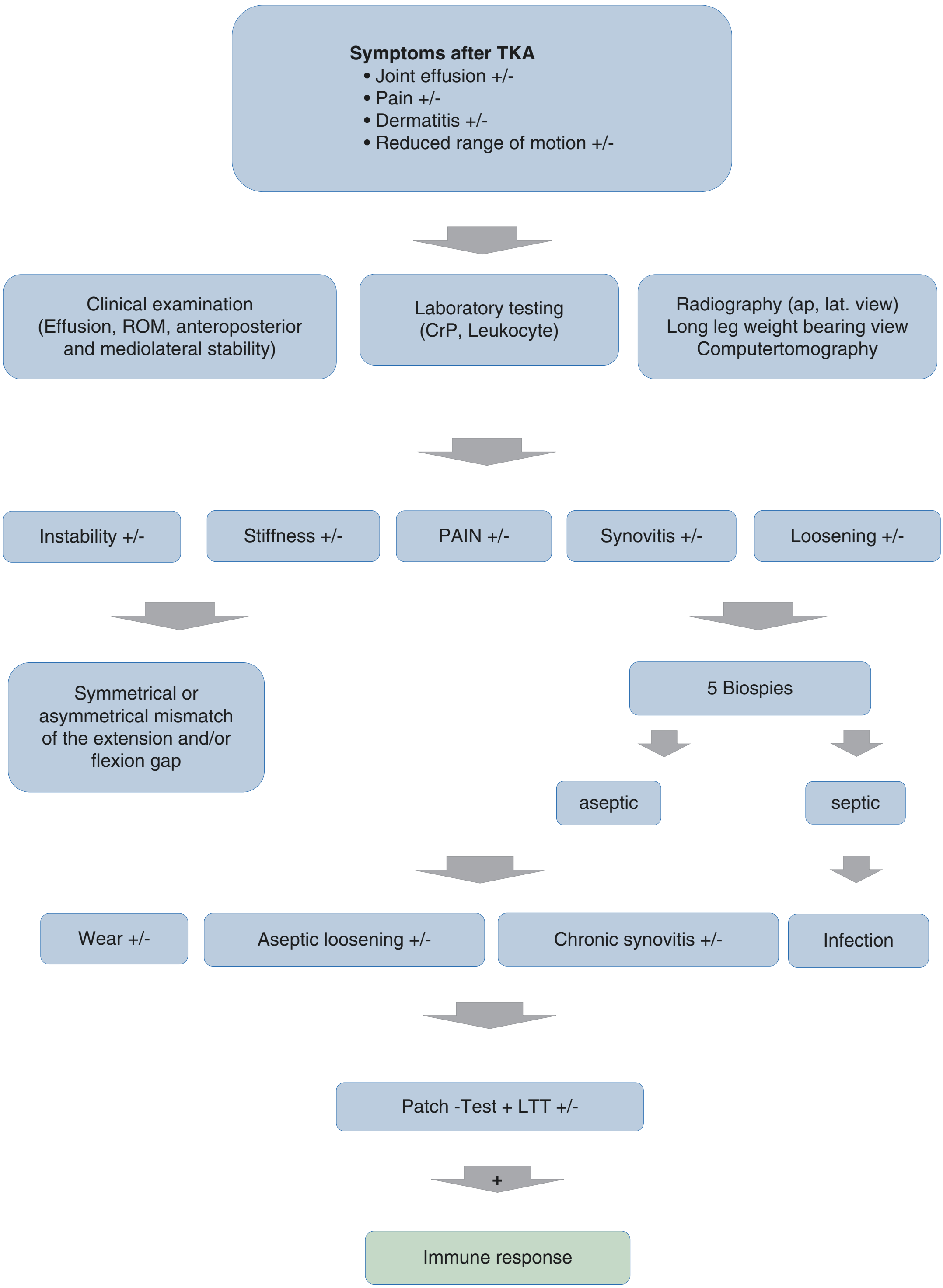

Fig. 56.1 Flowchart of the diagnostic algorithm in patients in whom immune response is considered

Fig. 56.2 BalanSys® knee system (Fa. Mathys, Bettlach, Switzerland). Chrome-cobalt implants coated with using titanium niobium nitride (Ti(Nb)N)

are typically unremarkable. The clinical picture is the same as a chronic or indolent infection.

Protocols for managing infected TKAs should be instituted, but there is no benefit in obtaining serum or urine metal levels [9]. Although patch tests and LTT are often performed, there is no standard care protocol available for the diagnosis of implant hypersensitivity. There is also no medical or nonsurgical management available to help these patients.

56.6 Alternative Implants

After careful counselling about the uncertainties of the diagnosis and the lack of alternative treatments, then removal of the implant should be considered. The cobalt-chromium implant is typically exchanged for a non-hypersensitive metal implants such as oxidized zirconium (ZrNb) alloys (oxinium), titanium alloy, or implants made of ceramics. There is no evidence that patients with metal hypersensitivity have higher revision rates to those without. The comparison between oxinium or cobalt-chromium femoral components did not show any difference in the hazard ratio for revision risk. The revision rate was 4.8% for the CoCr group and 7.7% of the oxinium group with no statistically significant difference at 12-year follow-up. Delta Ceramic® femoral components were introduced by Fa. Lima (San Daniele, Italy) in 2006 [27]. Delta Ceramic® is made of 75% of aluminium oxide and 24% of zirconium oxide. The surgeon needs to be aware that the Delta Ceramic implant has to be cemented. Thus, hypersensitivity to bone cement and gentamicin also has to be excluded.

Alternatively cobalt-chromium implants might be passivated by coating to a thickness of 4 μm using titanium niobium nitride (Ti(Nb)N) (Fig. 56.2). No clinical difference has been reported when comparing Ti(Nb)N-coated implant with conventional cobalt-chromium implants at 2 years of follow-up [28]. Careful insertion is required to protect the surface from scratches and third body wear.

All-polyethylene tibial components, if available, might also be considered. A meta-analysis of the literature looking at outcomes of more than 12,000 TKAs showed no difference in revision rates and clinical scores between all-polyethylene and metal-backed tibial components. It was noted the all-polyethylene design had improved over time with better outcomes for more recent implants [29].

There is little evidence on the outcomes of revision to non-metal hypersensitivity implants. Resolution of systemic or localized eczema and the painful persistent synovitis is typical. Lionsberger et al. [24] reported the minimum 2.5-year follow-up of their 32 patient cohort showing no difference in increase in outcome for the Knee Society functional or clinical scores between the nickel-sensitive group and the comparator, but a better increase in range of motion. They did not report the absolute pre- and follow-up scores, making comparison with other studies impossible. Longer term outcomes and further revision rates are unknown [9].

Take Home Message

Although the hard evidence about managing patients with potential metal hypersensitivity is lacking, a management plan to manage the patient with a painful TKA and persistent synovitis is important. An algorithm is shown in Fig. 56.1. Metal hypersensitivity is a diagnosis of exclusion. When a patient presents with a painful TKA, and all the usual diagnoses are excluded, then metal hypersensitivity should be considered. This is especially true of women, and those presenting between 2 months and 2 years of the primary TKA. It is yet to be shown if non-metal-sensitive implants have better longer term outcomes than the traditional implants.

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57 Does Digital Support Influence Outcome After Total Knee Arthroplasty?

Bernhard Christen

Keynotes

1. Computer navigation in total knee arthroplasty (TKA) has significant advantages in coronal alignment and reduction of outliers compared with conventional TKA.
2. Some studies also confirm more precise sagittal alignment mainly for tibial slope for computer-assisted surgery (CAS).
3. For correct alignment of femoral and tibial rotation, CAS-TKA did not show any significant differences in terms of clinical outcomes including patient-related outcome measures (PROM), function or patient satisfaction.
4. Computer navigation has recently shown to improve survival of patients younger than 65 years after TKA.
5. The higher direct (e.g. start-up, education, maintenance) and indirect (e.g. additional time for surgery) costs of CAS-TKA can only be justified in future when reducing complication or revision rates in long term and/or improving clinical outcome and patient satisfaction.
6. Preoperative CT scan to increase accuracy in rotational alignment of TKA and intra-operative robotics might overcome the limitations of existing image-free computer navigation.

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57.1 Introduction

The acronym for computer-assisted orthopaedic surgery is CAOS, CAS stands for computer-assisted surgery (CAS).

Computer-assisted systems are divided into three categories: active robotic system, semi-active robotic system and passive system [1].

The semi-active system does not perform surgical steps, but limit the placement of tools such as cutting jigs or drill bits.

The passive system relies mostly on passive reflecting markers fixed on the patient's body and pointers on tools and a camera sending and receiving infrared light (optical tracking system) (Fig. 57.1). Referencing of the target objects defines points in virtual space with a pointer probe which can be triangulated by the tracking system [2]. The tracking system triangulates to obtain the *x*, *y* and *z* coordinates of each marker, and is linked to a computer. The accuracy of image-free referencing depends on the system and on the expertise of the surgeon in choosing the correct reference points. Validation studies

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Fig. 57.1 Passive navigation system with infrared camera, computer and navigated probe

of optical tracking systems have demonstrated a high reliability and accuracy, with a translational error of 0.25 mm and an angular error of 1° [3]. There are two methods of referencing: kinematic and bone morphing.

Side Summary
Optical tracking system shows a translation error of 0.25 mm and angular error of 0.5°.

Kinematic referencing is simple and useful in determining the centre of the hip and ankle. Because the hip centre is not directly visible, this method is accomplished by tracking the femur as it is rotated in a circular motion.

The bone morphing method selects numerous surface match points by digitising the bone with a pointer probe (Fig. 57.2). Based on this point cloud, a virtual image is created. It then allows prosthetic sizing, bone resection level and kinematic assessment [4].

Computer-assisted navigation can be differentiated into ‘closed’ or ‘open’ systems. Closed, or proprietary, systems only provide support limited to a specific prosthesis or surgical technique. Open systems are general and support implantation of various prostheses from different manufacturers.

Computer navigation systems can be grouped into four different types according to the referencing methods based on CT scan, fluoroscopy, ultrasound or image free [4].

Fluoroscopy or ultrasound-based computer navigation has not been very successful and is less commonly used due to the need of additional technical equipment and increased set-up time. CT-based navigation has the disadvantage of increased radiation burden due to the preoperative CT scan. However, this disadvantage is outweighed by the fact that it overcomes the weakness of navigation systems in terms of rotational alignment. The defined rotational alignment of the femoral and tibial component can be transferred to the computer and matched with the entered landmarks and surface points by the image-free navigation. CT-based navigation in combination with image-free approach enhances the accuracy of computer navigation and is mandatory for robotic surgery. The current state of the art of CAS-TKA has been recently described [5].

CAS was first developed in neurosurgery to improve accuracy and precision. Computer navigation in TKA was introduced by Delp et al. in 1997, most commonly used is the image-free navigation system [4].

Side Summary
The image-free computer-assisted system is most commonly used.

The main driving force was to improve alignment and component positioning and reduce outliers with the aim to extend the survivorship of TKA [6, 7] as malalignment and malposition are associated with decreased function and higher revision rates [8, 9]. The second target was to improve the clinical results and functional scores after TKA. The technology was recognised to be useful, in particular, in cases of extra-articular deformities [10, 11]. Nevertheless, only <5% of the surgeons in the United States currently use computer navigation in TKA [12]. The rates

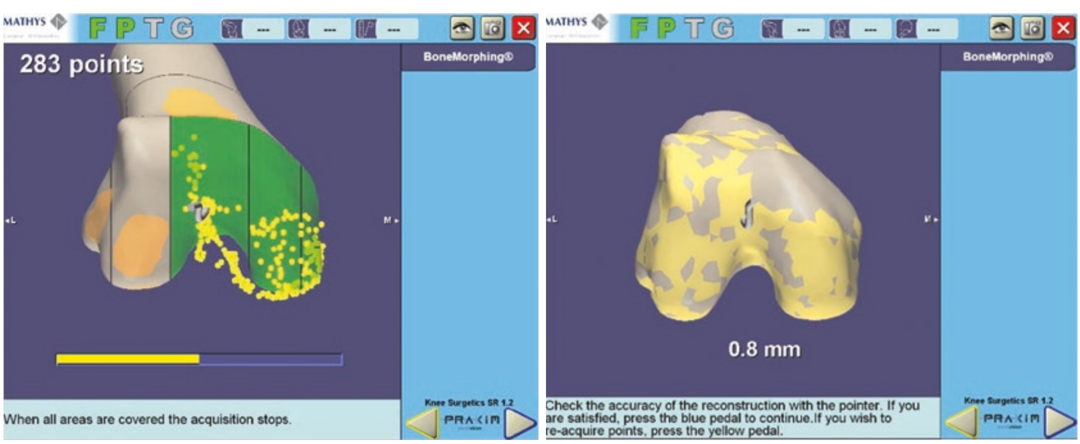


Fig. 57.2 Bone morphing by collecting points and resulting virtual bone model

Fig. 57.3 Optical trackers fixed at the tibial and femoral bone (femoral tracker arm entered through the surgical wound not holding optical markers at the picture), mobile tracker at the tibial cutting jig

Fig. 57.4 Mobile tracker on a tool to check accuracy of tibial cut

decreased from estimated 20% to 25% 10 years ago in Switzerland to 12.9% in 2015 [13]. Only in Australia, the rate of CAS-TKA increased from 2003 and 2012 by 2.4% and currently reaches 22.8% [14].

Image-free computer navigation in TKA starts by calibrating the system after fixing the passive markers on the bone (one at the tibia and one at the femur, the latter possibly entered through the surgical wound) (Fig. 57.3). Entering selected bony landmarks and defining hip centre by kinematic referencing the system deliver the alignment of the limb. From this time point on each surgical step can be planned and then validated before and after bone cuts. Thus, not only the accuracy of cutting planes but also positioning of trial and final implants can be controlled.

Besides technical errors inherent to the registration process, some errors exist with regard to placement of markers. This error generally ranges from 0.1 to 1 mm for each of the three *x*, *y* and *z* coordinates or 1° [3]. Additional errors may occur when bony landmarks are digitised. The pointer might miss the bone due to the overlying soft tissues or cartilage. In addition, the navigation system could have a malfunction due to dirty reflectors or camera. If the patient has severe osteopenia, the pins placed in the bones to hold the trackers may move, making all further measurements inaccurate. As only the cutting guides are navigated, the surgeons may make an error during the bone resection by bending the saw blade, especially when attempting to cut through the sclerotic area of bone. Also, differences in cement thickness during implantation may lead to malalignment even though the bone resection is accurate [4]. This is the reason why each cut and the positioning of the implants have to be checked by computer navigation for validation of accuracy (Fig. 57.4).

Side Summary
CAS allows not only the planning of the cutting and position of the components, but also each bony resection is confirmed by the system and thus monitors the accuracy during surgery.

The technology of computer navigation has entered a new dimension with the introduction of robot assistance in TKA. The use of a robot makes an infrared camera mandatory and can be based on imageless or CT-based technology.

57.2 Learning and Teaching CAS-TKA

It is well-known that surgeons starting with a novel technique or approach undergo a learning curve [15]. This was also confirmed for computer navigation in TKA [16]. Smith et al. compared results of a consultant surgeon performing his first CAS-TKA with an expert who performed more than 1000 CAS-TKA. After 20 cases, operative time of the beginner equalised those of the expert being significantly higher for the first 20 cases (surgical time 92 vs. 73 min) [17]. Nizard et al. found the learning curve to be completed after 27 TKA for a CT-based system (Navitrack®) [18]. Jenny et al. confirmed these results in a multicentre study using an image free navigation system (OrthoPilot®) [19]. They found that the learning curve only affected the operating time which reached 107 ± 26 min after 30 TKAs, starting at 118 ± 23 min ($p < 0.001$) for inexperienced surgeons. For accuracy of implantation of the femoral or tibial component, outcomes or complication rates, there was no significant difference between the beginner and the experienced CAS-TKA centres. All studies confirmed that CAS-TKA has a short learning curve with accurate results from the beginning and reaching an optimal operating time after 20–30 cases [20].

Besides improving the accuracy of bone cuts, which will be discussed extensively later in this chapter, some studies state that experienced surgeons improve their skills in soft tissue balancing when using CAS for TKA [21–24]. Iorio et al. demonstrated that a high volume knee surgeon can improve the component positioning with conventional technique after using CAS-TKA for a short period of time and is more accurate with his conventional technique optimised by computer navigation (optimal component placement in 68% with conventional TKA, 92% with CAS-TKA and 82% with conventional technique after having used CAS) [25]. Obviously, computer navigation has a teaching effect even for experienced surgeons [20, 26]. Love and Kinninmonth stated that computer navigation is an excellent learning and simulation tool in TKA [27]. Khakha et al. showed that trainees could achieve equal results compared to a consultant orthopaedic surgeon for coronal alignment, blood loss and functional scores when using CAS-TKA [28]. Only the tourniquet time differed. This was already found by Schnurr et al. in 662 CAS-TKA operated by consultants or trainees [29]. Cutting errors did not differ in the two groups neither did coronal alignment. The only significant difference was operation time (139 min for trainees, 122 for consultants).

Side Summary
CAS improves the understanding of TKA surgery and is a very good teaching tool.

57.3 Pros and Cons of CAS-TKA

57.3.1 Blood Loss and Blood Transfusion Requirements

As the intra-medullary canal is not opened in CAS-TKA, one could expect less blood loss than in conventional TKA [29–34]. Others found no significant difference comparing the CAS-TKA with the conventional TKA [1, 13, 35, 36]. With modern blood saving techniques (e.g. low blood pressure, application of tranexamic acid, no drainage), this should not be an important argument anymore speaking for or against the use of computer navigation in TKA.

57.3.2 Embolism

Eliminating the intra-medullary canal instrumentation in CAS-TKA will reduce fat and marrow embolisation showed with trans-oesophageal ultrasound [33, 37]. Other studies could demonstrate by the same method that maximum emboli load occur immediately after tourniquet release and continues for 15–120 s [38–41]. In a meta-analysis, Bauwens et al. could not detect any difference in thromboembolism events in conventional or CAS-TKA [42].

57.3.3 Fractures Around the Pin Sites

Pins are necessary to mount the optical trackers at the tibia and femur for CAS-TKA. Pin site fractures are therefore a unique complication when using computer navigation and occur close to the pin holes [30, 37, 42–49]. The published incidence is approximately 1% [50], fractures are located mostly at the distal femoral diaphysis [43, 47, 51], but have also been reported at the tibia [10, 52–55]. The fractures may occur during surgery or with a delay up to 12 months [30, 56]. The aetiology is multi-factorial and includes osteoporosis, larger pin diameter, multiple pin tracks and thermal necrosis of the bone [30, 37, 48, 57]. The incidence of this severe complication can be reduced by the use of thinner pins with a self-drilling and self-tapping design and distalisation of the femoral pin(s) into the metaphysis.

According to the meta-analysis of Cheng et al., including 18 RCTs, the complication rate for CAS-TKA does not differ to that of conventional TKA, taking into account all the possible complications [58].

57.3.4 Costs and Operative Time

Costs are an important factor associated with CAS-TKA due to start-up costs, training, software, maintenance and upgrade, additional operating room time, learning curves and complications. If a preoperative CT scan is necessary, the costs will even increase [31, 43, 44, 59].

The increase in operating room time is variable and ranges from 8 to 63 min with a mean lengthening time of 20–25 min or additional 23% of the operation time for conventional TKA in mean [1, 6, 42–44, 50, 60–68]. Additional time for navigation is much depending on learning curve and standardisation of the process.

> **Side Summary**
> Additional surgical time of up to 25 min has been reported.

It has been estimated that CAS in TKA can be cost saving considering additional cost of $629 US or less due to reduction in revision TKA within the first 15 years after the index surgery due to better accuracy of the coronal alignment within ±3° [69]. Dong and Buxton calculated savings when additional costs would not surpass $430 US per case in a different model also by the potential reduction of revision rates and lower complications with navigated TKA [70]. Comparing patient-specific instruments PSI with navigated TKA, Watters et al. found that operating room time can be reduced by 67 min in the PSI group [71].

57.3.5 Effect on Alignment and Component Placement

57.3.5.1 Accuracy and Outliers

CAS-TKA reduces outliers, decreases standard deviation in coronal alignment and can increase accuracy, precision and repeatability of TKA. This could be confirmed in several RCTs [5, 13, 32, 36, 39, 43, 44, 46, 53, 57, 63, 66, 68, 70, 72–83].

57.3.5.2 Coronal Alignment

Mechanical axis and the position of components in the frontal plane are significantly better placed in CAS-TKA than with conventional instrumentation [3, 43, 67, 75, 77, 79, 84–88]. According to the meta-analysis of Mason et al., malalignment >3° occurred in 9% of CAS-TKA and in 31.8% of conventional TKA [79]. Others have found no significant differences [66, 89–91].

57.3.5.3 Sagittal Alignment

Improvement in sagittal alignment with CAS-TKA compared to conventional TKA could be confirmed in several studies [8, 68, 70, 75, 76, 92]. However, in a meta-analysis of 41 RCTs or quasi RCTs, outlier percentage of tibial slope with a cut off at ±2° was higher for the navigated than the conventional TKA, the difference was not significant when defining the cut off to ±3° [58].

57.3.5.4 Rotational Alignment

Assessment of the transepicondylar axis is as difficult as clinically. The navigation cannot compensate for the intra- and inter-observer error of the digitisation of the medial and lateral femoral epicondyles [93–95]. Nevertheless, Chauhan et al. [30], Jenny and Boeri [53], Schmitt et al. [96] and Stockl et al. [97] found the rotational alignment to be better in CAS-TKA than with conventional technique. Others [44, 59, 70, 98–100] could not confirm this and found no improvement in mean or in percentage of outliers for component rotation. No study demonstrated better mean rotation or less outliers in rotation of the tibial component. In a cohort study of Czurda et al. comparing malrotation and post-operative pain using WOMAC, pain score in navigated and non-navigated TKA found no difference of chronic pain between the two groups and pain did correlate with femoral malrotation >3° measured with CT scan in both groups [101].

Side Summary
Significant reduction of outlier in sagittal, coronal and rotational alignment can be achieved with CAS.

57.3.6 Joint Line Level, Mediolateral and Sagittal Stability

Only few studies have evaluated the joint line level after navigated TKA [60, 68], although joint line elevation might cause mid-flexion instability and lead to a relative patella infera causing pain and reducing ROM. Luyckx et al. could show that already an elevation of the joint line of 2 mm on the medial side leads to a significant coronal instability in 30° and 60° of flexion [102, 103]. Babazadeh et al. found no difference in joint line level between the two techniques and no difference in ROM or SF-12 with respect to joint line change [60]. Song et al. examined AP and mediolateral stability using fluoroscopic stress view and found no difference in stability, ROM or KSS score 1 year after navigated or conventional TKA respectively [104].

57.4 Clinical Outcomes

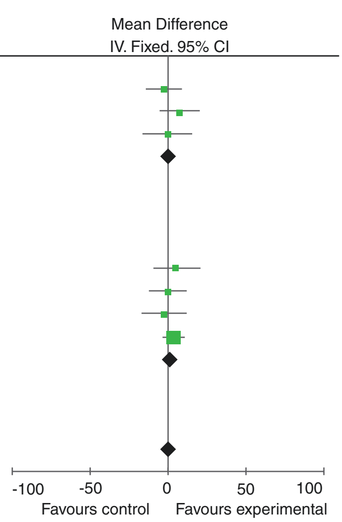
No study could detect any major differences comparing clinical and functional knee scores, quality of life or patient satisfaction between CAS and conventional TKA [32, 33, 43, 44, 47, 60, 66, 68, 70, 74–77, 88, 90–92, 98]. Cheng et al. [58] analysed 21 level I or II studies including 2333 knees. They found no statistically significant differences between the navigated and conventional groups for complications, Knee Society Score or WOMAC at the 3 and 6 months follow-up (Table 57.1).

57.4.1 Long-Term Results

The Norwegian Arthroplasty Register [39, 105] reported a higher rate of revision at 2 years in

Table 57.1 Comparing clinical results after CAS with conventional TKA

Study or Subgroup	CAS Mean	CAS SD	CAS Total	Conventional Mean	Conventional SD	Conventional Total	Weight	Mean Difference IV. Fixed. 95% CI
5.1.1 3 months								
Bertsch C 2007	148.4	21.9	34	151	25.6	35	12.4%	-2.60 [-13.83, 8.63]
Decking R 2005	167.7	24.8	27	160.6	22.2	25	9.6%	7.10 [-5.68, 19.88]
Spencer JM 2007	125.2	30.5	30	125.9	32.1	30	6.2%	-0.70 [-16.54, 15.14]
Subtotal (95% CI)			**91**			**90**	**28.2%**	**1.11 [-6.33, 8.56]**
Heterogeneity: Chi^2 = 1.31, df = 2 (P = 0.52); I^2 = 0%								
Test for overall effect: Z = 0.29 (P = 0.77)								
5.1.2 6 months								
Matziolis G 2007	149	29	32	144	29	28	7.2%	5.00 [-9.71, 19.71]
Mizu-uchi H 2008	173.2	27.2	37	173	26.3	39	10.8%	0.20 [-11.84, 12.24]
Spencer JM 2007	149.1	24.5	30	151.8	29.8	30	8.2%	-2.70 [-16.50, 11.10]
Zhang W 2008	158	13	41	155	14	41	45.7%	3.00 [-2.85, 8.85]
Subtotal (95% CI)			**140**			**138**	**71.8%**	**2.13 [-2.53, 6.79]**
Heterogeneity: Chi^2 = 0.80, df = 3 (P = 0.85); I^2 = 0%								
Test for overall effect: Z = 0.90 (P = 0.37)								
Total (95% CI)			**231**			**228**	**100.0%**	**1.84 [-2.11, 5.80]**
Heterogeneity: Chi2 = 2.17, df = 6 (P = 0.90): P = 0%								
Test for overall effect: Z = 0.91 (P = 0.36)								
Test for subgroup differences: Chi^2 = 0.005, df = 1 (P = 0.82), I^2 = 0%								



navigated TKA (using a mobile-bearing implant) compared with a conventional technique. The findings were attributed to the learning curve and technical aspects of navigated TKA, which introduced new variables to the surgical process of TKA. Baier et al. found a clearly significant reduction of revision at 10–12 years after index surgery for the computer navigated group in a matched pair analysis of 157 navigated versus 188 conventional TKA [85]. In 2015, the Australian joint registry published a cumulative revision rate of 5.2% for non-navigated versus 4.6% for CAS-TKA, which gave a non-significant hazard ratio of 1.05 after 9 years [14]. For patients younger than 65 years of age, at surgery, hazard ratio was 1.13 (95% CI = 1.03–1.25) with a revision rate after 9 years of 7.8% for conventional TKA and 6.3% for CAS-TKA, which was significant. Computer navigation led to a significant reduction of loosening (HR = 1.38) in this group of patients (Table 57.2).

Studies comparing CAS-TKA versus conventional TKA have been compared by five meta-analysis [42, 51, 58, 69, 79] and one systematic review [108] during the past years. Interestingly, Bauwens et al. [42] and Mason et al. [79] later in the same year did not agree about the results. Bauwens et al. reported on 33 studies combining 3423 patients comparing navigated TKA with conventional TKA with statistical heterogeneity. The main conclusions included no difference in infection, thromboembolic events or the overall mechanical axis alignment between the two groups with a 23% increase in operating room time for navigated TKA. There was inconclusive evidence with regard to functional improvement and complications. However, navigated TKA did demonstrate a lower risk of malalignment at the 3° and 2° thresholds for mechanical axis outliers. When the outlier degree in coronal alignment was increased from 0° up to 6°, the authors demonstrated the decreasing advantage of navigated TKA. Mason et al. had conflicting results despite including similar studies [79]. Navigated TKA showed improvements in mechanical axis (within 3° in 9% of navigated TKA vs. 31.8% of conventional TKA), frontal tibial and femoral component alignments within 3° and tibial slope and femoral flexion angles within 2°. This study included comparative cohort studies and did indicate that doing so may have inherent selection bias. The authors were critical of and concluded there may have been an analytic and design error in the study by Bauwens et al., explaining the differences.

Several RCTs [7, 8, 33, 35, 39, 43, 44, 57, 60, 62, 66, 68, 70, 74–77, 85, 86, 92, 101] comparing navigated with conventional TKA including midterm results [98] found improvement of coronal, sagittal and axial alignment on CT scans but no improvement in clinical or functional knee scores, quality of life or patient satisfaction.

Side Summary

Despite the improvement in accuracy of component placement after CAS, no difference in clinical outcome has been reported when compared with conventional surgery.

The literature supports that computer navigation in TKA is an efficient teaching tool for trainees and experienced surgeons [20]. This is true irrespectively if navigation is used as simulation or training tool outside the operating theatre or during surgery. CAS-TKA has a significant effect in component placement even when the surgeon returns to conventional technique [25, 26]. Computer navigation could help to shorten learning curve for trainees, limit surgical errors and improve accuracy of bone cuts and coronal

Table 57.2 Mid- and long-term survival of navigated and conventional TKA

Study	FU years	Better with CAS	Better conventional	No difference
Gothesen et al. [39, 105]	2		×	
Australian registry [106]	12	× (under 65 years)		
Cip et al. [107]	12			×
Baier et al. [85]	10	×		
Babazadeh et al. [60]				×

alignment for trainees and experienced orthopaedic knee surgeons [20, 27–29].

In short and mid-term, computer navigation shows no difference in TKA survival compared to conventional instrumentation. After 9 years, the slight difference in favour for CAS-TKA is not significant for the total number of TKA in Australia, but the advantage of the computer navigation is clearly visible in the group of patients younger than 65 years [14]. This is the first time that computer navigation shows an advantage compared to conventional surgical technique other than improvements of coronal alignment and reducing outliers. These results were confirmed by Baier et al. in 2017 analysing results of a matched pair group. Differences in survival were visible already after 2 years and increased till 12 years after index surgery with the better results for the computer-assisted group. This risk reduction for revision was statistically significant. It seems logical that differences in survival will show up only at long term, thanks to modern prosthetic design, polyethylene and cementing technique quality. Therefore, the significant difference in survival and revision rate for younger (and more active) patients could be the start of a revival for computer navigation.

Image-free computer navigation has the main disadvantage of not being more accurate in defining tibial slope and mainly rotational alignment of the femoral and/or tibial component due to the fact that conventional and CAS-TKA rely both on bony landmarks which are difficult to define intra-operatively [94]. If one would add a preoperative CT scan, an MRI or a 3D X-ray, this would further increase complexity and costs for total knee arthroplasty. On the other hand, the single flexion axis of the femur and its relationship to the posterior condylar line and tibial rotation could be more accurately defined.

57.5 Robotics in TKA

The introduction of robotics in TKA could be a reason for revival of computer navigation as robotics is not possible without optical computer navigation. As mentioned earlier, robot technology actually exists imageless (Fig. 57.5) and based on a CT scan (Fig. 57.6).

The imageless robot technology is relying on the collection of classical bony landmarks during operation which is enhanced by generating a surface model using a database. Additionally, soft tissue tension can be included until navigated burr enables to prepare the surface in a unicondylar knee arthroplasty or drilling holes for positioning of conventional cutting jigs in TKA. In both cases, fine-tuning by using the navigated burr is possible at any time of the surgery after performing surfaces or cuts to correct, for example, one additional degree of varus or 1-mm deeper resection.

The CT-based technology takes in account the knowledge that all the visible landmarks are not reliable and have a high inter-individual and inter-observer variation not making it possible to estimate correct single flexion axis of the femur nor rotational alignment of the femur or the tibia or tibial and femoral flexion accurately [94].

The image-based robotic technology starts with a CT scan of hip and ankle centre and the knee. The 3D geometry is reconstructed by segmentation of the knee including all classical landmarks. This enables the system to create a first virtual 3D planning of the knee defining sizing, positioning of the femoral and tibial in three dimensions. This plan can be adjusted by the surgeon before and during surgery at any time according to the planning and own philosophy. The system is closed, but allows the application of any surgical technique including ligament balancing if desired.

To start the surgery, the robot, infrared camera and navigated instruments have to be calibrated first. Then the surgeon has to fix femoral and tibial markers with the aid of intra-osseous pins as in conventional navigation systems. Hip centre is defined with a pivoting algorithm, medial and lateral malleolus by palpation with a probe. Then the knee has to be opened according to the surgeons preferred technique. To match the anatomy with the 3D CT, 40 points have to be registered at the femoral and tibial surface and then confirmed with additional two times six points given by the

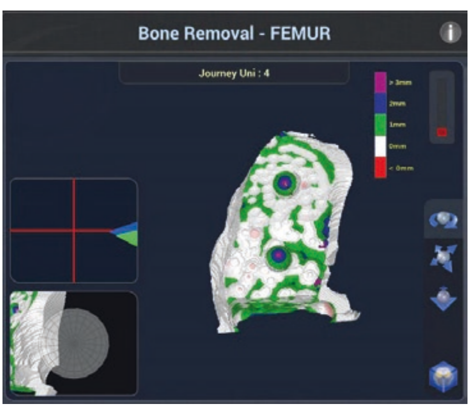
Collection of landmarks	Creating a surface model
	
Checking the soft tissue tension	Navigated robotic burr
	
Navigated burring of bony surface or drilling holes for classical cutting jigs	
	

Fig. 57.5 Imageless robotic-assisted surgery

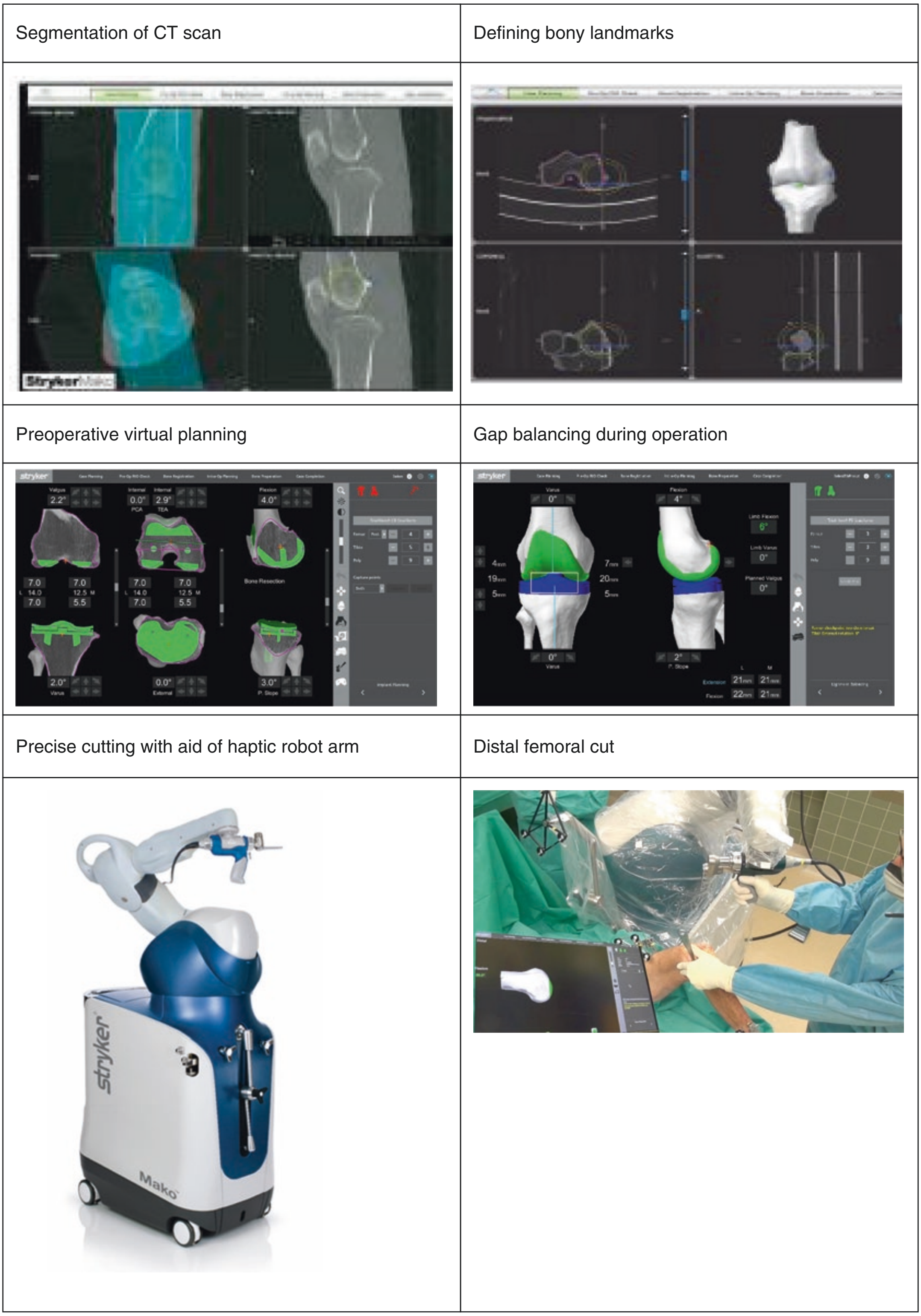


Fig. 57.6 CT-based robotic arm-assisted surgery

system which gives an accuracy below 0.5 mm. Only now the osteophytes are removed to balance the knee.

As soon as the surgeon approves the planning, with the aid of the haptic robot arm, the main femoral and tibial osteotomies can be performed with high accuracy (±0.5 mm or ±0.5°). The robot is led by the surgeon, but limits activity to the bony landmarks (based on the CT scan) and will make it impossible to drill (for UKA application) or saw (for TKA) incorrectly nor injure the adjacent soft tissues as it stops when guided outside in a range of ±0.5 mm or ±0.5°. Cutting jigs are not necessary for TKA as the robot leads a 2-mm thick saw blade directly. The thick blade gives precise cuts also in very sclerotic bone. If moved gently, the haptic robot will follow the knee real time as well as the drill bit or the saw blade are depicted real time on the screen making visible the remaining work to do. The green parts have to be removed, white indicates the correct cutting level, red means an error in depth of maximally 0.5 mm.

To enhance accuracy of the plan during operation—before cutting or drilling—soft tissue balancing can be included as well as original cartilage level on the lesser damaged parts of the arthritic knee with the possibility of fine-tuning the bony referenced virtual planning to reconstruct joint geometry and joint line accurately. At any time of the surgery, bone or osteophyte resection and positioning of the implants can be controlled with the navigated probe in three dimensions [109].

In unicondylar knee, all the published studies show a reduction of the early revision already 1 year after surgery [110–112]. Australian joints registry confirms this reduction to 0.8% revisions after 1 year versus 1.4% for the best conventional technique [106]. As expected, the effect on TKA could not been demonstrated so far, as the system was only introduced in 2016. For clinical data, only studies with small samples and short-term results exist which are derived from author centres. Kholpas et al. [113] and Kayani et al. [114] found less soft tissue damage in robotic arm-assisted compared to conventional surgery. Three studies [114–116] described less pain, less painkiller consumption, less physiotherapy sessions, better knee flexion, shorter hospital stay and better outcome scores in short term until 6 months after surgery in the robotic arm-assisted groups.

Side Summary

Less soft tissue damage has been found when robotic-assisted surgery is performed, which may result in earlier recovery and better function.

Enhanced CAS-TKA by robotics should show clear advantages at least in mid-term for clinical results including PROMs and patient satisfaction compared to conventional technique. Only when the rate of revision can be reduced significantly, the direct and indirect additional costs for computer navigation including CT scan and robot can be justified and financed in future. As in classic computer navigation, robot-assisted surgery has to be compared with conventional techniques for clinical results and PROMs. The bench mark would not only be to reduce the rate of unsatisfactory results after TKA, but also to improve functional results in patients mainly with high demands which were classified as satisfied after TKA.

Take Home Message

- Imageless navigation provides better alignment (coronal) and better survival in long term than conventional TKA. However, clinically and for the outcome scores, no significant difference can be detected. Thus, the main difference between the CAS and conventional techniques consists of additional time for surgery (about 15 min) and costs for the navigations system and disposals.
- The main problem of the image-less navigation is that the method depends on the same bony landmarks as conventional technique, which is not accurate and reliable. Except in Australia com-

puter navigation is used less and less in the other continents.

- Robotics in TKA could effect a revival of navigation as it is indispensable for the optic control during operation. As in classic computer navigation, robotics has to be compared to conventional TKA carefully for years not only to prove more precise positioning of the implants, but also for better clinical outcome, reduction of unsatisfactory results, lower complication and revision rates and longer implant survival to justify higher costs and operation time.

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58 Registries—How Important Are They?

Daniel Guenther

Keynotes

1. Registries in modern knee arthroplasty were first established in 1975 when the Swedish Knee Arthroplasty Register was started.
2. Registry data are classified into four levels: basic data, demographic and comorbidity data, patient-reported outcome data, and radiographic data.
3. Each type of registry (institutional, regional, national, and global) offers different strengths and weaknesses.
4. A strength of institutional databases is the opportunity to include radiographs or lab samples to answer specific questions.
5. National registries incorporate an enormous number of patients leading to high statistical power.
6. Societies like the International Society of Arthroplasty Registries (ISAR) link national registries.
7. Effective use of quality registries can lead to better health outcomes at a lower cost for society.
8. Registries are an irreplaceable tool to ensure quality control, enable high-grade research, and improve cost-effectiveness.
9. Feedback mechanisms should be easy and comfortable to identify, implement and share best practices, and discover less effective treatment options.
10. To answer certain questions, researchers may move from randomized control trials (RCTs) to more clinical outcome-based strategies like evaluation of registries' data.

58.1 Introduction

Registries in modern knee arthroplasty were first established in 1975 when the Swedish Knee Arthroplasty Register was started [1]. They have proliferated since then on institutional, regional, national, and global bases. Registries offer a unique tool to evaluate methodologies, concepts, and treatment options in the short and long term in a mono- and/or multicentric setting with a high case load. Due to optimized data gathering, multiple publications have been accomplished, especially during the last decade [2–7].

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As modern medicine becomes more and more individualized to optimize patient outcomes, randomized control trials (RCT) may not be able to reflect clinical practice sufficiently. Too many variables need to be controlled to achieve valuable conclusions. In contrast, registries present data providing implant-specific survival rates and the influence of patient-/technique-related factors on clinical outcome. The purpose of this chapter is to give an overview of the existing registries worldwide and illuminate their characteristics and prospects.

Side Summary
Registries offer a unique tool to evaluate methodologies, concepts, and treatment options in the short and long term in a mono- and/or multicentric setting with a high case load

58.2 History

Today's quality registries stem from surgeons wanting to achieve systems for tracking their patients over time and documenting outcomes in a detailed and organized manner. In comparison to a single surgeon series, registries have the big advantage that the number of patients is increased, ensuring adequate statistical analysis and preventing the risk of performance bias [8–10]. The first nationwide arthroplasty registries were developed in the 1970s in Sweden [1]. Many more countries including Australia, Belgium, Canada, Croatia, Denmark, the Netherlands, Egypt, Finland, France, Germany, Hungary, New Zealand, Norway, Pakistan, Portugal, Romania, Slovenia, Slovakia, Switzerland, and the United States have developed arthroplasty registries since then.

Side Summary
In comparison to single surgeon series, registries have the big advantage of larger sample size, ensuring adequate statistical analysis and preventing the risk of performance bias

58.3 Geological Aspects

Not only national, but also institutional and regional registries are present in the modern world of arthroplasty.

Examples for regional registries are the Registro dell'implantologia Protesica Ortopedica (R.I.P.O) in Italy and the Catalan Arthroplasty Register in Spain.

The National Joint Registry of England, Wales, Northern Ireland, and the Isle of Man (NJR) covers most of the United Kingdom but does not include Scotland, which has its own registry [5].

The United States is a good example of a "melting pot" of national, regional, and institutional arthroplasty registries. The registries of Mayo Clinic [11], Massachusetts General Hospital (Harris Joint Registry) [2], and Hospital for Special Surgery (HSS Hip and Knee Joint Replacement Registry) are institutional arthroplasty registries. HealthEast [12], Kaiser Permanente [13], and Michigan Arthroplasty Registry Collaborative Quality Initiative (MARCQI) are regional registries [4]. The HealthEast, which started in 1991 in the twin cities, Minneapolis and St. Paul, is the oldest regional registry in the United States. The Kaiser Permanente registry is an integrated health system and is primarily located in California but has hospitals across the country [5]. MARCQI is a state-wide registry in Michigan that started in 2012 and collects data on 95% of the elective total knee arthroplasty cases performed in Michigan [4].

Starting in 1997, the Musculoskeletal Outcomes Data Evaluation and Management System (MODEMS) was an American Academy of Orthopaedic Surgeons (AAOS) initiative that attempted to develop a national registry. The project was terminated by AAOS in 2000 due to low participation rates and incomplete data [14]. The American Joint Replacement Registry (AJRR), which was incorporated as an independent not for profit organization in 2009 with support from professional, consumer, healthcare payers, and industry representatives, collects data from hospitals in all 50 states. The AJRR has compiled data on over one million procedures to date, but it is still capturing much <50% of the nearly one million arthroplasties performed in the United States each year.

Side Summary
Registries are performed on an institutional, regional, national, and global level (Table 58.1)

58.4 International Associations

Several international associations aim to pool data of national registries. Again, there are regional societies like the Nordic Arthroplasty Register Association (NARA), continental societies like the Network of Orthopaedic Registries of Europe (NORE), and global societies like the International Society of Arthroplasty Registries (ISAR).

Side Summary
Regional societies like the Nordic Arthroplasty Register Association (NARA), continental societies like the Network of Orthopaedic Registries of Europe (NORE), and global societies like the International Society of Arthroplasty Registries (ISAR) aim to pool data of national registries

58.4.1 Nordic Arthroplasty Register Association (NARA)

NARA was established by the Danish, Finnish, Norwegian, and Swedish national registries in 2007. The Nordic countries are world leading and "role models" in the field of National Quality Registers. The network's main target is to further improve and facilitate the Nordic research concerning implant surgery. NARA aims to perform analyses of the patient demographics of the participating countries, outcomes in general and for specific implants, and

Table 58.1 Important registries worldwide

Register	Established/year	Joints	Procedures/Tsd.	Type
Mayo Clinic	1969	Miscellaneous	>100,000	Institutional
Massachusetts General Hospital (Harris Joint Registry)	1969	Miscellaneous	>100,000	Institutional
HSS Hip and Knee Joint Replacement Registry	1978	Miscellaneous	>100,000	Institutional
Registro dell'implantologia Protesica Ortopedica (R.I.P.O)	2000	Miscellaneous	>100,000	Regional
Catalan Arthroplasty Register	2005	Miscellaneous	>100,000	Regional
Kaiser Permanente	2001	Miscellaneous	>100,000	Regional
Michigan Arthroplasty Registry Collaborative Quality Initiative (MARCQI)	2012	Miscellaneous	>100,000	Regional
Swedish Knee Arthroplasty Register	1975	Knee	>275,000	National
Finish National Arthroplasty Register	1980	Miscellaneous	>400,000	National
Norwegian Arthroplasty Register	1987	Miscellaneous	>200,000	National
Danish Knee Arthroplasty Register	1997	Knee	>150,000	National
New Zealand National Joint Register	1998	Miscellaneous	>130,000	National
Australian National Joint Registry	1999	Miscellaneous	>1,200,000	National
UK National Joint Registry	2003	Miscellaneous	>2,350,000	National
Slovak National Arthroplasty Register	2003	Miscellaneous	>40,000	National
Dutch Arthroplasty Register	2007	Miscellaneous	>250,000	National
American Joint Replacement Registry	2009	Miscellaneous	>1,000,000	National
German Arthroplasty Registry	2012	Miscellaneous	>1,000,000	National

try to construct a standardized "case-mix indicator" to be used in comparisons.

58.4.2 Network of Orthopaedic Registries of Europe (NORE)

NORE is an international registry network built up as a standing committee of the European Federation of National Associations of Orthopaedics and Traumatology (EFORT) and was founded in 2015. NORE focuses on medical device surveillance and arthroplasty outcome in order to support improvements in patient care. This ranges from data capture (e.g., nomenclature on implant attributes) through data analysis and reporting techniques to new methodologies for evaluating performance of medical devices.

58.4.3 International Society of Registries (ISAR)

ISAR was established in 2004 as a voluntary international organization. The goals of the society are to utilize the strength of linkage and to develop a framework that supports the activities of established and upcoming registries, including data sharing, interpersonnel exchange, and conformity of terminology [15–17]. Full membership requires participation of over 80% of national hospitals and reporting of a minimum of 90% of procedures from each unit. Data collection must be validated. Associate members include registries with <80% coverage. Currently ISAR consists of 15 full members and 23 associate members.

58.5 Quality Characteristics of Registries

During the last decades several important concepts of registries have emerged like data coverage, data completeness including response rate, and data accuracy.

Data coverage is the percent of the target population captured by the registry. Each case has a number of data fields to be completed. Data completeness refers to the extent that all of these fields are complete for the cases entered. Data accuracy refers to the correctness of the data entered.

It needs to be defined how missing values should be handled. If patient reported outcome measurement (PROM) surveys are used, the response rate must be reported at all follow-up times. Incomplete variables or unanswered questions in surveys are missing values and should be included in all statistical analyses.

The terminology needs to be clearly defined, like the definition of a revision. While the definition of a revision procedure may seem obvious at first, it is more subtle when implementing a registry and understanding registry data. A registry may define it as the replacement of any implanted device or just a bone-fixed device. This affects, for example, whether a liner exchange is coded as a revision procedure.

Processes for estimating internal validity and external validity should be made publicly available.

Side Summary
Data coverage, data completeness, response rate, and data accuracy are important quality characteristics of registries

58.6 Data Capturing

Arthroplasty registries typically capture information about implanted devices in order to compute revision risk statistics for implants. Data capture methods range from paper forms to web-based entries and administrative file uploads of the hospital's supply chain data. They usually include barcode information. To get from barcode data to meaningful fields to analyze, the data should be transformed to manufacturer, product name, and feature information. Feature fields may include material, bearing surface, surface coating, etc. This is done using a device library, which is a database of catalog numbers, manufacturer names, product names, and feature fields. Registries have developed their own libraries over time, and they are not all the same. However, there is an effort being led by the International Consortium of Orthopaedic Registries (ICOR) to harmonize the libraries. Much progress has been made and the resulting library will be made available to all registries through the ISAR. It is important to note that the developer of a library has to decide on which implant taxonomy to use [2]. For example, suppose a company chooses to make a new version of a cobalt chromium alloy implant using titanium instead, but with the exact same dimensions and surface coating. Are the two stems the same or different? The materials are different; the geometry is the same. The library developer has to make such a decision when creating a label to use when reporting the implant. Inconsistencies in library taxonomy can complicate the interpretation of registry data [14].

58.7 Classification of Data

Registry data are classified into four levels [14]:

Level I: Basic data about the patient and procedure (name, medical record number/national medical ID, type of procedure, primary/revision, device data, etc.)

Level II: Demographic and comorbidity data about the patient

Level III: Patient-reported outcome data

Level IV: Radiographic data

58.8 Report of Data

Almost all registries publish annual reports in PDF format on their websites. The reports provide information on demographics, surgical techniques, and quality measures. Many, but not all, also provide implant-specific revision risk data over time. Some registries have moved from a PDF report to an online report-generating system.

58.9 How Should An Optimal Registry Be Performed?

Compliance of participating centers and individual surgeons is key to a successful registry. The first prerequisite to reach high compliance is to get consensus within the profession on the purpose of the register and the variable content. Once this is achieved, there are a number of steps to be taken: Most registries currently have a decentralized web-based data capture. It is therefore of importance that there is a specific contact person at each unit, and also to give specific training on the registry's web form. Efforts should be made to capture a limited number of variables but still get an adequate description of the intervention and outcome. Whether paper or web collection is used, the design must be "intuitive" and user-friendly. The most important feature to optimize compliance in a national quality registry is the opportunity for the participating unit to easily get feedback online. Users must initially see the benefits of the registration burden. Coverage and completeness analyses should be performed and published on a regular schedule, for example, annually. Monitoring of the individual units is a validation process, which will ultimately facilitate "completeness" [18].

58.10 Discussion

The differing structures of institutional, regional, national, and global registries offer different strengths and weaknesses.

Cost-effectiveness is inevitable in modern healthcare systems. This comes along with the need for quality control. Especially, institutional and regional registries enable feedback mechanisms to be easy and comfortable. It is easy to identify, implement and share best practices, and discover less effective treatment options. Effective use of quality registries can lead to better health outcomes at a lower cost for the society.

Besides cost improvement and quality control, registries offer a platform to support and augment clinical studies, nest clinical trials within national registries, and pool registry data to effectively monitor the introduction of new technologies [19]. A national observational study has some obvious advantages compared to an RCT: a large number of patients, high statistical power, the possibility to perform adequate analyses of uncommon complications, and the ability to avoid performance bias. As surgery becomes more and more individualized, registries may offer a tool to evaluate patient outcomes and give recommendations for future treatment. Implant survival rates can be estimated. By collecting tissue and blood samples on joint arthroplasty patients, a correlation of individual patient genetic characteristics with outcomes of joint surgery can be established. This could open a new dimension of understanding of the determinants of outcomes of joint replacement. The recent large head metal-on-metal disaster is a very illustrative and unfortunate example [7].

In this light, a strength of institutional databases is the opportunity to include radiographs or lab samples and add further individuals' data to answer specific questions. National registries incorporate an enormous number of patients leading to high statistical power.

Future aim should be to utilize the different structures of registries to answer specific research questions, improve quality and cost-effectiveness, and maximize a patient's individual outcome.

Side Summary

Registries with high coverage and completeness have large potential to be used as a health economic instrument, especially if the registries include PROMs and can be linked to reimbursement in health care and other insurance and societal costs

Take Home Message

Registries are an irreplaceable tool to ensure quality control, enable high-grade research, and improve cost-effectiveness. To answer certain questions, researchers may move from RCTs to more clinical outcome-based strategies like evaluation of registries' data.

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59 Most Common Scores for Patients' Evaluation

Daniel Guenther

Keynotes

1. The baseline data collection may begin at any point in a patient's treatment for osteoarthritis (OA), whether at diagnosis of OA in the knee, upon starting a new OA treatment regimen or at the time of surgery.
2. Once data collection begins, it is recommended that it continues annually for as many years as feasible.
3. The combination of a disease-specific patient-reported outcome measurement (PROM) with a generic PROM is recommended.
4. Disease-specific PROMs are the Oxford Knee Score (OKS), Knee Injury and Osteoarthritis Outcome Score (KOOS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and Hospital for Special Surgery (HSS) Score.
5. The Knee Society Clinical Rating System (KSS) is a 'hybrid' disease-specific measurement, which requires both patient and clinician responses.
6. Common generic PROMs are the Visual Analogue Scale (Pain), EuroQol 5 Dimension Health Outcome Survey (EQ-5D), Short Form 36 Health Survey (SF-36), Short Form 12 Health Survey (SF-12), and Veterans RAND 12-Item Health Survey (VR-12).
7. Performance-based tests should be used complementary to PROMs and generic scores and should be assessed each time the patient presents to the outpatient clinic.
8. Recommended performance-based tests are the 30-s chair-stand test, 40-m fast-paced walk test, a stair-climb test, timed up-and-go test, and 6-min walk test as tests of typical activities relevant to individuals diagnosed with knee OA and following knee arthroplasty.
9. Clinicians and researchers should be aware of the strengths and weaknesses of each test to choose reasonable test combinations preventing repetition.
10. A well-organized and structured schedule for data acquisition leads to high patient and examiner satisfaction, thus enabling thorough sets of data and a desirable follow-up.

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59.1 Introduction

Do we have the optimal measurement tools for the evaluation of patients with osteoarthritis (OA) and also for patients treated by knee arthroplasty?

Patient-reported outcome measurements (PROMs) are a hot topic of ongoing debate, as there is currently no consensus on the most appropriate measure to use. Multiple PROMs are described in the literature and are more or less widely spread in the clinical or research setting. Each PROM has its strengths and weaknesses, and it is important to choose the appropriate PROM for the given setting. Another important issue to address is choosing the correct time points to acquire patient data pre- and post-surgery. In addition, it is of utmost importance to standardize data acquisition to ensure comparability.

In general, outcome measures can be divided into three different domains [1]:

1. Performance-based outcome measures to track physical ability, such as stair climbing or walking.
2. Disease-specific outcome measures specific to OA and/or knee arthroplasty. The majority of these questionnaires are PROMs. There are also 'hybrid' disease-specific measures, which require both patient and clinician responses.
3. Generic outcome measures to assess overall health and well-being of the patient. Generic outcome measures are typically applied to a greater diversity of diseases and are all considered PROMs.

In this chapter, the author gives an overview of the common scores for patient evaluation in basic knee arthroplasty, elucidates their strengths and weaknesses and provides the reader with a guideline for which time points the data should be acquired.

Side Summary
Outcome measures can be divided into three different domains: Performance-based outcome measures to track physical ability, disease-specific outcome measures specific to osteoarthritis (OA) and/or knee arthroplasty, and generic outcome measures to assess overall health and well-being of the patient.

59.2 Outcome Measures

Side Summary
The 30-s chair-stand test, 40-m fast-paced walk test, stair-climb test, timed up-and-go test, and 6-min walk test demonstrated sufficiently small measurement errors, indicating they are adequate for measuring change over time in individuals with knee osteoarthritis (OA).

59.2.1 Performance-Based Scores

The Osteoarthritis Research Society International (OARSI) recommends the 30-s chair-stand test, 40-m fast-paced walk test, a stair-climb test, timed up-and-go test, and 6-min walk test as tests of typical activities relevant to individuals diagnosed with knee OA and following knee arthroplasty (Fig. 59.1) [2].

Fig. 59.1 Osteoarthritis Research Society International (OARSI) recommended set of performance-based tests of physical function for patients with knee osteoarthritis (OA), including end-stage disease or following joint replacement [2]

Of these tests, the 30-s chair-stand test, 40-m fast-paced walk test, 6-min walk test, and 10-m fast-paced walk test demonstrated, at minimum, acceptable levels of both between and within-rater reliability and measurement error. All tests demonstrated sufficiently small measurement errors, indicating they are adequate for measuring change over time in individuals with knee OA [3]. It should be noted that some tests described in the recommended set require further clinimetric evidence for patients with OA. However, this set of tests represents what is currently considered the best available tests for patients with OA [2]:

30-second chair-stand test: The maximum number of chair-stand repetitions possible in a 30-s period [4–6].

Stair climb test: The time (in seconds) it takes to ascend and descend a flight of stairs.

The number of stairs will depend on individual environmental situations. Where possible, the 9-step stair test with 20-cm (8-inch) step height and handrail is recommended [7, 8].

40-m (4 × 10 m) fast-paced walk test: A fast-paced walking test that is timed over 4 × 10 m (33 ft) for a total of 40 m (132 ft) [9].

Timed up-and-go test: Time (seconds) taken to rise from a chair, walk 3 m (9 ft 10 inches), turn, walk back to the chair, then sit down wearing regular footwear and using a walking aid if required [7–10].

Six-minute walk test: A test of aerobic walking capacity over longer distances. The maximal distance covered in a 6-min period is recorded [7, 8, 10, 11].

59.2.2 Disease-Specific Scores

59.2.2.1 PROM

Side Summary

Each patient-reported outcome measurement (PROM) has its strengths and weaknesses, and it is important to choose the appropriate PROM for the given setting. A combination of a disease-specific PROM with a generic PROM is recommended.

Oxford Knee Score (OKS)

The OKS is a knee joint specific 12-item questionnaire originally developed and validated in 1998 for use in randomized controlled trials in total knee arthroplasty (TKA) [12]. The OKS consists of 12 items, 5 for assessing pain and 7 for assessing function. Each item is weighted equally from 1 to 5 for a total possible score ranging from 12 to 60. A lower score indicates a better outcome. The OKS has also been used to evaluate pharmacological and conservative interventions and other knee surgery procedures in knee OA [13]. An updated scoring method is available, whereby each item is scored between 0 (worst outcome) and 4 (best outcome), to provide an overall score between 0 and 48 [13]. A weak floor effect (7%) has been reported for the OKS prior to TKA [14]. Ceiling effects were reported at 6 months (14%) and 12 months (22%) following surgery [15].

Knee Injury and Osteoarthritis Outcome Score (KOOS)

The KOOS is a knee joint specific questionnaire developed in 1998 originally for the purpose of evaluating short-term and long-term symptoms and function in subjects with knee injury and OA. It was originally validated in patients undergoing anterior cruciate ligament reconstruction [16]. The KOOS is a 42-item survey. A higher score indicates a better outcome. The KOOS is widely used in younger and/or more active patients with knee injury and knee OA [17]. The KOOS has been validated for measuring outcomes in TKA [17], anterior cruciate ligament reconstruction [16] and post-traumatic knee OA [18]. The KOOS has also been used to evaluate other OA interventions, including minor knee surgery procedures [19], conservative treatments [20, 21], and nutritional [22] and pharmacological interventions [23], and population-based reference data have been published [24]. In addition, a short-form version (KOOS-PS) which is a 7-item questionnaire derived from the original KOOS has been validated [25]. Each of the 42 items carries equal weighting (0–4). There are five subscales, each measuring a specific outcome: pain (9 items), symptoms (5 items), activities of daily living (17 items), sports and recreation function (5 items), and knee-related quality of life (4 items). Scores for each subscale are calculated separately and then transformed into a score between 0 and 100 [16]. Floor and ceiling effects have been reported for studies of TKA in some domains of the KOOS [17]. Preoperatively, the percentage of patients undergoing TKA with the worst possible score have reached 48% for the sports and recreation domain of the KOOS. Ceiling effects at 6 months (15% for pain scores and 16% for sports and recreation) and 12 months (22% for pain scores and 17% for quality of life scores) have also been reported.

Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)
The WOMAC was initially developed in 1982 and was first validated in 1998 for the purpose of evaluating patients with hip and knee OA following various treatments [26]. The WOMAC underwent multiple subsequent revisions and refinements between 1996 and 1999 [27]. The WOMAC is a 24-item questionnaire with three subscales measuring pain (5 items), stiffness (2 items), and physical function (17 items). Each of the 24 items has five possible responses for a possible score of 0–4 for each response. A total WOMAC score is calculated by summing the items for all three subscales, for a total score between 0 and 96. A lower score indicates a better outcome. Since its initiation, numerous validation studies have been conducted using the WOMAC [27]. The WOMAC has been validated for measuring outcomes in clinical trials of TKA [28] and for measuring treatment response of pharmacological interventions for knee OA [29]. It has also been used to evaluate many knee OA interventions, both surgical and conservative [30]. A short-form version (WOMAC-SF), which is a 7-item questionnaire derived from the physical function subscale of the WOMAC, has been validated for assessing function in knee OA and TKA [31, 32]. Minimal floor effects for the WOMAC have been reported with the exception of the quality of life subscale which was reported at 14% [17]. Ceiling effects have been reported for TKA at 6 months (27% for the pain subscale and 15% for the stiffness subscale) and at 12 months (17% for the quality of life subscale, 30% for the pain subscale, and 27% for the stiffness subscale) [17, 33].

Hospital for Special Surgery (HSS)
First described in 1973 [34], the HSS score has been shown to be a reliable, valid and responsive outcome measure. The HSS score assesses six components: pain, function (walking and stair climbing), range of motion, muscle strength, deformity, and instability. A higher score indicates a better outcome. A perfect knee receives 100 points, and an arthrodesed knee receives 60 points. The HSS is open access and widely used in outcome studies for partial and total knee replacement. Floor effects were reported to be minimal. Ceiling effect at 2 years was reported with 17%.

59.2.2.2 Hybrid Scores

Side Summary
The Knee Society Clinical Rating System (KSS) is the most popular outcome measure in randomized controlled trials on knee arthroplasty. The drawbacks of ‘hybrid’ outcome measures are increased administration cost by virtue of their requirement for clinician input and examination findings, and the risk of overestimation of actual outcomes if physicians are more optimistic about the surgical outcome than patients.

Knee Society Clinical Rating System (KSS)
The KSS is a knee joint specific questionnaire originally developed and validated in 1989 for use in assessing the outcome of TKA [35]. The KSS has two components: a knee rating (0–100 points) and function score (0–100 points), worth a total of 200 points. The knee rating is divided into pain (0–50 points) and a knee score which assesses range of motion, stability, and alignment (0–50 points). A higher score indicates a better outcome [36–38]. Due to criticism of the

clinician-completed scoring system and aspects of its validity [39], a revised knee society scoring system (2011-KS Score) has been developed [40]. The KSS includes range of motion and alignment measurements, and this may in part contribute to its popularity. The KSS has also been used to evaluate outcomes in other orthopaedic procedures such as patellofemoral arthroplasty [41] and high tibial osteotomy [42]. The function subscale (0–100) is based on walking distance (0–50) and ability to climb stairs (0–50), with deductions for use of a gait aid (0–20). The pain subscale is (0–50) and the knee rating (0–50) is based on range of motion (0–25) and knee stability (0–25), with deductions made dependent on the existence and severity of flexion contracture (0–15), extension lag (0–15) and malalignment (0–20) [35]. A negative score is possible and should be converted to zero. The 2011-KS expands on the KSS and includes subscales for patient satisfaction (5 items, 0–40 points), expectation (3 items, 0–15 points), and functional activities (19 items, 0–100 points), which is divided into functional activities (5 items, 0–30 points), standard activities (6 items, 0–30 points), advanced activities (5 items, 0–25 points), and discretionary knee activities (3 items 0–15 points) [40]. Satisfaction, expectation and function should be reported as separate scores. A composite score is not recommended. Ceiling effects have been reported for studies of TKA in both the knee (25%) and function (43%) subscales of the original KSS at 12 months [43]. Floor effects did not occur preoperatively, and ceiling effects did not occur at 6 months after TKA [44].

59.2.2.3 Generic Scores

Side Summary
Generic outcome measures are typically applied to a greater diversity of diseases and are all considered patient-reported outcome measurements (PROMs). Most generic PROMs assess physical and mental health.

Visual Analogue Scale (Pain)

The Visual Analogue Scale (VAS) consists of a line with endpoints defining extreme limits such as 'no pain' and 'extreme pain' [45]. The patient is asked to mark his pain level on the line between the two endpoints. The distance between 'no pain at all' and the patient's mark then defines the subject's pain. This tool was first used in psychology in 1923 [46]. If descriptive terms like 'mild', 'moderate', 'severe' or a numerical scale are added to the VAS, this is considered a Graphic Rating Scale (GRS) [45]. Difference in pain intensity measured at two different points of time by VAS represents the real difference in magnitude of pain which seems to be the major advantage of this tool compared to others [47, 48]. As the distance between 'no pain' and the patient-made mark must be measured, scoring is more time-consuming and susceptible to measurement errors than a rating scale. Hence, a mechanical VAS has been developed where subjects position a slider on a linear pain scale instead of marking a cross on a drawn line. The investigator is then enabled to directly read the pain intensity on a millimetre scale on the other side of the slider (Fig. 59.2).

Several studies have shown this system to be strongly associated with the original VAS [49, 50]. Moreover, it has been shown that the mechanical VAS does have a good test-retest reliability and appears to have ratio qualities as well [51].

EuroQol 5 Dimension Health Outcome Survey (EQ-5D)

EQ-5D is a standardized measure of health status developed by the EuroQol Group [52]. The EQ-5D 3-level version (EQ-5D-3L) was introduced in 1990. It consists of a descriptive system and an EQ Visual Analogue Scale (EQ VAS). The EQ-5D-3L descriptive system comprises five dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. Each dimension has three levels: no problems, some problems, and extreme problems. The EQ VAS records the respondent's self-rated health on a

Fig. 59.2 Mechanical Visual Analogue Scale (VAS). Subjects position a slider on a linear pain scale (**a**). The investigator is enabled to read the pain intensity on a millimetre scale on the other side of the slider (**b**)

vertical, visual analogue scale where the endpoints are labelled 'best imaginable health state' and 'worst imaginable health state'. Ceiling effects have been reported, particularly when used in general population surveys but also in some patient population settings.

A new version of the EQ-5D (EQ-5D-5L), established in 2005, includes five levels of severity in each of the existing five EQ-5D dimensions [53]. The EQ-5D-5L still consists of the EQ-5D-5L descriptive system and the EQ VAS. The descriptive system comprises the same 5 dimensions as the EQ-5D-3L (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression). However, each dimension now has five levels: no problems, slight problems, moderate problems, severe problems, and extreme problems. The digits for five dimensions can be combined in a 5-digit number describing the respondent's health state. The numerals 1–5 have no arithmetic properties and should not be used as a cardinal score. The EQ VAS records the respondent's self-rated health on a 20-cm vertical, visual analogue scale. EQ-5D-5L health states, defined by the EQ-5D-5L descriptive system, may be converted into a single index value [52].

Short Form 36 Health Survey (SF-36)

The SF-36 is a multi-purpose, short-form health survey with 36 questions. The SF-36 is for use in adults (18 years of age and older). Scores are calibrated so that 50 is the average score or norm. The norm-based score allows comparison across the more than 19,000 studies published in the past 20 years. The survey has eight scales, which are hypothesized to form two distinct clusters due to the physical and mental health variance they have in common. The scales that include Physical Functioning, Role Physical, and Bodily Pain correlate most highly with the physical component and contribute most to the scoring of the Physical Component Summary (PCS) measure. The scales Mental Health, Role Emotional, and Social Functioning correlate most highly with the mental component and contribute most to the scoring of the Mental Component Summary (MCS). The scales Vitality and General Health have correlations with both components [54].

Short Form 12 Health Survey (SF-12)

The SF-12 is a multipurpose short-form survey with 12 questions, all selected from the SF-36 Health Survey [55, 56]. The questions were combined, scored and weighted to create two scales that provide glimpses into mental and physical functioning and overall health-related quality of life. The SF-12 is a generic measure and does not target a specific age or disease group. It has been developed to provide a shorter, yet valid alternative to the SF-36. The SF-12 is weighted and summed to provide easily interpretable scales for physical and mental health. The test consists of

12 questions and ranges from 0 to 100. A zero score indicates the lowest level of health measured by the scales, and 100 indicates the highest level of health.

Veterans RAND 12-Item Health Survey (VR-12)

The VR-12 is a patient-reported global health measure that is used to assess a patient's overall perspective of health. VR-12 includes 12 original question items from the VR-36. The questions in this survey correspond to seven different health domains: general health perceptions, physical functioning, role limitations due to physical and emotional problems, bodily pain, energy/fatigue levels, social functioning, and mental health. Answers are summarized into two scores, a Physical Component Score and a Mental Component Score, which then provide an important contrast between the respondent's physical and psychological health status [57, 58].

59.3 How to Use Scores in Clinical Practice?

> **Side Summary**
> Annual data collection is intended to provide data for comparing outcomes across providers. In the ideal setting, annual measures are patient reported to enable collection outside the context of clinical practice. A time-window of 2–4 weeks should be allowed for collecting these measures.

The baseline data collection may begin at any point in a patient's treatment for OA, whether at diagnosis of OA, upon starting a new OA treatment regimen, or at the time of surgery. Once data collection begins, it is recommended that it continues annually for as many years as feasible. Annual data collection is intended to provide data for comparing outcomes across providers. As the timing of this data collection may not match the timing at which patients are seen in clinical practice, in the ideal setting, annual measures are patient reported to enable collection outside the context of clinical practice (e.g. via mail or email). The working group of the International Society of Arthroplasty Registries (ISAR) [59] and the International Consortium for Health Outcomes Measurement (ICHOM) [60] recommend using a combination of a disease-specific PROM with a generic PROM [59, 60]. A time window of 2–4 weeks should be allowed for collecting these measures. Performance-based tests should be used complementary to PROMs and generic scores and should be assessed each time the patient presents to the outpatient clinic. Table 59.1 summarizes the scores presented in this chapter.

59.4 Discussion

> **Side Summary**
> Many studies use multiple outcome measures from the same category, suggesting uncertainty over the relative merits of each measure. Recent reviews have recommended appropriate patient-reported outcome measurements (PROMs) for use after joint arthroplasty based on scientific merit.

This chapter aims to provide a guideline and orientation for how to navigate the 'jungle' of different scores for patient evaluation in knee OA and knee arthroplasty. However, what does the reality of patient-reported outcomes look like? A recent meta-analysis [1] has shown that a 'hybrid' outcome measure, the KSS for knee arthroplasties, is the most popular outcome measure in randomized controlled trials and study protocols registered with clinical trials registries on knee arthroplasty. This is in contrast to the above-mentioned recommendations to use a combination of a disease-specific PROM with a generic PROM [59, 60].

Reasons may lie in the belief that clinician involvement in 'hybrid' measures provides more objective outcomes and in existing confusion regarding the validity of each outcome measure. The drawbacks of 'hybrid' outcome measures are increased administration cost by virtue of their requirement for clinician input and examination findings, and the risk of overestimation of actual

Table 59.1 Scores and their attributes used for patient evaluation in knee osteoarthritis (OA) and total knee arthroplasty (TKA)

Outcome measure	Type of measure	Licensing/open access	Estimated testing time (min)
30-s chair-stand test	Performance based	N/A	0.5
Stair-climb test	Performance based	N/A	0.1–2
40 m (4 × 10 m) fast-paced walk test	Performance based	N/A	0.5–5
Timed up-and-go test	Performance based	N/A	0.1–1
Six-minute walk test	Performance based	N/A	6
Oxford Knee Score (OKS)	Disease-specific PROM	Licensed	5
Knee Injury and Osteoarthritis Outcome Score (KOOS)	Disease-specific PROM	Open access	10–15
Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)	Disease-specific PROM	Licensed	10
Hospital for Special Surgery (HSS)	Disease-specific PROM	Open access	
Knee Society Clinical Rating System (KSS)	Disease-specific hybrid	Licensed	10
Visual Analogue Scale (Pain)	Generic	N/A	0.25
EuroQol 5 Dimension Health Outcome Survey (EQ-5D)	Generic	Licensed	8
Short Form 36 Health Survey (SF-36)	Generic	Licensed	5–10
Short Form 12 Health Survey (SF-12)	Generic	Licensed	2
Veterans RAND 12-Item Health Survey (VR-12)	Generic	Licensed	2

outcomes if physicians are more optimistic about the surgical outcome than patients [61].

Many studies use multiple outcome measures from the same category, suggesting uncertainty over the relative merits of each measure. Tradition may play a role. Existing studies may have created a self-perpetuating cycle, whereby researchers continue to use the same outcome measures that have been used historically, to ensure that their results can be compared to previous publications. Recent PROM-focused reviews have recommended appropriate PROMs for use after joint arthroplasty based on scientific merit [62, 63]. To date, limited studies have objectively compared PROMs to other ‘hybrid’ and performance-based measures for assessing the success of joint arthroplasty [64].

Take Home Message

In conclusion, clinicians and researchers should be aware of the strengths and weaknesses of each test to choose reasonable test combinations preventing repetition. A well-organized and structured schedule for data acquisition leads to high patient and examiner satisfaction, thus enabling thorough sets of data and a desirable follow-up.

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