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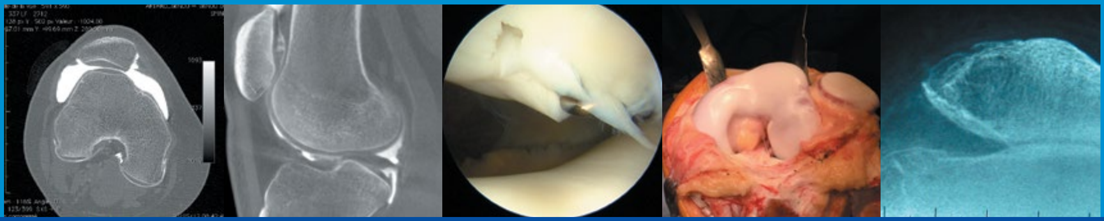

# Patellofemoral Pain, Instability, and Arthritis

## Clinical Presentation, Imaging, and Treatment

*Second Edition*

European Society of Sports Traumatology, Knee Surgery & Arthroscopy
ESSKA

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# Preface

Dear readers, ESSKA Members, and Patellofemoral devotees,

2010 to 2020: it has been a decade between the first edition of Patellofemoral Pain Instability and Arthritis book and the second edition presented by this book.

The editors, the ESSKA Patellofemoral committee, and ESSKA are proud to offer you this updated and revised book.

The patellofemoral disorders remain a major topic to debate and exchange. Patellofemoral disease and injury are still a mystery for some orthopedic surgeons, physicians, physiotherapists, and scientists because it is a melting pot between pain and instability; this could present with objective patellar dislocation or be reported as instability due to reflex quadriceps inhibition. We often face the dilemma between pain and cartilage damage and/or true arthritis characterized by kissing lesions with the bone exposed.

What is special with this third compartment of the knee?

- Genetics definitely! It is now well known that patellar dislocation is related to certain anatomic risk factors (trochlear dysplasia, patella alta, excessive TTTG, torsional abnormalities), which makes this pathology distinct by affecting the very young children, the adolescent, and the young adult. The psychologic impact is huge in that many children never encounter a normal way of life, and the parents are concerned and possibly feel responsible for the knee difficulties of their own children. Knowledge of these abnormalities is the key to success in treating our patients; the lack of knowledge of these bony abnormalities and PF disorders is the best explanation for the large amount of iatrogenic poor outcomes that continue in this field.
- Global approach is necessary because the patella as a sesamoid bone and as such affects the lower limb, the pelvis, and the back. This could lead to imbalances in the pulley system which may result in overloading and stress on the cartilage contributing to pain.
- Multiple elements to control and correct the surgical treatment is most of the time a combination of several individualized procedures to correct the abnormalities; the key is not to overcorrect but also not to hypocorrect; one can result in recurrent dislocation, the other to pain and arthritis. Everything is a matter of equilibrium!

With this book, we want to give you the keys of a successful approach of the patellofemoral pathology. From the very early start in the embryogenesis you will follow the developmental process and then discover how to evaluate the risk factors of your patient. Listening first to the patient history, be sure that it was a true and documented patellar dislocation, interview the patient as if you are a detective, perform thorough physical exam, request appropriate imaging exams, discuss with your radiologist to have them perfectly done, and measure with a ruler or use a radiologist software to do accurate measurement. This is the first step. The second step is how to classify your patient? Is she/he eligible for surgery or conservative treatment, and what are her/his risks to have a recurrent patellar dislocation? There are some objective data that you will learn by reading this book. Nothing is empiric; everything is science. Finally, the time to surgery is decided, you will have the best overview of all the procedures available with the indications, the techniques, the results, and the complications. Very detailed, very precise, very useful for your daily practice.

As your patient ages, you will deal with pre- and true PF arthritis, and some chapters will be proposed to you to be conservative or to be surgical with or without arthroplasty.

We conclude by (hopefully) convincing you that this book is the best update in patellofemoral disorders and will become new and valuable stone to build your best practice in PF surgery.

We hope you will enjoy, appreciate, and use this tool that ESSKA is happy to offer to you.

Patellofemoral greetings…

| | |
|---|---|
| Lyon, France | David Dejour |
| Bologna, Italy | Stefano Zaffagnini |
| Minneapolis, MN | Elizabeth A. Arendt |
| Tampere, Finland | Petri Sillanpää |
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# Acknowledgment

We thank deeply Ms. Julie Agel, our book manager, who did an extremely professional work; she was there in our 2010 edition and after 10 years she managed to give us the opportunity to deliver such a homogeneous and outstanding book.

# Contents

# Patellofemoral Pain, Instability, and Arthritis

# 1

Panagiotis G. Ntagiopoulos and David Dejour

## 1.1 General Considerations

Patellofemoral (PF) disorders are a very special entity in knee practice, and although they are very common to encounter, very often their treatment is cumbersome and time-consuming for both the patient and the surgeon. The cornerstone of most PF pathology is the abnormal tracking of the patella over the trochlea, which may extend from obvious patellar dislocation to insidious abnormal patellar tracking [1]. The anatomy is central and gives often the solution to classify and treat the patients. Two big entities can be distinguished: pain or instability (e.g. dislocation). They may appear seperately or they may overlap, something that can lead to missdiagnosis or iatrogenic overtreatment [2].

True patellar dislocation or lateral patellar dislocation is caused by two main risk factors or instability factors: it results either from a traumatic event during childhood or adulthood, but it may also be predisposed by genetic and congenital abnormalities and appear earlier in life; the latter form an abnormal PF anatomy, which very soon leads to recurrent patellar dislocation. On the other hand, PF pain is a more insidious pathology that results from many other components of the knee anatomy, like abnormal patellar tracking or as a post-traumatic or postoperative result and is mostly attributed to cartilage wear on either trochlear or patellar side. In order to properly identify which of these elements contributes to PF pain, global clinical and imaging analysis of the patient, including the postural status, the muscle asymmetry, and the muscle stiffness, has to be checked and quantified. Finally, either factor that originally led to true patellar dislocation or cartilage wear may finally result to PF arthritis that involves bone-on-bone contact and osteophyte formation on the two surfaces [3–5].

Therapeutic indications are only indicated to treat documented factors that lead to true dislocation or that have led to arthritis, which a surgical gesture can correct. PF pain is a problem that mainly has a nonsurgical solution, if any. Treatment options are decided after careful clinical and imaging analysis of very specific anatomical predisposing factors that contribute to PF instability. Evaluation of the results of a single surgery is therefore very difficult, since in most of the series reported in literature, a number of different surgical procedures are performed concomitantly. Yet, imaging evaluation with the use of X-rays and cross-sectional imaging (e.g., CT and MRI) dictates a certain algorithm for the surgical treatment of recurrent patellar dislocation [6–10].

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## 1.2 Classification

Patellofemoral pain, instability, and arthritis can present in the following different clinical forms:

**Objective patellar dislocation** (or luxation) is defined as the complete loss of contact between patellar and femoral trochlear articular surface. It represents a true mechanical and objective instability and can occur in high-energy activities, frequently associated to a symptomatic and (lipo) knee hemarthrosis (that suggests MPFL rupture combined with bony avulsion). It is of paramount importance, especially in the case of children and adolescent, to actually have a documentation of the dislocation episode or the physician to be able to show an actual patellar dislocation to the young patient and receive a confirmation, because a lot of episodes of patellar "subluxations" may be perceived or described as true dislocation, causing further confusion. That is why the term "subluxation" is of no clinical importance and is not advised to use. The loss of contact may be spontaneously reduced or irreversibly fixed in a dislocated position that needs immediate medical care. This is the second thing that is very important to record in cases of acute patellar dislocation. A dislocated patella that is reduced easily and spontaneously by the patient with no pain usually implies loss of normal containment anatomy of the patella by the trochlea. On the other hand, a difficult-to-reduce patellar dislocation, which may demand sedation or other medical care, usually happens over a more normal PF anatomy. In this group of objective patellar instability, one or more pathological anatomic factors are found in the imaging analysis that they will be later studied (trochlear dysplasia, patellar height, TT-TG distance, patellar tilt, MPFL tear) [11–13].

**Subjective (potential) patellar dislocation** is the second group of PF instability patients: this group of patients reports a feeling of instability, but never an actual record of patellar dislocation as previously described. This may be secondary to inhibition of the quadriceps muscle function by a nociceptive reflex. Patients usually report a rather generic feeling of instability with the knee giving way but without a true dislocation and without hemarthrosis. It occurs frequently during daily living and low-energy activities such as walking, climbing up and down stairs, or rising from a seated position. In this group of subjective patellar instability, one or more pathological anatomic factors are also recorded, but with no clinical episodes of dislocation [12, 14, 15].

**Patellofemoral pain syndrome** is the third group of patients, where a feeling of instability, giving way, or pain is frequently recorded, but with no imaging findings of any PF pathology and neither an episode of patellar dislocation.

Patellofemoral instability may be further classified according to the frequency of patellar dislocations to recurrent patellar dislocation, where the patella dislocates frequently during knee flexion (more than three episodes are required), and habitual patellar dislocation, where the patella dislocates during early knee flexion (<30°) *every time* the knee flexes. Finally, permanent patellar dislocation is the condition in which the patella is always dislocated throughout normal knee range of motion and never faces femoral trochlea.

As stated before, PF pain if considered an isolated entity has rarely a surgical solution. Its treatment mostly lies on physiotherapy regimes and other nonsurgical modalities like orthotics, activity modification, etc [16–18].

**Patellofemoral arthritis** occurs less frequently as one compartment arthritis than the arthritis in the medial or the lateral compartment of the knee. It is mostly found in women, and in 50% of the patient, it is bilateral. Anterior location of the pain especially while lifting from chair and while descending stairs is the predominant clinical sign. Lateral and skyline X-rays are mandatory for diagnosis, but CT and MRI can also help to determine the extent of cartilage loss. Its etiology is directly related to trochlear dysplasia which founded in 78% of the cases, although extensor mechanism malalignment (valgus knees), hypermobile patella, excessive lateral hyper-pression syndrome, patella alta or patella infera, and iatrogenic causes have been described. Two other causes often discussed are sequelae of articular fractures (e.g., patella fractures) and rheumatoid disease (such as chondrocalcinosis). But the most consistent factor leading to PF arthritis is untreated recurrent patellar dislocation (33% of patient with PF arthritis have a history of patellar dislocation). PF arthritis has been classified by Iwano (with the use of skyline views of the patella) into four different grades: ranging from cyst and osteophyte formation to bone-on-bone disease [19, 20].

The treatment of PF arthritis is generally addressed by an orthopedic surgeon when it affects patient's quality of life. If conservative means (activity modification, physiotherapy, anti-inflammatory, etc.) fail, surgical correction is needed. This can be achieved by tibial tuberosity osteotomy (that have faded the last decades) or by most successfully by either partial knee arthroplasty (of the patellofemoral compartment alone) or by tri-compartmental (total) knee arthroplasty, most commonly.

## 1.3 PF Instability

### 1.3.1 Anatomic Factors Causing PF Instability

#### 1.3.1.1 Major Instability Factors

In 1987 H. Dejour originally described four instability factors that lead to patellar instability; since then, further knowledge has enriched our armamentarium, out of which, the following have the highest significance [1].

**Primary Factors Contributing to PF Instability**

*Trochlear dysplasia*: it is the abnormally shaped femoral trochlea that becomes flat or convex (instead of concave) and causes loss of joint congruence and abnormal patellar tracking. The patella is not contained inside the pathologically shaped and shallow groove, thus resulting in lateral dislocation.

*Patella alta*: excessive patellar height keeps the patella away from engaging into the trochlea during flexion predisposing to PF joint instability. The patella is anteriorly to the femoral metaphysis instead anteriorly to the trochlear groove.

*Excessive tibial tubercle-trochlear groove (TT-TG) distance*: this represents an axial malalignment of the extensor mechanism raising valgus stresses on the patella. The tibial tuberosity is usually placed more medially than normally, thus resulting in excessive lateral forces on the patellar bone.

*Excessive patellar tilt*: previously considered a major factor, it is now considered a resultant of one or more of the other three factors associated to medial patellofemoral ligament (MPFL) rupture. The medial stabilizing structures (e.g., MPFL) are torn after a patellar dislocation, while the lateral structures remain intact. In more chronic cases (recurrent patellar dislocation), these unequivocal and asymmetrical forces on the patellar bone result in an excessive lateral tilt [1].

**Secondary Factors Contributing to PF Instability**

Anatomic factors including excessive femoral anteversion, excessive tibial external rotation, knee recurvatum, and knee valgus deformity are considered of secondary surgical importance, due to insufficient literature data to confirm pathological values to which they lead to patellar dislocation and values at which they are surgically corrected and lead to treatment of previous patellar dislocation.

The treatment algorithm for PF instability lies on the principle of identifying and correcting every abnormal anatomic factor that leads to dislocation. More specifically, trochlear dysplasia requires surgical correction with trochleoplasty procedure; excessive TT distance requires medialization of tibial tuberosity osteotomy, increased patellar height (patella alta) demands correction with distalization of tibial tuberosity osteotomy, excessive patellar tilt may require lateral release, and every of the previous procedure must be partnered with the restoration of the normal anatomical checkrein of the patella into the trochlear groove: the reconstruction of the medial patellofemoral ligament [1, 19, 20].

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# 2

# Genetics and Syndromes with Patellofemoral Disorders

Siebren Tigchelaar and Sander Koëter

## 2.1 Patellar Development

The patellofemoral joint is an exceptional joint, unlike any other joint in the human body. The patella, albeit just a small part of the knee, has an important function as a fulcrum for the extensor mechanism of the knee. Complaints related to this part of the knee joint frequently occur and are usually related to pain and instability of the patella. Unlike instability in other joints, patellofemoral instability is usually the direct consequence of congenital malformations of the patella and femoral trochlea. These malformations result from aberrations and disruptions in the evolutionary, embryological, and genetic development of the patellofemoral joint. This chapter will address the development of the patellofemoral joint in order to better understand the causes of congenital patellofemoral disorders.

## 2.2 Evolution

The human knee dates back 320 million years in the evolutionary scale, to Eryops, the common predecessor of reptiles, birds, and mammals (Fig. 2.1). The Eryops knee was bicondylar, with a femorofibular articulation, cruciate ligaments, and asymmetric collateral ligaments. The patella appeared at a much later stage, about 70 million years ago in the Cenozoic era. It was found to have developed separately in birds, some reptiles, and in mammals [1, 2]. The overall design of most terrestrial mammalian knees can be divided into three broad categories, based on the form of the pes: unguligrade, digitigrade, and plantigrade (Fig. 2.2). The unguligrade knee, which is seen in pig, sheep, goats, and horses, lacks full extension and therefore is permanently loaded in flexion. Such knees have separate tibiofemoral and patellofemoral articulations. The digitigrade knee as seen in carnivores such as the cat and dog can be nearly fully extended but is most frequently loaded in flexion and has a narrow confluence between the trochlea and the femoral condyles. The plantigrade knee, seen in the human and bear, is functionally loaded in full extension, during portions of the gait cycle and during stance. This type of knee has a broad confluence between the femoral condyles and a much more shallow trochlea as both the tibiofemoral joint and the patellofemoral joint share the contact surface of the femoral condyles [1]. After evolving to bipedal stance, the modern patellofemoral joint developed in hominids 1.3 million years ago [2]. One might consider that this shallow trochlea, in conjunction with the bipedal stance (and thus greater rotational forces on the knee) of humans, leads to a decreased intrinsic stability of the patella when compared to other mammals.

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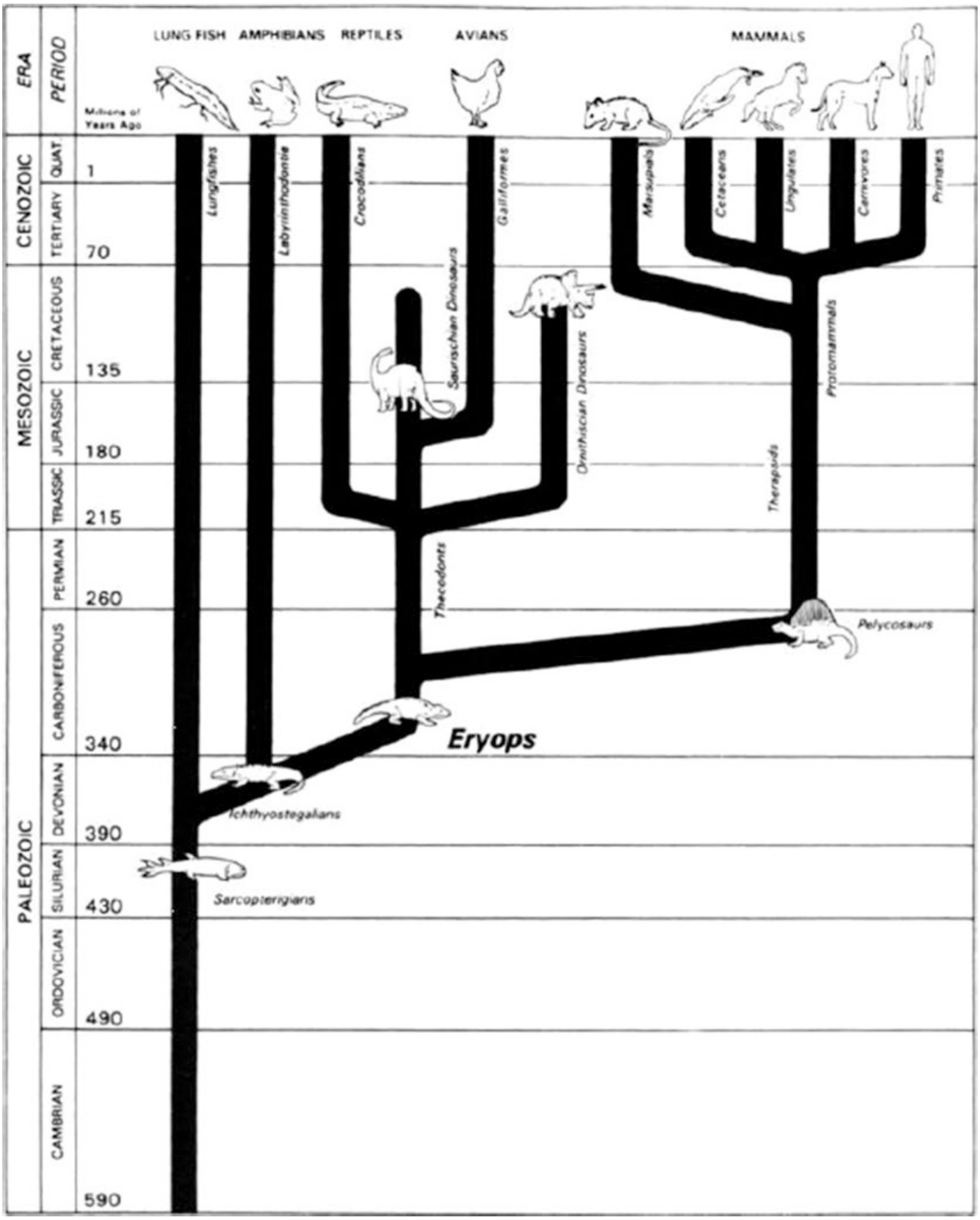

**Fig. 2.1** Schematic representation of the relationship of different classes of tetrapods with the Eryops as common ancestor about 320 million years ago. (From: *Dye SF. An evolutionary perspective of the knee. J Bone Joint Surg Am 1987;69:976–83*. With permission)

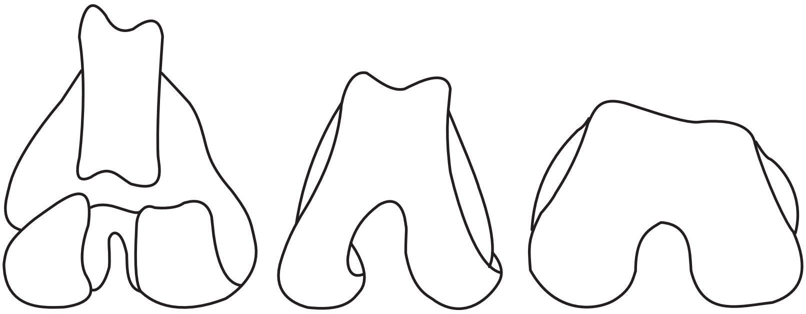

**Fig. 2.2** Representations of the distal femoral articulations of unguligrade (left), digitigrade (middle), and plantigrade (right) mammals. (From: *Dye SF. An evolutionary perspective of the knee. J Bone Joint Surg Am 1987;69:976–83*. With permission)

## 2.3 Embryonic Development of the Lower Limb

Embryonic development of the limbs begins when condensations of mesenchyme cells protrude as small buds at the designated craniocaudal levels of the lateral body wall, determined by *Hox* genes, at the end of the fourth week of gestation. This limb bud core of undifferentiated mesenchymal cells is encased by ectodermal cells. The mesenchymal cells, which originate from the lateral plate mesoderm, give rise to skeletal elements, cartilage, and tendons [3]. By the fifth week, the skeletal elements of the limb are developed from a column like mesodermal condensation that is formed along the axis of the limb bud. The cartilaginous precursors of limb bones develop by chondrification within these condensations. Shortly after chondrification of the articular ends of the femur and tibia, the complex consisting of the presumptive quadriceps tendon, patellar ligament, and patella is visible as a continuous band of fibrous connective tissue spanning the mesenchymal interzone along the anterior surface of the knee joint [4]. The differentiation of the patella and the patellar tendon starts at day 37 with chondrification of the patella starting at day 45 of gestation. The patella increases in relative size up to the sixth month of fetal life, after which it increases at the same rate as the other bones of the lower extremity. Initially, the medial and lateral patellar facets are equal in size, but at week 23 of gestation, the lateral facet has become the more predominant which is a key characteristic of the adult patella. Ossification of the patella usually starts at age 5–6 years but is sometimes visible on radiographs at age 2–3 years [4].

The three-dimensional spatial development of the lower limb can be viewed along three primary axes: the proximo-distal (pelvis-digit direction), the anteroposterior (great toe-little toe direction), and the dorsoventral (back of feet-plantar direction). Limb bud patterning along these axes is regulated by a complex system of reciprocal signaling pathways. Three signaling centers are, to a great extent, responsible for development of each of these three axes. The first is the apical ectodermal ridge (AER), a condensation of ectoderm cells at the distal end of the limb bud and the boundary between the ventral and dorsal side of the limb, which controls outgrowth along the proximo-distal axis (Fig. 2.3). Development along the anteroposterior axis is controlled by the zone of polarizing activity (ZPA) which is a small zone of mesenchymal cells just below the AER (Fig. 2.4). Development of the dorsoventral axis begins when the dorsal ectoderm produces the signaling molecule Wnt7a which stimulates the underlying limb bud mesenchyme to express the transcription factor Lmx1b, a molecule that regulates the dorsal character of the mesoderm underlying the dorsal ectoderm [5, 6]. Lmx1b expression has been found in patellar mesenchyme which ultimately leads to the formation of proximal and distal dorsal limb structures such as

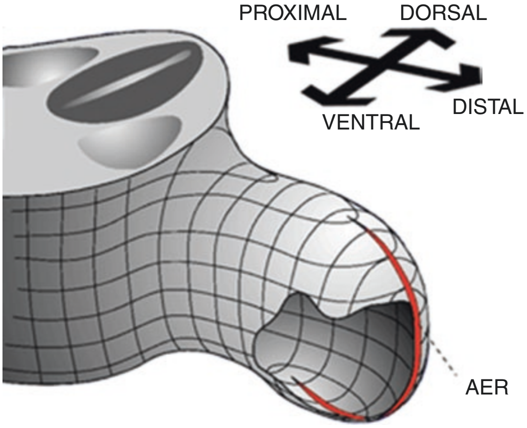

**Fig. 2.3** The apical ectodermal ridge (AER). The AER is a condensation of ectoderm cells at the distal end of the limb bud and the boundary between the ventral and dorsal side of the limb. Reproduced with permission and adaptation from https://doi.org/10.1371/journal.pbio.1000420.g001, under the Creative Commons Attribution 4.0 International Public License

the patellae and the nails [3]. The ventral ectoderm produces Engrailed-1 (En-1), which represses the expression of Wnt7a and therefore the formation of Lmx1b which results in a ventral limb mesoderm [5, 6] (Fig. 2.5).

During human embryonic development, limb patterning along these three axes is accompanied by rotation of the limbs. Initially, the upper and lower limb buds extend laterally from the body wall with the thumb and great toe facing cranially, and the flexor surfaces face ventrally. Subsequently, the limbs shift into a more ventral position with both the thumb and great toe still facing cranially, but the flexor surfaces now facing medially. The limbs rotate around their proximo-distal axis between the sixth and eighth weeks of embryonic development. The upper and lower limbs rotate in opposite directions, the upper limbs rotate dorsally, and lower limb rotation occurs in the ventral direction. At this end stage of limb rotation, the flexor/palmar surfaces of the hands face ventrally and the flexor/plantar surfaces of the feet dorsally; the elbows and knees face outward (Fig. 2.6). Consequently, the patella, which primordial anlage is a dorsal structure, comes to lie ventrally during limb development [3]. It is argued that the patellar instability, which is always lateral, is frequently caused by a deficiency in this dorsoventral and rotational development.

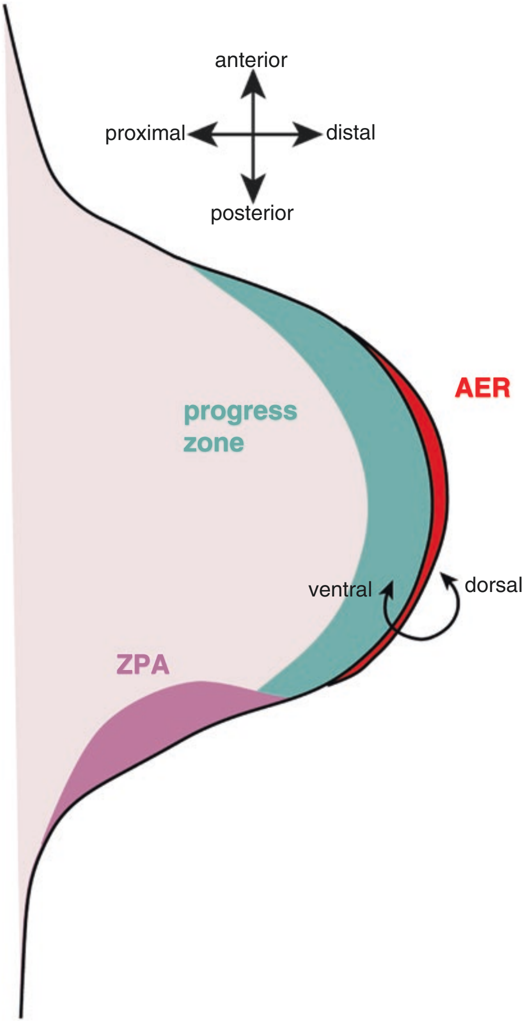

**Fig. 2.4** The zone of polarizing activity (ZPA). The ZPA is a small zone of mesenchymal cells just below the AER which controls development along the anteroposterior axis. Figure by Terrasigillata at English Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=42013411

In the embryo, the knee develops in a position of ≥90° flexion. This means that the patella initially conforms to the distal aspect of the femoral condyles, the part that will articulate with the tibial plateau in stance. The general adult form of the trochlear surface of the femur is achieved very early in fetal life, before movement has occurred. This means that it is not formed in contact with or in response to the patella but to the quadriceps musculature. As with most anatomic structures, form follows function, and the final shape of both the patella and the femoral trochlea will be modified by use [7].

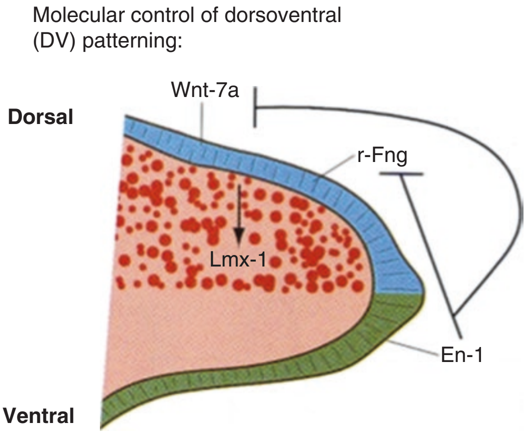

**Fig. 2.5** Molecular control of dorsoventral patterning. The ventral ectoderm produces En-1, which represses the expression of Wnt7a and therefore the formation of Lmx1b which results in a ventral limb mesoderm

## 2.4 Genetic Syndromes

There are several genetic disorders that can lead to specific anatomic patellar anomalies. These genetic alterations influence the development and morphology of both the patella and the distal femur and lead to (radiologically) identifiable patellofemoral anomalies.

Human syndromes in which patellar a- or hypoplasia is the key feature are nail patella syndrome (NPS), small patella syndrome (SPS), and isolated patellar aplasia. In other syndromes such as, but not exclusive to, Meier-Gorlin syndrome, RAPADILINO syndrome, and genitopatellar syndrome, other symptoms are more at the forefront, but patellar anomalies are still an important clinical clue toward their diagnosis. Lastly there are syndromes in which patellar malformations are present in the background of more profound limb deformations [3, 8].

For further reading the following articles are recommended:

- *Bongers EM, van Kampen A, van Bokhoven H, Knoers NV (2005) Human syndromes with congenital patellar anomalies and the underlying gene defects. Clinical genetics 68*

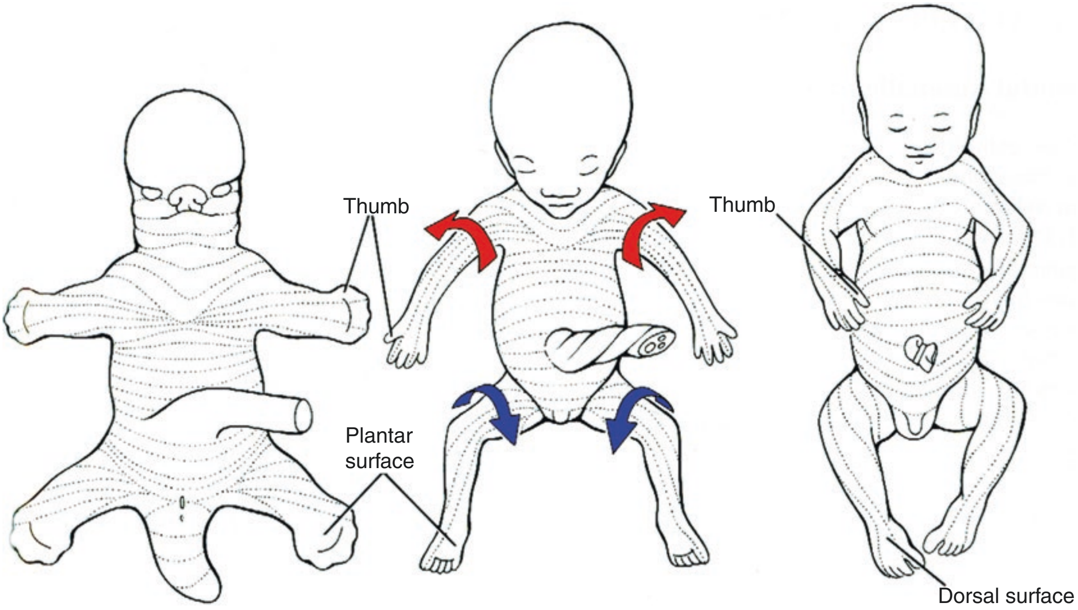

**Fig. 2.6** Rotation of the upper and lower limbs between the sixth and eighth week of gestation

*(4):302–319.doi:*https://doi.org/10.1111/j.1399-0004.2005.00508.x

- *Vanlerberghe C, Boutry N, Petit F (2018) Genetics of patella hypoplasia/agenesis. Clinical genetics 94(1):43–53. doi:*https://doi.org/10.1111/cge.13209

Clinically, NPS and SPS are most relevant to recognize. In the next section, we will focus on these two specific human syndromes. Two genes, *TBX4* and *LMX1B*, are crucial in patterning along the dorsoventral and anteroposterior axes and are highly involved in the development of syndromal changes. TBX4 is involved in the development of dorsal and posterior elements of the lower limb, such as the patella, and mutations in the *TBX4* gene are the cause of small patella syndrome [9]. LMX1B is important for patterning of dorsal and anterior skeletal and surface structures of the upper and lower limb during later stages of development [3]. Nail patella syndrome (NPS) is an autosomal dominant hereditary disorder and is caused by heterozygous mutations in the *LMX1B* gene. These mutations disrupt the normal dorsoventral development of the limbs [10]. This leads to dysplasia of dorsal limb structures such as the nails and patella but also includes elbow dysplasia and exostoses of the ilia. With respect to the knee, this genetic mutation can result in a patellar a- or hypoplasia and patellofemoral maltracking, leading to pain and instability [11].

## 2.5 Small Patella Syndrome

Small patella syndrome (SPS) is a rare autosomal dominant disorder characterized by patellar, pelvic, and feet abnormalities. SPS is caused by haploinsufficiency of the *TBX*4 gene. *TBX4* belongs to the T-box gene family and encodes a transcription factor involved in hind limb development [9].

Patellar malformations and abnormal ossification of the ischiopubic region and/or infra-acetabular axe cut notches (Fig. 2.7a) are essential features to diagnose SPS. The patellar malformations consist of small or absent patellae, frequently dislocated, and a shallow trochlear groove (Fig. 2.8). Foot anomalies, including a wide space between the first and second toes ("sandal gap"), short fourth and fifth rays of the feet, and pes planus may accompany SPS (Fig. 2.7b).

Complaints in SPS are generally related to the absent or dislocated patellae. No complaints related to pelvis and foot anomalies have been reported in SPS [3]. More recently other features have been revealed which include developmental dysplasia of the hip, spine deformities, and dental issues [12].

There is scarce literature on the surgical treatment of patellofemoral problems in SPS. One study reported good results with medial and lateral retinaculum plasty in 12 patients, all aged under 16 years [13].

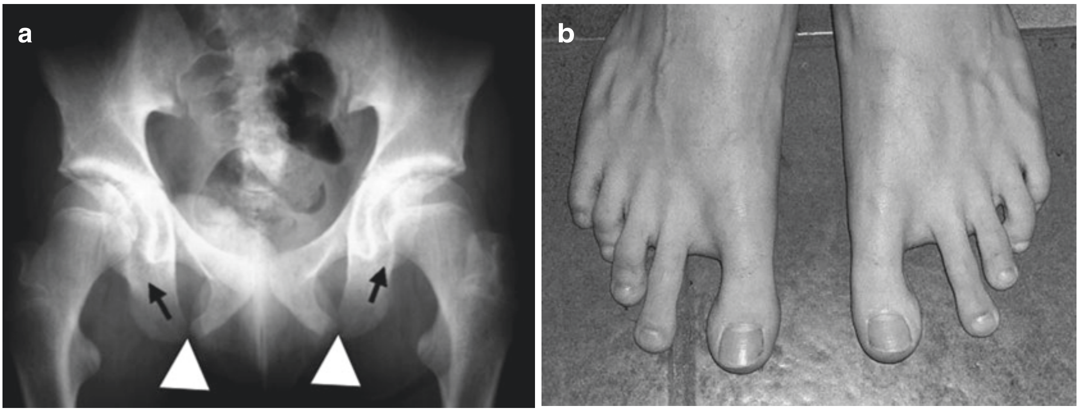

**Fig. 2.7** (**a**) Ischiopubic malformations in SPS, abnormal ossification of the ischiopubic region (white arrows), and/or infra-acetabular axe cut notches (black arrows). (**b**) Feet deformities in SPS. An increased space between the first and second toe (sandal gap deformity) and shortened fourth and fifth rays

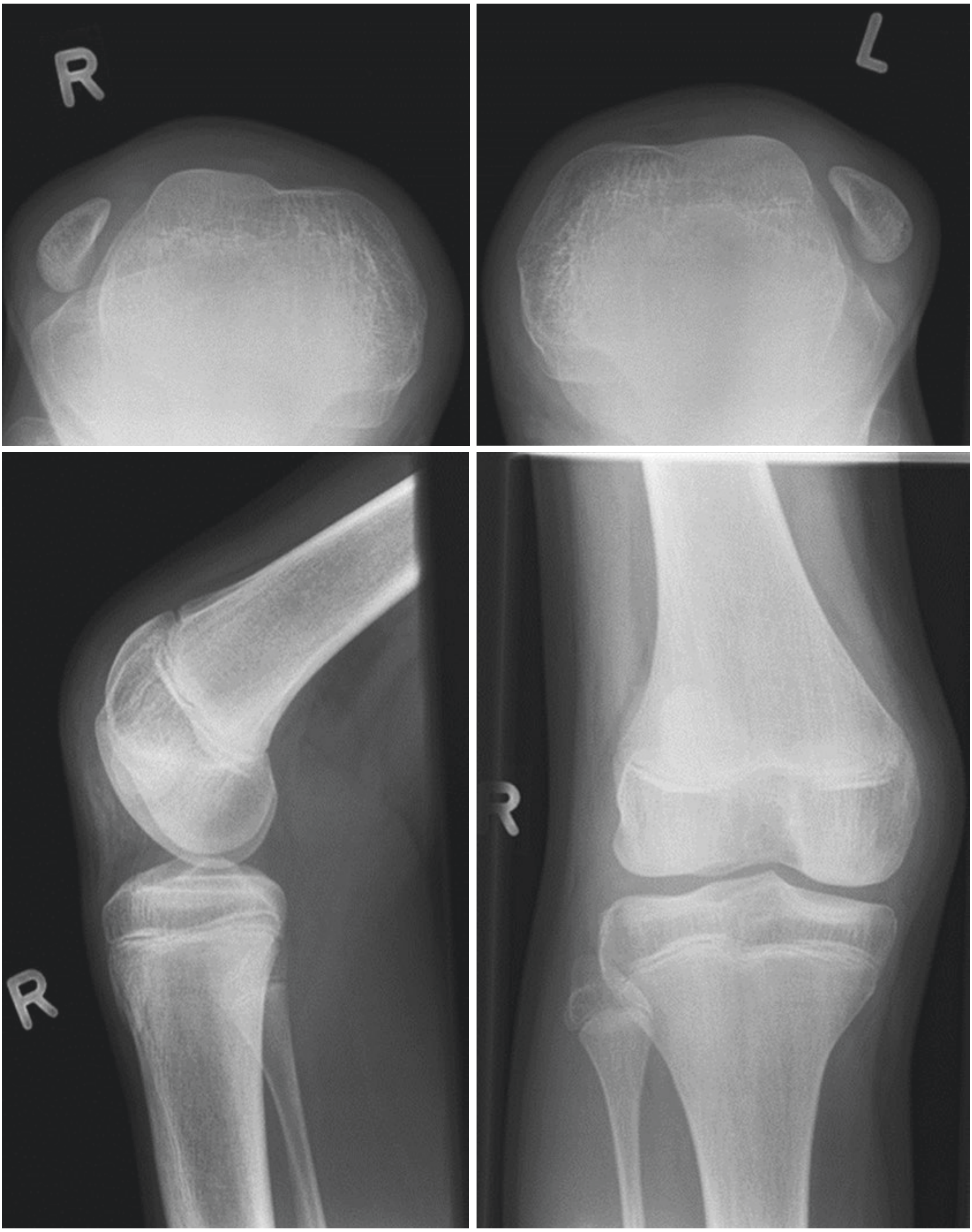

**Fig. 2.8** Patellofemoral malformations in SPS. The patella is small or absent and often dislocated on the lateral side of the knee, and the trochlea is frequently shallow

## 2.6 Nail Patella Syndrome

Nail patella syndrome (NPS) is a skeletal dysplasia characterized by dysplasia of the nails, elbows, and knees [11]. The prevalence of NPS has been estimated at 1:50,000 [11, 14].

This autosomal dominant hereditary disorder is caused by a heterozygous mutation in the *LMX1B* gene [14], which results in developmental defects of dorsal structures in the limbs [3]. Studies in *Lmx1b* knockout mice showed patellar aplasia and abnormalities of the knee similar to those observed in NPS [15]. The cardinal features of NPS are nail dysplasia, encompassing hemi-anonychia or anonychia with triangular lunulae (Fig. 2.9), and absent or hypoplastic patellae [11, 14, 16–19].

Other skeletal deformities found in NPS include hypoplasia and subluxation of the radial head, hypoplasia of the capitellum, pes equinovarus, and contractures of major joints. While iliac horns are pathognomonic for the syndrome, they are only reported in between 70% and 80% of cases (Fig. 2.10) [11, 14].

Aside from the skeletal features, patients with NPS may develop progressive nephropathy and glaucoma; as a result, careful clinical evaluation is necessary in patients who present with these distinct orthopedic abnormalities [11, 20–23]. Early diagnosis and treatment of comorbidities are essential, and patients should be referred for annual screening for renal disease and glaucoma.

**Fig. 2.9** Nail dysplasia in NPS. These consist of hemi- or complete anonychia or of nails with triangular lunulae (digits 3 and 4)

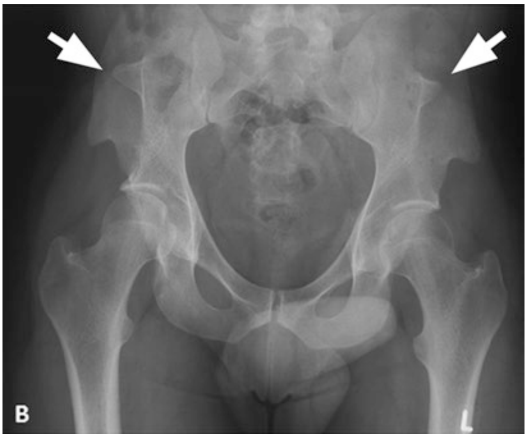

**Fig. 2.10** Iliac horns in NPS. The iliac horns are clearly visible on pelvic X-rays (white arrows) and might be clinically palpable

Complaints of the knee are reported in up to 74% of patients with NPS [11] and result from patellofemoral malformations, including patellar aplasia or hypoplasia, patellofemoral instability and dysfunction, and osteoarthritis [11, 19, 24, 25]. However, the clinical features of NPS are highly variable, both within and among families [11, 14, 26]. These complaints were assessed in a group of 103 NPS patients using the Knee injury and Osteoarthritis Outcome Score (KOOS) and Kujala knee score. Mean KOOS (73.04) and Kujala (74.01) scores showed a wide range and variability between patients, and patellofemoral instability was present in 48.5% of patients [26].

### 2.6.1 Radiologic Characteristics

Conventional radiologic evaluation of the knee is usually sufficient for diagnosis of the syndrome and may reveal a number of distinct and easily recognizable abnormalities. In a series of 95 mature NPS patients, Tigchelaar et al. showed patellar aplasia in 4% and patellar hypoplasia in 86% of patients. The prevailing patellar shapes according to the Wiberg classification were type III, type IV, and Hunter's cap, so mainly shapes

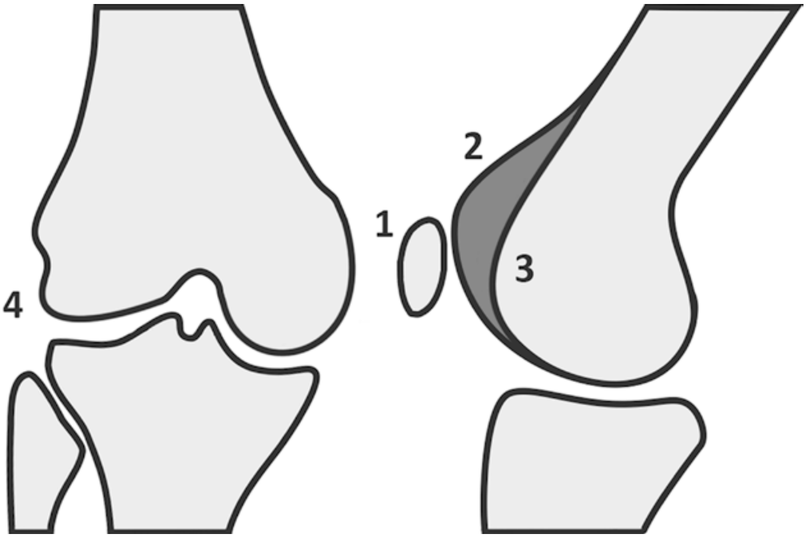

**Fig. 2.11** Representation of the characteristic NPS knee and the most frequently observed malformations. (1) Patellar aplasia or hypoplasia. (2) A prominent anterior side of the lateral femoral condyle (darker area). (3) A flat anterior side of the medial femoral condyle. (4) A distal shortening of the lateral femoral condyle

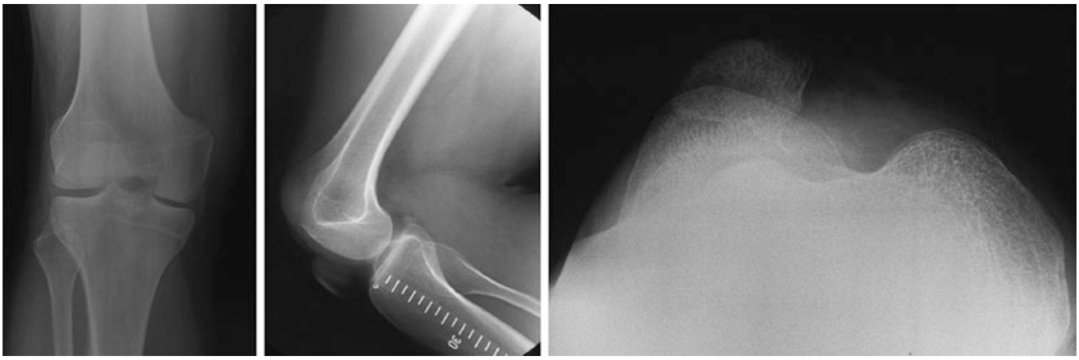

**Fig. 2.12** Conventional radiographs of a right knee in nail patella syndrome with typical characteristics. A small Wiberg type IV patella is present. The distal aspect of the lateral femoral condyle is short on the anteroposterior radiograph. On the lateral view, the anterior surface of the lateral femoral condyle is prominent with a flat anterior surface of the medial condyle

with a small medial facet and larger lateral facet. There was no patellar shape genotype-phenotype association. In the distal femur, three distinct malformations which can be diagnosed on conventional radiographs were present: a shortening of the lateral femoral condyle in 55% of patients, a prominent anterior surface of the lateral femoral condyle in 56%, and a flat anterior surface of the medial femoral condyle in 92%. In 67% of NPS patients, at least three out of four of these malformations (patellar a- or hypoplasia and the malformations of the distal femur) are present (Figs. 2.11 and 2.12) [27].

### 2.6.2 Treatment of NPS

Several studies have described knee surgery in case reports of patients with NPS [28–31] or smaller series [17, 19, 32]. In several cases a synovial plica or septum is described which lies centrally in the trochlea, essentially dividing the knee in a medial and lateral compartment. After resection of this plica, complaints resolved. However, the majority of reported procedures involved patellar realignment surgery [17, 19, 30, 32]. The physician-reported results of these procedures are generally good with low redislocation rates. The patient-reported outcome of surgical treatment of knee symptoms in NPS is good with a high patient satisfaction [26].

It is the authors' opinion that, given the high variability of symptoms, the surgical treatment of these patients depends on the malformations encountered. Usually the combination of a tibial tuberosity transfer and MPFL reconstruction is sufficient. In patients with more aberrant trochlear morphology, a trochleoplasty might be necessary. In almost all cases requiring surgical intervention, a lateral release is needed due to the far lateral tracking of the patella (Fig. 2.13).

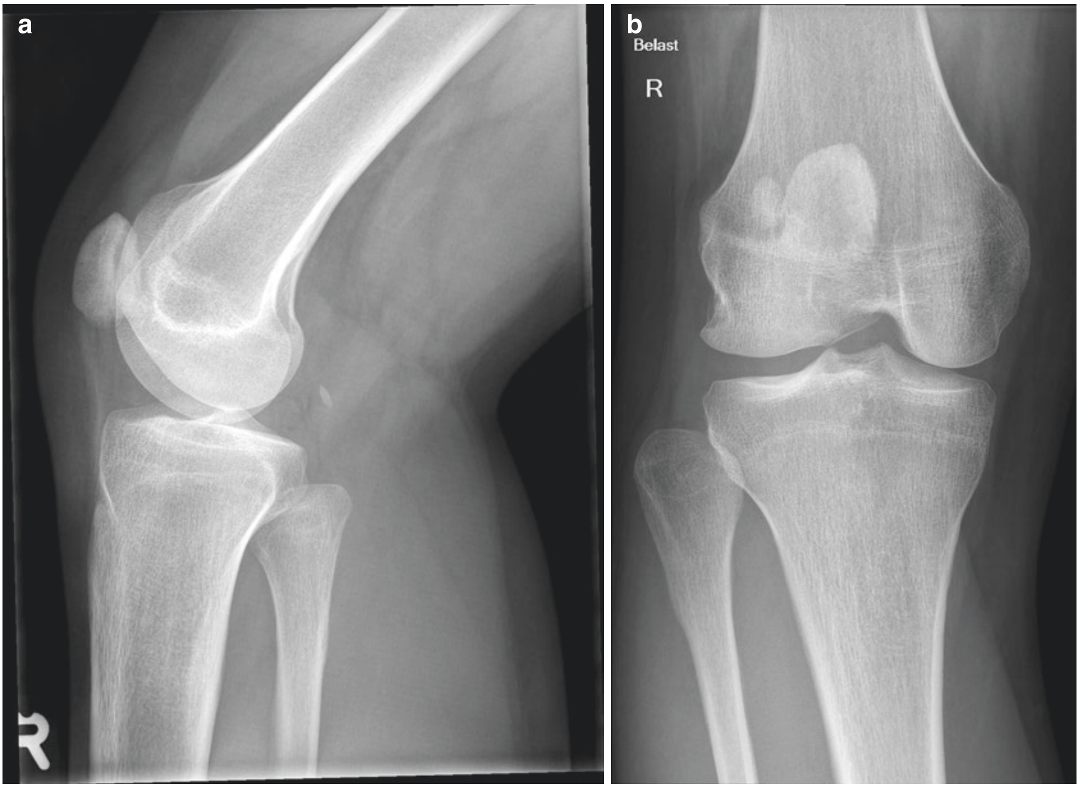

**Fig. 2.13** The following figures describe a female patient with NPS who was surgically treated for recurrent dislocations of the patella in the right knee. The conventional X-rays of the knee (**a** and **b**) show a small bipartite patella, a relative short lateral femoral condyle, and a prominent anterior surface of the lateral condyle. The MRI (**c**) shows that the patella tracks mainly over the lateral condyle. A tibial tubercle medialization was performed (**d**) accompanied by an extensive lateral release, and a MPFL reconstruction was performed (**e**). We removed the loose part of the bipartite patella. Intraoperative inspection of the patellar cartilage showed extensive cartilage damage (**f**). We noticed a plica running from the anterior horn of the lateral meniscus through the trochlear groove to the superior recessus of the knee (**g**). This plica was largely resected as we felt it interfered with the engagement of the patella in the trochlear groove. Postoperative X-rays show a well-aligned patella, central in the trochlea (**h** and **i**)

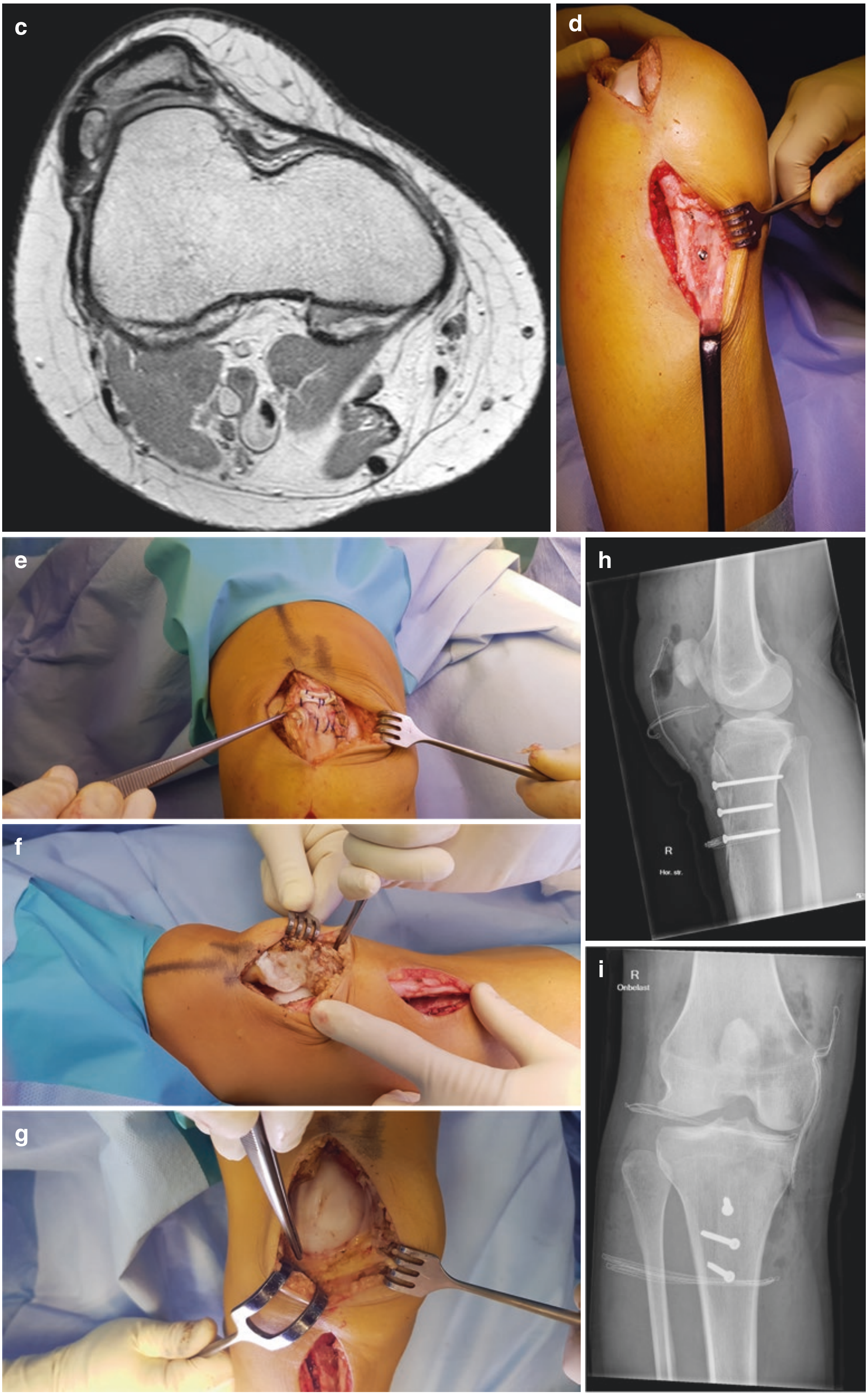

**Fig. 2.13** (continued)

## 2.7 Recommendations

In this chapter we hope to clarify embryologic and genetic pathways and the relation with patellofemoral disorders.

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# 3 Detecting and Addressing Psychological Factors

Richmond M. Stace

## 3.1 Introduction

It is the psychological dimension that brings life to the lived experience, much like colour and textures enliven a painting. Contemporary understanding of the lived experience via the study of phenomenology, enactivism and embodied cognition informs us that 'what it is like' is not separate to the physical body or the circumstances within which the experience arises. One can consider thoughts and emotions, which emerge together, and bodily sensations to be embodied and embedded within a context. This context is modern society.

Whilst these may not be your first considerations when a person comes to see you for a knee problem, considering the bigger picture allows you to be closer to the reality of the human experience. This can sound akin to the biopsychosocial (BPS) model [1], which is the contemporary way to be patient-centred. Yet the BPS model must remain fluid in the mind of the clinician and be a basis for considering the human being in front of you rather than overfocusing on a body part. Further, it is important to avoid the trap of using the BPS model as three silos instead of understanding that the three dimensions are unified. This chapter will meet you at the BPS model but then attempt to take you further into the lived experience, offering an understanding and practical approaches to achieve the real results that people, both patients and clinicians, desire.

The psychological dimension of a pain problem or health issue has existed as long as the individual has had a thought and a feeling about their situation. The recognition of this fact as a primary focus has taken time to develop in society, with the main concern typically being the search for pathology, disease or tissue injury. Whilst identifying such factors and diagnosing conditions remain important, any attempt to remove the lived experience from the presentation will fail to reach the person who is suffering.

Clinicians and therapists are always working with a whole person. There is nothing new or radical about this biopsychosocial approach. Oliver Sacks, the great neurologist and most human of doctors, made it clear that it is always as much about the person as the condition [2]. In terms of pain, Pat Wall one of the foremost founders of modern pain science and medicine was direct in stating that the pain experience is related to the state of the person rather than that of the tissues [3].

To separate the psychology creates a false dichotomy [4]. To ask someone about how they feel about their situation is an enquiry into their embodied state of mind. The body is always present, experienced intermittently within the apparent flow of consciousness as a constant stream of percepts. Many different sensations will provoke our attention as they appear in awareness.

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Pain as an example of a demanding sensation is one of the most notable. The intensity, nature and the qualities of pain can vary, just as the responses vary according to the context. Multiple studies have shown that the experience of pain is significantly modified by context [5–8], including illusory resizing of the painful knee [9]. Clearly this has nothing to do with the tissue state, pathology or disease but instead the way that the sensory information is interpreted and the experience predicted as with any perception [10].

Patellofemoral pain (PFP), instability and arthritis are distinct issues, yet they can often be concurrent conditions. Arthritis is a diagnosis, whereas PFP and instability are more descriptive. It will be the meaning rather than the word per se that is important for the patient. For instance, the term instability conjures a range of images and thoughts that will have a bearing on the patient's willingness to move and exercise. If it is thought that the joint will dislocate because this is the meaning that makes most sense, the person will likely move with great trepidation and seek to avoid certain activities. For this reason, clinicians must explain their terms so that the patient has a good understanding and is confident to engage in the rehabilitation.

In this chapter, we will review the evidence for psychological approaches for pain, consider how we can use a comprehensive approach to establishing the nature of the person's experience, discuss different practical strategies and techniques that can be used in the clinic to address psychological factors and, finally, introduce concepts of coaching as a means to motivating an individual to follow certain principles to achieve their picture of success. In the main, this chapter targets clinicians and therapists who want to integrate a range of effective tools into their existing practice to deliver best care. To deliver such care necessitates insight into one's current approach.

## 3.2 Your Approach to Pain: What Do You Know? What Must You Know?

Healthcare professionals must engage in reflective practice if they are to develop, grow and learn [11]. This is continuous until the end of one's career. Indeed, one appeal of the healthcare is the fact that our knowledge is ever-expanding.

One of the most puzzling and concerning gaps in healthcare education is pain. Arguably pain is the most common reason why people seek professional help, yet the study of pain at undergraduate and postgraduate levels remains inextricably low on the agenda. It is known that veterinary practitioners receive more training in pain than doctors (ref). It is only if the individual clinician has an interest or feels the need to advance his or her knowledge is the field explored. Undoubtedly pain is a complex area that draws upon a multitude of co-existing fields. To truly understand pain requires the study of perception, consciousness, neuroscience, philosophy and beyond and in fact where all of these domains meet.

The predominant model for pain in practice is biomedical. This is based upon searching for a structure or a pathology to explain the pain. However, we have known for many years that this approach does not explain pain. Pain is a perception and cannot be observed. As soon as one delves into the study of pain, you soon realise that there are a vast array of factors that influence whether the person feels pain or not, none of which include the incidental tissue state. These include fear, catastrophising, beliefs and expectations (refs).

Knowing one's own level of understanding creates the opportunity to build on and revise existing knowledge. Not only must we help people to understand their pain and symptoms, but then we encourage specific actions so that their suffering may ease. The act of getting better is something only the person suffering can engage with and is the bulk of what should be supported and encouraged by clinicians treating pain. To overcome pain, which means that pain becomes less and less predominant in that person's life, hopefully resolving entirely, is an active process on the part of the person.

With so many people suffering persistent pain [12, 13], we have an urgent need for a model that can account for the range of experiences, which include ongoing pain and placebo. Certainly the biopsychosocial (BPS) model [1] delivers a whole person perspective, where the meeting point of the biology, sociology and psychology is the lived experience. Whilst the BPS model has existed for some years, the whole person approach appears to remain in the shadows. The balance must now tip towards prioritising true care over figures.

A shift to the BPS could be considered a psychological move. Revising the model of thinking and the framework for treatment and management towards the whole rather than reduction to the knee in this case is a psychological shift in part. This is true for both the clinician and the patient. Many in society continue to believe that pain is related to the tissue state as this is how we have been conditioned to think. However, in cases of chronic pain, the ongoing focus upon the local tissues rarely provides anything but short-term relief, if at all. Widening the lens to consider the person, the reasons for their suffering (e.g. unable to work or play, disconnection with people) and how they can improve their life proves to be more effective (refs).

In fact, such therapy begins with the first contact made with the patient. This is often through an administrator, so arguably reception and support staff should also have a basic knowledge of pain so that they can create a smooth path to the clinic room. Certainly the approach taken by the clinician is an important determinant of the therapeutic process. A wonderful description of this encounter was penned by Anatole Broyard [14] in his essay, 'The patient examines the doctor' (ref), where he gives a personal account of meeting a consultant for the first time. Considering manner, language and gestures and practising deep listening, empathy and compassion are all key ingredients for a successful consultation.

Reflective practice then is not merely about advancing one's knowledge of a condition or the science of pain, for example. It is also an opportunity to build a repertoire of communication skills that dissolves boundaries between the patient and the clinician.

The advance of pain understanding has had a number of realisations since the study began 60 years ago. The key messages that have emerged from this vast body of scientific research include thinking of pain as a need state [3], a homeostatic mechanism [15], a motivator to take action in the face of a perceived threat [16], an embodied experience that is embedded in a societal context [7, 8] and, most recently, an inference within a predictive coding model [7, 8]. Alongside these developments have been insights into the social factors. In other words, considering the embedded nature of pain, where it happens in society, the messages and beliefs held in society influence experience. Some authors have argued that we should adopt a public health approach to pain [17, 18], whilst others argue that pain is a societal issue due to the costs and the impact [19–21]. The way that heart disease and diabetes are tackled includes a range of services that look at the person and their life. Treatment of pain compares unfavourably when the focus is merely on the place that hurts in the body compared to the whole person and their life.

By the very fact that two people are together discussing a pain problem means that it is always a whole person approach. A person suffering patellofemoral pain does not stay at home whilst his or her knee goes for an appointment. Further, it is always the person who feels pain, not the body part. Therefore, it is always the person we encourage, enable and empower. The natural state is person to person, so reducing a consultation to a knee is to falsely impose the wrong paradigm. The major problem that emerges is that the misunderstanding of pain results in the wrong choices and ongoing suffering [7, 8]. From the outset then, the clinician must deliver the right messages about pain and focus on what the person can do actively to improve their life, starting with some clear goals.

Psychological therapies are grounded in and emerge from the clinician's constructs of themselves, healthcare, pain and more. Therefore, to spend time reflecting upon one's existing models, beliefs and practices is an essential part of being a professional clinician. To do our best for patients, we must revise our thinking according to what is most important for our role and not only the areas we are interested in. Pain is a feature and driver of a huge number of consultations and treatment programmes. The question is whether you have the specialist knowledge and skill set to deliver best care, which most definitely includes knowing features of the narrative that are influential in pain.

## 3.3 Psychological Features

The psychological features of PFP, instability and arthritis are the way in which the individual thinks (cognitions) and feels (emotions) about their experience. There is also the level of metacognition: thoughts about thoughts. Of course this is why understanding the true nature of the problem is vital from the outset. Commonly patients will say that they felt better after the initial consultation despite there being no active treatment. However, where does the whole person approach become an intervention? Deep listening, validating the story, expressing compassion and offering feasible explanations can often rapidly change a pain experience. When pain is understood, these experiences are also understood and sought after by insightful clinicians.

Anxiety [22], depression [23], fear avoidance [24, 25] and catastrophising [26, 27] have been identified as factors that impede recovery from painful episodes. In a recent systematic review, it was concluded that people suffering PFP can experience increased anxiety, depression, catastrophising and pain-related [28]. This work was based on 25 studies that exhibit limited evidence for this particular problem and highlight the usual need for further research to clarify any causation. However, whilst there are always limitations of the research process, this does demonstrate the need to think beyond the knee.

A more recent cross-sectional study investigated the relationship between PFP and psychological wellbeing [29]. The authors compared 100 people with PFP (72 female) with 50 controls (36 females) matched for sex, age and activity levels. Participants completed the Knee injury and Osteoarthritis Outcome Score (KOOS), the Hospital Anxiety and Depression Scale (HADS), the Pain Catastrophizing Scale (PCS), the Tampa Scale for Kinesiophobia (TSK) and the Kujala Patellofemoral Score (KPS). On subgrouping the subjects based on severity, the more severe cases were significantly more depressed and demonstrated higher levels of catastrophising versus the controls. In compassion to those with milder symptoms, the severe group experienced more fear of movement (kinesiophobia), depression and catastrophising. In conclusion, kinesiophobia was identified as a noteworthy feature of PFP that clinicians should be aware of and address within the treatment and management programme. Clues are often given within the narrative, but the use of the TSK would be a simple inclusion.

Knee instability can be a characteristic of osteoarthritis of the joint. Often this is explained by changes in the knee structures such as increased ligament and capsule laxity together with greater joint space resulting from the degeneration. One study looked at the relationship between instability and function. The results highlighted instability as a common problem in knee arthritis (63%) and that it affected physical function day to day (44%). The authors concluded that the rehabilitation programme should address knee instability as an issue beyond the pain, mobility and strength [30]. They do point out the important difference between passive laxity that is testable and functional knee instability that is the occurrence of giving way whilst being active. Understanding sensorimotor control is important here because the clinician can talk to the patient about the episodes and ascertain how they feel about being active. It is not enough to know that the knee is unstable. The clinician needs to be aware of the context and the person's thoughts and feelings about the instability.

Fear of movement, trepidation and anticipation that the knee may give way will affect how the person moves. Contemporary motor control studies describe movement as fulfilling a prediction that has already been made by the brain [31]. We move with the implicit knowledge of what we will achieve, depending upon affordances in the immediate environment [32]. Therefore, any expectation, even subconsciously (where most processing takes place), will create evidence that giving way explains the sensation. This explanation uses predictive coding as a framework to describe the hierarchical cortical processing of information that emerges as a perception [33, 34]. The significance of this very brief outline is to emphasise the importance of helping the patient establish a firm grip on what is happening and why before moving onto what can be done in terms of training. The rehabilitation should include proprioception and motor control exercises that are specific to the needs of the patient (i.e. functional) but also encouragement and coaching so that they prepare and focus on what they are doing rather than intrusive thoughts and other distractions. Addressing fears and beliefs directly within the context of the rehabilitation programme, not in a silo, is important as simply strengthening the knee is unlikely to be adequate to deal with such issues in patellofemoral pain [35]. In building confidence and motor control ability (movement without thought), the person is more likely to engage with day-to-day activities.

Patellofemoral instability is a common problem. Much of the literature focuses upon the structural aspects, with little comment upon the psychological aspects specific to an unstable patellofemoral joint. For example, Sanchis-Alfonso [36] identifies subgroups dependent upon the degree of knee flexion when the instability occurs. In the younger population, the consensus appears to be conservative treatment initially, only turning to surgery if absolutely necessary [37]. Of course, this is not to say that psychological features described above are absent. The thorough clinician will be alert to fear avoidance, catastrophising, hypervigilance, anxiety and depression within the narrative and during the examination. Observing a person move is revealing in as much as we can note reluctance, apprehension and refusal. Once identified, the clinician can explore in more detail what the person is thinking and why.

Arthritic pain is typically considered from a biomedical perspective similar to other pains. Whilst this is a consideration, a truly biopsychosocial view both captures the lived experience as previously mentioned and offers ways forward to address the issues. Purely focusing on the knee does not help the person suffering persistent pain to deal with relationships, work limitations, financial concerns, what to say to other people or even give a useful perspective on how to ease suffering. Instead, to listen to and validate the full picture of the person's life and why the pain is such a dominant feature open the door of possibility for a range of positive actions. This is the approach encouraged by contemporary authors and clinicians who understand pain [38] and work that has identified the discordance between what is seen on an X-ray and the description given by the patient [39]. These authors conducted a search of the literature and highlighted that observable changes on radiographs do not provide a reliable guide to pain and disability. An X-ray is objective and measurable, whereas pain is a subjective experience that varies according to range of factors including context. In that sense, there is no reason for these to be well related compared to the relationship between the state of the person and the pain they suffer.

Twenty percent of people with arthritis experience depression and anxiety [40]. A systematic review by Phyomaung et al. [41] showed the significant role that depression plays in knee pain. This is supported by a cross-sectional study by Iijima et al. [42] that looked at psychological health in people with osteoarthritis. The authors found that depression was significantly associated with slower walking and timed up and go (TUG), more knee pain during daily living and limited function in a group of patients radiographically diagnosed with osteoarthritis ($n = 95$).

Efforts to identify knee osteoarthritis subgroups could provide a focus for specific or tailored treatments to target particular dimensions of the condition. To this end, Cruz-Almeida et al. [43] looked at the psychological profiles of older adults with knee osteoarthritis to examine the relationships between such profiles, the nature of the pain experience and the results of quantitative sensory tests (QST). The results of the study highlighted individual differences, which is unsurprising in as much as knee osteoarthritis is a very common condition [44], affecting people across society.

Recent studies suggest that depression could be associated with inflammatory processes in the brain [45, 46]. Other so-called inflammatory conditions are often linked with depressive symptoms. For example, a high prevalence of depression and anxiety was found in systemic lupus erythematosus patients when authors undertook a systematic review and meta-analysis [47]. A similar picture was revealed in a systematic review of patients with inflammatory bowel disease (IBD) [48]. Largely involving the immune system, inflammation is an underpinning biology of the sickness response [49].

Arthritis becoming more prevalent with age, there are likely to be other health factors to consider. Again, this is a strength of the biopsychosocial model that demands all dimensions be examined. Asking about the medical history reveals co-existing conditions that could also be inflammatory-driven, together with pro-inflammatory contributors such as poor dental health [50], chronic stress [51] and loneliness [52].

Hypervigilance and catastrophising are well-documented features of persistent pain. Hypervigilance is the consistent search for bodily sensations that are deemed to be threatening and appears to be related to fear of pain [53]. It is also likely to be associated with the intensity of pain and catastrophising [54]. More specifically to knee osteoarthritis, Herbert et al. [55] found that hypervigilance to pain was associated with more severe pain, concluding that this kind of focused attention could contribute to the overall experience and sensitivity under experimental conditions.

Sullivan et al. [56] define catastrophising as ‘an exaggerated negative mental set brought to bear during actual or anticipated painful experience.’ There have been a number of associations made with catastrophising including opioid misuse [57], work absenteeism [58], depression (Edwards et al. 2011), pain intensity, disability, anxiety and healthcare use [27]. There will be reasons why an individual engages in catastrophising about their pain, including past experiences (learning) used as a reference, beliefs about pain and what it means and personality traits. Goodin et al. [59] measured dispositional optimism and pain catastrophising in adults with symptomatic knee osteoarthritis ($n = 140$). The authors found that greater optimism related to lesser catastrophising about pain, supporting the notion that personality traits affect the pain experience.

In summary, there are a number of psychological features that the clinician must be aware of during the assessment and as the treatment programme unfolds. We attempt to capture the lived experience by allowing the person to tell their story with unique expression and description. We can add to the subjective narrative by administering outcome measures. Of course the data that is created must be bridged to the phenomena bringing relevance to the figures. A baseline offers the opportunity to remeasure at a later time point as a means of demonstrating improvement. Again this must be meaningful for the patient as opposed to a mere clinical change. For example, a further 10° of knee flexion maybe celebrated by the clinician, yet the patient feels that this has no bearing on his or her quality of life. That would be different measure.

We know that a comorbidity exists between pain and mental illness. A recent 10-year prospective study by Bondesson et al. [60] demonstrated the bidirectional relationship between the two, highlighting the need to look at the bigger picture. Individuals are suffering in their lives, within a modern society that promotes self-interest, isolation and quick fixes [61, 62]. None of these are comparable with easing or ending suffering, which should always be our goal. People can revise their thinking based on new information about their pain and decide to take positive action, yet they will usually need the support, encouragement and guidance of the clinicians(s) involved in their care. The clinician has a role in educating, empowering and enabling using an approach that is open to all dimensions of the lived experience, truly biopsychosocial, where the focus remains firmly on the person improving their life.

## 3.4 Psychological Strategies: The Practicalities of Assessment and Treatment

The very fact that in front of us is a person describing their experience means that psychology in unavoidable. The way in which we address the person in our manner, voice tone and chosen language all within the clinical context will create a safe environment or not. Being aware of one's own approach offers the opportunity to craft these skills. In particular, deep listening is essential for the person to feel heard and validated and that due time has been granted for them to tell their story. This is such a valuable start point when first meeting a patient who will arrive with their past experiences and expectations. In complex and persistent pain, there is frequently a history of consultations with different clinicians and therapists. This results in many ideas, concepts and experiences that shape the way the person is thinking about their pain and future.

On the first meeting, the person tells their story using their own words. Giving them time to recount their tale without interruption is a skill in itself. A recent study showed that clinicians commonly interrupt their patients, the median being 11 s [63]. There is usually a pro forma or template to follow that gives the clinician the necessary information to make a diagnosis. The focus is typically on the problem, followed by an offering of what can be done to solve the issue. With experience, there is less reliance upon the standard set of questions and more of a conversation when the patient is the primary contributor. The quality of the asked questions will hence determine the quality of the information gathered. It can be tempting by habit to interject, and indeed there may be a time for this when there is a clear point that needs explanation. Otherwise, gentle guidance with open questions permits organic reflection together with pauses and time to think. One often has to become comfortable with such pauses as they can be deemed to be 'uncomfortable silences,' yet this time allows the person to go deeper into their thoughts. Further, we can simply ask if there is anything else to add and then pause. Often there are other thoughts that then come to mind. In this, psychological strategies are not so much specialised tools but instead a genuine inquiry into the person's life and how this problem has come to be so dominant.

To relate to others requires a grounded sense of self and being fully present in the room. The clinician needs to be calm, focused on the patient and alert to their needs. These are some of the ingredients of peak performance when we seek to be at our best: relaxed but relentless in our ability to empathise, listen, make sense of the story and offer a way forward. The study of peak performance has a long history in sport and business. It is about getting the best of individuals by practising what works consistently. This is applicable for both clinicians and patients of course. There are many examples of practices that we can use day to day, for example, learning to focus one's mind and pay attention to what is happening right now. Not only is this vital for performance but is also a key ingredient for our happiness. Killingsworth and Gilbert [64] published a study that demonstrated how much the mind wanders and how this relates to how we feel. In essence, as the title of the study states, 'a wandering mind is an unhappy mind.' It appears that what we are thinking about has more of an influence than what we are doing. One of the most common ways to practise focused attention is through meditative practices.

There are many misunderstandings around meditation and mindfulness. The practices maybe better thought of as mind training techniques to improve one's ability to pay attention. There are also ways to study one's own direct experience. To train the body is a familiar concept in Western culture, yet to train the mind through which we have our actual lived experiences largely remains alien or abstract. In fact, both are vital for wellness. The mind can be considered embodied [65], which means that the way we think is influenced by our body and its state (the person's state) and we use our body as a means of cognition, enacting our thoughts in the world. There is an acknowledged gap between cognitive science and the human experience that Varela et al. [65] have attempted to bridge. We can and must measure certain outcomes such as the range of motion at the knee, but this tells me nothing about the person's experience. For that we must listen to their narrative—the first person perspective. Then we need to draw the two together for the fullest picture. The desired outcome will be the person's satisfaction with their life improving as they feel that they have moved on to a better life. Indeed their knee may bend further, but if they continue to suffer, what is the real result?

The real results that the person wants to achieve should be established and clarified at the outset. Clinicians will naturally be interested to know what the patient considers to be an attainable outcome. With a picture of success in mind, the programme can be designed, created and started with all involved parties contributing towards the steps being taken. The basic model of success necessitates a direction and a reference point: Where are we going? What does this look like? What is actionable and must happen to maximise the chances of success? To this we can add the questions: Who is responsible for what? What are the timelines and how can we measure the wins along the way? Outcome measures are a simple way to monitor progress. We can determine a start point and follow an agreed time point remeasure. This creates data and scores that can be used to encourage. Scores can also cause people to lose focus as they keep their eyes on the prize rather than the steps that need to be taken day to day. For example, a measure maybe collected on a challenging day that somewhat skews the figures. It must be borne in mind that such measures are just that, a measure. A number does not tell us about the human experience and what it is like, much like a scan or an X-ray. One is objective and one subjective. They are different.

There are many outcome measures to choose. A comprehensive review is beyond the scope of this chapter. However, for cases of persistent pain, the clinician may like to collect data on dimensions such as catastrophising, fear avoidance and quality of life. In this case, measures such as the Tampa Scale of Kinesiophobia (TSK) [66], the Pain Catastrophizing Scale (PCS) [67] and the SF-36 [68] may be selected. The three measures mentioned are simple to complete and score. Deciding which to use soon becomes part of the assessment and evaluation of progress, keeping the picture of success in mind.

Catastrophising and hypervigilance have been mentioned. As the person tells their story, it becomes clear if these coping mechanisms feature. Further, there may be fear avoidance described as limiting activities in case of further injury or pain. Again this is a coping strategy. There will be others, which is why listening carefully is important. We need to know which defensive mechanisms the person is using. They should not be dismissed or eliminated but instead added to as we expand the options [69]. There are consequences of such strategies. Either they help the person to move forward or they meet a short-term need that somehow relieves their pain and suffering. Yet in the longer term, the coping mechanism may not deliver the desired results. In the case of the quick fixes or addictions, we must establish what the person is gaining. In some cases they describe pain relief or an easing of suffering, making it understandable why they would employ such an approach despite the lack of any sustained positive change in their life. In others, they may not experience any significant relief yet feel some control over their destiny by choosing a particular action. On establishing what the person gains, we can offer alternative choices, expanding their repertoire. The coping strategies offered by the clinician provide a way of dealing with challenging moments before resuming their proactive steps towards their picture of success.

One of the first interventions that addresses fear and catastrophising is education—we fear what we don't understand. There has been an emphasis on pain education for some years although there is no standardised clinical guideline for this as an intervention. The aim is to help the person understand their pain to reduce fear and anxiety about what the pain could mean. It is also a means to help the person engage with the strategies and training that can take them forward and improve their life. Whilst the focus is upon the pain, the outcomes are typically poor as the coping mechanisms are defensive. Whilst in the short term this may help the person to feel better, as in the case of avoiding an activity, and perhaps even feeling a reward, this does not contribute to achieving the goals of the treatment programme. A systematic review and meta-analysis of studies that looked at the effect of primary care-based education upon patients with acute low back pain were published in 2015 by Traeger et al. [70] The authors reviewed 14 trials and determined that there was moderate- to high-quality evidence that the intervention increased the feeling of reassurance in both the short and long terms.

A range of factors affect the impact of pain education, for example, the clinician's understanding of and beliefs about pain, the language and mode of delivery [71], the context, the patient's pre-existing beliefs and experiences and whether the person is able to pay attention at the time. Coudeyre et al. [72] performed a cross-sectional study in primary care to look at general practitioner's (GP) fear avoidance beliefs about low back pain and whether they affected their following of the clinical guidelines. The results showed that GPs' beliefs had a negative effect. For example, a higher score on the Fear Avoidance Belief Questionnaire (FABQ) was associated with recommending bed rest, whereas there was less focus upon maintaining activity levels, despite the guidelines to remain as active as possible.

Whilst it remains intuitive to explain to the patient why they experience pain, to reassure them, to develop trust and to build a foundation from where a treatment programme can be created, we need to deepen our knowledge of the best ways to go about the intervention. It is likely that each session of learning will need to be tailored to the individual as they have a unique story of suffering. Which details are particularly important? Is it necessary to delve into the complex biology of pain and discuss chemicals? This will not be necessary nor desirable for many people who want to know what to do when they feel pain, not be thinking about the physiology of the brain. It may well be enough for the person to recognise their triggers, for example, certain contexts (pain is contextual), activities and states such as stress and tiredness. Knowing that these are states of protect and that this is a response to how they are perceiving the situation consciously and subconsciously begins the practice of stopping and creating calm so that the next best decision can be made.

When we think of psychological strategies, we often consider different ways of coping with challenging situations, reframing thought processes and building resilience. However, we can argue that the prescription of a medicine is a psychological intervention on one level, as there is an expectation together with an action. All the whilst that a human is present and involved, there is psychology at play. The interaction between the patient and the doctor or healthcare professional has been examined and contains some unique features compared with other contexts. For one, there are clear roles to be played out and an expectation of what a consultation is like, based on prior experiences and social conditioning. This is brilliantly illustrated by Anatole Broyard in his essay 'The patient examines the doctor' [14].

Broyard writes upon his own prior encounter that he had '…a very curious relationship with the doctors' as a patient in hospital. He goes on to describe how the doctors '…came in groups of six. They seemed to be attached to each other like Siamese sextuplets. They looked at me. They shook their heads, and they left me lying in a pool of sweat. I was never diagnosed.' We can now consider how this framed his current situation as he entered a medical premise. The noting of past medical history then is not about making a list of complaints and diseases but also about understanding the priming experiences to date. It is not just about a procedure but how that procedure was experienced and whether the desired outcomes were achieved from the patient's perspective.

As Broyard sought medical attention for his prostatitis, he stipulated a doctor who was 'potent' and whom could be described as a 'metaphysician' who can 'treat body and mind.' He goes on to say that 'There's a physical self who's ill, and there's a metaphysical self who's ill.' Notable are the characteristics of the doctor that erode his sense of 'magic' and his potency: the words he uses and how he wears his surgical cap without any style. Broyard clarifies the reason for describing his feelings is simply to illustrate '…how irrational such transactions are, how far removed from any notion of dispassionate objectivity.' There is very little, if anything, to be gained from being entirely objective, not that this is even possible. The attempt would merely come across as being robotic or cold-hearted. Written literature is full of examples of interactions attempting to capture the essence. It was unsurprising that a recent study that examined comorbidity between pain and mental illness should discover that the relations are bidirectional. We are never dealing with a condition. Instead a person who suffers the consequences of aid conditions in their own unique way. To try to reduce a person to a body part or system misses the point of what we do to care for a human being.

On visiting a doctor, it is common to receive a prescription, so this can be implicitly anticipated without necessary thought. On this prediction being met, there is no surprise, and in fact there may even be a reward as you. This together with a diagnosis can help the person to feel better as they now understand the problem and have a solution. This is the same when someone goes to see any clinician where they have a known role. We all hold certain beliefs and expectations about what should happen. If they do, we usually feel happy about the outcome. If they are not met, we can feel disgruntled and that we have not been heard or treated in the 'right way.' This is despite the fact that the treatment offered may have been correct. For example, a patient may believe that she has an infection and needs antibiotics. On visiting the GP, she is advised to drink plenty of water, keep normal activities going as best as she can and rest at times, and the problem will pass. The fact that she has not received the antibiotics that she thought she should have received causes an uncomfortable mismatch.

Bingel et al. [73] studied the effects of treatment expectancy upon an opioid in healthy people. A fixed concentration of remifentanil (μ-opioid agonist) was administered under three different conditions, to subjects who were experiencing constant heat pain. The conditions were no expectation of relief, expectancy of positive analgesia and expectation of more pain. This was done by telling the subjects that they were receiving remifentanil or not. Positive expectancy doubled the benefits, whereas the negative expectancy eradicated the analgesic effect. Note that it was only the expectancy that was changed – the remifentanil administration was fixed. The authors concluded that the consideration of patients' beliefs and expectations should be part of the drug prescription process and regime.

In truth, there are actually no interventions that do not have a psychological dimension when it comes to humans interacting and trying to influence each other. Experiences are always contextual, and this very context has a bearing on the experience itself. Changing the context [5], using certain language to prime expectations and performing therapeutic procedures all have an impact on the person's experience [73]. The best studied psychosocial context effects are the placebo and nocebo, involving a number of biological mechanisms that have been identified: dopaminergic, opioidergic and cholecystokinergic in pain and dopaminergic in Parkinson's disease [26, 74, 75]. Of course it is important to remember that whilst we can highlight purported biology, objectively measuring chemicals and brain activity, this tells us nothing about the human experience: what it is like or the quality. For this we must engage the person and consider what it is like from their perspective.

Empathy, the ability to understand and share the feelings of another (Oxford, 2019), is deemed to be a vital skill in medicine and healthcare [76]. Many people are drawn to the caring professions as this is one of their strengths; they are at their best when caring for others. However, it has been deemed important to integrate empathy training into healthcare education programmes, to develop the skills to optimise patient-clinician relationships. The results of such training for medical students [77], resident physicians [78] and nursing students [79] appear to be positive. Broyard [14] wrote: 'My ideal doctor would resemble Oliver Sacks. I can imagine Dr. Sacks entering my condition, looking around at it from the inside like a kind of landlord, with a tenant, trying to see how he could make the premises more live-able. He would look around, holding me by the hand, and he would figure out what it feels like to be me. Then he would try to find certain advantages in the situation. He can turn disadvantages into advantages. Dr. Sacks would see the genius of my illness. He would mingle his daemon with mine. We would wrestle with my fate together, like Rupert and Birkin in the library in D.H. Lawrence's *Women in Love*.

The key for clinicians is to understand how the embodied psychological effects can be harnessed in the best way to help patients get better. It is of course this bottom line that we seek to achieve. Defining getting better is down to the person as they are encouraged to identify their picture of success. Initially many will respond to this by saying that they do not want to feel their pain anymore. This is true, yet if the focus continues to be on the pain, it is then not on the steps to take to improve life. To be successful in achieving the real results that we desire, we must remain focused on what must happen right now, the rest being mere thoughts about past or future. 'What is my best decision now? And now?,' are the ongoing questions to ask. This is coaching, which is simply a means to encourage and enable individuals to achieve their best. Surely this is what we seek.

The concept of being a coach is familiar in sport and business but less so in healthcare and certainly not in pain. There has been an emergence of health coaching and health coaches to offer ways that people can lead healthier lives. Much of healthcare remains reactive rather than being proactive. To be well is a skill, requiring practice each day much like cleaning one's teeth. Incorporating skills of being well into a programme helps people to increase their focus, build resilience for life's inevitable challenges, improve physical tolerance and fitness and expand their repertoire of choices. People typically value their independence, their health, relationships and work amongst many other important parts of their life. Realising these allows the person to make value-based decisions, for example, physical fitness allowing for work and full participation in family activities. Therefore, a daily training plan is a key part of the schedule, planned for and prioritised. Again, the focus is always upon what the person wants to achieve in their life, which means that we need to consider them as a whole person within the context of their life.

## 3.5 Summary

It is the person that we seek to help so that they can improve their life in ways that are important to them. Whatever the physical intervention, it is always the person who has the experience. It is not the knee that hurts; it is the person experiencing pain located in the knee. There is a huge conceptual difference that is relevant to how we treat someone and the clinical decisions that we make. We have known for many years that pain is related to the state of the person and not the tissue state or injury [3]. In the clinic if we listen closely to the narrative, we hear the lived experience described, often the symptoms being worse when the person is feeling stressed or anxious. All are part of the way we protect ourselves, including pain that is a need state like hunger or thirst.

Psychological strategies do not exist in isolation to other treatments. Instead they are interwoven into the clinician's approach as he or she compassionately enquires about the person and their experience, examines their condition in the light of their life to date, clarifies the outcome that they desire and then provides options and ways forward towards that picture of success.

In this chapter we have touched upon a huge topic and hence provide a taster for the reader to explore how they can be the most effective clinician. This is an opportunity to build upon existing strengths. The development of several key psychological skills can make a significant impact upon one's practice, for example, deep listening. Consider whether you like to be truly heard? How do you feel when it appears the other person is not fully present and paying attention to you and what you are saying? The patient is there to give you all the information that you need to advise them on the next best course of action. Without that information it becomes best guesswork. One simple method involves taking a 3–4 cm length of sellotape and applying it over one's lips. See what happens when you just listen, allowing for lengthy pauses, followed by more in-depth descriptions of the experience. You will notice your own biases – if you are only listening for certain things, you will only hear those things. The sellotape practice is in jest, but imagine what that would be like in terms of listening.

Once viewed as perhaps 'soft' skills, we know now of their importance. Much of the suffering is caused by fear of movement, concern for the future and what life will hold. All of these can be addressed with a compassionate approach that focuses on the outcomes that the patient wants to achieve. If asked, they will tell us, giving a clear route forwards in most cases: What can I offer? Who else will be needed in this person's care to move forward? What is the (shared) picture of success?

The hope is that now you can see that the whole person approach, 'you are more than a knee,' goes beyond the BPS model to consider different and broader ways of thinking. These represent the innumerable variable that exists in any given moment, most of which are hidden states in the world. Now, when you face a patient who does not respond in the way you expect or who presents with a complex story (is there ever a simple one really?), you can offer an ear and either advise accordingly or refer to a therapist who can help them address contributory factors such as anxiety, wrong thinking about pain and fear avoidance. On this, it is worthwhile knowing one or two therapists and clinicians who truly specialise in complex pain as this is a specific skill set.

Looking forward, we have a choice. We can choose to play to our strengths, as this is when we are at our best. However, there are other dimensions of our practice that may need development so that we can truly reach our potential. One of the attractions of being a healthcare professional is the ongoing learning. However, it can be choosing areas that we are less comfortable with that really stretch us so we move on to being even more skillful. Surgical techniques are learned and practised, as are ways to communicate and manage people. There are parallels with the understanding of leadership, when the art of a great leader is to listen, to show courage but ultimately to be followed. Whilst the relationship between a clinician and a patient is filled with expectations and roles, it is actually using this dynamic to improve the patient's life that is important. This may include asking a question about the person and receiving an answer that you listen to, throw compassion upon and ultimately dare to do so knowing that you may not be able to do anything other than allow the person to be heard in a safe place. That in itself is therapeutic.

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# 4

# Imaging Analysis of Patella Instability Factors

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Imaging has been considered of primary importance in the analysis of patellofemoral (PF) joint instability factors since the earlier experiences in this subject [1–4]. In the past few years, magnetic resonance imaging (MRI) has progressively become one of the most important exams for analysis of pathologic anatomy of an unstable PF joint and for eventual surgical planning. Following the Lyon's School, it is possible to identify three major anatomic factors of instability: trochlear dysplasia, excessive patellar height, and pathological tibial tubercle-trochlear groove (TT-TG) distance [1]. MRI is applicable for assessment of each of these factors with increasing evidence on reliability and reproducibility. The MRI study of the patellofemoral joint should present specific characteristics such as the inclusion of the proximal part of the trochlea and the anterior tibial tuberosity, in order to allow the measurement of the specific indexes required for the assessment of patellar instability. These characteristics should be put on the specialist prescription in order to avoid missing reference points. The aim of this chapter is to give the reader an overview on this continuously evolving field of research and provide a guide for everyday clinical practice in treatment of PF joint instability.

## 4.1 Trochlear Dysplasia

Trochlear dysplasia is considered as one of the most important factors in patellar instability and it's found in up to 96% of these patients [1].

The current trochlear dysplasia classification, proposed by D. Dejour et al., relies on the CT scan femoral axial cut and lateral X-rays [5] to classify *trochlear dysplasia* into four degrees.

There is disagreement about the possibility to apply this classification to the MRI methodic [6].

Staubli et al., comparing cryosectioned cadaver knees with their respective MR arthrotomograms, reported a congruence between the trochlear cartilaginous shape and the subchondral bone shape in only 4 of the 30 analyzed specimens, highlighting the importance of the reference selection in determining the real trochlea geometry [7].

Thus MRI allows to appreciate the trochlear shape closest to the in vivo conditions; nevertheless, it lacks the ability to properly assess the trochlear bump, which is required in order to classify trochlear dysplasia according to the Dejour classification.

Using the MRI, Steensen et al. reported the presence of trochlear dysplasia in 68% of patients with recurrent patellar dislocation, in comparison to 5.8% in the control group [8].

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A low agreement in the trochlear dysplasia assessment has been evidenced by Tscholl et al. comparing the X-ray and MRI of 228 knees, ranging from 25.4% to 45.2% depending on the selected level of analysis. The author remarked the importance of level height in order to perform a proper identification of the trochlear dysplasia anatomic landmarks and the lack of clear definitions on axial MRI [9]. Similar results were reported by Lippacher and co-authors, who estimated a low-mid intraobserver and inter-observer agreement ranging from 24% to 78% [10].

Notwithstanding, comparing MRI and CT scan in detecting trochlear dysplasia, higher values of intra- and inter-observer accordance were reported using the MRI [9, 11]. The four-type classification is the most used in the literature, but some authors reported better results and reliability using a modified version including two main types of trochlear dysplasia: low grade and high grade [10, 12].

In order to perform a more quantitative evaluation of trochlear dysplasia, Carillon et al. proposed the use of the *lateral trochlear inclination*, determined as the angle between the tangent to the posterior femoral condyles on an axial view and the line tangent to the lateral trochlear facet [13] (Fig. 4.1). In a literature review by Pavia et al., performing a quality assessment of the radiological tool to determine trochlear dysplasia, the lateral trochlear inclination scored the highest value [14]. According to the over-mentioned study, two more indexes were recommended for the trochlear dysplasia evaluation: the trochlear depth and the ventral trochlear prominence.

The *trochlear depth* is defined as the difference on an axial view between two measures: (a) the average height of the medial and lateral condyle and (b) the distance from the deepest point of the trochlear groove to the line tangent to the femoral condyles (Fig. 4.2). The image used in order to determine trochlea depth may vary from 1 cm to 3 cm above the joint line. The mean values for the 1 cm, 2 cm, and 3 cm slice were, respectively, 9.0, 6.6, and 5.2 mm [15]. A lower trochlea depth may be associated with an increased risk of future dislocation [1]; nevertheless, its reliability is currently questioned [14].

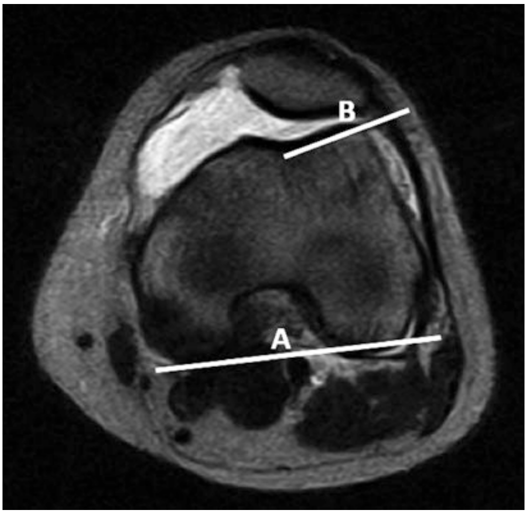

**Fig. 4.1** The Lateral Trochlear Inclination is measured as the angle between the tangent to the posterior femoral condyles (*A*) on an axial view and the line tangent to the lateral trochlear facet (*B*)

The *ventral trochlear prominence* represents an easy and reliable diagnostic tool in trochlear dysplasia assessment. It's reported in 69% of knees with dysplastic trochlea [15]. Its value in determining the risk of further patellar dislocation is uncertain; nevertheless, it represents the most reliable tool to detect dysplastic trochlear shape and in particular in the presence of a supratrochlear spur (Dejour type B and D).

It's measured as the distance between the line tangent to the anterior femoral cortex of the distal femur and the most anterior cartilaginous point of the trochlear surface. Pfirrmann et al. reported a value greater than 6.9 mm in all patient with dysplastic trochlea [15], while the threshold value in order to detect trochlear dysplasia is set to 5 mm [16, 17].

## 4.2 Patellar Height

Historically, patellar height has been determined on plain lateral radiographs. Since the introduction of the MRI, many authors tried to adapt the previous methodic to the MRI sequences in order to provide an X-ray free tool for patellar height evaluation [18, 19].

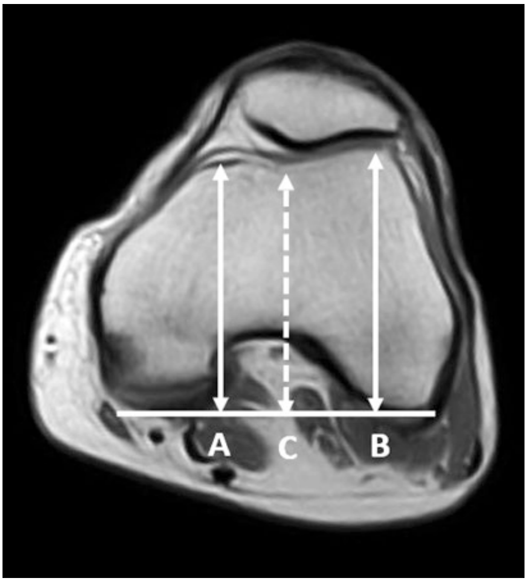

**Fig. 4.2** Trochlear depth is defined as the difference on an axial view between two measures: a) the average height of the medial and lateral condyle [(*A*+*B*)/2] and b) the distance from the deepest point of the trochlea groove to the line tangent to the femoral condyles (*C*). The image used in order to determine trochlea depth may vary from 1 cm, 2 cm and 3 cm above the joint line

**Fig. 4.3** Patellar height is determined using the MRI slice showing the greatest patellar articular cartilage. The Insall-Salvati is measured as the ratio (*A*/*B*) between the length of the patellar tendon from the lower pole of the patella to its tibial insertion (*A*) and the greatest pole-to-pole distance of the patella (*B*). The Caton-Deschamps is defined as the ratio (*A'*/*B'*) between the distance from the anterosuperior angle of the tibia to the lower edge of the joint surface of the patella (*A'*) and the length of the patellar joint surface (*B'*)

The *standard X-ray measurement technique* used for the patellar height assessment has been proved to be reliable using the MRI methodic [18]; however, attention should be paid in selecting the proper MRI cut. The sagittal slice with the greatest patella length should be the one used for the patella height assessment using the MRI (Fig. 4.3).

Yue and coworkers reported relatively higher values using the MRI in comparison to plain radiographs (Insall-Salvati ratio, +0.11; modified Insall-Salvati ratio, +0.07; Caton-Deschamps index, +0.18; Blackburne-Peel index, 0.08) and good to excellent ICC values for both the Insall-Salvati ratio (0.830) and the Caton-Deschamps index (0.702) [20].

Similar findings were supported by Lee et al. comparing plain X-rays and MRI. The authors reported a mean difference of +0.13 and + 0.09 in favor of MRI considering the Insall-Salvati and Blackburne-Peel indexes, respectively [21].

The wide range of values reported in literature could be attributed to the different modalities adopted to perform the exams. In comparison to the X-ray methodic, in which the knee is flexed at 20–30°, the MRI setting usually requires the knee in full extension.

Furthermore the coils used during the MRI could alter the knee flexion, depending on their size and type, thus affecting measurements conditions.

Laugharne et al. reported the results of both Insall-Salvati ratio and Caton-Deschamps index obtained in full extension and 30° of flexion, with and without quadriceps contraction. No statistical significant differences were assessed related to both degrees of knee flexion and quadriceps contraction [22].

Notwithstanding the author reported some patients in whom quadriceps contraction led to pathological values, therefore suggesting the 30° flexed position as the standard setting for patellofemoral MRI imaging due to its protective effect over involuntary quadriceps contraction. These aforementioned indexes represent good tools in order to assess patellar height but do not describe properly the relationship between the trochlea and patella, which represents the key-point in patellofemoral instability. Indeed the heterogeneous morphologies of the patellofemoral joint, in terms of both trochlear length and patellar cartilage surface, should be kept into consideration in order to recognize correctly the etiology of the patellar instability [23–25].

Some subjects could present patella alta without experiencing instability, due to the increased trochlear length which could improve patellofemoral engagement. Conversely some subject with non-pathological patellar height values could report patellar instability due to a short trochlea or a small patellar articular surface leading to an inadequate engagement.

In order to overcome these limitations, Biedert and Albrecht proposed the measurement of the *patellotrochlear index (PTI),* described as the ratio between articular cartilage of the patella and trochlear cartilage [23] (Fig. 4.4). The most adopted cutoff for pathological values reported in literature ranges from 0.125 to 0.28 [23, 26].

The PTI measurement is obtained from a single sagittal MRI slice including the maximal patellar length; however it could be unreliable in cases of patella instability. In these patients the patella may be positioned more laterally than the center of the trochlea, lying in a different sagittal plan, therefore leading to a mismatch between the trochlear and patellar references [7]. Given these considerations, Dejour et al. proposed the measurement of the *sagittal patellofemoral engagement (SPE)* as an additional tool in patellar height evaluation [27].

According to the author, two MRI slices are selected: the first one is the cut in which the patella shows its largest sagittal articular cartilage, and the second one is the slice in which the articular cartilage of the femoral trochlea extends more proximally. Using the first slice, a line from the upper to the lower border of the patellar articular surface is traced (PL), thus superimposed to the second slice. Using the second slice, a line parallel to the previous one is traced from the uppermost cartilaginous profile of the trochlea to the distal end of the previous line (TL). The ratio between TL and PL determines the SPE (Fig. 4.5), quantified in 0.439 ± 0.18 considering a population with objective patellar instability.

**Fig. 4.4** The Patello-Trochlear Index (PTI) is described as the ratio between the trochlear cartilage length (*A*) and the articular cartilage of the patella (*B*)

Another index available for estimating the relationship between the patella and the trochlear surface was published in 2016 named *patellar articular overlap (PAO)* [28].

This index represents the percentage ratio between the patellar cartilage total length and the length of patellar cartilage overlying the trochlear cartilage, as measured parallel to the subchondral surface of the patella. Different from the over-mentioned indexes, the knee is examined in flexion using a single MRI slice, and a good correlation with the Caton-Deschamps index was estimated; nevertheless, there are no validated cutoff values (Fig. 4.6).

The engagement relation between the trochlea and patella could be also assessed in the axial plane by using the patellofemoral *axial engagement index (AEI)* proposed by Guilbert and co-authors [29]. The axial slice showing the greatest lateral border of the trochlea is selected

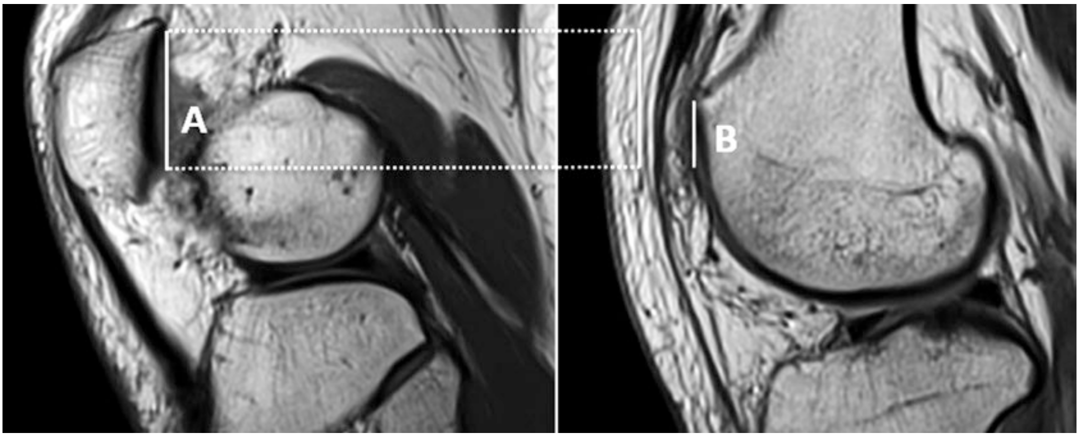

**Fig. 4.5** Sagittal Patellofemoral Engagement (SPE) Index. Using the slice showing the greatest patellar cartilaginous surface, a line from the upper to the lower border part of the patellar articular surface is traced (*A*). Thus this line is superimposed to the slice where the femoral trochlea extends more proximally. A line parallel to the previous one is traced from the uppermost cartilaginous profile of the trochlea to the distal end of the previous line (*B*). The ratio between A and B determines the SPE

**Fig. 4.6** Patellar Articular Overlap represents the percentage ratio (*A*/*B**100) between the length of patellar cartilage overlying the trochlear cartilage (*A*), as measured parallel to the subchondral surface of the patella, and the total patellar cartilage length (*B*)

and the most lateral point of the trochlea (T) projected on the bicondylar line (BC). A second axial slice in which the patella is the widest is selected and the previous references transposed. Using this slice both the most medial (M) and lateral (L) cartilaginous points of the patella are projected on the bicondylar line. The distance between the projected points MT and ML is measured. The ratio between these measurements represents the patellar axial engagement (MT/ML) (Fig. 4.7).

Considering the MRI evaluation of the extensor mechanism, another advantage of MRI is the possibility to measure the *patellar tendon length*. As reported by Neyret, analyzing the relationship between patellar tendon and proximal tibia, the patellar tendon was significantly longer in patients with patellar instability in comparison to healthy subjects (52 ± 6 mm vs. 44 ± 7 mm), despite any difference in the distance between tibial plateau and tendon insertion (28 mm vs. 29 mm) [30]. These data confirmed the results previously reported by Kujala et al. in a small series of 13 patients with patellar instability, who reported a mean tendon length of 51 mm [31].

The MRI measurement is performed selecting the sagittal slice with the longest longitudinal axis of the patella, and tendon length is measured considering its posterior surface from patellar apex to tibial insertion (Fig. 4.8).

The measurement is comparable to the one obtained using X-rays as [30]. The pathological threshold in order to define a patella Alta is set to

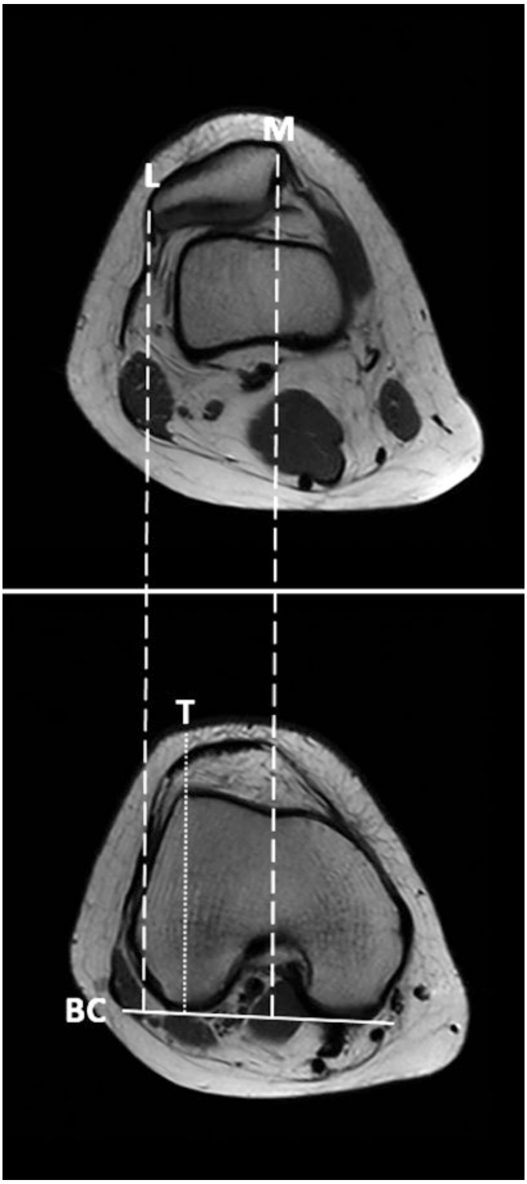

**Fig. 4.7** Patellofemoral Axial Engagement Index measurement. The axial slice showing the greatest lateral border of the trochlea is selected and the most lateral point of the trochlea (*T*) projected on the bicondylar line (*BC*). A second axial slice in which the patella is the widest is selected and the previous references transposed. Using this slice both the most medial (*M*) and lateral (*L*) cartilaginous point of the patella are projected on the bicondylar line. The distance between the projected points *MT* and *ML* is measured. The ratio between these measurements represents the patellar axial engagement (*MT*/*ML*)

52 mm; therefore a patellar tendon tenodesis could be evaluated in these cases as proposed by Mayer et al. [32]. Patient's height should be considered also during threshold evaluation, since a weak but significant correlation was evidenced in the literature between height and patellar tendon length [33, 34].

**Fig. 4.8** Excessive Patellar Tendon Length

## 4.3 Tibial Tubercle-Trochlear Groove (TT-TG) Distance

Based on the original X-ray technique proposed by Goutallier and Bernageau, Dejour published in 1994 the use of the CT scan for the TT-TG measurement [4]. Later on, following the introduction of the MRI methodic, many other authors proposed to adapt the CT methodic to the MRI in order to spare patients from high radiation exposure. The TT-TG quantifies in millimeters the distance between the tibial tuberosity and the deepest point of the cartilaginous trochlear groove projected on the line tangent to the posterior femoral condyles on an axial view.

Similar to the CT methodic, two axial cuts are superimposed in order to perform the measure: the one including the most proximal part of the trochlear cartilage and the one including complete attachment of the patellar tendon to the tuberosity. As over-mentioned, the MRI methodic allows to use cartilaginous references in order to obtain a more reliable evaluation of the patellofemoral joint; therefore the anatomical references slightly differ from the CT scan technique.

The proximal reference is represented by the deepest cartilaginous point of the trochlear groove, while the distal one is represented by the center of patellar tendon insertion on the tibial tuberosity.

The mean value for patients with objective patellar instability varies in literature from 14.7 to 18.2 mm [11, 35, 36], while in control patients the mean values range from 10.1 to 13.9 mm [11, 35, 37]. Previous studies were not concordant about the equivalence of the CT and MRI measure, probably due to the data variability intrinsic to the different patient positioning and the use of knee coils. Schoettle et al. reported no difference between MRI and CT scan [37], analyzing a small series of 11 patients who had a history of patellar instability or anterior patellofemoral pain syndrome. Contrarily Campbell et al. evidenced an underestimation of the TT-TG values using the MRI, therefore denying the interchangeability of the two values [36]. In a recent study, Ho et al. analyzed 59 knees determining for each of them the TT-TG distance using both the CT and MRI methodic [35]. The author reported a good inter- and intraobserver reliability for both techniques but also a systematic bias toward lower TT-TG distances on the MRI in comparison to the CT scan, confirming the non-equivalency of the two methodic. At the current time, the major accepted threshold in order to propose a tibial tubercle medialization is considered 15 mm. Interestingly, as reported by Dornacher et al., the TT-TG is independent from both knee size and body height, therefore making this value easily adaptable to the majority of patients [38].

In the last decade, an increasing number of studies increased the evidence that the TT-TG measurement could be affected by many different factors, including knee flexion, rotation, trochlear dysplasia, and rotational laxity [39]. In order to overcome these limitations, Seitlinger et al. proposed the *tibial tubercle-posterior cruciate ligament distance* [40]. The index quantifies the lateralization of the tibial tubercle in relation to the PCL tibial attachment. A reference line tangent to the posterior wall of the tibia is traced using a slice below the joint line but more proximal than the tip of the fibular head. The cut with the best view of the medial border of the PCL tibial insertion is selected and the medial border of the PCL is projected perpendicularly on the reference line. In the same way, the slide including the anterior tibial tubercle is selected, and the center of the patellar tendon attachment to the tibial tubercle is projected on the reference line [41]. The distance between the two projected points represents the TT-PCL distance.

In this way, maintaining all the reference points on the tibia, all the other confounding variables should be minimized (knee flexion, rotation, trochlear dysplasia) focusing only on the tibial tubercle lateralization [39].

The mean reported values of TT-PCL distance reported in literature range from 11.9 + 4.67 mm [40, 42] to 20.32 + 3.45 mm [39] in a mixed population with patellofemoral disorder including pain or instability. Values greater than 20 mm are considered to be pathological [40, 42, 43]. Nevertheless, the role of this variable in patellar instability is still questioned.

Brady et al. reported only 55% of patients with a pathological TT-PCL distance having a TT-TG distance greater than 20 mm on the CT scan; conversely considering patients with pathological TT-TG values, only 24% of them had an abnormal TT PCL distance. These values resulted lower than the ones proposed by Seitlinger et al. who reported that 57% of patients with abnormal TT-TG had abnormal TT-PCL measurement [40]. A moderate-to-strong positive correlation between TT-TG and TT-PCL was evidenced by Boutris et al. considering 300 knees with patellar instability and 144 controls, proposing 21 mm as threshold for pathological TT-PCL values [43].

Conversely, Clifton et al. considering a pediatric population determined a mean TT-PCL value of 20.1 mm and no significant difference between patients with patellofemoral instability and controls [44].

The inter-observer reliability of this index is ranged from moderate to excellent [39–41], but its correlation with the TT-TG and its role in patellar instability diagnostic pathway are still debated. Considering these data, many authors proposed to adopt this index in case of patients with normal TT-TG but ongoing patellar instability symptoms [42, 45] or in the presence of a

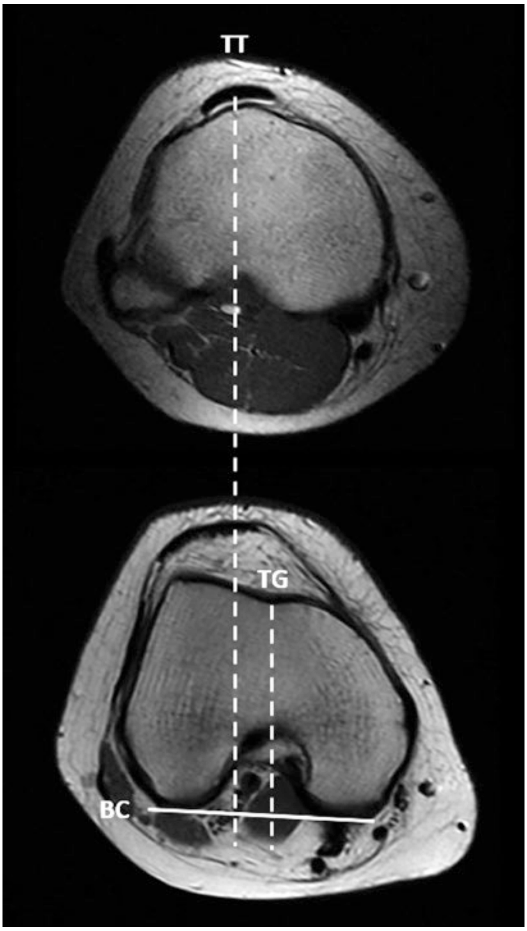

**Fig. 4.9** Tibial Tubercle-Trochlear Groove (TT-TG) measurement. The proximal reference is represented by the deepest cartilaginous point of the trochlear groove (TG), the distal one is represented by the central part of patellar tendon insertion on the tibial tuberosity (TT). The distance between these 2 points projected on the bicondylar line (BC) represents the TT-TG distance

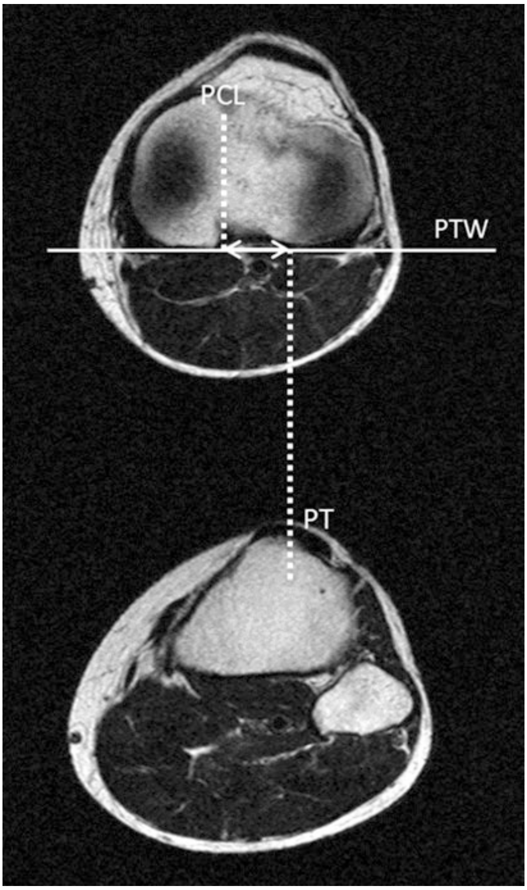

**Fig. 4.10** TT-PCL distance. A reference line tangent to the posterior wall of the tibia is traced (PTW). The medial border of the PCL is projected perpendicularly on the reference line. In the same way, the slide including the anterior tibial tubercle is selected, and the center of the patellar tendon attachment to the tibial tubercle is projected on the reference line (PT). The distance between the two projected points estimate the TT-PCL distance

severe trochlear dysplasia which can confound the choice of trochlear reference (Figs. 4.9 and 4.10).

## 4.4 Rotational Alignment of Femur and Tibia

In comparison to the sagittal and transverse-plane lower limb deformities, which can be easily assessed by the clinical and standard radiographic examination, axial-plane deformities are often missed or underestimated [46].

An increased femoral anteversion and an increased external tibial rotation could lead to an abnormal lateral patellofemoral load, therefore determining a greater risk of patellar dislocation. The gold standard for the study of lower limb rotation deformities has been considered the CT scan, due to the possibility to overimpose axial images from different sections [47, 48].

Galbraith and Bauman were the first to popularize the role of MRI in detecting axial-plane deformities [49, 50] and Guenther described the MRI ability to orient the cut parallel to the femoral neck, therefore giving an advantage of this technique over the CT scan [51].

*Femoral anteversion* is defined as the angle between the femoral neck axis and the parallel to the posterior femoral condyles. By using the cut parallel to the femoral neck, the neck axis is determined connecting the middle section of the neck to the center of the femoral head.

The axial cut through the center of the femoral condyles is selected and the neck axis line is transposed over the current slice. A line tangent to the posterior border of the femoral condyles is drawn, and the angle between these lines is determined, quantifying the femoral anteversion [47].

Tomczak reported a mean MRI femoral anteversion of 16.2° ± 9.5° in a mixed population of 19 children and 25 adults, evidencing the excellent reliability and reproducibility of this technique in comparison to the CT scan [47]. Similar values were reported by Schneider et al. considering the rotational profile of 42 extremities, 16.7° ± 6.3°. These values resulted higher than the ones obtained using the CT-scan, 11.2° ± 5.4° [52]. Lower values were reported by Botser and Sutter in more recent studies analyzing a larger population, 7° and 9.2° ± 8.4°, respectively [53, 54]. Comparing the rotation profile of 30 patients with patellar instability with 30 healthy patients, Diederichs reported statistical significant greater values of femoral anteversion in the instability group, 20.3° ± 10.4° vs. 13.0° ± 8.4° [55]. Conversely, Balcarek et al. didn't evidence any difference between patients with patellofemoral pain syndrome and patient with patellar instability, respectively, 20.03° ± 7.91° and 20.02° [56].

According to many authors, MRI and CT scan measurements should not be considered interchangeable due to the significant discrepancy in absolute values [52, 53]. This could be explained by the different patient positioning, the use of coils, and the possibility to obtain cuts parallel to the femoral neck using the MRI methodic.

*Tibial torsion* is defined as the twist of the proximal tibia, on the longitudinal axis, in relation to the articular axis of the distal tibia [57]. The axial cut just below the proximal tibial articular surface and proximal to the fibular head is considered, and a line tangent to the posterior portion of the proximal tibial cortex is traced. The axial section just below the ankle joint is selected and the previous line copied over the current image. A new line is traced, connecting the center of a circle fitted on the tibial pilon with the midpoint of a line across the tibial fibular notch. The angle between the two lines estimates the degrees of tibial torsion. An alternative distal reference was proposed by Tamari et al., defined as true tibiofibular torsion, considering the line connecting the center of the circle fitted on the tibial pilon with the most prominent part of the lateral malleolus [58].

Schneider and coworkers reported a mean value of 41.7° ± 8.8° studying the rotational profile of 98 extremities of healthy adult volunteers [52]. Overlapping results were reported by Balreck et al. in an MRI study (41.24° ± 7.28°) [56] and by Jend et al. in a CT scan study (40 ° ± 9°) [59], while lower values were reported by Diederichs et al. (25.3° ± 6.9°) [55]. The same author reported no difference in the mean tibial torsion between patellar instability patients and controls. Considering both MRI femoral anteversion and tibial rotation measurements, an excellent reproducibility has been reported in literature, endorsing the MRI as a reliable alternative to the CT scan in lower limb torsional profile assessment [55, 60, 61] (Figs. 4.11 and 4.12).

## 4.5 Conclusions

The MRI could be useful in the study of the patellofemoral instability factors, but for each of them, some specific considerations should be required based on the published literature and should be executed according to a specific methodology:

- Trochlear dysplasia
  - Classification According to Dejour: there is no consensus using the MRI in the classification of trochlear dysplasia, which is currently based on X-ray lateral images and axial-CT scan.
  - Lateral Trochlear Inclination Angle: the line parallel to the subchondral bone should be considered in order to assess the inclination of the lateral trochlea.

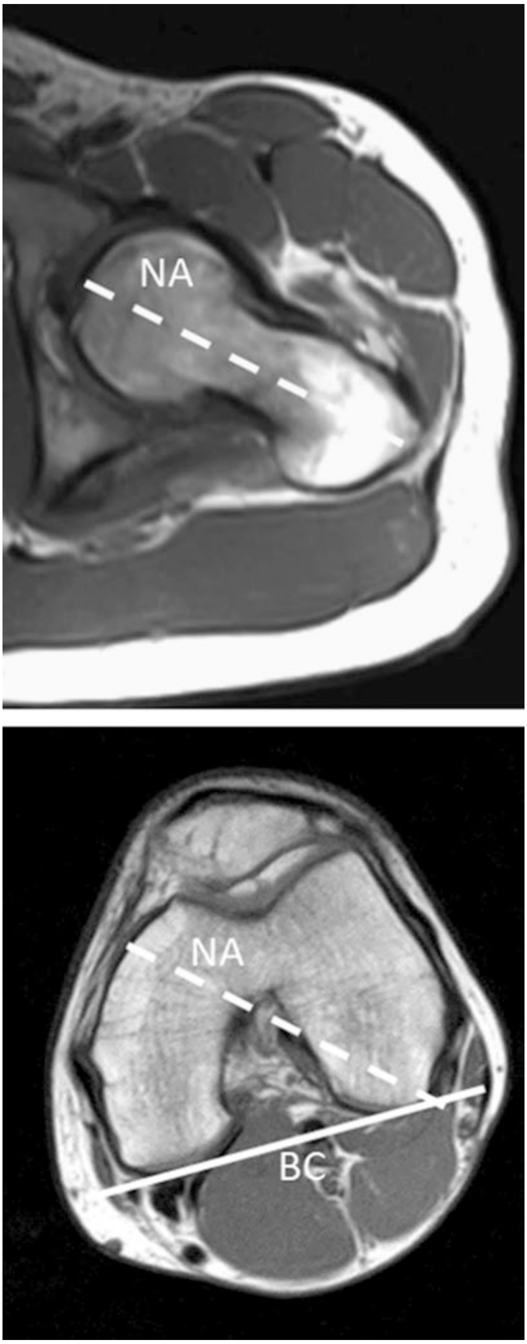

**Fig. 4.11** Femoral anteversion measurement. By using the cut parallel to the femoral neck, the neck axis is determined connecting the middle section of the neck to the center of the femoral head (*NA*). The axial cut through the center of the femoral condyles is selected and the neck axis line is overimposed. A line tangent to the posterior border of the femoral condyles is drawn (*BC*), and the angle between these lines is determined, quantifying the femoral anteversion

  - Trochlear Depth: there is no consensus about the level to use in order to properly assess this index (1, 2, or 3 cm). A more proximal cut could provide more reliable information about the patellofemoral relationship during the first degrees of knee flexion.
  - Ventral Trochlear Prominence: different from the CT scan examination, the most anterior cartilaginous point of the trochlear surface should be considered.
- Patella height
  - Standard Patellar Height Measurement: the MRI with the knee at 30° of flexion could reduce the effect of the quadriceps contraction and provide more reliable results. The slice presenting the maximum extension for the patellar cartilaginous surface should be used as reference cut.
  - Patellotrochlear Index: MRI slice including the maximal patellar length should be selected as reference. Caution should be used in patients presenting the patella laterally displaced.
  - Sagittal Patellofemoral Engagement: the cut in which the patella shows its largest sagittal articular cartilage and the slice in which the articular cartilage of the femoral trochlea extends more proximally are the ones that should be considered. The uppermost cartilaginous profile of the trochlea and the patellar cartilage surface should be considered as reference points.
  - Patellar Articular Overlap: the knee should be examined in flexion, and the reference line should be considered as the one parallel to the subchondral surface of the patella.
  - Axial Engagement Index: the axial slice showing the greatest lateral border of the trochlea and the one in which the patella is the widest should be taken into account.
  - Patellar Tendon Length: the measurement should be performed considering the posterior surface of the tendon. Care should be taken in threshold evaluation according to the patient's characteristics such as body height.
- TTT-TG
  - Tibial Tubercle-Trochlear Groove Distance: Different from the CT scan, the proximal

**Fig. 4.12** Tibial torsion measurement. The axial cut just below the proximal tibial articular and proximal to the fibular head is considered and a line tangent to the posterior portion of the proximal tibial cortex is traced. The axial section just below the ankle joint is selected and the previous line copied over the current image. A new line is traced, connecting the center of a circle fitted on the tibial pilon with the midpoint of a line across the tibial fibular notch. The angle between the two lines estimates the degrees of tibial torsion

  reference is represented by deepest cartilaginous point of the trochlear groove while the distal one by the center of patellar tendon insertion on the tibial tuberosity.
  - Tibial Tubercle-Posterior Cruciate Ligament Distance: The cut with the best view of the medial border of the PCL tibial and the slice including the anterior tibial tubercle patellar tendon attachment are required to perform the measurement.
- Rotation alignment
  - Femoral anteversion: Different from the CT scan technique, the cut parallel to the femoral neck should be used to perform the neck axis measurement.
  - The distal slice should be the axial cut through the center of the femoral condyles. CT and MRI values shouldn't be interchanged.
  - Tibial torsion: The axial cut just below the proximal tibial articular surface and proximal to the fibular head and the axial section just below the ankle joint are the ones to be selected in order to perform tibial torsion measurement.

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# 5

# Magnetic Resonance Imaging of the Patellofemoral Articular Cartilage

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## 5.1 Introduction

Anterior knee pain is the leading cause of knee pain in patients younger than 45 years and can be caused by cartilage lesions in the patellofemoral compartment, which is frequently involved in cartilage disease of the knee [1]. Although the true incidence of cartilage lesions is unknown, numerous studies report chondral injuries in 60–66% of knees undergoing arthroscopy [2–4]. Cartilage injuries of the knee affect just under a million Americans annually and result in more than 200,000 surgical procedures [2]. Lesions are most commonly found on the weight-bearing femoral condyle (43–58%) with the majority of them located on the medial femoral condyle. While patellar lesions account for 11–36% of all cartilage lesions, trochlear lesions are less frequently encountered, accounting for approximately 6–16% of all lesions [3–5]. In 90% of cases, the defect size is reported to be less than 4 cm$^2$ in the knee. Athletic activities are frequently associated with the diagnosis of chondral lesions [3, 6]. Patellofemoral osteoarthritis accounts for approximately 65% of patients with symptomatic knee osteoarthritis (OA) [7]. Even small changes in the patellofemoral articular cartilage surfaces have a profound activity-limiting effect on normal function. A recent meta-analysis revealed that in up to 52% of patients with knee pain or symptomatic osteoarthritis, MRI revealed cartilage lesions in the patellofemoral joint [8]. Despite its high prevalence, patellofemoral cartilage lesions remain underdiagnosed clinically and on multimodality imaging studies [9].

Articular cartilage has unique viscoelastic characteristics. Its principal functions are to provide a smooth, lubricated surface for low-friction articulation and to facilitate the transmission of loads to the underlying subchondral bone [10]. Articular cartilage has very limited healing potential secondary to the poor regenerative capacity and avascular nature of the cartilage. Once articular cartilage is damaged, full recovery of its structure, function, and biomechanical property is unlikely and marks a step toward progression to osteoarthritis [11–14]. It is crucial to utilize the appropriate imaging modality to iden-

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tify chondral defect(s) in symptomatic patients at an early stage, because treatment may be limited to partial or total knee arthroplasty rather than biological knee resurfacing techniques in advanced patellofemoral osteoarthritis [7].

Multiple imaging modalities have been utilized for the diagnosis of cartilage lesions: radiography, ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI), and optical coherence tomography (OCT). MRI is the modality of choice for the evaluation of articular cartilage. Articular cartilage on an MRI was first described in the early 1980s [15]. Since then, the field of cartilage imaging has markedly grown due to the heightened demand for preoperative, noninvasive cartilage evaluation in the setting of rapid developments of new pharmacologic and surgical cartilage regenerative therapies. MRI enables the assessment of normal articular cartilage, cartilage lesions, and cartilage repair tissue because of its excellent soft tissue contrast, multiplanar capability, and ability to assess the morphological changes and biochemical properties of articular cartilage [12]. Currently, MRI plays an important role in a cartilage patient's continuum of care from initial MR imaging characterization of cartilage abnormality and utilization of treatment algorithms to select the appropriate therapeutic intervention to postoperative assessment and monitoring of the reparative cartilage tissue.

## 5.2 Applied Cartilage Anatomy

Articular cartilage is a hypocellular and highly specialized tissue, with only 4% of its wet weight consisting of chondrocytes. The main components of articular cartilage are water (65% to 85% of weight) and the extracellular matrix (ECM) composed of type II collagen (15–20% of weight) and proteoglycans (PGs) (3–10% of weight) [16]. The ECM of mature articular cartilage production is related directly to the chondrocyte volume or function and is composed of three major types of macromolecules, fibers (collagen and elastin), proteoglycans, and glycoproteins, which are synthesized and maintained by chondrocytes [17]. Together, these components help to retain water within the ECM, which is crucial in maintaining its unique mechanical properties. Articular cartilage has a highly organized structure composed of four zones: the superficial (tangential) zone, middle (transitional) zone, deep (radial) zone, and calcified zone [18]. The chondrocyte phenotype, cell shape, and ECM structure vary among the different zones [19]. The deep zone is separated from the calcified zone by the tidemark, which is a thin basophilic line that can be usually seen in a slide stained with hematoxylin and eosin and represents the boundary between the mineralized and unmineralized regions of the cartilage [17]. The subchondral bone plate is deep to the calcified zone, and the relationship between the cartilage and the underlying subchondral bone is of particular importance when assessing joint health and determining treatment strategies. The articular cartilage is anchored to the subchondral bone via an interface of calcified cartilage, which together makes up the "osteochondral unit." This unit functions primarily by transferring load-bearing weight over the joint to allow for normal joint articulation and movement. Consequently, the cartilage and the subchondral bone should be evaluated together.

A meta-analysis by Harris et al. [20] reported that MRI performed significantly better for the detection of patellar articular cartilage defects compared with trochlear articular cartilage defects across all parameters and that the sensitivity for detecting trochlear cartilage defects was only 72%. The comparatively poor visualization of the distal trochlea could be explained by an axial plane, which does not provide imaging that is directly perpendicular to the cartilaginous surfaces of the trochlea. However, a recent study by LaPrade et al. [21] compared the diagnostic utility of a standard axial MRI sequence with an axial-oblique MRI sequence of the knee for the detection of trochlear articular cartilage lesions and found low sensitivity in detecting trochlear articular cartilage lesions for both sequences. Therefore, sagittal, axial, and if available axial-oblique imaging planes should be utilized to evaluate the articular cartilage of the trochlea.

## 5.3 MRI Technique

Articular cartilage is a challenging tissue to image because it is a very thin and layered structure covering a complex 3D osseous base. In order to evaluate the articular cartilage, MRI techniques need to achieve high spatial resolution with excellent signal-to-noise ratios (SNR) and contrast-to-noise ratios (CNR) in a time-effective manner [22]. An MR system with high magnetic field strength (≥1.5 T) and dedicated multichannel-phased array extremity coil is recommended for articular cartilage evaluation [12, 23, 24]. Numerous sequences have been developed and advocated for optimal cartilage evaluation. These include conventional 2D fast-spin-echo sequences [7, 25–27] (Fig. 5.1), specialized techniques including biochemical imaging [28], 3D gradient sequences [29], and 3D double-echo steady state (DESS) [30] (Fig. 5.2). However, in clinical practice, conventional 2D fast-spin-echo (FSE) sequences are performed most commonly for global assessment of the intra-articular structures of the knee, including evaluation of the articular cartilage. There is a wide reported range of diagnostic performance of 2D FSE MR for assessment of the knee cartilage, with sensitivity ranging from 26% to 96%, specificity 50% to 100%, and accuracy 49% to 94% [7, 25–27]. The 2D FSE sequences are limited by issues such as partial volume artifacts due to thick sections and gaps between sections. Confinement to the traditional cardinal imaging planes may not optimally depict the thin and curving articular cartilage. Slice thickness of 2.5–3.5 mm with a slice gap of 0.25–0.35 mm is acceptable; however, this is dependent on field strength of the MR scanner and use of dedicated knee coil. The MRI sequences most commonly used in the assessment of joint cartilage are 2D T1-weighted, proton density-weighted, and T2-weighted imaging sequences with or without fat suppression [23, 24, 31]. T1-weighted images show intrasubstance anatomic detail of hyaline cartilage but do not provide adequate contrast between joint effusion and the cartilage surface, a shortcoming that limits its usefulness in the assessment of focal cartilage defects [32]. Furthermore, T1 weighting has a poor capability for depicting other internal structures in the knee, such as ligaments, and may lead to overestimation of meniscal abnormalities. T2-weighted

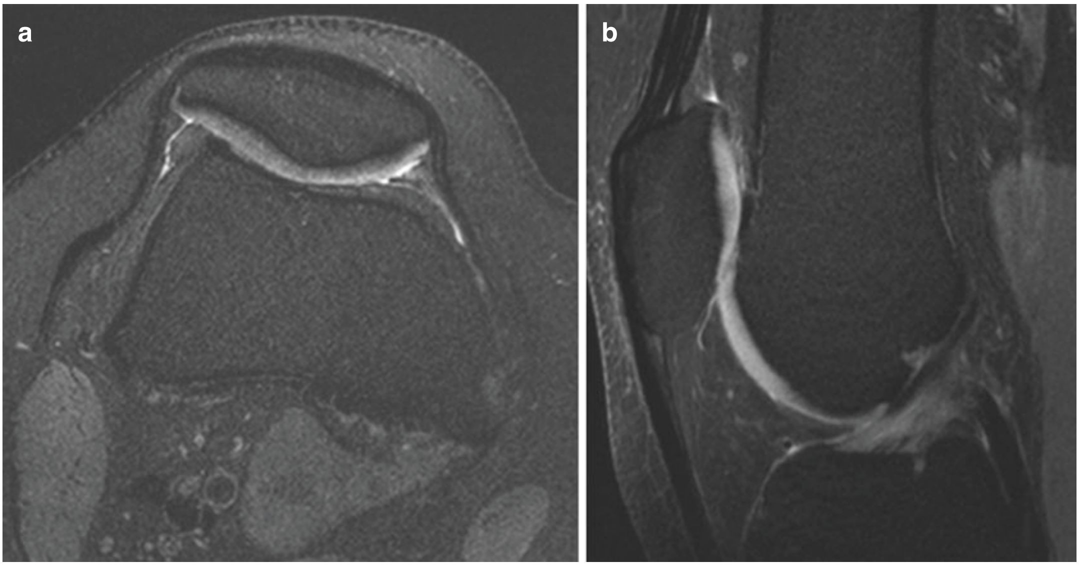

**Fig. 5.1** Conventional 2D fast-spin-echo sequence magnetic resonance imaging (7 Tesla) of normal patellofemoral cartilage. Axial (**a**) and sagittal (**b**) fat-suppressed intermediate-weighted images of normal cartilage in the patellofemoral compartment

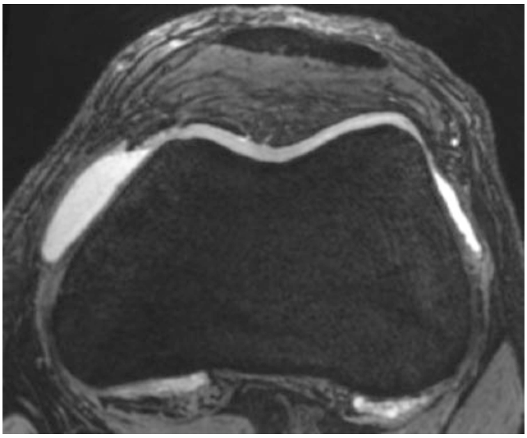

**Fig. 5.2** Double-echo steady-state (DESS) magnetic resonance imaging (7 Tesla) of normal trochlea cartilage. Axial image of the normal trochlea cartilage

imaging provides excellent contrast resolution between the cartilage surface and joint effusion, which is useful for detecting focal areas of delamination or other defects. However, this is at the expense of the internal cartilage signal, which is weakened because of inherent short T2 value of the cartilage. For direct evaluation of articular cartilage, the proton density-weighted sequences are considered to yield the most accurate information about chondral defects [33]. Recently, the use of high-field-strength magnets has increased in clinical practice, especially 3 Tesla magnets (3.0 T). The advantages of 3.0 T MRI include improved spatial resolution and contrast resolution, without increasing acquisition time.

Although conventional MRI provides sufficient tissue contrast to detect morphological changes in the cartilage, changes in cartilage physiology prior to morphological changes cannot be measured with standard imaging techniques [34]. More advanced MRI techniques offer assessment of the biochemical composition of the cartilage. Following initial injury, the cartilage microstructure breaks down, and the tissue begins to lose its functional capacity resulting in decreased organization of the collagen matrix, decreased fixed charge density (FCD) due to loss of PGs, and increased water content [13]. In the cartilage degradation process, MRI has demonstrated the ability to detect these early biochemical changes prior to the morphological changes.

Delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) utilizes the FCD within the cartilage to indirectly measure glycosaminoglycan (GAG) content [35]. While dGEMRIC is the most established imaging tool for indirect measurement of GAG content in vivo, there are several limitations that must be considered. First, administration of contrast agent is a crucial part of the technique. This adds an invasive element to the protocol that is not present in other quantitative MR methods. Second, the delay required for the contrast to distribute throughout the joint makes for a long examination time. T1rho mapping is another technique which allows the measurement of GAG that is noninvasive [36]. Sodium MRI provides an additional technique for quantifying the biochemical composition of the cartilage (GAG concentration); however, its numerous limitations make it a less popular technique [37].

T2 mapping is a commonly used tool for measuring water content in the cartilage [38]. This method allows for the indirect assessment of collagen content and orientation, which are important indicators for early OA. The collagen matrix of healthy cartilage traps and immobilizes water protons, so signal intensity on T2-weighted images is low [39]. In the earliest stages of OA, the matrix begins to break down and becomes more permeable to water, causing an elevation in T2 relaxation times [40].

Diffusion-weighted imaging (DWI) technique measures the translational motion of extracellular water molecules by applying diffusion-sensitizing gradients that cause mobile water protons to lose phase coherence and MR signal [41]. In the cartilage, this movement of free water is dependent upon the quality and orientation of collagen fibers. DWI has been currently used to track cartilage composition following cartilage repair surgery [42, 43]. The field of quantitative MRI is rapidly evolving, and numerous other MR techniques exist that show a promise in providing reliable quantitative analysis of cartilage composition. In the near future, determination of biochemical correlates for each quantitative technique will be essential in developing and tracking interventions to prevent OA progression.

## 5.4 Normal Osteochondral Unit Imaging

By using MRI techniques with high spatial resolution and good soft tissue contrast, a three-layer pattern can be observed in the hyaline cartilage: (1) surface layer with low-intensity signal, (2) intermediate layer with high-intensity signal, and (3) deep layer with low-intensity signal and a “palisade” transition into the intermediate zone. This three-layer appearance is more evident in the cartilage of greater thickness, such as the patellar and femoral trochlear cartilage. The patellar articular cartilage is the thickest in the body, measuring 4–6 mm in young healthy adults, correlating with the significant mechanical stresses placed on the joint (Fig. 5.1) [44].

In clinical research, especially in knee osteoarthritis trials, morphologic evaluation of the cartilage with MRI has been performed by using semiquantitative scoring methods such as those known by the acronyms WORMS (Whole-Organ MR Imaging Score) [45], BLOKS (Boston-Leeds Osteoarthritis Knee Score) [46], and KOSS (Knee Osteoarthritis Scoring System) [46]. In such scoring systems, morphologic characteristics of joint cartilage are assessed in conjunction with those of other structures around the knee (e.g., menisci, subchondral bone, osteophytes, and synovium) to establish morphologic risk factors for pain and progression of disease in patients with knee OA.

Normal MRI variants can mimic pathologic articular cartilage on FSE sequences [47]: (1) ambiguity and pseudolaminar appearance of the cartilage surface contour of the posterior femoral condyle, (2) truncation artifact in the patellofemoral compartment, (3) linear high-signal-intensity deep zone adjacent to the subchondral bone of femoral condyle, (4) decreased signal intensity in the distal trochlear cartilage, (5) cartilage thinning adjacent to the anterior horn of the lateral meniscus, (6) focal cartilage thinning in the posterior region of the femoral condyle, and (7) susceptibility artifact on the cartilage surface from gas or microscopic metallic debris (Fig. 5.3). In order to distinguish between normal and abnormal cartilage on MRI, understanding the normal appearance of articular cartilage and recognition of variants mimicking cartilage pathology and MRI artifacts is of utmost importance.

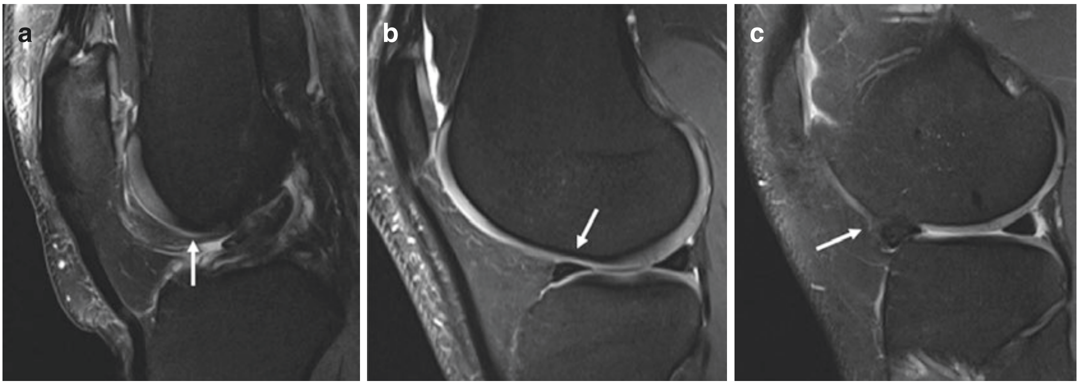

**Fig. 5.3** Normal magnetic resonance imaging (3 Tesla) variants that mimic pathologic articular cartilage. Sagittal fat-suppressed intermediate-weighted images of decreased signal intensity in the distal trochlear cartilage (white arrow) with full-thickness cartilage defect on the patella (**a**), cartilage thinning adjacent to the anterior horn of the lateral meniscus (white arrow) and signal heterogeneity in the patella cartilage (**b**), and susceptibility artifact on the cartilage surface from metallic debris (white arrow) (**c**)

## 5.5 Osteochondral Lesions

Cartilage lesions should be evaluated in conjunction with the underlying subchondral bone. MRI is able to detect changes of the articular cartilage, the adjacent subchondral bone, and the underlying bone marrow [22, 48].

Cartilage evaluation: Signal heterogeneity, fissuring, delamination, and partial- or full-thickness cartilage loss (Fig. 5.4). Several established scoring systems are available for arthroscopic assessment of cartilage defects. The most common scoring systems are the Outerbridge classification [49] and the International Cartilage Repair Society (ICRS) score. Currently, the modified Outerbridge classification is the most widely utilized MRI cartilage defect grading system (Table 5.1). This grading scale has been modified for MRI and has seven stages that range from signal heterogeneity to full-thickness cartilage loss. Cartilage heterogeneity is the earliest finding in cartilage damage and corresponds to chondral softening with normal contour at arthroscopy. The patellar cartilage and trochlea cartilage are best assessed in the axial and sagittal planes (Fig. 5.1). Imaging of the trochlear cartilage is significantly more difficult than the patellar cartilage because of comparatively indistinct margins, irregularity of the curved surfaces, and thinner cartilage [7, 9, 20, 21]. Patellar lesions can usually be seen in both planes regardless of the location. Proximal trochlea lesions are normally seen in the axial plane, while distal trochlea lesions are often missed [20]. These distal lesions can be frequently identified on the sagittal images.

Bone evaluation: Subchondral bone changes include underlying subchondral cystic change, bone marrow edema, and sclerosis (Figs. 5.5, 5.6, and 5.7). Generally, bone marrow edema is recognized as a non-specific reaction of the bone to trauma, both acute and chronic repetitive injuries from overload, and may represent numerous non-specific histological changes

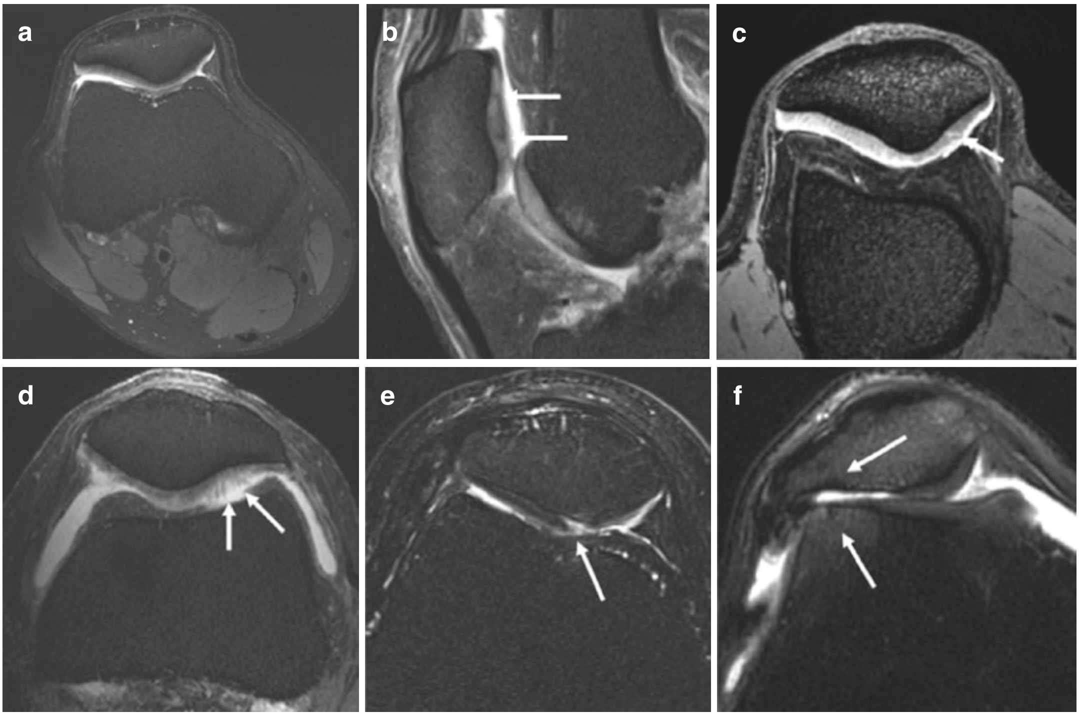

**Fig. 5.4** Magnetic resonance imaging (3 Tesla) of different depth patellofemoral cartilage lesions. Axial images of fat-suppressed intermediate-weighted normal cartilage (**a**), signal heterogeneity (**b**), small fissure (**c**), deep fissuring (**d**), flap delamination (**e**), and full-thickness degenerative cartilage loss in the lateral patella and trochlea (**f**)

[50, 51]. The presence of focal edema-like signal in the subchondral marrow may indicate the presence of an overlying full-thickness cartilage defect and is easier to detect than the cartilage defect itself (Figs. 5.5 and 5.6). Bone marrow edema has a large differential diagnosis and can include etiologies such as traumatic bone contusions, stress fractures, degenerative lesions, inflammation, ischemic lesions (avascular necrosis), infection (septic osteomyelitis), metabolic lesions, neoplastic lesions, or iatrogenic lesions [52]. Focal cartilage defects can also result in subchondral changes. Left untreated, these regions can increase in size over time and result in subchondral overgrowth or bone loss [53]. Moreover, numerous studies have shown postoperative changes in the subchondral bone plate after prior marrow stimulation techniques (MST) (e.g., intralesional osteophyte formation), which might be the underlying reason behind three to eight times higher failure and decreased satisfaction rates among patients who underwent MST prior to autologous chondrocyte implantation (ACI) [53–58]. Consequently, the MRI assessment of a patient with symptomatic cartilage defect should include the evaluation of the subchondral bone in particularly the bone marrow signal intensity, the subchondral lamina, the presence of intralesional osteophytes, the granulation of tissue or sclerosis, and the underlying cystic change [53, 59]. However, the overall spatial resolution of MRI is inadequate to assess trabecular structure changes, loss of subchondral plate thickness, or the presence of smaller subchondral cysts. Therefore, in those cases when the subchondral bone assessment is imperative, computed tomography (CT) should be considered due to its superior structural evaluation of trabecular and subchondral bone [53].

Although MRI has proved very sensitive for detecting defects, it has limitations with regard to accurately defining the depth (grade) and size of articular cartilage lesions. MR images tend to underestimate the size and depth of

**Table 5.1** Outerbridge classification

| Grade | Arthroscopic findings |
|---|---|
| 0 | Normal cartilage |
| I | Cartilage with softening and swelling |
| II | Partial-thickness defect with fissures on the surface that do not reach subchondral bone or exceed 1.5 cm in diameter |
| III | Fissuring to the level of subchondral bone in an area with a diameter more than 1.5 cm |
| IV | Exposed subchondral bone |

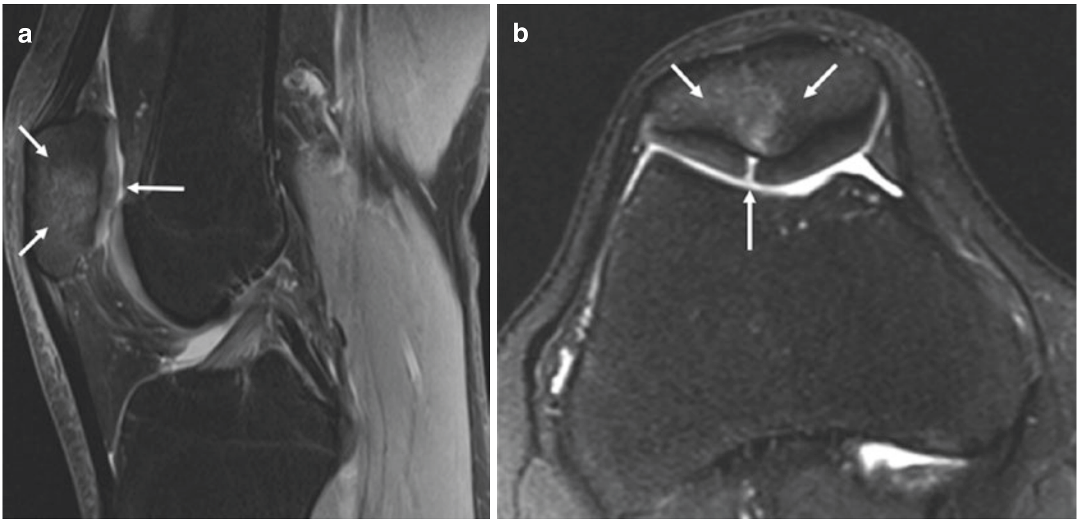

**Fig. 5.5** Magnetic resonance imaging (3 Tesla) of deep cartilage lesion with bone marrow changes in the patella. Sagittal (**a**) and axial (**b**) fat-suppressed intermediate-weighted images demonstrating a deep cartilage lesion with underlying bone marrow changes

**Fig. 5.6** Axial (**a**, **b**) and sagittal (**c**, **d**) fat suppressed intermediate-weighted images demonstrating a full-thickness cartilage lesion with underlying bone marrow changes

cartilage lesions, significant lesions may exhibit very subtle findings on MR images, and lesions may be visualized accurately on only one image [22]. Although MRI is a valuable tool in detecting cartilage defects and planning treatment, arthroscopy remains the gold standard and is often used for accurate diagnosis and sizing.

## 5.6 Evaluation of Cartilage Repair Procedures

While arthroscopy is considered to be the standard for postoperative assessment of surgical cartilage repair, it is an invasive procedure and requires postoperative rehabilitation. Thus, in practice, arthroscopy is usually reserved to times

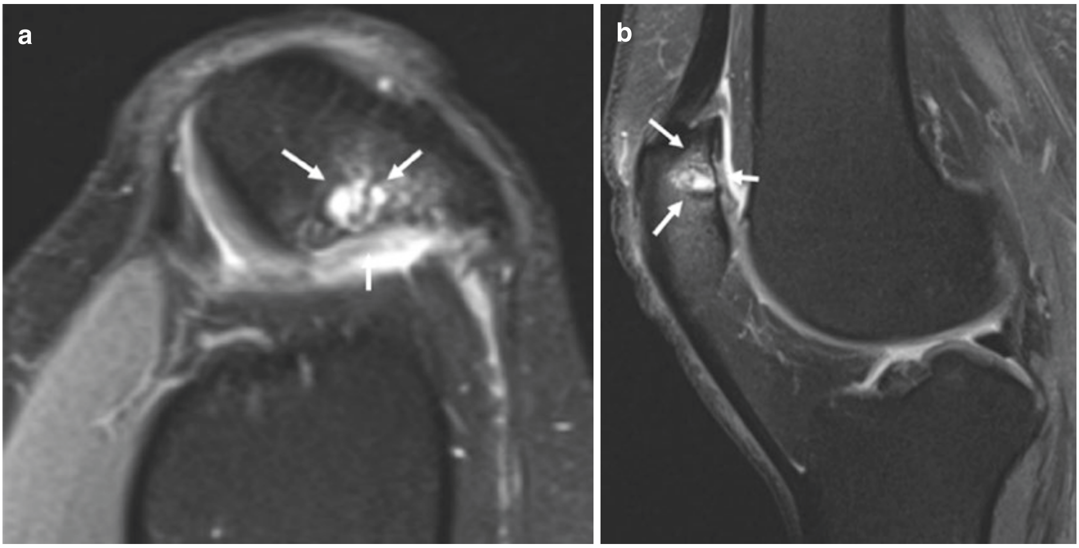

**Fig. 5.7** Magnetic resonance imaging (3 Tesla) of a full-thickness cartilage defect with a subchondral cyst. Axial (**a**) and sagittal (**b**) fat-suppressed intermediate-weighted images demonstrating a full-thickness cartilage lesion with an underlying subchondral cyst

when there are concerns about the integrity of the graft. Although MR imaging cannot provide as accurate assessment of cartilage repair tissue as arthroscopic evaluation in terms of color, stiffness, and fine fibrillations, it can provide information about the defect fill, graft integration, and subchondral bone [7, 32]. Furthermore, MRI is noninvasive and can be easily repeated. Several MR scoring systems have been developed to help standardize postoperative cartilage assessment [60–63]. At our institution, we use the Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) [63] scoring system and the Osteochondral Allograft MRI Scoring System (OCAMRISS) [62].

The MOCART [63] is one of the most frequently used scoring systems for evaluation of cartilage repair tissue and is composed of nine parameters: defect filling, repair tissue integration, repair tissue surface, repair tissue structure, repair tissue signal intensity, subchondral lamina status, subchondral bone status, presence or absence of adhesions, and presence or absence of synovitis (Table 5.2). In 2009, Welsch et al. proposed 3D-MOCART [61] as a

**Table 5.2** 2D Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) scoring system

| Parameter | Item | Points |
|---|---|---|
| Defect fill | Complete | 20 |
| | Hyperthrophy | 15 |
| | Incomplete >50% of the adjacent cartilage | 10 |
| | Incomplete <50% of the adjacent cartilage | 5 |
| | Subchondral bone exposed | 0 |
| Cartilage interface | Complete (complete integration with adjacent cartilage) | 15 |
| | Demarcating border visible (split-like) | 10 |
| | Defect visible <50% of the length of the repair tissue | 5 |
| | Defect visible >50% of the length of the repair tissue | 0 |
| Surface | Surface intact | 10 |
| | Surface damaged <50% of repair tissue depth | 5 |
| | Surface damaged >50% of repair tissue depth or total degeneration | 0 |
| Adhesions | Yes | 5 |
| | No | 0 |

(continued)

**Table 5.2** (continued)

| Parameter | Item | Points |
|---|---|---|
| Structure | Homogenous | 5 |
| | Inhomogenous or cleft formation | 0 |
| Signal intensity | Normal | 30 |
| | Nearly normal | 10 |
| | Abnormal | 0 |
| Subchondral lamina | Intact | 5 |
| | Not intact | 0 |
| Subchondral bone | Intact | 5 |
| | Granulation tissue, cyst, sclerosis | 0 |
| Effusion | No | 5 |
| | Yes | 0 |
| **Total points** | | 100 |

**Table 5.3** Osteochondral allograft MRI Scoring System (OCAMRISS)

| | MRI feature | MRI score | |
|---|---|---|---|
| Cartilage features | 1. Cartilage signal of graft | 0 | Normal |
| | | 1 | Altered intensity (either hypointense or hyperintense, but not fluid) |
| | | 2 | Fluid signal intensity on all sequences |
| | 2. Cartilage “fill” of graft (percentage of volume) | 1 | 51%to75%or > 100% |
| | | 2 | <50% |
| | 3. Cartilage edge integration at host-graft junction | 0 | No discernible boundary |
| | | 1 | Discernible boundary |
| | | 2 | Discernible fissure >1 mm |
| | 4. Cartilage surface congruity of graft and host-graft junction | 0 | Flush |
| | | 1 | <50% offset of host cartilage |
| | | 2 | >50% offset of host cartilage |
| | 5. Calcified cartilage integrity of graft | 0 | Intact, thin, and smooth |
| | | 1 | Altered (disrupted, thickened, or blurred) |
| Bone features | 6. Subchondral bone plate congruity of graft and host-graft junction | 0 | Intact and flush |
| | | 1 | Disrupted or not flush by >1 subchondral thickness |
| | 7. Subchondral bone marrow signal intensity of graft relative to epiphyseal bone | 0 | Normal |

modified version of the MOCART system adapted for higher-resolution imaging, including isotropic three-dimensional acquisitions. This version improves evaluation by delineating all the assessed variables of the repair site to the weight-bearing and non-weight-bearing regions of the joint, localizing the features within the repair site, evaluating the repair tissue-cartilage interfaces or “border zones” in every plane, and providing a detailed subchondral bone assessment. The MOCART systems are used for monitoring tissue following either marrow stimulation techniques or cell-based therapies. One disadvantage of these systems is that they do not provide adequate assessment of the bony changes, which is especially important for thorough evaluation of the osteochondral allograft transplantation [64]. OCAMRISS [62] grades five cartilage parameters, four bone parameters, and four additional joint findings and is an established and reproducible technique following osteochondral allograft transplantation (Table 5.3) [64]. Furthermore, OACMRISS score is a validated score in an experimental model with histopathologic and micro-computed tomography reference standards. At our institution, 2D-MOCART score is utilized to monitor cell-based therapies

**Table 5.3** (continued)

| | MRI feature | MRI score | |
|---|---|---|---|
| | | 1 | Abnormal (bone marrow edema pattern or hypointensity on all sequences) |
| | 8. Osseous integration at host-graft junction | 0 | Crossing trabeculae |
| | | 1 | Discernible cleft |
| | 9. Presence of cystic changes of graft and host-graft junction | 0 | Absent |
| | | 1 | Present |
| Ancillary features | 10. Opposing cartilage | 0 | Normal |
| | | 1 | Abnormal |
| | 11. Meniscal tears | 0 | Absent |
| | | 1 | Present |
| | 12. Synovitis | 0 | Absent |
| | | 1 | Present |
| | 13. Fat pad scaning | 0 | Absent |
| | | 1 | Present |

(Fig. 5.8), while OCAMRISS is used to assess osteochondral allograft transplantation (Figs. 5.9, 5.10, and 5.11).

There is a controversy about the correlation between the qualitative MRI assessment scores and clinical outcomes in the current literature. Although some studies report correlation between clinical outcomes and the MOCART score following cartilage repair [65], the majority of studies reveal no correlation [66–68]. Furthermore, a recent systematic review demonstrated the lack of reliable evidence in predicting clinical outcome after cartilage repair [69]. A similar controversy exists between the clinical outcomes and quantitative MRI findings [70]. The use of 3D-MOCART [61] and OCAMRISS [62] scoring system may be more accurate in longitudinal monitoring of cartilage restoration therapies and providing new insights into its clinical significance. Therefore, postoperative MRI should be reserved for research purposes or for evaluation of patients who are having non-satisfactory outcomes.

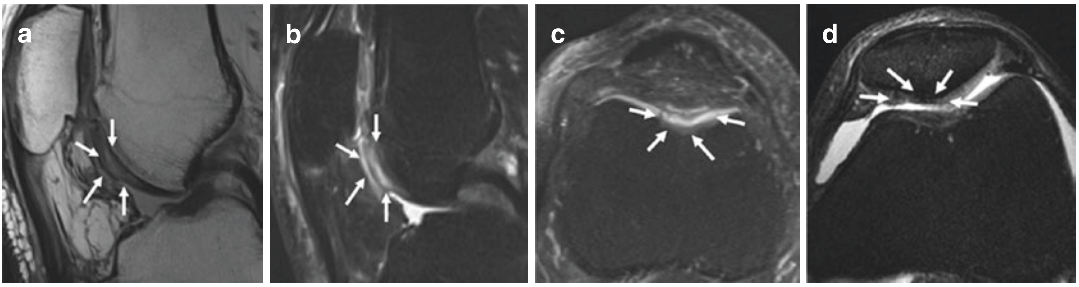

**Fig. 5.8** Magnetic resonance imaging (3 Tesla) following autologous chondrocyte implantation to the trochlea. Sagittal (intermediate-weighted (**a**) and fat-suppressed intermediate-weighted (**b**) and axial fat-suppressed intermediate-weighted (**c**) images of a trochlea lesion treated with autologous chondrocyte implantation and an axial (**d**) image of a patella lesion treated with autologous chondrocyte implantation, demonstrating a thin repair tissue

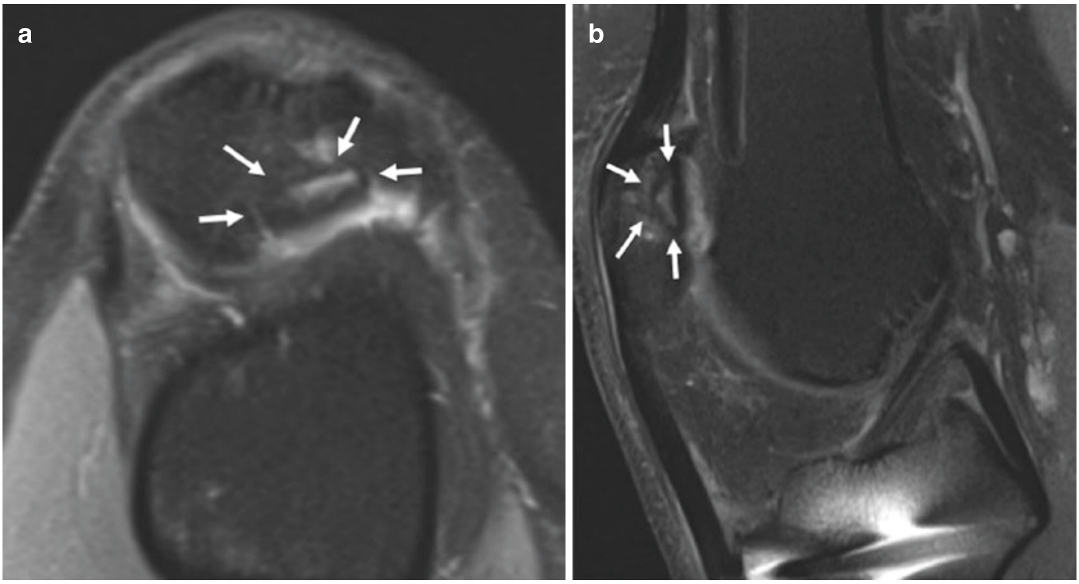

**Fig. 5.9** Magnetic resonance imaging (3 Tesla) following osteochondral allograft transplantation to the patella. Axial (**a**) and sagittal (**b**) fat-suppressed intermediate-weighted images of an osteochondral allograft transplantation in the patella. Artifact is present in the proximal tibia due to the hardware used for fixation of tibial tuberosity osteotomy

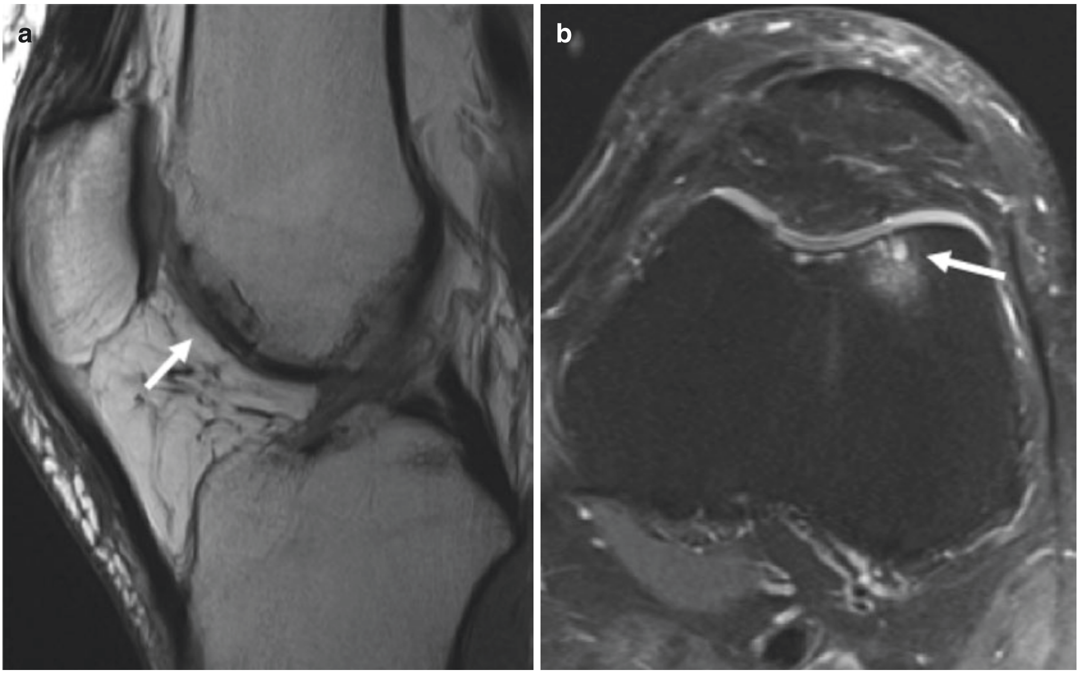

**Fig. 5.10** Magnetic resonance imaging (3 Tesla) after osteochondral allograft transplantation to the trochlea. Sagittal intermediate-weighted (**a**) and axial (**b**) fat-suppressed intermediate-weighted images of an osteochondral allograft transplantation in the trochlea. White arrow in image **b** indicates a cyst formation in the subchondral bone

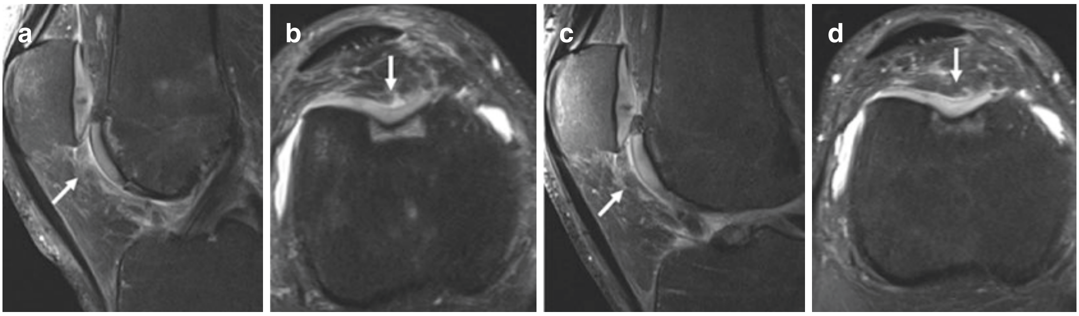

**Fig. 5.11** Magnetic resonance imaging (3 Tesla) following osteochondral allograft transplantation to the trochlea in different follow-up visits (6 months and 1 year) after surgery. Sagittal (**a** and **c**) and axial (**b** and **d**) fat-suppressed intermediate-weighted images. Representative example of graft integration following osteochondral allograft transplantation (OCA) to the trochlea. Images **a** and **b** demonstrate OCA graft which is still under integration 6 months after OCA transplantation

## 5.7 Conclusion

MRI is an established diagnostic tool for articular cartilage defects and a crucial part of the diagnosis and treatment algorithm; however, it has limited accuracy in regard to diagnosis, sizing of cartilage lesions, and bone evaluation. The correlation between postoperative imaging and clinical outcomes is controversial. Therefore, surgeons should use MRI findings as a supplemental tool to their clinical evaluation.

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# 6

# Computed Tomography and Arthro-CT Scan in Patellofemoral Disorders

Paolo Ferrua, Daniele Tradati,
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Patellofemoral (PF) joint stability is the resulting of the balance between both soft tissue and bony/cartilaginous structures [1]. As stated in the AOSSM/PFF consensus, patellar instability is defined as a deficiency of the patellar passive constraint (patholaxity) such as that the patella may escape partially or completely from its asymptomatic position with respect to the femoral trochlea under the influence of a displacing force. Such a displacing force could be generated by muscle tension, movement, and/or externally applied forces [2].

Computed tomography (CT) has been used for the last decades for PF joint imaging and historically played a very important role in determining pathological features of patellar instability. The seminal paper from Henri Dejour et al. in 1994 set the pathological threshold values present in the dislocation population using traditional X-rays and CT scan [3].

CT scan is useful for assessing bony abnormalities, including the three major anatomical factors of instability described by the Lyon's school:

- Trochlear dysplasia.
- Excessive patellar height.
- Excessive TT-TG distance.

Moreover, CT scan can be used to assess and measure all the other factors that could potentially increase patellar instability (secondary factors).

Some authors advocated the use of the arthro-CT scan due to its high sensitivity in detecting cartilaginous lesions; nevertheless the technological improvements of magnetic resonance imaging (MRI) filled the gap between these techniques making the MRI an X-ray-free diagnostic tool with even superior diagnostic abilities.

Additionally, the increasing focus on both soft tissue and cartilaginous structures reduced furthermore the key role of the CT scan in favour of the MR imaging. Given this preliminary consideration, CT scan still plays a role in the diagnostic protocol of PF instability. CT scan allows evaluation of both knees and lower limbs for comparative analysis or rotational abnormalities assessment. Moreover it is suitable also for patient bearing metallic hardware or devices contraindicating MRI. The aim of this chapter is to present how CT scan can be used in a diagnostic process and in an eventual preoperative planning of a PF joint instability case.

## 6.1 Exam Protocol

In order to obtain reproducible results, strict assessment conditions are mandatory. Based on the publications of Dejour and Walch, a standardized protocol for obtaining data related

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to patellofemoral instability was described, the so-called Lyon's protocol [3–5].

The patient is placed supine on the table, with the knee in full extension and with the feet fixed at 15° of external rotation in order to make the patella almost parallel to the floor.

A scout image is obtained, and the following sections are acquired using these criteria:

- Hip section:
  - Through both the femoral necks at the top of the trochanteric fossa.
- Knee sections (obtained with both relaxed and contracted quadriceps):
  - Through the centre of the patella, over its larger transverse axis.
  - Through the proximal trochlea (where the intercondylar notch looks like a Roman arch and there is a slight condensation of the trochlear lateral facet subchondral bone).
  - Through the proximal tibial epiphysis, just beneath the articular surface.
  - Through the proximal part of the tibial tuberosity.
- Ankle section:
  - Near the ankle joint, at the base of the malleoli.

The protocol includes both relaxed and contracted quadriceps evaluation. The rationale relies on the fact that the quadriceps could act as a dynamic stabilizer or not of the patellofemoral joint in in vivo conditions. Quadriceps activation does not affect patellar tilt in normal knees. Differently, an increased tilt in response to the quadriceps contraction may be observed in patients with patellar instability, probably due to a muscular unbalance caused by a VMO deficiency and MPFL incompetency or other manifestations of quadriceps/trochlear dysplasia [5].

## 6.2 Patella Height

Several methods have been described using tibial reference in order to assess patellar height on plain lateral X-rays. The most cited in literature at the current time are the Insall-Salvati index [6], the Blackburne-Peel ratio [7] and the Caton-Deschamps index [8]. Since the upcoming of the CT scan technique, many authors proposed to apply these indexes to CT scan images, even if they were originally described for application in traditional X-rays imaging [9–11]. One of the limits of these transpositions is that the degree of flexion used of traditional X-rays evaluation is different from CT scan which is normally performed in extension.

The Insall-Salvati index represents the ratio between the length of the patellar tendon from the lower pole of the patella to its tibial insertion and the greatest pole-to-pole distance of the patella on a sagittal view (Fig. 6.1).

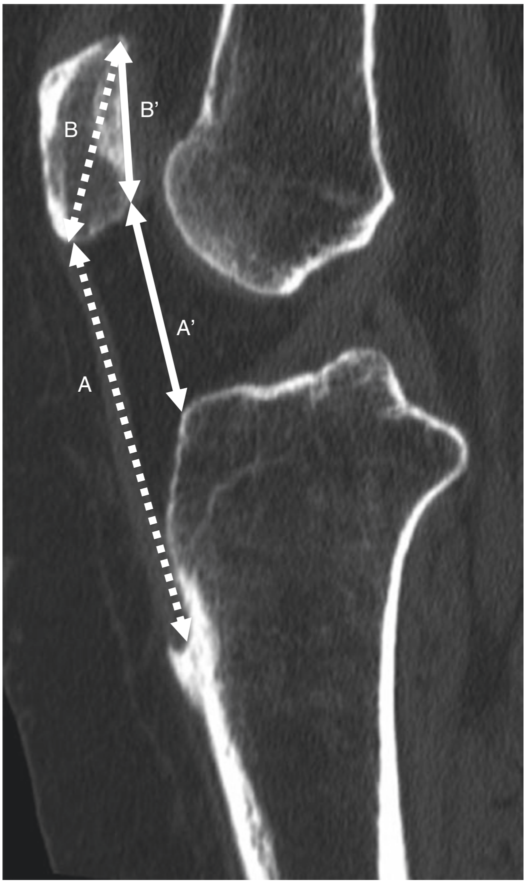

**Fig. 6.1** The Insall-Salvati index is measured as the ratio (*A*/*B*) between the length of the patellar tendon from the lower pole of the patella to its tibial insertion (*A*) and the greatest pole-to-pole distance of the patella (*B*). The Caton-Deschamps index is defined as the ratio (*A'*/*B'*) between the distance from the anterosuperior angle of the tibia to the lower edge of the joint surface of the patella (*A'*) and the length of the patellar joint surface (*B'*)

Schueda et al., considering the Insall-Salvati index, performed a comparative study between radiographs a CT scan assessment of the patellar height. The author proposed a formula to obtain the patellar height value on CT in extension, 20° of flexion and quadriceps contraction using the X-rays obtained value [10]. In a further study, the same author analysed the CT scans obtained patellar height of 961 patients, defining this variable as one of the best tomographic tools available for the diagnosis of patellar instability [12]. Supporting the possibility to apply this index to the CT patellar height measurement, Lee et al. reported a mean + 0.10 difference between CT and plain X-ray [9].

Another patellar height index is the one described by Blackburne-Peel. This index measures the ratio between the articular surface length of the patella and the perpendicular distance from the patellar pole to the tangent to the tibial plateau. An excellent ICC value (>0.94) is reported in literature considering this technique in CT scan patellar height measurement; moreover no discrepancies between radiographical and CT scan obtained values were described [9].

Similarly to the previously cited index, the Caton-Deschamps can also be measured using sagittal CT scan with the knee at 30° of flexion. This index is defined as the ratio between the distance from the anterosuperior angle of the tibia to the lower edge of the joint surface of the patella and the length of the patellar joint surface (Fig. 6.1); nevertheless it could present difficulties regarding the correct identification of the joint surface, as well as a discrete variability in defining the anterosuperior angle of the tibia [13]. Despite these considerations the Caton-Deschamps index showed the highest interobserver concordance in comparison to the other index, as reported by Seil et al. [14], and moreover is the one least influenced by the degree of knee flexion. Given these considerations, CT scan may not be the first choice for assessing patellar height, but it has probably to be considered as a complementary exam to X-rays and MRI.

## 6.3 Trochlear Dysplasia

Trochlear dysplasia is considered one of the most important risk factors for patellar dislocation. The CT scan allows a better analysis of the three-dimensional shape of trochlear groove and the relative position of the patella avoiding the over impositions of the bony references that occurs using plain X-rays. In a recent literature review performed by Pavian and coworkers, 33 radiological index characteristics for trochlear dysplasia were reported [15]. Considering CT scan, two indexes demonstrated the highest score in the quality assessment: the lateral trochlear inclination and the classification of trochlear dysplasia by Dejour.

The lateral trochlear inclination angle, firstly described by Carrillon et al. [16], was the one which showed the highest score according to the expert panel.

This index is measured based on the angle between the tangent to the subchondral bone of the lateral facet and the tangent to the posterior borders of the femoral condyles on an axial view (Fig. 6.2).

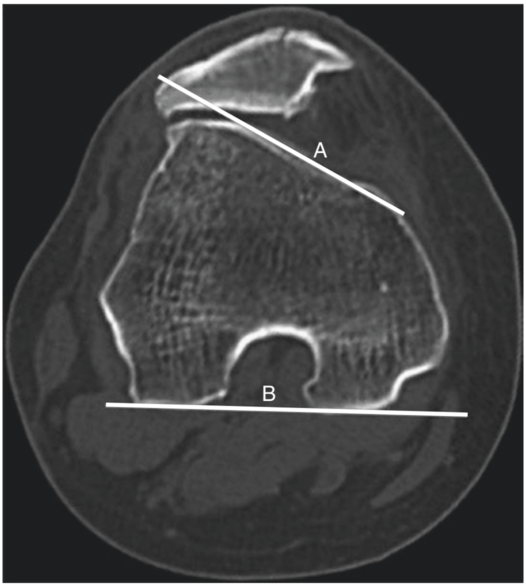

**Fig. 6.2** The Lateral trochlear inclination (LTI) is measured based on the angle between the tangent to the subchondral bone of the lateral facet (*A*) and the tangent to the posterior borders of the femoral condyles on an axial view (*B*)

In patients without trochlea dysplasia, the mean value is 16.9°, and the diagnostic threshold in order to define a dysplastic trochlea is set to 11° (sensitivity of 93% and a specificity of 87%) [17].

Dejour et al. classified trochlear dysplasia into four types based on both X-ray and CT scan [18, 19]. The CT image characteristics for each type of trochlear dysplasia are type A, shallow trochlear with sulcus angle >145°; type B, flat trochlea appearance; type C, convex lateral facet plus medial facet hypoplasia; and type D cliff pattern (Fig. 6.3).

This classification is currently the most popular in the standard practice. Despite this fact, the intra- and interobserver reliability is still under discussion, because these signs highly depend on subjective evaluation and underestimation of the severity of the trochlear dysplasia was reported [20, 21]. Nelitz et al. investigated the relationship between lateral trochlear inclination and the Dejour classification, demonstrating an excellent correlation with the higher degrees of trochlear dysplasia while a poor correlation with the lower ones [22].

In the last years, a new focus was directed towards the 3D CT scan reconstructions in order to simplify the visual assessment of the dysplastic trochlea, but the lack of a quantitative approach reduces the clinical relevance of this approach. Nevertheless, the renewed interest on soft tissue and moreover on the role of the cartilage mitigates the rising of this method in favour of the 3D reconstructions obtained using the MRI.

**Fig. 6.3** High-grade trochlear dysplasia (Dejour type D) with a characteristic cliff pattern, lateral crest, and medial condyle hypoplasia

## 6.4 Tibial Tubercle-Trochlear Groove (TT-TG) Distance

Firstly described by Goutallier and Bernageau in 1978 using X-rays [23], the CT scan measurement of the TT-TG was popularized by Dejour et al. in 1994 [3]. This index quantifies in millimetres the distance between the tibial tuberosity and the deepest point of the trochlear groove projected on the line tangent to the poster femoral condyles on an axial view.

The TT-TG measurement relies on two axial images that are superimposed. The first one is the cut in which the trochlear cartilage lies more proximal, while the second cut is the one including the proximal part of the anterior tibial tubercle (Fig. 6.4). In a healthy group of patients, a mean

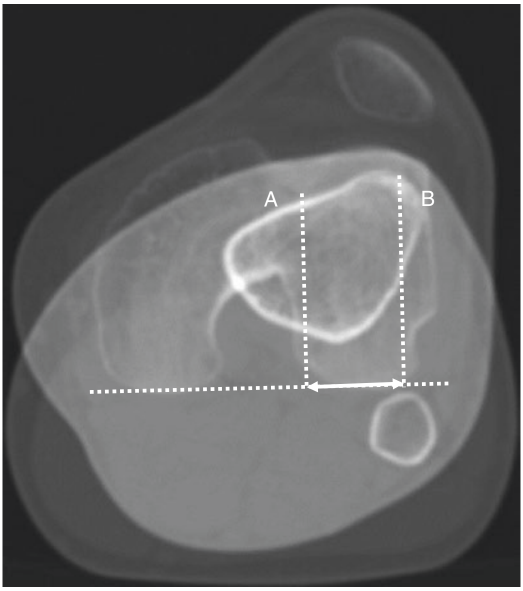

**Fig. 6.4** Pathological tibial tubercle-trochlear groove (TT-TG) distance. This index quantifies in millimetres the distance between the deepest point of the trochlear groove (*A*) and the tibial tuberosity (*B*) projected on the line tangent to the poster femoral condyles on an axial view

TT-TG value of 13.6 ± 8 mm [24] is considered normal, but there is no full concordance in the literature about this topic, and some authors proposed higher values due to the large variability of this parameter in the population [25]. Moreover, since it is an absolute value, it does not take into account patient's height and weight [26].

A TT-TG distance greater than 20 mm has been identified in 56–93% of patients with objective patellar instability by [3, 27]. Given these data an acceptable cutoff value in order to propose a tibial tubercle medialization could be quantified in 20 mm; nevertheless the reliability of this value used alone has been questioned recently [28] since approximatively 20%–28.6% of asymptomatic knees also showed a TT-TG distance exceeding this threshold [29, 30].

Knee position during TT-TG evaluation should also be considered. Goutallier defined the standard position at 30° of flexion since the patella dislocation usually occurs at this level of flexion [23]. Dejour et al. reported more reliable results with the knee in full extension since tibial rotation may vary less due to the limitation of the screw-home mechanism of the tibia that increases the external rotation of the tibia during knee flexion. Considering the role of the tibial rotation in the TT-TG evaluation, an undiagnosed rotational laxity could, therefore, affect the measurement, as well as a patient with a lack of full extension that could result in a slightly externally rotated tibia [26]. Considering these statements, a rigorous protocol is mandatory in order to obtain comparable results and reducing the effect of the other variables in the TT-TG assessment.

## 6.5 Patellar Tilt

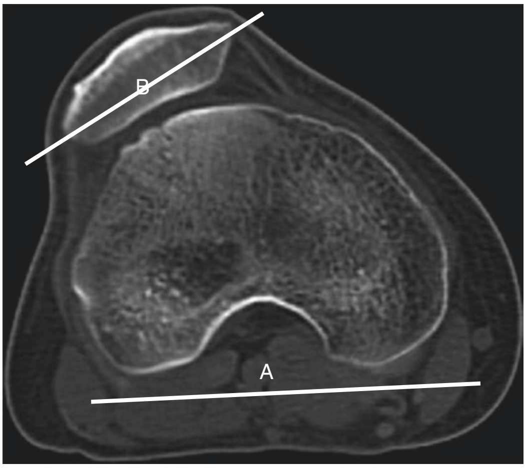

**Fig. 6.5** Excessive lateral patellar tilt. Patellar tilt is defined as the angle between the posterior bicondylar line (*A*) and the one passing through the major axis of patella (*B*)

Patellar tilt has been counted for years as a major factor of instability due to its high prevalence among unstable patients and because of the role of tight lateral structures that was considered primary in causing PF joint symptoms including instability. More recently it has been highlighted that patellar tilt is seldomly present alone, and it is more frequently function of other major anatomic factors, namely, trochlear dysplasia and increased TT-TG distance. Similarly to TT-TG, patellar tilt is measured by superposing two axial cuts: the one where patella is larger and the one used for identifying posterior femoral bicondylar line for TT-TG distance measurement. Patellar tilt is defined as the angle between the posterior bicondylar line and the one passing through the major axis of patella (Fig. 6.5). Schueda et al. considering 1792 knees determined a mean patellar tilt value with relaxed quadriceps of 22.2° ± 9.1° in patients with objective patellar instability in comparison to 9.6° ± 3.5° in the control group. The corresponding values with contracted quadriceps were 27.5 ± 11.0 and 10.2 ± 3.8, respectively [12].

## 6.6 Femoral Anteversion

Femoral anteversion is measured superimposing the axial trochlear cut with the axial cut including the femoral head and neck. A line connecting the middle section of the femoral neck to the centre of the femoral head is traced. A second-line tangent posterior femoral condyles are drawn.

The angle between these lines represents the degrees of femoral anteversion.

Dejour et al. reported a mean value in a healthy population is 10.8 ± 8.7, while in a population of patients with patellar instability, the mean value is 15.6 ± 9° [3].

More recently similar values were reported by Prakash et al. comparing 31 patients with recurrent patellar dislocation with 68 healthy patients, 15.7 ± 4.4 and 11.4 ± 5.5, respectively [31].

In contrast, higher values were reported by Liebensteiner et al. who determined a mean value of 25.9 + 9.4° in a randomly selected population [32].

In a recent study, Takagi et al., using a 3D CT scan reconstruction, reported values of 30.9 ± 9.6 and 17.0 ± 8.4 in a group of patients with recurrent patellar dislocation and a control group, respectively [33].

The heterogeneity of these data reinforces the necessity of a standardized protocol for a proper data collection in order to improve study comparisons. Some authors speculated also that the femoral anteversion could be directly correlated to the trochlear dysplasia, reporting a positive association between increasing CT values of femoral anteversion and higher degrees of trochlear dysplasia according to the Dejour classification [32].

## 6.7 External Tibial Torsion

External tibial torsion is measured superimposing the axial cut just below the proximal tibial articular surface with the axial section near the ankle joint at the base of malleoli gout [34]. A line tangent to the posterior cortex of the proximal tibia is drawn, and a second line is traced through the malleolar axis. The angle between these lines estimates the degrees of external tibial torsion (Fig. 6.6). Dejour and coworkers reported a mean value of 33° in a cohort of patients with objective patellar instability and 35° in the control group [3]. Conversely Prakash et al. reported higher mean values in the recurrent patellar dislocation group rather than controls, 30.9 ± 5.7 and 25.2 ± 6.4, respectively [31].

Both authors didn't evidence a statistical significant difference between the two groups in terms of external tibial torsion, leading to a lack of cutoff value required for clinical purposes.

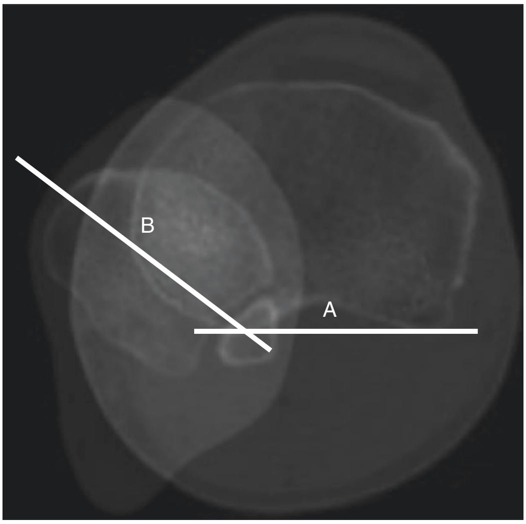

**Fig. 6.6** Excessive external tibial torsion. The tibial external torsion is measured as the angle between the line tangent to the posterior cortex of the proximal tibia (*A*) and the line passing through the malleoli (*B*)

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# 7

# The Role of Tibial and Femoral Rotational Torsion Abnormalities in the Treatment of Patellofemoral Dysfunction

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## 7.1 Introduction

Due to the complex nature of the patellofemoral (PF) joint, many different structural factors need to be examined to identify the source of patellofemoral dysfunction. One such source is torsional abnormalities. One explanation for undertreatment of rotational issues may be an underrecognition or unfamiliarity with long bone rotational assessment. A further explanation could rest in the wide variations of reported "normal" anatomy and difficulty in identifying what constitutes "excessive" bony rotation. Furthermore, a thorough understanding of the influence transverse plane abnormalities have on patellofemoral mechanics, pain, and overall function is complex. Torsional effects on the PF joint have been studied, and questions remain as to the true biomechanical origin for pain and the consequences of its surgical treatment [1]. A recent study on lower limb torsion revealed that trochlear dysplasia but not torsion predicted lateral patellar instability [2]. Conversely, several recent studies outline the effects of increased torsion, in particular excessive femoral anteversion, on patella instability [3–6].

It is of primary importance to define normal transverse plane anatomy of the femur and tibia and discuss their variations. Femoral anteversion is defined as the relationship between the axis of the femoral neck and the femoral condyles in the transverse plane [7]. At birth, the average femoral anteversion measures 40°, which decreases to an average of 15° by age 8. After this age, most authors consider there to be minimal change in the magnitude of femoral anteversion into adulthood [8], although some large cohort studies have suggested small amounts of remodeling can contribute thereafter [9]. It is well established that femoral anteversion typically decreases from birth to adulthood, but in certain conditions including cerebral palsy, myelomeningocele, and Down syndrome, "fetal anteversion" or persistent internal torsion of the femur may persist [10]. Femoral anteversion may also remain idiopathically in normally developing children, leaving them with rotational deformities in adulthood.

Staheli et al. (1985) [11] described tibial rotation as the relationship between the transcondylar axis of rotation of the knee and transmalleolar axis and tibial torsion as rotation more than two standard deviations from the mean. Intrauterine positioning and normal development of the limb buds result in internal rotation of the fetal tibia [8]. Postnatally, the tibia rotates externally until skeletal maturity with most rotation occurring in

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**Table 7.1** Variation of mean femoral torsion values in adults

| Cadaver | Physical exam | CT | EOS |
|---|---|---|---|
| Kingsley and Olmsted [64][a]—8°<br>Toogood [65]—9.73°<br>Archibald [66]—11.3°<br>Weinberg [67]—11.4°<br>Durham [68]—11.9°<br>von Mikulicz-Radecki [69]—12°<br>Pick [70]—14°<br>Soutter and Bradford [71]—14.3°<br>Parsons [72]—15.5° | No studies could be found describing an average or range of exam values | Buck [48][b]—11.6°<br>Reikerås [38]—13°<br>Folinais [20][c]—13.4°<br>Sugano [40][a]—19.3°<br>Rosskopf [53][b]—24°<br>Murphy [73]—31°<br>Sangeux [35][c]—31° | Buck [48][b]—11.6°<br>Folinais [20][c]—13.4° |

[a] Central neck axis (does not use the head neck axis)
[b] Method of Hernandez et al. [74]
[c] Method of Reikerås and Høiseth [38]

**Table 7.2** Variation of mean tibial torsion values in adults

| | Transcondylar tibia | Posterior condylar tibia | Other |
|---|---|---|---|
| Cadaver | Weinberg [67][a]—7.9°<br>Hutter [75]—21°<br>le Damany [76][a]—23° | Eckhoff [77]—34°<br>Butler-Manuel [78][a]—36° | Yoshioka [79]—24°<br>Elftman [80]—27° |
| Physical exam | | Staheli and Engel [28]—14° | Khermosh [81]—10°<br>Ritter [82]—11°<br>Malekafzali and Wood [83]—14°<br>Turner [24]—19°<br>Wynne-Davies [84]—20° Staheli [11]—25° |
| Radiography | Yagi [85]—24°<br>Jakob [86][a]—30° | Rosskopf [52]—27°<br>Waidelich [87][a]—33°<br>Butler-Manuel [78][a]—36°<br>Tamari [88][a]—40°<br>Jend [89][a]—41° | Clementz [90]—30°<br>Reikerås [38]—33° |

[a] Does not reference the bimalleolar axis distally

the first 4 years of life. Additional information was provided by Kristiansen et al. (2001) [12] who used CT scans of the tibia showing the average external tibial rotation of 28° at age 4 (20–37 range). Progressive external rotation continued at a rate of 1° per year until age 10. Thereafter only 4° of change occurs until maturity with an average adult external tibial torsion of 38° (range 18–47). Staheli (1993) [13] discovered tibial torsion of 2–4° external at birth, remodeling to 10–20° external at adulthood with a wide range of normal (0–40°). As with femoral anteversion, many neuromuscular or idiopathic conditions can result in deviations from this process. These studies illustrate the wide variance of normal due to numerous different methods and reference points which have been used for measurement. Multiple cadaveric and radiographic studies have attempted to define normal anteversion as well as tibial rotation (Tables 7.1 and 7.2). Within these studies, a wide range of mean values for femoral and tibia torsion are emblematic of the difficulty a surgeon faces in correctly identifying and treating pathologic torsion.

## 7.2 Biomechanics

A proposed mechanism for patellofemoral pain that is widely recognized is altered mechanics and magnified force, or stress, across the PF joint secondary to abnormal lower limb alignment [14]. Femoral anteversion often leads to a compensatory dynamic internal rotation of the hip to facilitate coverage of the femoral head. This internal rotation at the hip, and thus the entire femur, has been implicated as a cause for altered patellofemoral kinematics leading to patellofemoral dysfunction [15–17]. Transverse plane abnormalities of the femur have been the subject of multiple biomechanical studies providing insight into the origin of patellofemoral pain. In an effort to compensate for excessive femoral anteversion, internal rotation of the hip can result in dynamic knee valgus and proximal (hip) muscle weakness, both altering patellofemoral mechanics [18]. This internal rotation of the femur results in (relative) lateral translation of the patella above the medialized trochlea; this leads to decreased PF contact area with resultant increased PF stress [14, 19]. Biomechanical cadaveric investigations [16] have identified a lateral center of force shift with internal rotation of the femur and increased lateral patellar tilt when compared to the unrotated state. This was supported by an MRI study performed by Salsich and Perman (2007) [14] who examined patients with patellofemoral pain. They found greater amounts of tibiofemoral rotation were associated with smaller overall contact area of the patella on the trochlea.

External tibial torsion has been associated with abnormal patellar contact pressures, dynamic knee moments, as well as decreased power generation of the foot/ankle complex resulting in lever arm dysfunction [21]. External tibial torsion may create a lateral position of the patellar tendon insertion, leading to a lateral rotation of the patella with increased lateral trochlea contact forces and a decreased total contact area of the patellofemoral joint on the lateral trochlea. It has been tempting for PF surgeons to try and solve this problem by medialization of the tibial tubercle, but this does not correct the out-of-plane foot position. Medial tibial tubercle osteotomy may reduce an elevated Q angle vector but does not restore faulty limb kinematics.

A cadaveric biomechanical study by Lee et al. (2001) [22] displayed the effects of tibial torsion on patellofemoral contact pressures and areas. By testing knees at different tibial rotations, it was discovered that at 15° of tibial external rotation above the neutral position, significantly increased average and peak patellofemoral contact pressures were appreciated at all knee flexion angles. Also noted was a decrease in total contact area of the patellofemoral joint at 0, 30, and 60° of knee flexion. In contrast, internal rotation of the tibia was found to have very little change in pressure for all knee flexion angles. External tibial torsion not only leads to shifts in contact areas and pressures favoring decreased contact area and increased pressures but can also be the source of dynamic alterations in gait. Schwartz and Lakin (2002) [23] found tibial extorsion leads to flexion, valgus, and external rotation accelerations of the knee joint leading to lever arm dysfunction and decreased ability of the soleus to extend the knee. These deviations can lead to kinematic and kinetic gait deviations and long-term compensations that can negatively affect the PF joint.

Internal tibial torsion has been associated with degenerative changes of the knee although the nature of this relationship is still not well understood. Turner and Smillie in their 1981 [24] study measured tibial torsion in 1200 consecutive patients attending a knee clinic. They found that pan-articular degenerative changes were associated with a significant reduction in external tibial torsion (average of 12.5° vs. control of 19°). An animal study of mice with progressive internal tibial torsion also showed the development of degenerative changes in the knee, first starting at the bilateral patellofemoral joints [25]. A cause for early degenerative changes and knee pain secondary to internal tibial torsion might best be established by examination of the functional effects internal tibial torsion has on gait. Abnormal moments of the knee caused by internal tibia torsion have been appreciated using instrumented 3D gait analysis (3DGA). This includes increased coronal plane varus knee moments as well as sagittal and transverse plane moments [26]. The long-term effects of these abnormal kinetic gait deviations, although still unknown, may include knee pain and early degenerative changes in this population.

## 7.3 Approach in Clinical Practice

It is difficult to pick up torsional issues in the patient history, but careful attention to gait as a child/adolescent could point the clinician to the need of further workup for transverse plane lower limb abnormalities.

Heightened awareness of potential torsional issues includes:

1. History of clumsiness or frequent falls as a child.
2. History of failure of treatment of anterior knee pain, especially ill-described pain that increases with weight-bearing activities.
3. Intoeing/out-toeing as child or adolescent.

At times torsional issues present with a history of patellar instability. It is important to establish whether this involves a true objective patellar dislocation event, typically associated with some degree of effusion and disability, or whether it is giving way episodes due to knee pain and quadriceps muscle dysfunction.

### 7.3.1 Physical Exam

The physical exam is done to rule out other pathologies and to ascertain when more advanced torsional workup might be of value. Exam includes:

- Observe the patient walking.
  - Intoeing/out-toeing (foot progression angle).
  - Internal rotation of hip in stance/medial pointing of patella (squinting patellae).
- Observe the patient standing with patellas pointing forward.
  - Genu varum/valgum.
  - Foot point in or out can be an indication of tibial torsion.
- Examination in prone position.
  - Increased internal rotation > external rotation of hip suggestive of femoral anteversion.
  - Trochanteric prominence angle (discussed below).
  - Thigh-foot angle, bimalleolar axis, second toe test (discussed below).
- Importance of foot examination: as pes planovalgus can mask anteversion/internal tibial torsion. Can also falsely diagnose external tibial torsion when true pathology is in the foot. Importance of holding foot in subtalar neutral position when examining torsion.

A hyperlaxity scale should be included in the physical exam, with specific attention paid to recording knee hyperextension.

Quantifying the rotational alignment of the lower extremity on physical examination is difficult to do reliably due to significant intra- and interobserver variability. For tibial torsion, the most commonly used examination techniques are the thigh-foot angle (TFA) (Fig. 7.1a), the transmalleolar axis (Fig. 7.1b), or the second toe test [11, 27, 28]. Because of anatomic variations, surface landmarks may not consistently represent the rotational alignment of the tibia [29].

For tibial torsion, Lee et al. [30] determined that interobserver reliability and concurrent validity with computed tomography (CT) were highest for TMA, followed by TFA, and then the second toe test [30].

The trochanteric prominence angle test (TPAT) is the physical exam method most widely used for femoral version (Fig. 7.2) [11, 31–34]; however studies are mixed when compared with intraoperative values [34] and CT scans [32, 35]. Some differences between studies are at least partly explained by the fact that intra-observer exam measurements are more consistent than interobserver measures of the transverse plane alignment for the femur and tibia [11, 30].

### 7.3.2 Imaging

Radiographs: AP standing alignment films—though torsion cannot be viewed with accuracy on a two-dimensional image, a hint into version can be gleamed from observing the lesser trochanters at the hip level, the intercondylar notch and fibula position at the knee level, and the fibular position at the ankle level (Fig. 7.3a–f). Standing films should be taken in a consistent manner within your institutions. Most techniques favor toes pointing straight ahead, while others favor knees pointing straight ahead.

#### 7.3.2.1 Computed Tomography (CT)

CT is widely used for measuring lower extremity rotation due to its availability and ability to visualize bony landmarks [36]. Its drawbacks are

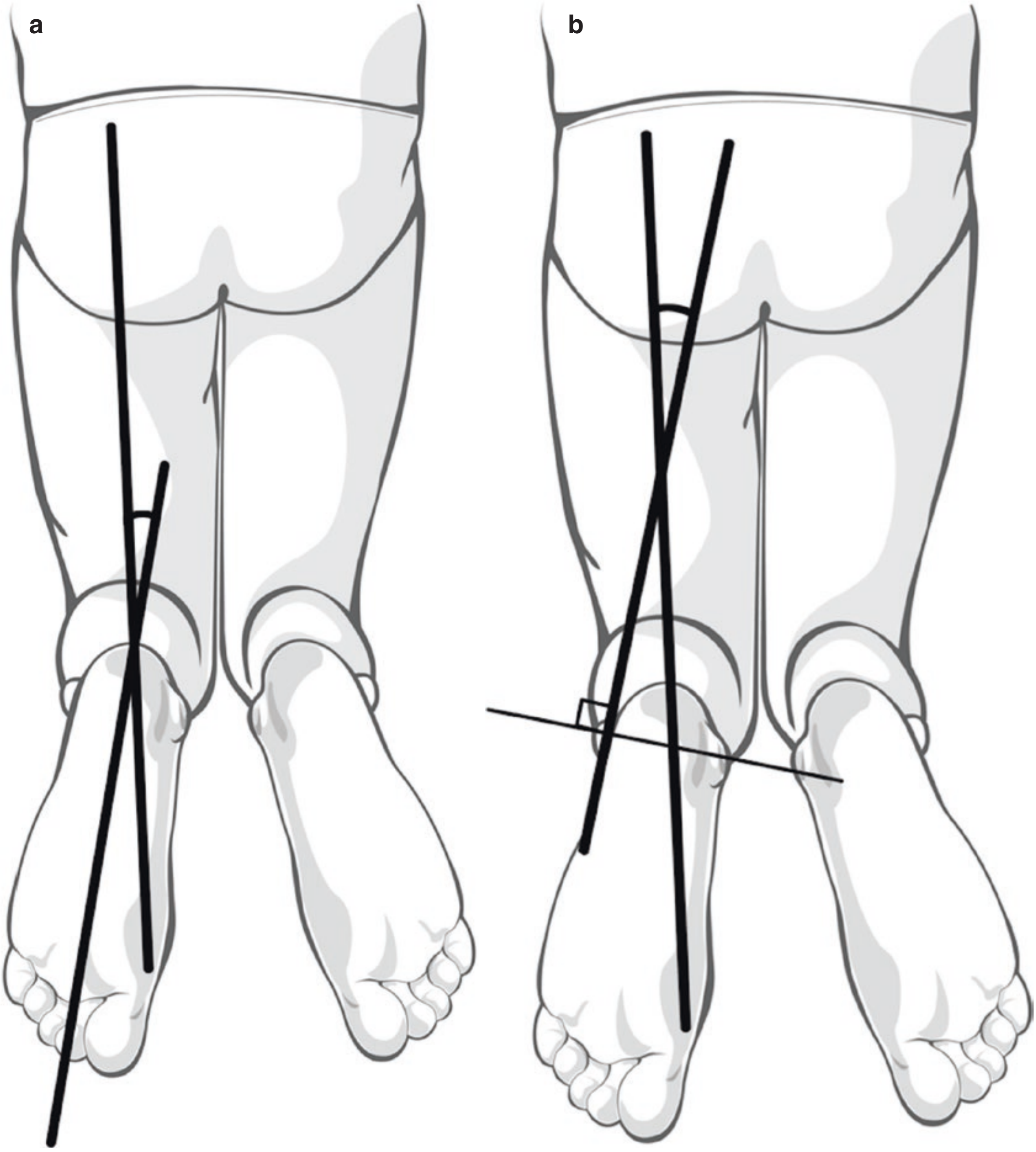

**Fig. 7.1** (**a**) Measuring tibial torsion using the thigh-foot angle. A line is measured down the midline of the thigh and the midline of the foot at 90° of knee flexion. External tibial torsion is 180° minus the goniometric measurement. (**b**) Measuring tibial torsion using the transmalleolar axis. External tibial torsion is the angle formed by the transmalleolar axis and the long axis of the thigh

high radiation exposure, expense, variation in user-defined reference axes causing interobserver discrepancy, and need for consistent patient positioning [37, 38].

Multiple CT techniques have been published to assess tibial and femoral torsion [1, 36, 37, 39, 40] and are beyond the scope of this review. In clinical practice however, it is important to have consistency in the technique used to measure the femur and the tibia, preferably done by the same radiology team, to reduce variance.

**Fig. 7.2** Measuring femoral torsion with the trochanteric prominence angle test: With the patient prone, anteversion is measured when the greater trochanteric is palpated in its most prominent position as the hip is internally and externally rotated. When the greater trochanter is most prominent, the femoral neck is horizontal. Unless there is a coronal plane deformity at the knee, the tibia is perpendicular to the posterior aspect of the femoral condyles. The angle between the vertical and the long axis of the tibia represents femoral neck anteversion

Due to the advancing use of magnetic resonance imaging (MRI) as a preferred imaging test, and the lack of radiation exposure, clinicians have utilized MRI slice imaging to assess limb torsion. MRI utilizes similar measurement techniques and has a high correlation with CT, although femoral neck angles on CT exceed those on MRI [31, 41]. The length of the scan time is considerably longer with a higher cost than CT scans in most institutions.

#### 7.3.2.2 Low-Dose Biplanar Radiography (EOS)

EOS is a low-dose biplanar radiographic imaging system, with great promise for skeletal radiography. Its main advantage is of transverse plane analysis with the patient standing and low radiation exposure [42, 43]. Radiation doses of EOS are significantly lower than standard radiography (3–43 times) [44–46] and CT (4–87 times) [20, 47].

For torsional measurements, AP/Lat images are taken with the capacity to have 3D modeling for torsional issues. Femoral and tibial torsion measurements obtained by EOS have comparable accuracy and interobserver agreement with CT in adults [20, 48, 49] and CT and MRI in children and adolescents [50–53]. At this time, EOS, physical examination, and 3DGA poorly correlate for femoral anteversion [54], suggesting that static and dynamic methods cannot be used to predict one another for hip rotational measurements.

### 7.3.3 Gait Analysis

The advent of three-dimensional gait analysis (3DGA) allows clinicians to move past static methods of patellofemoral joint assessment and limb rotation, to explore the dynamic function of the lower extremity through kinematics and kinetics. Three planes (sagittal, coronal, transverse) of motion can be evaluated throughout an entire gait cycle to obtain functional data including segmental position, dynamic movements, power, moments, speed, and energy. The effects of femoral anteversion can be assessed by dynamic hip rotation, while the tibial torsion is often evaluated by knee rotation. 3DGA is a powerful tool providing applicable and objective deviations in kinetics and kinematics and is advocated when planning surgical correction for rotational deformities.

Numerous studies have relied on 3DGA to better understand the dynamic concerns of the patellofemoral joint as a result of femoral and tibial torsion. By obtaining preoperative and postoperative analysis, objective data can be acquired on the functional effects rotational abnormalities have on the lower extremity, as well as improvements after derotation.

The dynamic effects of limb torsion primarily lie in the “out of plane” nature of joint motion in comparison to the direction of progression. When the axis of the joint is not well aligned for forward gait, this leads to moments and accelerations

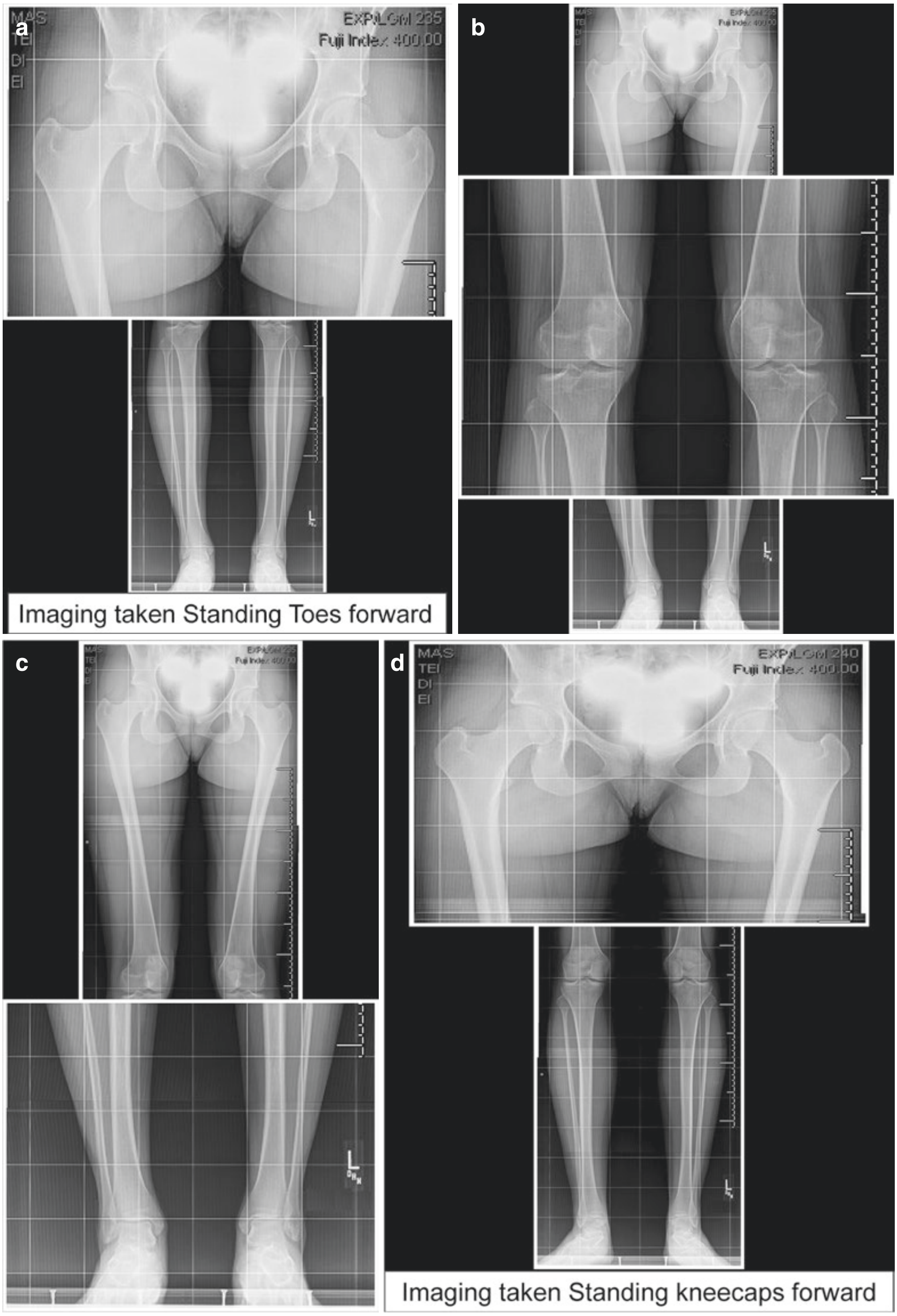

**Fig. 7.3** (**a**) Standing long-leg radiograph with toes pointing forward. The hips show hidden lesser trochanters. (**b**) Standing long-leg radiograph with toes pointing forward. The knees are rotated and not aligned forward. (**c**) Standing long-leg radiograph with toes pointing forward. The ankles show a true AP image. (**d**) Standing radiograph with knees forward. The lesser trochanters visible. (**e**) Standing radiograph with knees forward. The knees show a true AP image. (**f**) Standing radiograph with knees forward. The ankles are rotated and not aligned forward

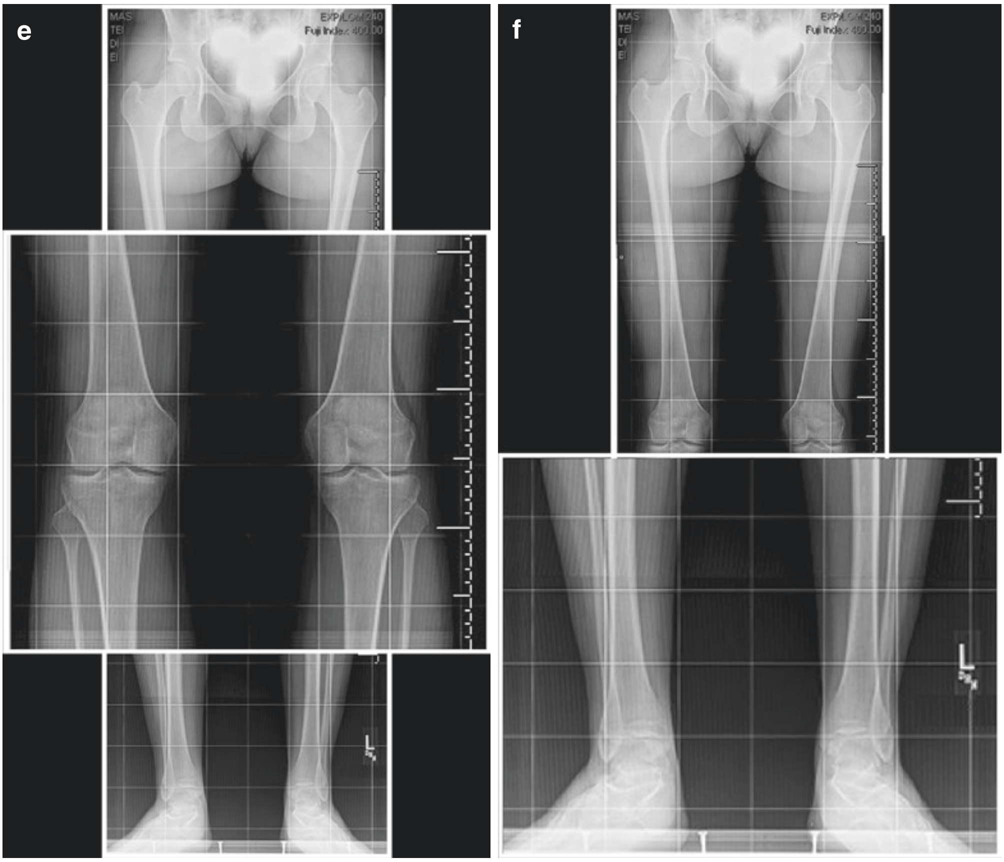

**Fig. 7.3** (continued)

which are inefficient for stance and swing and could have deleterious effects on joint health by compounding forces. For example, limb torsion typically leads to abnormalities in foot progression (intoeing or out-toeing). This leads to a divergence of the plantar flexor musculature and axis of the ankle in relation to forward progression of the body, thus causing lever arm dysfunction and reduced ankle plantar flexion moment. Since ankle plantar flexion is coupled with knee extension in gait, this also leads to a reduction in knee extension moment. With the efficiency of the plantar-flexor/knee-extensor couple diminished, other muscles, primarily the quadriceps, will need to be recruited to assist with knee extension which can lead to even greater patellofemoral forces [10]. The multiaxial nature and wide range of motion of the hip joint allow for a greater degree of compensation through hip rotation, and often non-operative treatment including emphasis on body movement patterns, gait, and core strengthening is sufficient.

External tibial torsion, in particular, can profoundly disrupt the distinctive and highly efficient composition of the entire lower extremity, leading to not only dynamic changes but also multi-planar deviations of gait. Long-term effects of these abnormal moments and forces on the patellofemoral joint secondary to transverse plane abnormalities could explain their association with patellofemoral pain.

The mechanism behind patellofemoral dysfunction with external tibial torsion continues to be incompletely understood. Alterations in the axis of motion and lever arm dysfunction can lead to abnormal coronal plane knee moments with decreased power of the ankle [21]. A 30° increase in external tibial torsion from average can reduce the capacity of the soleus, gluteus medius, and gluteus maximus to extend the hip and knee by 10% [55]. Aiona et al. (2012) [21] examined 26 limbs of patients with cerebral palsy and external tibial torsion with pre- and post-op gait analysis after distal tibial derotation osteotomies. Varus moments of the knee seen on preoperative gait analysis improved in 88% of limbs after tibial derotation osteotomy with improvement in knee pain in all patients reporting preoperative pain. Improvements in frontal knee moments have also been found for both internal and external tibial torsions after distal tibial derotation osteotomy [10].

Kinetic and kinematic dysfunction has also been studied in patients with internal tibial torsion. Davids et al. (2014) [26] examined the 3D gait analysis of normally developing children with internal tibial torsion performed preoperatively and postoperatively. Compared to normal controls, those with internal tibial torsion showed significantly increased sagittal knee moments at opposite toe off, opposite initial contact, in single support, and in loading response. A trend was also discovered toward increased external varus moment of the knee at opposite initial contact. Postoperative gait analysis after distal tibia derotation displayed significantly decreased coronal plane varus knee moment and improvements, but not normalization, of the sagittal and transverse moments. Tripping, falling, foot/ankle pain, and knee pain all significantly improved postoperatively.

The patellofemoral joint is a complex articulation which does not function in biomechanical isolation, rather it resides in an ever-changing environment with constantly changing forces and stresses. While 3D gait analysis does not replace static methods of patellofemoral assessment, it provides a valuable tool to any surgeon treating patients with patellofemoral dysfunction, especially in the setting of rotational plane abnormalities, by examining the dynamic nature of lower extremity movement in a plane that is difficult to access under direct vision.

## 7.4 Surgical Treatment

### 7.4.1 Tibial Derotation Osteotomy

There have been numerous techniques described in the literature for tibial derotation osteotomies. Many of these studies are based on children with neuromuscular conditions including cerebral palsy, clubfoot, and myelomeningocele, while several include patients with idiopathic tibial torsion. Discrepancies in technique include the level of osteotomy: proximal to the tibial tubercle vs distal to the tubercle (midshaft vs supramalleolar), method of fixation (cast, K-wires, intramedullary nails, plates), and if a fibular osteotomy is included in the procedure [56]. While no “gold standard” procedure has been exposed, in part due to multiple variables including skeletal maturity, magnitude of correction, or need for concomitant procedures, published studies have provided valuable information about risk of complications and functional outcomes.

Plate fixation for tibial derotation osteotomies was first described by Selber et al. (2004) [57] in which a T-plate was inserted for stability after 91 distal tibia derotation osteotomies in patients with neuromuscular disease. A major complication rate of 5.3% was reported including one aseptic nonunion, one fracture after plate removal, and one distal tibial growth arrest secondary to plate position across the physis. They cite the main advantage of plate fixation is the ability to place a below-knee cast and earlier weight-bearing than allowed with K-wire fixation. In a growing child, plates are typically removed after healing, but due to the lack of growth in an adult patient, a second procedure for removal could be avoided unless discomfort develops at the plate. This technique also provides advantages over intramedullary nail fixation in that it can be performed in the skeletally immature (Fig. 7.4a–i).

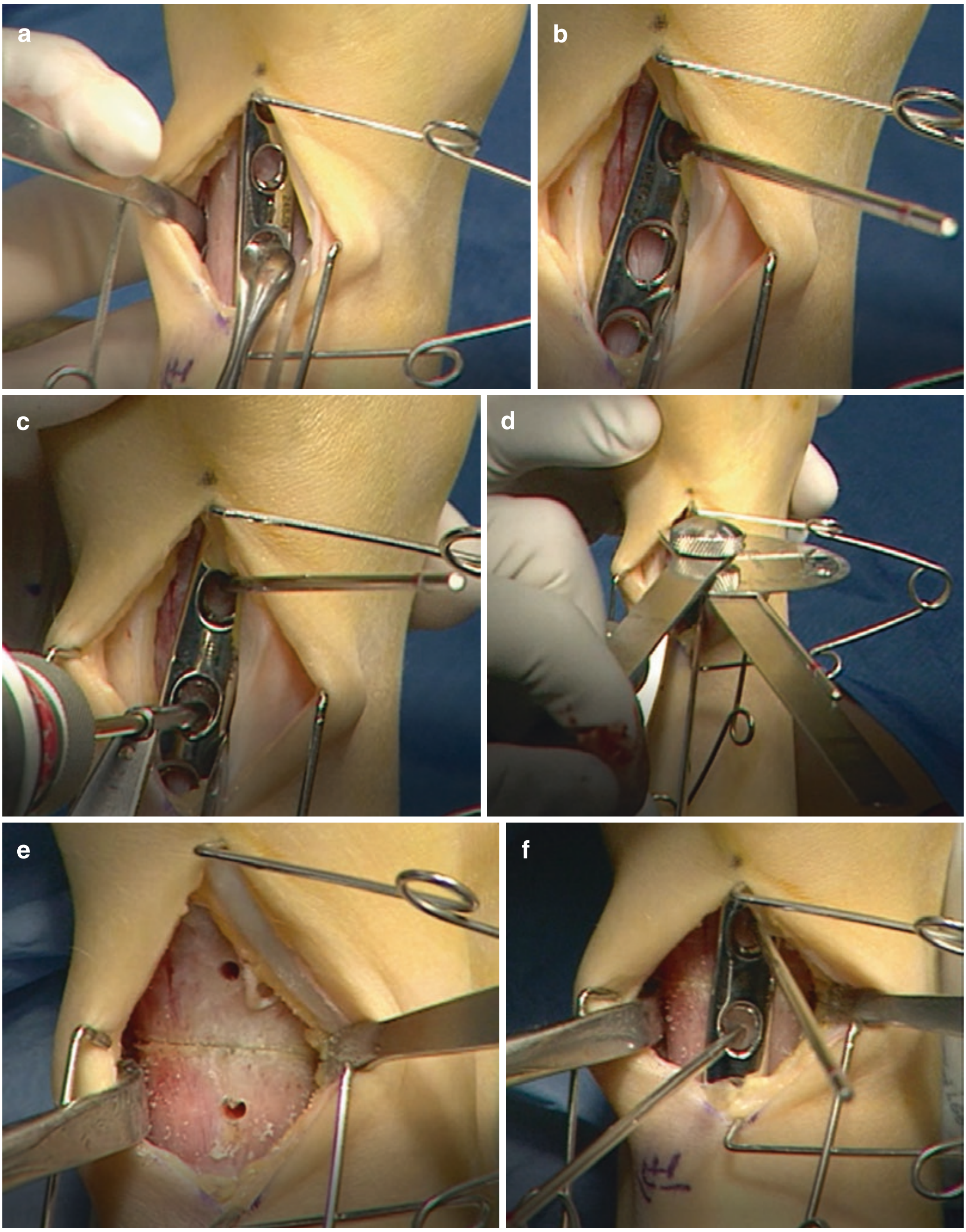

**Fig. 7.4** (**a**) Distal tibia incision made just medial to tibialis anterior tendon and subperiosteal dissection performed. A four-hole LC-DCP plate placed to ensure proper position above the joint line or physis. (**b**) The second to last hole is drilled in line with the second toe, measured, and a smooth Steinmann pin is placed for alignment. (Note: in this case the procedure is performed in prone position with ankle superior). (**c** and **d**) The second hole from the top is then drilled at the angle of correction. Notice the plate is angled, and so will be more vertical after derotation. (**e**) Plate removed and osteotomy is made between the drill holes. (**f** and **g**) Plate is placed into position with Steinmann pins and derotated until the pins are parallel. This is then held in position, while previously measured screws are placed. (**h** and **i**) After placement of most proximal and distal screws, X-rays are performed to ensure proper plate position and length of screws. Acknowledgment to Dr. Thomas Novacheck for pictures of distal tibia derotational osteotomy

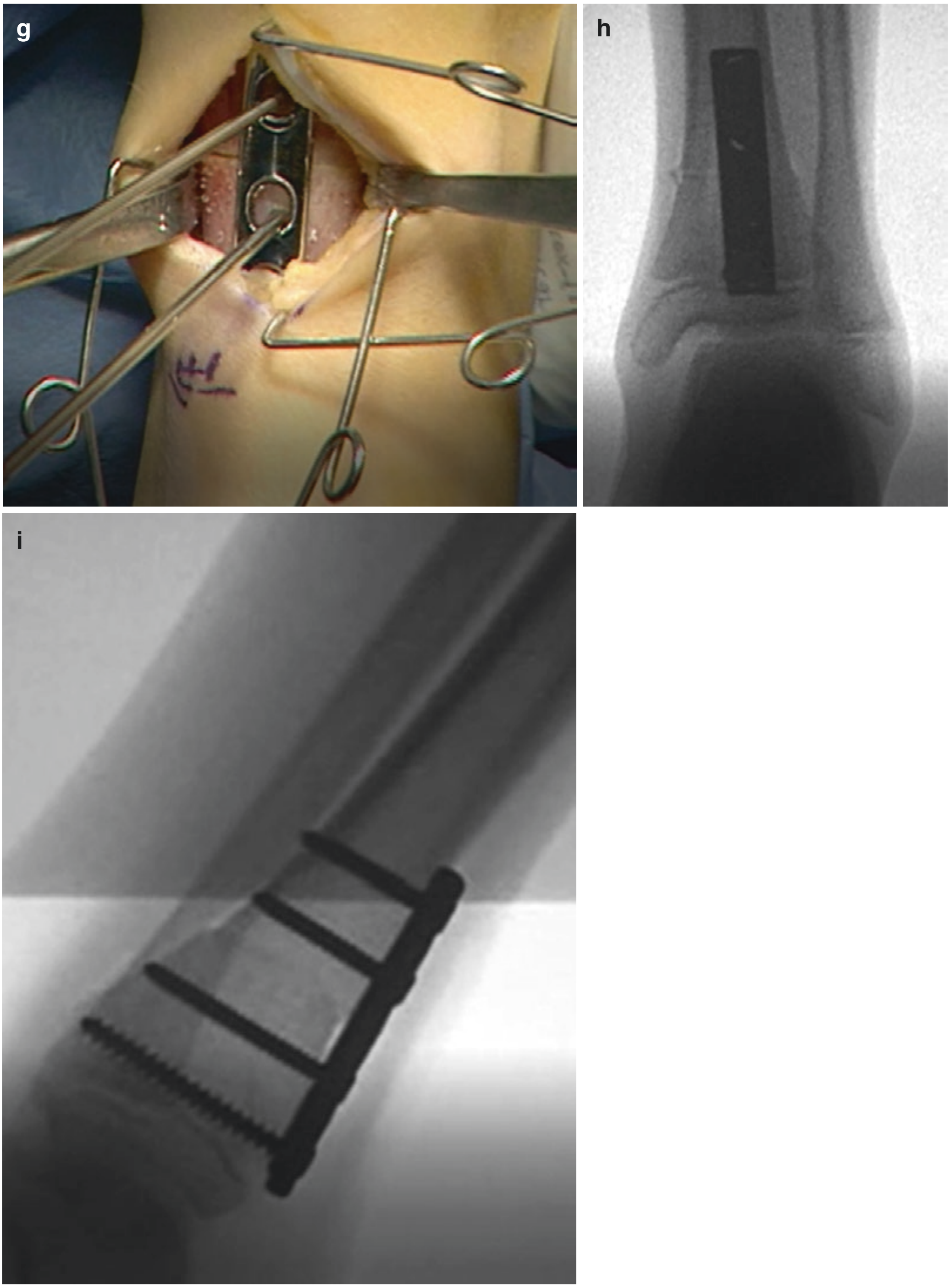

**Fig. 7.4** (continued)

Questions have been raised previously as to the ideal level to perform a tibial osteotomy: proximal (above the tibial tubercle) vs distal (below the tibial tubercle). Distal osteotomies can be further divided into mid-shaft. vs supramalleolar (Fig. 7.5a–c). Many studies have tried to answer this question by investigating the complication profile and technical complexity of each. Cameron and Saha (1996) [58] published their results of 18 knees with recurrent patellar instability and external tibial torsion with previous attempts at patellar realignment. Proximal tibial derotation osteotomies were performed proximal to the patellar tendon in an effort to decrease the quadriceps angle. Overall 76% had good to excellent results with only two complications of hardware pain, which improved with removal. Other authors have cautioned against the use of proximal tibial osteotomy due to concerns of peroneal nerve palsy and compartment syndrome secondary to the tethered and unforgiving nature of the neurovascular structures at this level and concern for disruption of the posterior knee capsule potentially increasing knee hyperextension [29, 58, 59]. One of the earliest reports of this was by Schrock in which peroneal nerve palsy occurred in 6/66 patients (9%) who underwent a proximal tibial

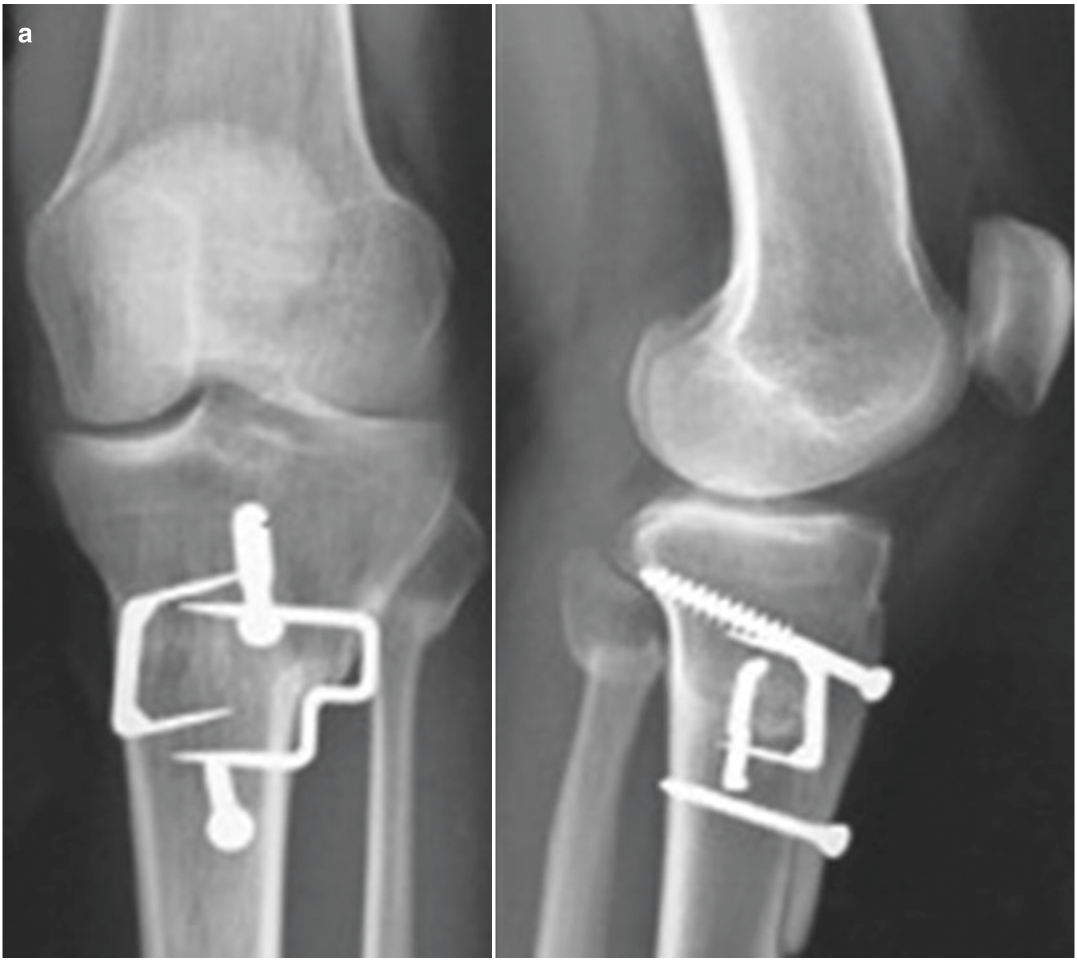

**Fig. 7.5** (**a**) AP and lateral knee view of a patient with a proximal derotation osteotomy combined with a tibial tubercle osteotomy. (**b**) Distal (below the tibial tubercle) osteotomy at the mid-shaft level using an IM rod as fixation. (**c**) Fig. 16 Distal osteotomy at the supramalleolar level

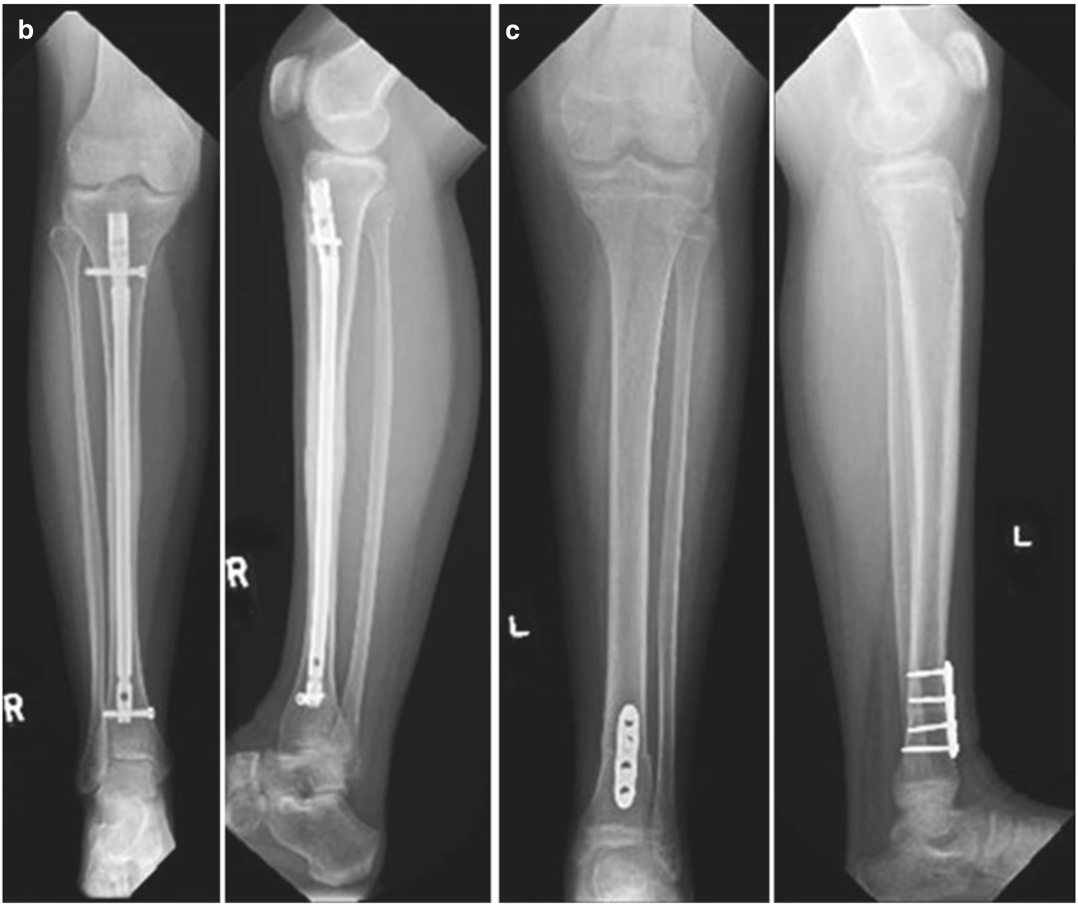

**Fig. 7.5** (continued)

osteotomy [59]. Krengel and Staheli (1991) [29] outlined their results on 52 tibial derotation osteotomies secondary to idiopathic tibial torsion. Of the 39 proximal osteotomies, serious complications occurred in 13% including 2 compartment syndromes, 2 peroneal nerve palsies, and 1 deep infection. In fact, 25% had complications that affected management or outcome which led to the abandonment of proximal osteotomies and movement to exclusively distal tibial osteotomies. No significant complications were seen in the distal osteotomy group leading them to recommend only a proximal tibial osteotomy when a correction is needed in the coronal plane. Due to concerns listed above, as well as its technically challenging nature, proximal tibial derotation osteotomies have been less frequently performed, in favor of the relatively simple, safe, and effective distal tibial osteotomy in the supramalleolar region for open or closed growth plates, and locked tibial intramedullary rods after physeal closure. They are recommended only for small corrections (<20°), when medialization of the tibial tubercle is felt to be advantageous as well as the tibial derotation. Though there is no gold standard for consideration of tibial derotation osteotomy, most clinicians feel a 15° correction is the minimum amount of correction for surgical correction, equating to an absolute value of 30–35° of external tibial torsion.

### 7.4.2 Is Fibular Osteotomy Needed?

Due to the robust ligamentous attachments between the tibia and fibula, it was classically presumed that derotation of the tibia without fibular osteotomy would be difficult to achieve. Traditionally, correction of tibial torsion has been performed with osteotomies of both the tibia and fibula; however the need for fibular osteotomy has been called into question. Rattey and Hyndman (1994) [60] examined 45 consecutive distal tibial derotation osteotomies immobilized in a cast without internal fixation. Group 1 had only a tibial osteotomy, while group 2 had both tibia and fibula osteotomies. Posterior and coronal plane angulation was significantly higher in group 2, as well as having one case of chronic lateral compartment syndrome. Mean operative time was 21% faster when a fibular osteotomy was not performed.

Dodgin et al. (1998) [56] added stability with K-wire fixation to distal tibia and fibula derotation osteotomies with a complication rate of 4.8% including no angular deformities, neurologic complications, delayed unions/nonunions, or compartment syndromes. In contrast, Deirdre et al. (2005) [61] presented 72 distal tibia derotation osteotomies without fibular osteotomy in children with cerebral palsy. An average derotation of 21° was performed without the need for concomitant fibular osteotomy. Their greatest amount of derotation was 35° and was performed without difficulty. By augmenting the stability with internal fixation (primarily K-wires) similar to Dodgin et al., they did not experience issues with angular deformities. Internal fixation with a plate has been described with no difference in results between groups with and without fibular osteotomy [57]. A randomized prospective study by Manouel and Johnson (1994) [62] in which 35 patients undergoing a supramalleolar osteotomy with K-wire fixation were randomized into “intact fibula” and “osteotomized fibula” showed a complication rate of 2/20 tibias in the “intact fibula” group vs 8/20 in the “osteotomized group.” Although this did not reach statistical significance, they recommend it may be advantageous to leave the fibula intact.

Based on the literature, the question of “if and when” a concomitant fibular osteotomy is needed is still unclear. Satisfactory results have been identified for each with relatively low risk. While it is not universally adopted, trends in the literature point to performing an isolated osteotomy of the tibia unless a full rotational correction cannot be achieved without a fibular osteotomy.

### 7.4.3 Femoral Osteotomy Stabilization

Fixation after completion of an osteotomy has evolved over time. While early reports relied on casting [60], today it is generally accepted that more stability is needed to allow desired results. K-wires, staples, plates, and intramedullary nails have all been utilized, each having their own advantages and disadvantages. Numerous studies have used K-wire fixation supplemented with long leg casting primarily in children and adolescents [56, 61, 62]. Proponents of this form of fixation cite low risks of iatrogenic deformity (0–10%) [61, 62] as well as no need for second surgery for removal of implants as K-wires are removed in clinic. While good results have been found in children, there is a lack of evidence if this form of stability is sufficient for an adult. Long leg casting is also required which can be burdensome.

Intramedullary (IM) nail fixation can provide immediate stability and eradicate the need for casting, but prominent and painful implants, specifically locking screws, can often lead to subsequent procedures. Ferri-de-Barros et al. (2006) [63] performed percutaneous rotational osteotomies in skeletally mature adolescents with cerebral palsy in both the tibia and femur. Of the 14 osteotomies of the tibia, there was 1 major complication (pseudoarthrosis of the tibia requiring revision) and 5 minor complications (pain at locking screw requiring removal). IM nails must be performed in the skeletally mature patient with a mid-diaphyseal osteotomy location, limiting its use in biplanar correction which at times is desired at the distal femoral level (to correct coronal and axial plane alignment). Issues with anterior knee pain (following proximal tibial IM nail insertion), prominent/painful implants (locking screws), and potential difficulty in removing the IM rod if needed years later are why some surgeons favor other methods to correct torsional deformities. This can include proximal (Fig. 7.6a–h) or distal

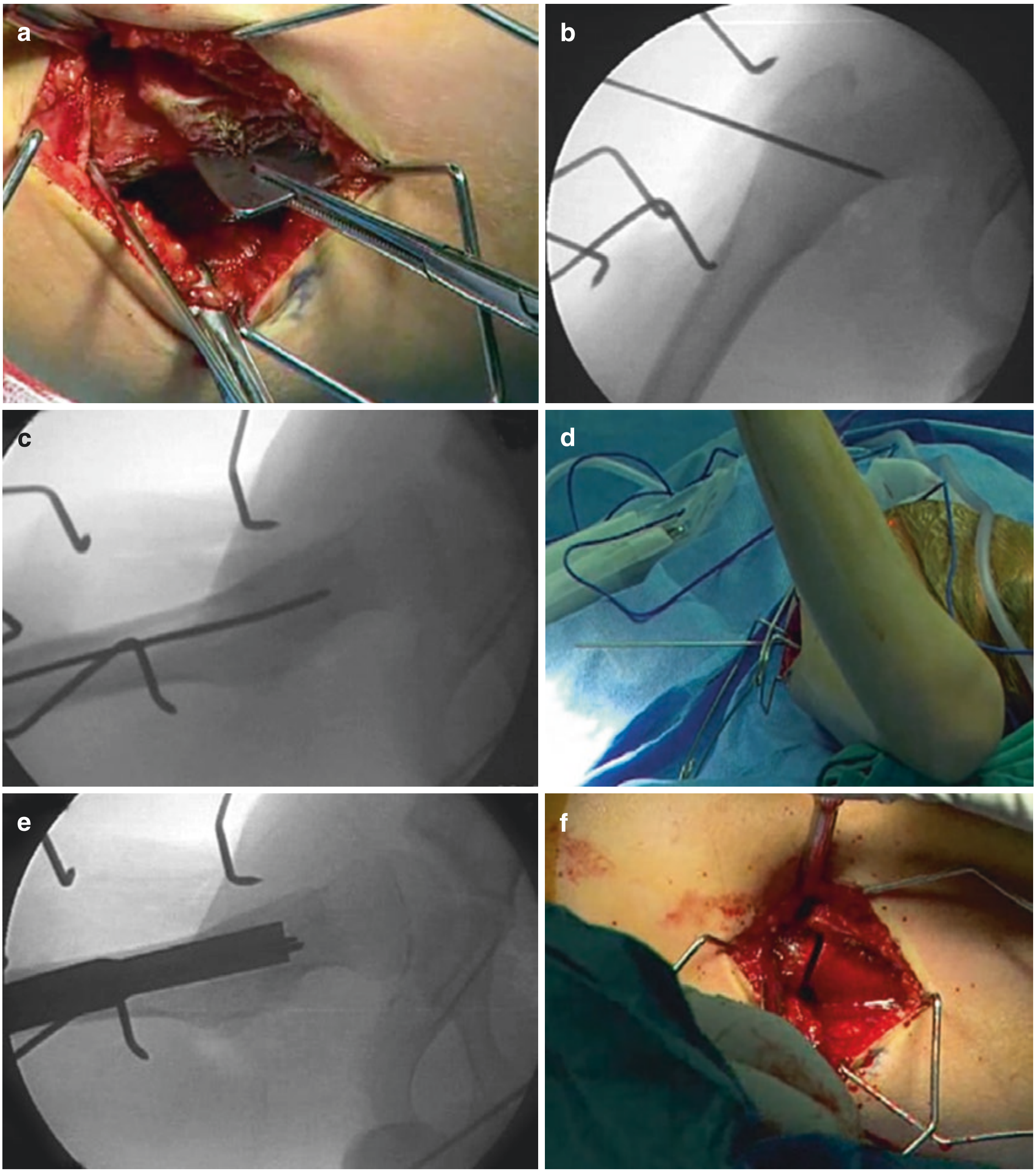

**Fig. 7.6** (**a**) Standard lateral approach to the femur is completed. Guidewire is placed using an 80-degree guide for a 100-degree blade plate to ensure no varus or valgus is performed. (**b** and **c**) Guidewire is placed at an 80-degree angle on the AP view and through the center of the femoral neck on the lateral view. (**d**) The degree of anteversion prior to the osteotomy is calculated by measuring the angle between the tibia and a vertical line as the guidewire is placed horizontal to the ground (similar to trochanteric prominence angle). (**e**) Chisel is then placed below the guidewire, ensuring it does not violate the cortex of the femoral neck. (**f**) Osteotomy is performed horizontally below the level of the chisel. (**g**) Derotation is performed and held with a clamp at the desired amount of anteversion. (**h**) Final construct after osteotomy is stabilized with screw fixation in the femoral shaft. Acknowledgement to Dr. Thomas Novacheck for pictures of femoral derotational osteotomy

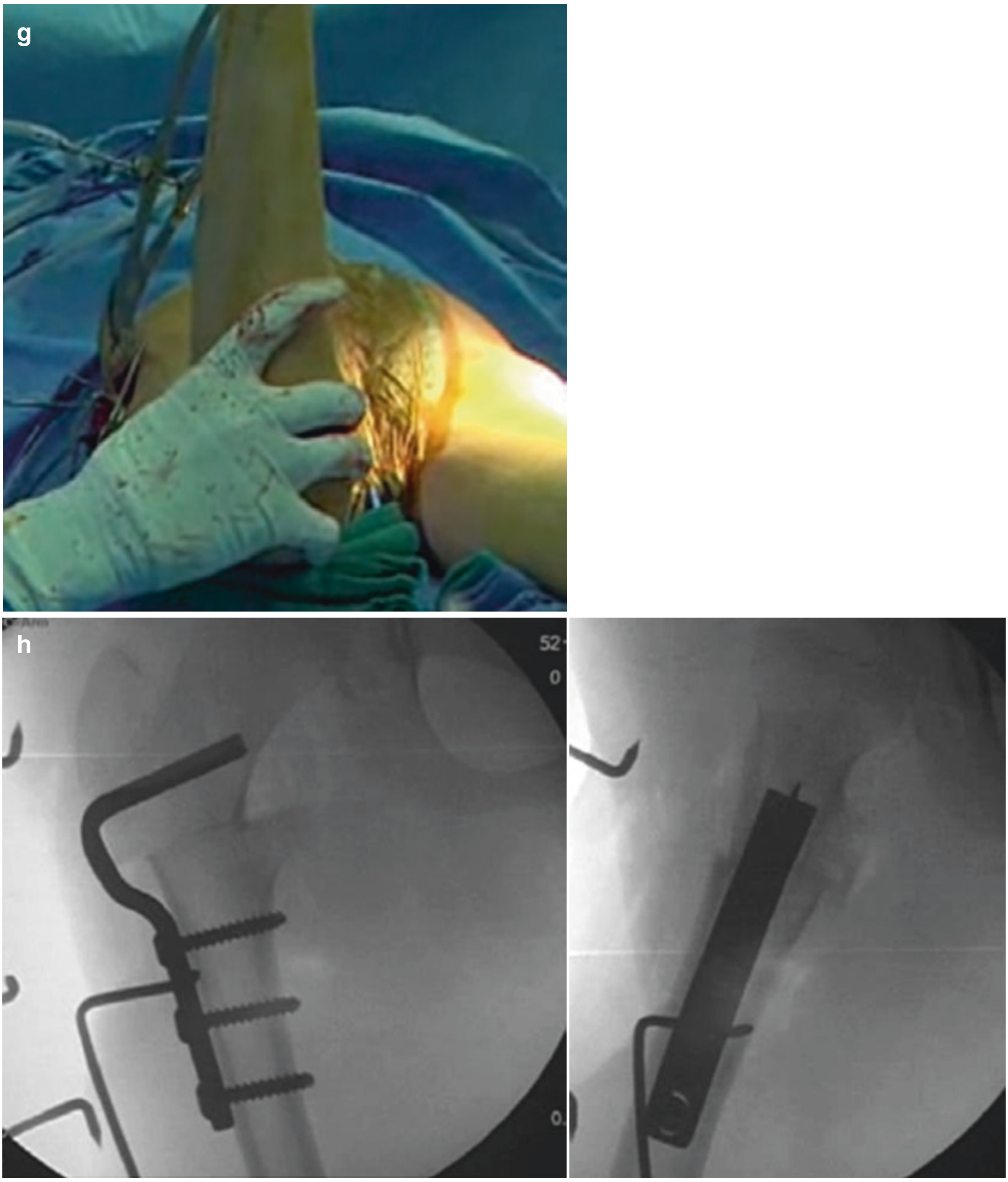

**Fig. 7.6** (continued)

femoral osteotomies utilizing plate and screw fixation which allow for quite accurate rotational correction and the ability for biplanar correction if desired. This can require larger incisions and scarring which may be an aesthetic concern, especially in the young adult.

At the femoral level, biplanar correction is most easily accomplished at the distal level and can be fixed with plate fixation (larger incisions, easier accuracy with correction) or an IM rod (smaller incisions, longer time to heal diaphyseal region) (Fig. 7.7a, b).

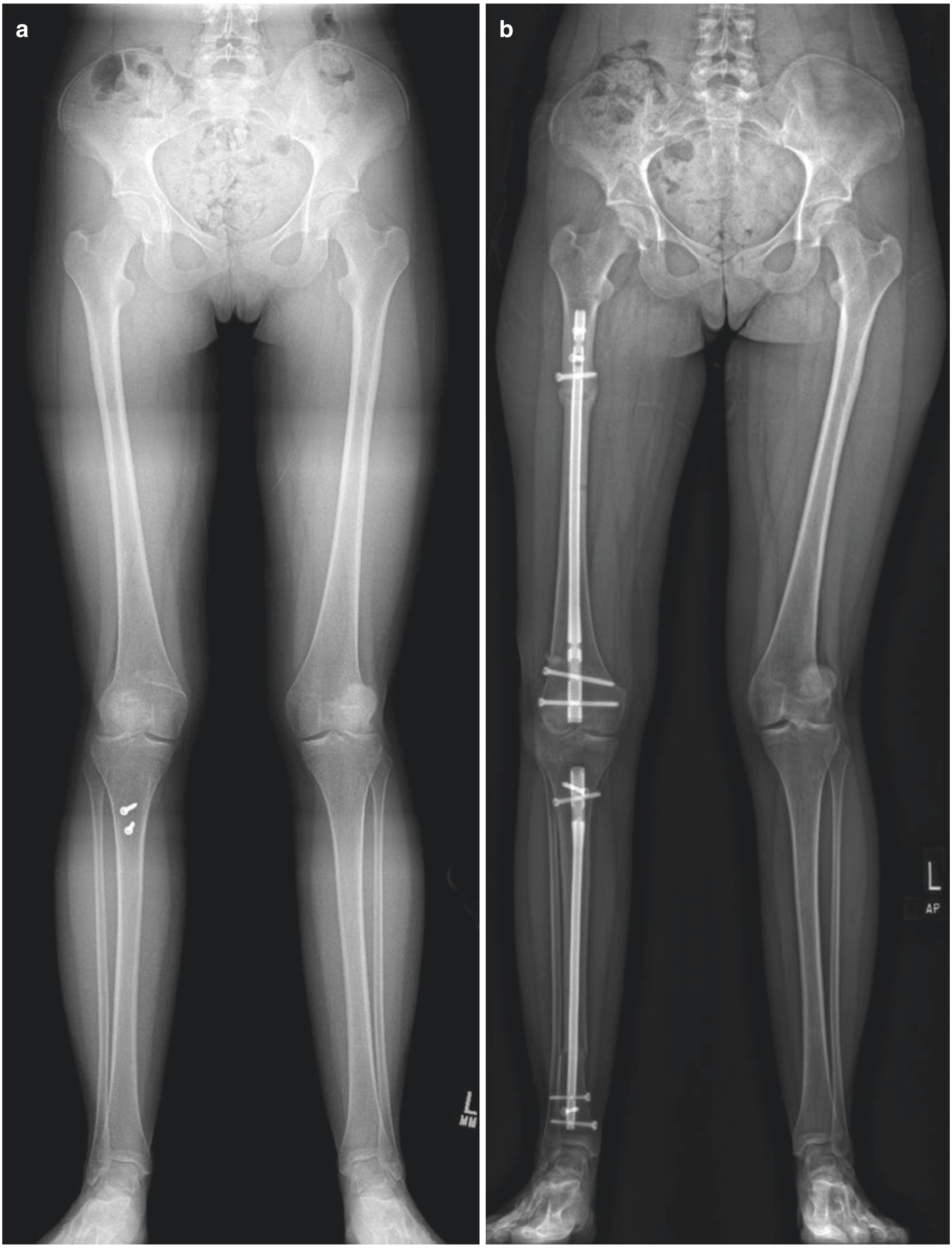

**Fig. 7.7** (**a**) Preoperative AP alignment films on a female with increased femoral anteversion and limb valgus. (**b**) Postoperative AP alignment films after right limb biplanar corrective femoral osteotomy using a proximal cut to correct axial plane and distal cut to correct coronal plane alignment. A derotation tibial osteotomy was added to place foot in the frontal plane with ambulation

## 7.5 Conclusion

Torsion of the femur and/or tibia can impair joint moment generation, which can result in adverse effects on joint health and gait compensation.

Under-detection and undertreatment of transverse plane malalignment of the tibia and femur result from lack of clinical awareness, as well as challenges of the accuracy and reliability of both physical examination and imaging measurements.

CT measurements of long bone rotational alignment are limited by variable reference axes, radiation exposure, and the static nature of the exam, with no ability to measure dynamic compensation. To date, there are no intraoperative applications.

Functional modeling in 3D gait analysis provides subject-specific kinematic data that can detect both static and functional alignment, though marker placement and body habitus can affect results.

EOS-generated 3D data holds promise for assessing multi-planar limb alignment and has its greatest potential application in imaging pre- and postoperative outcomes of surgical technique.

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# 8 Pathophysiology of Anterior Knee Pain

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## 8.1 Introduction

Anterior knee pain (AKP) is the most common reason for adolescents, adults, and physically active people to consult with an orthopedic surgeon who specializes in the knee [1]. Despite the high incidence and prevalence of AKP [2] and an abundance of clinical and basic science research, the etiology of the disorder is often difficult to pinpoint. However, it is typically thought to be multifactorial, which can complicate its treatment [3, 4]. The objective of this paper is to analyze the structural and functional changes that accompany AKP in order to define a logical therapeutic approach. This chapter synthesizes our research and clinical experience on pathophysiology of AKP in the young patient.

## 8.2 Theories on the Genesis of AKP

Until the end of the 1960s, AKP was attributed to chondromalacia patellae, a concept from the early twentieth century [5] that has no clinical value because it offers no specific diagnostic, therapeutic, or prognostic implications. In fact, many authors have failed to find a clear connection between AKP and chondromalacia patellae [6, 7]. Unfortunately, many doctors and physical therapists continue to ascribe any pain in the anterior aspect of the knee to chondromalacia patellae. Although this concept should be abandoned, chondromalacia patellae continues to be included in the International Statistical Classification of Diseases and Related Health Problems (ICD-10, Version 2016), with the code M22.4 [8].

In the 1970s AKP was related to the presence of patellofemoral malalignment (PFM) [9–13]. PFM was defined as an abnormality of patellar tracking, with lateral displacement, lateral tilt, or both affecting the patella in extension but reducing in flexion. Excessive lateral pressure syndrome, for example, would be a type of PFM [9, 13]. For many years, PFM has been widely accepted as an explanation for the genesis of AKP in the young patient. In addition, this theory had a great influence on orthopedic surgeons, who subsequently developed several surgical procedures to "correct the malalignment." Unfortunately, when PFM was diagnosed,

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it was treated too often with surgery, with poor results in many cases. The overreliance on surgical treatment based on PFM theory is responsible for the negative reputation of AKP and its treatment because the surgery itself often failed or led to iatrogenic complications. Currently, the PFM concept is questioned and is not universally accepted as an underlying factor in AKP. In fact, the number of realignment surgeries has dropped dramatically in recent years due to a reassessment of the validity of the PFM paradigm.

An obvious problem with the PFM concept is that not all patellar malalignments, even those of significant proportions, are symptomatic (Fig. 8.1). A person with PFM may not experience pain if the joint is never stressed to the extent that the tissues are irritated. Such individuals probably learn early that "my knee hurts when I do sports" and therefore stop being active. Further, only one knee may be symptomatic, even though the underlying patellar malalignment is entirely symmetrical in both knees. In addition, patients with normal patellofemoral alignment on computed tomography (CT) can also experience AKP. Therefore, although the patellar malalignment theory is biomechanically appealing, it has failed to explain the presence of AKP in many patients.

We must also remember that significant differences have been demonstrated between subchondral bone morphology and the geometry of the articular cartilage surface of the patellofemoral joint (PFJ), in both the axial and sagittal planes [14]. Therefore, a radiographical PFM may not be real, and realignment surgery to correct the nonexistent problem could lead to a worsening of preoperative symptoms.

At the end of 1970s, skeletal malalignment of the limb was suggested as the genesis of AKP in some cases [15]. Skeletal malalignment, which is not the same as PFM, is the malalignment of the limb measured in the transverse, coronal, and sagittal planes. In particular, rotational abnormalities are important. Malalignment applied to the PFJ indicates malposition of the patella on the femur and malposition of the axis of the limb with respect to the trunk and the ground-reaction forces [16]. The presence of excessive femoral anteversion, excessive external tibial torsion, or increased varus or valgus abnormalities has a definite effect on the PFJ [16]. James in 1979 presented a comprehensive review of AKP in which he described the condition of *miserable malalignment*, that is, increased femoral anteversion and increased external tibial torsion [15]. In 1995 he reported on seven patients with miserable malalignment who had been treated with internal rotation tibial osteotomy during an 18-year period [17]. Several years earlier, Cooke (1990) [18] described internal rotation proximal

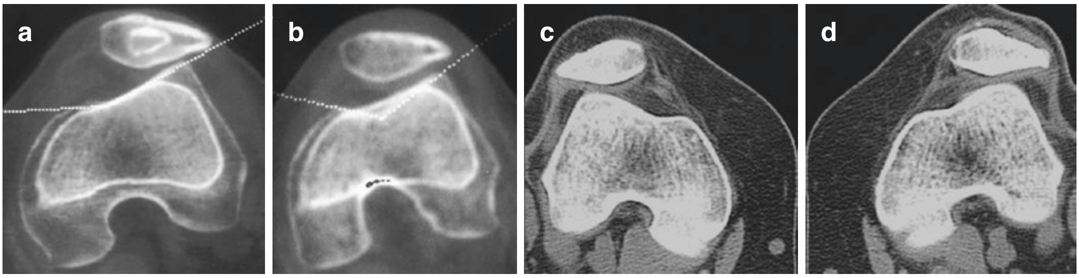


**Fig. 8.1** Disabling AKP and patellar instability of the left knee. The right knee was asymptomatic in spite of the fact that PFM was symmetric in both knees. (**a**) Preop CT at 0°. (**b**) Postop CT at 6 months of proximal realignment surgery. (**c**) CT of the right knee. (**d**) CT of the left knee at 13 years of follow-up—the patient is completely asymptomatic in spite of the presence of a visible PFM. (a-Reused with permission from Thieme. From: Sanchis-Alfonso V. American Journal of Knee Surgery. Volume 7, Issue 2. Usefulness of computed tomography in evaluating the patellofemoral joint before and after Insall's realignment. Thieme: New York. 1994. b, c, d-Reused with permission from Springer. Pathogenesis of Anterior Knee Pain in the Active Young: Is There a Relation Between the Presence of Patellofemoral Malalignment and Pain? In: Sanchis-Alfonso V. Anterior Knee Pain and Patellar Instability. Springer 2011)

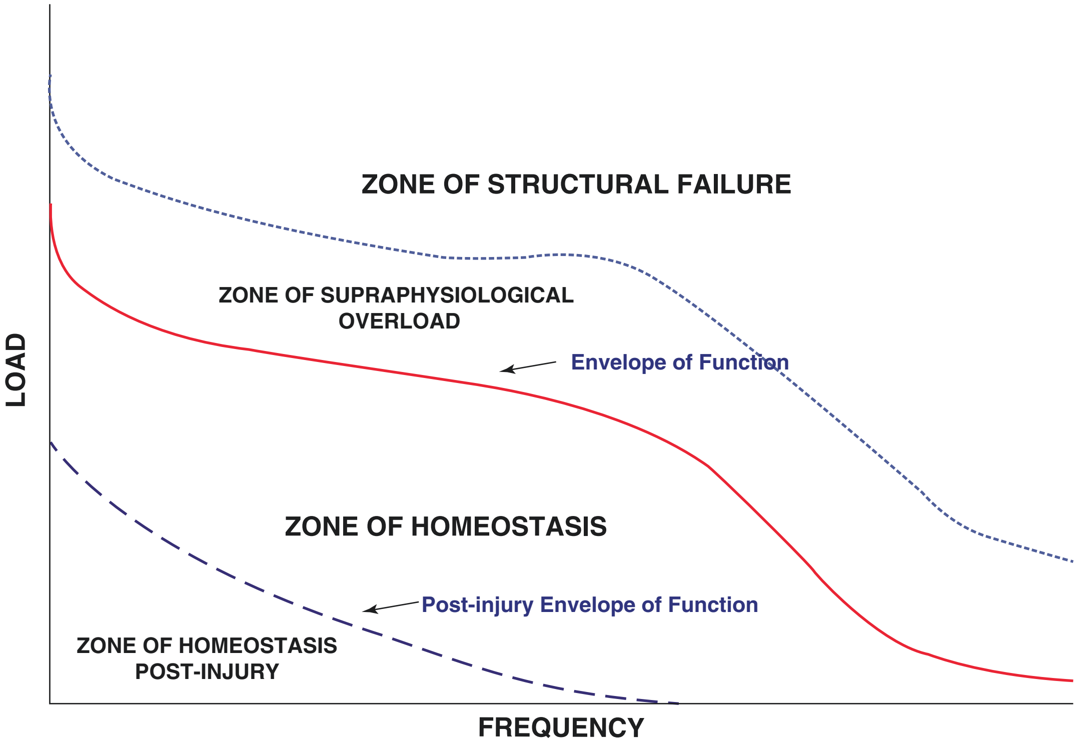


**Fig. 8.2** The envelope of function theory. (Reused with permission from SAGE. From Sanchis-Alfonso V, Dye SF. "How to Deal with Anterior Knee Pain in the Active Young Patient" Sports Health. 2017; 9(4):346–351)

tibial osteotomy in seven patients presenting with AKP and drew attention to the inwardly pointing knee as an unrecognized cause of AKP. Unlike the concept of PFM, however, the concept of skeletal malalignment was almost unnoticed and has had very low influence on orthopedic surgeons. In fact, very few publications refer to skeletal malalignment as a cause of AKP.

In the 1990s, Scott F. Dye and his research group at the University of California, San Francisco, proposed the tissue homeostasis theory [19, 20]. According to this theory, joints are not simply mechanical structures; they are systems that are alive and metabolically active [19]. Pain arises from a physiopathological mosaic of causes, including increased osseous remodeling, increased intraosseous pressure, or peripatellar synovitis leading to a reduced "envelope of function" (or "envelope of load acceptance") (Fig. 8.2) [6, 19, 20]. This envelope of function is defined by the range of loading and energy absorption that coexists with normal tissue healing and maintenance (i.e., tissue homeostasis). According to Dye, in the vast majority of AKP cases, the loss of homeostasis of both osseous (Fig. 8.3) and soft tissue in the peripatellar region is more important than biomechanical/structural issues in the genesis of AKP. He suggests that AKP patients are often symptomatic because of supraphysiologic loading of anatomically normal knee components [6, 19, 20]. In fact, patients with AKP often lack an easily identifiable structural abnormality to account for their symptoms. According to Dye's theory of envelope of load acceptance, overuse or cyclical overload of soft tissue or bone areas may explain AKP in many patients. However, it should be noted that this biological perspective is compatible with the biomechanical approach. The diagnostic challenge is to find the cause of the loading which is "in excess of the envelope of function or load acceptance."

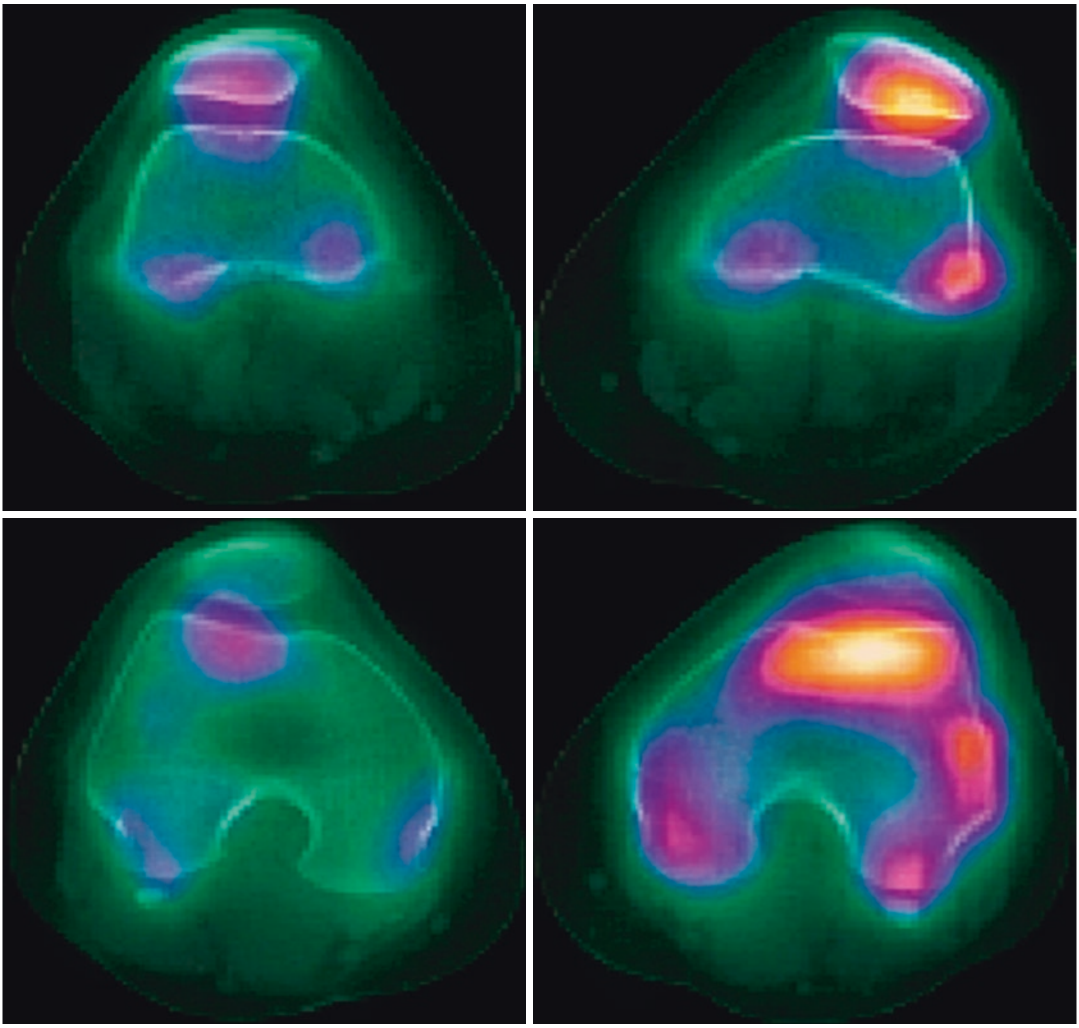


**Fig. 8.3** SPECT-CT in a patient with disabling AKP due to excessive external tibial torsion showing the loss of osseous homeostasis

## 8.3 A Critical Analysis of Realignment Surgery for PFM

After wide usage of certain surgical techniques, surgeons may come to question the basic tenets justifying the procedures and devise clinical research to test the underlying hypotheses. Realignment surgery for treating PFM is no exception. In 2005, Sanchis-Alfonso retrospectively evaluated 40 Insall's proximal realignments (IPRs) performed on 29 patients, with an average postsurgical follow-up of 8 years (range: 5–13 years) [21]. One of the objectives of this study was to analyze whether a relationship existed between the presence of PFM and that of AKP. In this study, IPR was found to provide a satisfactory centralization of the patella into the femoral trochlea in the short-term follow-up, and the surgery was associated with resolution of AKP [21, 22]. This outcome appears to support the PFM theory; however, the success of realignment surgery may have been due to factors independent of the relative patellofemoral position, such as denervation of the patella, extensive postoperative rest (unload), and postoperative physical therapy. Unfortunately, the satisfactory centralization of the patella observed at the short-term follow-up was lost by the long-term follow-up in almost 57% of the cases, based on CT scans [21]. That is, IPR did not provide a permanent correction of patellofemoral congruence in all cases. Nonetheless, this loss of centralization did not correlate with a worsening of clinical results. In short, a relation between the result (satisfactory versus nonsatisfactory) and the presence or absence of postoperative PFM was not found in the long term [21].

Out of 29 patients in the study, 12 presented with unilateral symptoms. In nine of these patients, the contralateral asymptomatic knee presented a PFM, and there was a satisfactory centralization of the patella into the femoral trochlea in only three cases [21]. If the presence of PFM is crucial in the genesis of AKP, how can we account for unilateral symptoms in patients with similar morphologic characteristics between both patellofemoral joints? With regard to unilateral pain in the presence of bilateral PFM, patients are known to preferentially load one limb more than the other (usually the dominant limb) in highly demanding activities, such as sports. This loading difference could be enough to cause unilateral pain, but we did not find a relationship between the lateral dominance and the affected side in cases with unilateral pain [23]. Further, in six patients with bilateral symptoms who received surgery on the knee with the most severe symptoms, the contralateral knee was pain-free at follow-up. Therefore, if the presence of PFM is crucial in the genesis of AKP, why do symptoms disappear without any change in the patellofemoral alignment? Loss of both tissue and bone homeostasis may be more important than structural characteristics in the genesis of AKP.

Viewing AKP as being necessarily tied to PFM is an oversimplification that has impeded progress toward better diagnosis and treatment. The great danger in using PFM as a diagnosis is that the unsophisticated or unwary orthopedic surgeon may think that he or she can correct it with surgical procedures. Pursuing this misguided path very often makes the patients' pain worse. The worst cases of AKP occur in patients that have had multiple PFM-oriented operative procedures for symptoms that initially were only mild and intermittent. We have observed that not all patellofemoral malaligned knees show symptoms, which is not surprising, because asymptomatic anatomic variations are not uncommon. Moreover, we have demonstrated that PFM is not a sufficient condition for the onset of symptoms, given that many patients with AKP do not have PFM. We can conclude that the pain does not arise from the patellar malalignment. That is, pain does not arise from the malposition of the patella on the trochlea. Thus, no imaging study should give us an indication for surgery. PFM diagnosed with plain x-ray, CT, or MRI is only an instant in time and does not describe the dynamics of motion. Moreover, we do not have adequate proof of the definition of normal alignment. History, physical exam, and differential injection must point toward surgery, with imaging only being used to confirm clinical impression.

## 8.4 Is There a Mechanical Overload of the PFJ Behind the AKP? Role of Patellofemoral Imbalance in the Genesis of AKP

Multiple approaches have been taken to determine the genesis of AKP, from the more traditional structural/biomechanical view to the newer tissue homeostasis perspective. Despite their differences, all potential explanations include joint loading as an important factor. This commonality is not surprising because the PFJ is very sensitive to stress.

Certain activities that highly load the PFJ, such as going down stairs or inclines or experiencing prolonged flexion while a person is sitting, kneeling, or squatting, are strongly associated with the genesis and persistence of AKP. In addition, a direct blow to the patella in a fall to the ground or with dashboard contact in an automobile accident can also cause pain that may persist for an extended time, even without an overt radiographically identifiable fracture. How can pain be explained in such cases by the tissue homeostasis perspective? The PFJ is one of the most highly loaded joints in the human body [24] as well as one of the most difficult musculoskeletal systems in terms of restoration of functionality after an injury and the subsequent loss of tissue homeostasis [25]. Joint reaction forces that are created within the PFJ with certain activities can be many times the body weight [26]. These high loads have been estimated to be 3.3 times the body weight with activities such as climbing up or down stairs, 7.6 times the body weight with squatting, and in excess of 20 times the body weight with jumping activities [27, 28]. In addition to the load applied to the joint, the actual stresses generated within the PFJ also depend on the surface areas of the patella and femur that may be in contact at any given moment [21]. Such high forces can easily result in loads that may exceed the safe load acceptance capacity of musculoskeletal tissues, leading to symptomatic damage and inducing a mosaic of pathophysiologic processes causing AKP [6, 20]. Further, patellofemoral overload could be secondary to inappropriate physiotherapy in some cases of AKP. Attempting to strengthen the quadriceps through open kinetic chain exercises will unacceptably overload the PFJ if the exercises are performed between 0° and 45° of flexion [29]. Likewise, closed kinetic chain exercises performed between 45° and 90° of flexion will also overload the PFJ [29]. Although there may be no obvious structural alteration, the PFJ can be overloaded, and AKP can be triggered.

In some cases, PFJ overloading is secondary to structural anomalies, such as trochlear dysplasia [30]. Patients with AKP are more likely to have trochlear dysplasia compared to pain-free individuals [31]. Moreover, in patients with a trochlear bump (severe trochlear dysplasia) and AKP, both hydrostatic pressure and water content increase in the patella [32]. Such increases potentially provoke episodes of tissular ischemia and mechanical stimulation of nociceptors, which are both associated with pain [3]. Along these lines, Barton and colleagues [33] have demonstrated that the patella contains an intraosseous nerve network that is the densest in the medial and central portions of the patella and significantly sparser laterally. Moreover, growing evidence shows that in the subgroup of patients with patellofemoral chondral lesions, some of their pain is related to such lesions due to the overload of the richly innervated subchondral bone interface [3]. Such subchondral bone overload is secondary to damaged cartilage and the loss of its capacity as a shock absorber.

However, of all the structural factors that can cause an overload of the PFJ, the most powerful is the skeletal malalignment of the lower limb (limb alignment in the three planes), specifically torsional alterations (femoral anteversion and/or external tibial torsion) [34, 35]. With regard to malalignment, Albert van Kampen [36] has demonstrated that patellar tracking is highly susceptible to tibial rotations. Therefore, patellar tracking biomechanical studies must take tibial rotation into account. However, classical PFM theory does not take “limb alignment,” that is, tibial and femoral torsion, into consideration, which represents another weak point in the PFM theory.

Limb alignment appears to very strongly influence the quadriceps vector [34, 35]. An abnormal quadriceps vector is an important contributor to AKP, and abnormal limb alignment is the underlying cause of the incorrect quadriceps vector [34, 35]. The direction of the quadriceps vector is likely more important than its magnitude [34, 35]. It should be noted that skeletal malalignment is not an abnormal Q-angle or an increased TT-TG distance, nor is it an increased tilt or increased shift of the patella. It instead involves the alignment of the limb in all three spatial planes—coronal, sagittal, and transverse. During a normal gait, the knee joint axis moves straightforward with minimal amounts of internal or external rotation, and the quadriceps force is directed posteriorly, compressing the patella into the trochlea. With abnormal limb torsion, the knee joint axis often moves forward in a manner that is oblique to the direction of motion. Such movement generates abnormal shear forces between the patella and the femur that will eventually cause tissue failure. If the force is not perfectly aligned, it can lead to an unbalanced distortion of the soft tissues surrounding the patella. It is very likely that one of the sources of AKP is in the peripatellar soft tissues due to the stress that the soft tissues undergo. However, we do not know the strain levels that must be reached to trigger the pain.

Some patients with torsional deformities have unilateral AKP, despite the deformity being symmetric. Why one side is symptomatic and the other is not remains an enigma. It is probable that most people limit their activity to avoid overuse or injury to the PFJ and thus AKP. Many of these patients are symptomatic only when they attempt an activity that causes increased loading; therefore, many select their activities based on what is comfortable. Once an injury (soft tissue lesion) or overuse (soft tissue strain) develops, quick recovery does not occur because of the underlying mechanical inefficiency. This situation may explain why disabling pain may occur on one side, while the opposite side remains asymptomatic. Moreover, the lack of symptoms on one side may be relative. In some cases, patients have asked for surgery on the asymptomatic side after the symptomatic side has been corrected because "they never knew what it was like to feel normal."

## 8.5 Neuroanatomical Bases for AKP in the Young Patient: Neural Model

Sanchis-Alfonso and colleagues have developed the *neural model* as an explanation for the genesis of AKP in young patients [37]. The origin of AKP can be in the lateral retinaculum (LR), medial retinaculum, infrapatellar fat pad, synovium, or subchondral bone [38–40]. Studies by Sanchis-Alfonso and colleagues on AKP pathophysiology have mainly focused on the LR retrieved during patellofemoral realignment surgery in patients with a diagnosis of PFM [23, 41–43].

### 8.5.1 Morphologic Neural Changes in the LR

Some studies have implicated neural damage in the LR as a possible source of AKP in the young patient. In 1985, Fulkerson and colleagues described for the first time nerve damage (demyelination and fibrosis) in the LR of patients with intractable patellofemoral pain requiring lateral retinacular release or realignment of the PFJ [44]. The changes in the retinacular nerves observed by these authors resembled the histopathologic picture of Morton's interdigital neuroma. Later, in 1991, Mori and colleagues found degenerative neuropathy in the LR in AKP patients [45].

Sanchis-Alfonso and colleagues have also observed nonspecific, chronic degenerative changes in nerve fibers, including myxoid degeneration of the endoneurium, retraction of the axonal component, and perineural fibrosis, in the LR in many cases (Fig. 8.4a) [43, 46]. Moreover,

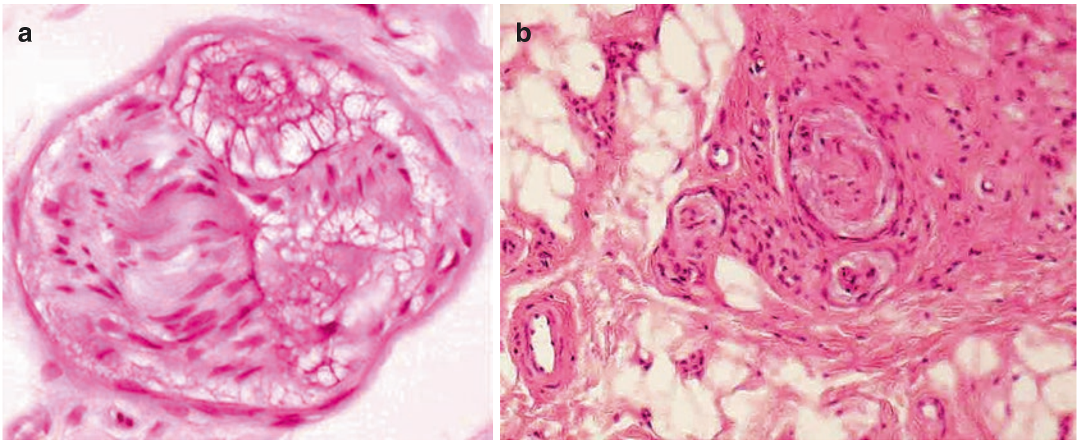


**Fig. 8.4** (**a**) Myxoid degeneration in the nerve fibers. No inflammatory cells are seen. (**b**) Microneuroma next to a rich vascular area (HE). (b-Reused with permission from SAGE. From: "Quantitative analysis of nerve changes in the lateral retinaculum in patients with isolated symptomatic patellofemoral malalignment" Am J Sports Med. 1998; 26:703–709)

Sanchis-Alfonso and colleagues have found that a smaller group of specimens presented nerve fibers mimicking amputation neuromas seen elsewhere in the body (Fig. 8.4b) [43, 46]. A clear relationship has been demonstrated between the presence of neuromas and AKP; however, a similar relationship between neural myxoid degeneration and pain has not been found [46].

Nerve damage occurs diffusely in the affected LR, and one must therefore consider the possibility of multiple neurologic sequelae in the peripatellar region. A possible consequence of such damage could be an altered proprioceptive innervation [44]. For example, Baker and colleagues observed an abnormal sense of the knee joint position (proprioception) in subjects with AKP [47]. Current research shows the importance of proprioceptive information from joint mechanoreceptors for proper knee function. Connective tissues, in addition to their mechanical function, play an important role in transmitting specific somatosensory afferent signals to the spinal and cerebral regulatory systems. Thus, the giving way in AKP patients can be explained, at least in part, by the alteration or loss of joint afferent information with regard to proprioception due to nerve damage in the ascendant proprioception pathway or a decrease of healthy nerve fibers capable of transmitting proprioceptory stimuli. It seems likely that, to a certain degree, the instability of the PFJ in patients with AKP arises not only from mechanical factors but also neural factors [48–50]. Such factors center on a proprioceptive deficit both in the sense of position and in the slowing or diminution of stabilizing and protective reflexes. In addition, Jensen and colleagues reported abnormal sensory function in the painful and nonpainful knee in some subjects with long-term unilateral AKP [51].

## 8.5.2 Hyperinnervation into the LR and AKP

Several studies have implicated hyperinnervation of the LR as a possible source of AKP in the young patient, with higher innervation in those with severe pain compared with those with moderate or mild pain [46]. Moreover, the LR of patients with pain as the predominant symptom has been shown to have a higher innervation pattern than the medial retinaculum or the LR of patients with patellar instability [46]. This nerve ingrowth consisted of myelinated and unmyelinated nerve fibers with a predominant nociceptive component (Fig. 8.5) [41].

The nociceptive properties of at least some of these nerves were shown by their substance P (SP) immunoreactivity (Fig. 8.6) [41]. SP, which is found in primary sensory neurons and C fibers (slow-chronic pain pathway), is involved in the neurotransmission pathways of nociceptive signals [52–64]. SP was detected in the axons of big nerve fibers, in free nerve endings, and in the vessel walls in some patients with pain as the predominant symptom [41]. Nociceptive fibers (i.e., neural fibers with intraaxonal SP) were fewer in number than NF fibers, indicating that not all the tiny perivascular or interstitial nerves were nociceptive [41]. Interestingly, the finding that SP fibers are more abundant in the LR than in its medial counterpart reinforces the role of the LR as the main source of pain in some AKP patients. Moreover, the number of these nociceptive fibers has been observed to be higher in patients experiencing pain as the main symptom relative to those with instability as the predominant symptom (with little or no pain between instability episodes) [41].

Nerve ingrowth is mostly located within and around blood vessels (Fig. 8.7) [41, 46]. Thus, within the LR of AKP patients, S-100 positive fibers in the adventitia and within the muscular layer of medium and small arteries resemble a necklace. S-100 protein is a good marker of nerves because it permits identification of the Schwann cells in the myelinated parts of axons. Myelinated fibers typically lose their myelin sheath before they enter the muscular arterial wall, but this was found to not be the case in AKP patients. In a study of myelinated fibers by S-100 immunostaining, we were surprised by the identification of S-100-positive fibers within the muscular layer of medium and small arteries given that the myelin sheath was expected to be lost before the nerve entered the muscular arterial

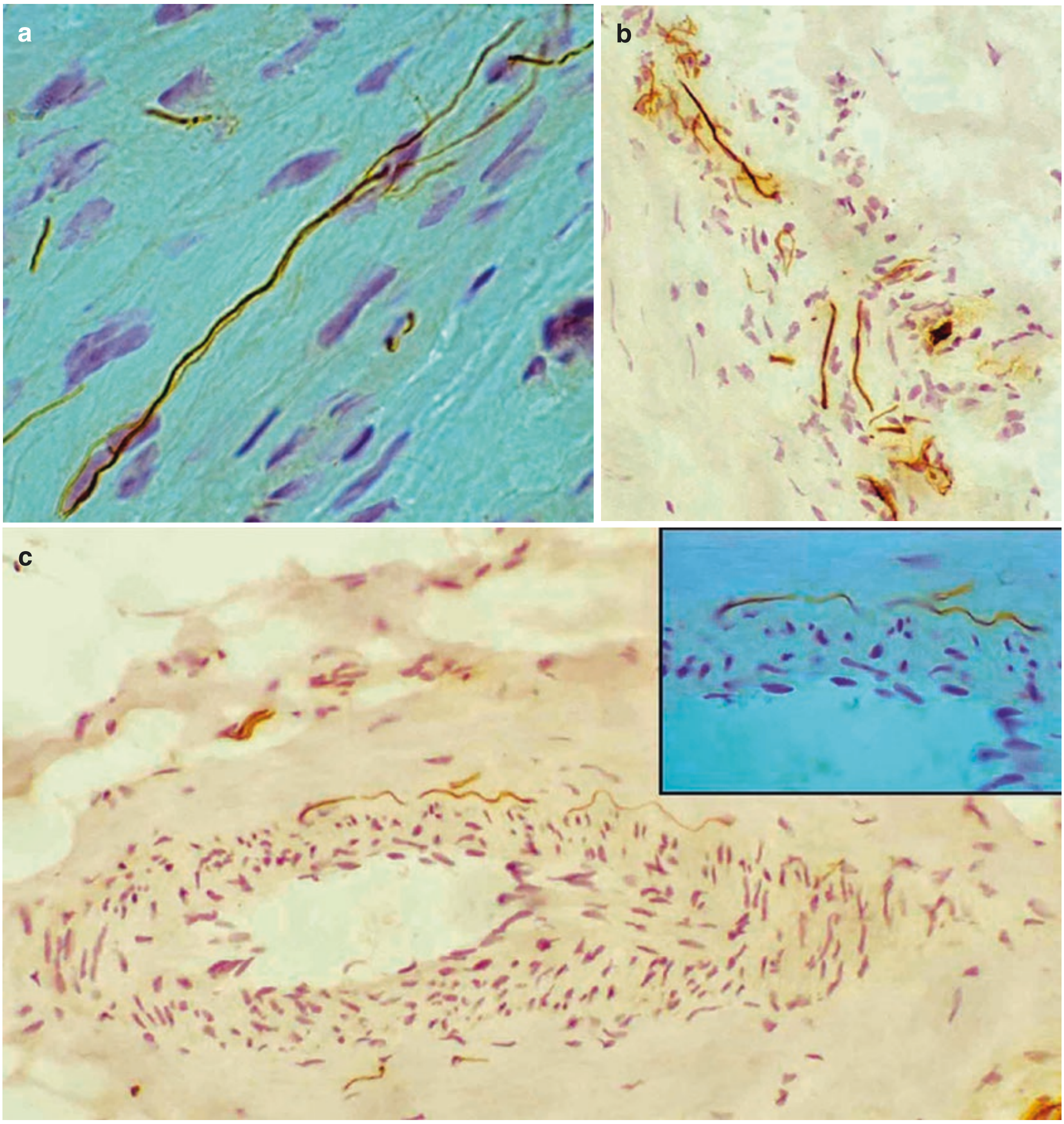


**Fig. 8.5** (**a**) Free nerve endings immersed in the connective tissue. (**b**) Hot spot of free nerve endings forming a microneuroma. (**c**) Nerve endings entering the arterial wall. (Neurofilament NF.) (Reused with permission from SAGE. From: "Immunohistochemical analysis for neural markers of the lateral retinaculum in patients with isolated symptomatic patellofemoral malalignment" Am J Sports Med. 2000; 28: 725–731)

wall [46]. Vascular innervation has been demonstrated to be more prominent (94%) in patients with severe pain, whereas this type of hyperinnervation has been found in only 30% of the patients with light or moderate pain [43]. These findings are in agreement with the statement of Byers, who postulated in 1968 that pain in an osteoid osteoma could be generated and transmitted by vascular pressure-sensitive autonomic nerves [65]. In reviewing the literature, we have seen that hyperinnervation is also a factor implicated in the pathophysiology of pain in other orthopedic abnormalities, such as chronic back pain and jumper's knee [56, 57, 66, 67]. On the

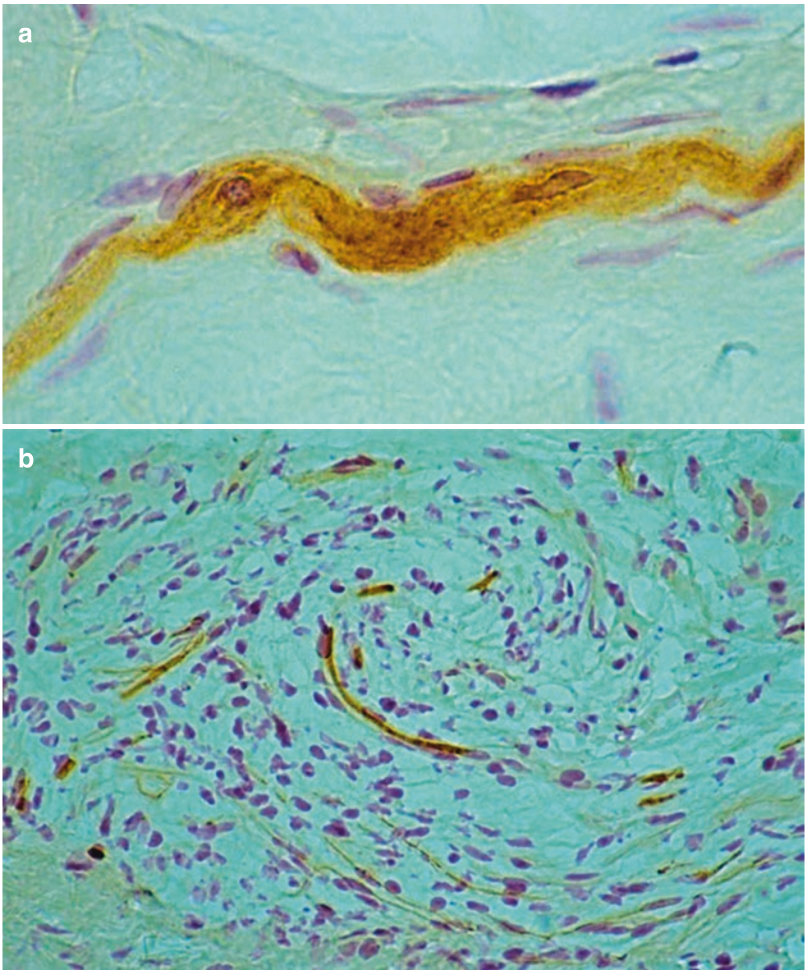


**Fig. 8.6** (**a**) Substance P, a marker of sensory fibers, is expressed in the nerve fibers in a granular pattern. (**b**) Neuromas are rich in nociceptive axons, as can be demonstrated studying substance P. (Reused with permission from SAGE. From: "Immunohistochemical analysis for neural markers of the lateral retinaculum in patients with isolated symptomatic patellofemoral malalignment" Am J Sports Med. 2000; 28: 725–731)

other hand, pain has also been related with vascular innervation in some pathologies, as is the case in osteoid osteoma, in which an increase in perivascular innervations has been found in all the cases, leading the authors to postulate that pain was more closely related to this innervation than to the release of prostaglandin E2 [68]. Grönblad and colleagues have reported similar findings in the lumbar pain of facet syndrome [69]. Finally, Alfredson and colleagues related pain in Achilles tendinosis with vasculo-neural ingrowth [66].

Hyperinnervation has been demonstrated to be associated with the release of neural growth factor (NGF), a polypeptide that stimulates axonogenesis [42]. NGF has two biologically active precursors: a long form with a molecular weight of approximately 34 kD and a short form of 27 kD [70]. The 34 kD precursor has been found in the LR of AKP patients [42]. Since some of the nerve fibers of the LR express NGF, these nerve fibers must still be in a proliferative phase. As expected, NGF expression is higher in PFM patients with pain that in those with instability as the main symptom (Fig. 8.8) [42]. Gigante and colleagues have also found NGF and TrkA (the NGF receptor) expression in the LR of patients with PFM, but not in patients with jumper's knee or meniscal tears [71]. Interestingly, NGF is related not only to neural proliferation in vessels and perivascular tissue but also to the release of neuroceptive transmitters, such as SP [72].

In short, in symptomatic PFM patients with pain as the main symptom, there are detectable levels of NGF that cause hyperinnervation and

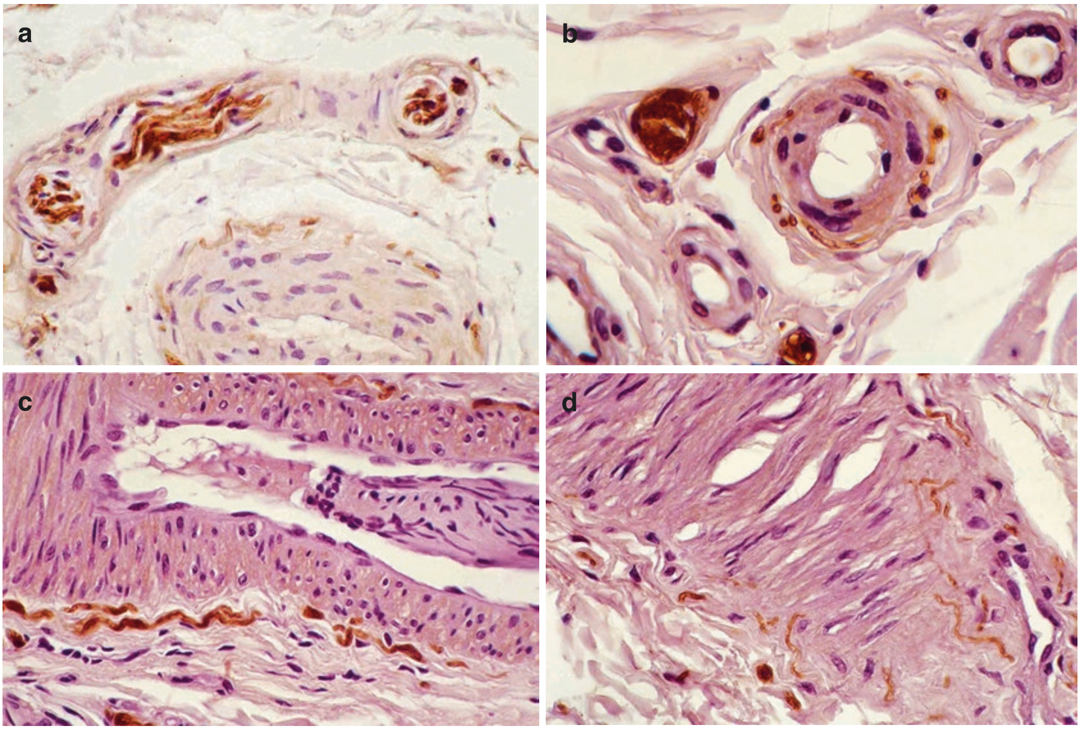


**Fig. 8.7** Lateral retinaculum vessels are richly innervated in some of our patients. The myelinated innervation enters the muscular wall from the adventitial tissue, forming a necklace (**a**, **b**). Transversal section (**c**) and tangential section (**d**). (Immunohistochemistry for protein S-100). (Reused with permission from SAGE. From: "Quantitative analysis of nerve changes in the lateral retinaculum in patients with isolated symptomatic patellofemoral malalignment" Am J Sports Med. 1998; 26:703–709)

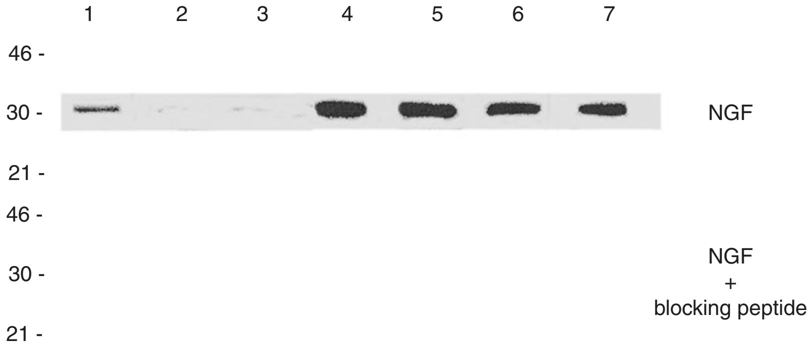


**Fig. 8.8** Immunoblotting detection of NGF showing a thicker band in cases with AKP (4,5,6,7) compared with cases of instability without pain (1,2,3). (Reused with permission from Springer. From: Biological Causes of Anterior Knee Pain. In: Sanchis-Alfonso V (Ed) Anterior Knee Pain and Patellar Instability. Springer, 2011)

stimulate SP release, whereas in patients with instability as the predominant symptom, there are lower levels of local NGF release, less neural proliferation, and less nociceptive stimulus [42]. Consequently, there must be some factors acting on a PFM that make the patient has pain or instability as the main symptom. PFM may in fact not have anything to do with the presence of pain. In other words, symptoms appear to be related to multiple factors with variable clinical expression, and our imperfect understanding of these factors may explain the all-too-frequent failure to achieve adequate symptom relief with the use of realignment procedures. The question is, what are the mechanisms that stimulate NGF release in these patients? We hypothesize that periodic short episodes of ischemia could be the primary mechanism of NGF release and hyperinnervation, and therefore could be implicated in pain, at least in a subgroup of AKP patients.

## 8.6 Role of Ischemia in the Genesis of AKP: Loss of Vascular Homeostasis

Despite numerous publications on AKP, the mechanism underlying the pain is controversial. The loss of vascular homeostasis has been proposed as an intrinsic pain mechanism in a subgroup of AKP patients.

### 8.6.1 Basic Science

According to some authors, ischemia can induce NGF synthesis [50, 73, 74]. Moreover, NGF has been shown to stimulate neural sprouting and hasten neural proliferation in blood vessel walls [75, 76], which is the same pattern of hyperinnervation that is seen in the LR of some AKP patients [41, 43, 46]. Similar changes have been studied in animal models and are present in the coronary innervation of patients with myocardial infarcts and brain ischemia [73, 74, 76]. Thus, short episodes of tissular ischemia due to vascular torsion or vascular bending have been hypothesized as the main problem in painful patellofemoral imbalance [41, 43]. Vascular bending could be induced mechanically by medial traction over the retracted LR with knee flexion [39].

Sanchis-Alfonso and colleagues have demonstrated histologic retinacular changes associated with hypoxia in painful PFM [43]. They have found lesions that can lead to tissular anoxia, such as arterial vessels with obliterated lumina and thick muscular walls, and other lesions that can arise from ischemia, such as infarcted foci of the connective tissue, myxoid stromal degeneration, and ultrastructural findings related with anoxia (degenerated fibroblasts with autophagic intracytoplasmic vacuoles, endothelial cells with reduplication of the basal lamina, young vessels with endothelial cells containing active nuclei and conspicuous nucleoli, and neural sprouting) [77].

Another phenomenon related to ischemia is angiogenesis. Chronic ischemia leads to release of vascular endothelial growth factor (VEGF), a potent hypoxia-inducible angiogenic factor that causes hypervascularization [78]. This hypervascularization creates blood vessels to supply the nutrient needs of the tissue. Sanchis-Alfonso and colleagues have performed a quantitative analysis of vascularization in the LR excised during surgical patellofemoral realignments, using a pan-vascular marker, anti-factor VIII-related antigen [43]. They have found an increase in the number of blood vessels in the LR of patients with painful PFM, with the severe pain group having greater numbers compared with those of moderate or mild pain group [43]. Moreover, as expected, they found a positive linear correlation between the number of blood vessels and number of nerves [43]. Tissular ischemia induces VEGF release by fibroblasts, synovial cells, mast cells, or even endothelial cells [79–82]. Based on these principles, Sanchis-Alfonso and colleagues performed a study of VEGF expression in the LR of patients with PFM, using immunohistochemistry and immunoblot analysis [43]. VEGF release begins 8 h after hypoxia, and the peptide disappears in 24 h if the ischemic crisis has ended [43]. Therefore, VEGF positivity reflects the presence of an ischemic process, or better said, 8–24 h has elapsed since the onset of the transitory ischemic episode. However, given that the average duration of VEGF is very short, its absence has no significance regarding whether a transitory ischemic process is occurring. Although this process has been well documented in joints affected by rheumatoid arthritis and osteoarthritis [81–84], it has never been documented in AKP until the study by Sanchis-Alfonso and colleagues [43]. They have shown VEGF production in stromal fibroblasts, vessel walls, certain endothelial cells, and even nerve fibers, including similar levels in axons as in perineurium (Fig. 8.9) [43]. Their immunohistochemical findings were confirmed by immunoblot analysis. VEGF levels were higher in patients with severe pain than in those with mild to moderate pain; the protein was barely detectable in two cases with mild pain (Fig. 8.10) [43]. VEGF expression is absent in normal joints, although inflammatory processes can stimulate its release [83, 84]. In such cases, synovial hypoxia secondary to articular inflammation is assumed to trigger VEGF production [83]. However, inflammatory changes have not been observed in the LR of AKP patients [43, 46]. Furthermore, peripheral nervous system hypoxia has been reported to be able to simultaneously trigger VEGF and NGF synthesis via neurons [85] or inflammatory or stromal cells [73, 74, 86]. VEGF induces hypervascularization, and NGF induces hyperinnervation. Both occurrences have been observed in AKP patients [43, 46]. In conclusion, ischemia could be the main trigger for pain in at least a subgroup of AKP patients.

### 8.6.2 Clinical Studies

The role of vascular insufficiency in AKP has not been studied extensively from a clinical point of view. In fact, only a few clinical papers have alluded to the possibility of hypoxia as a factor in the pathogenesis of AKP.

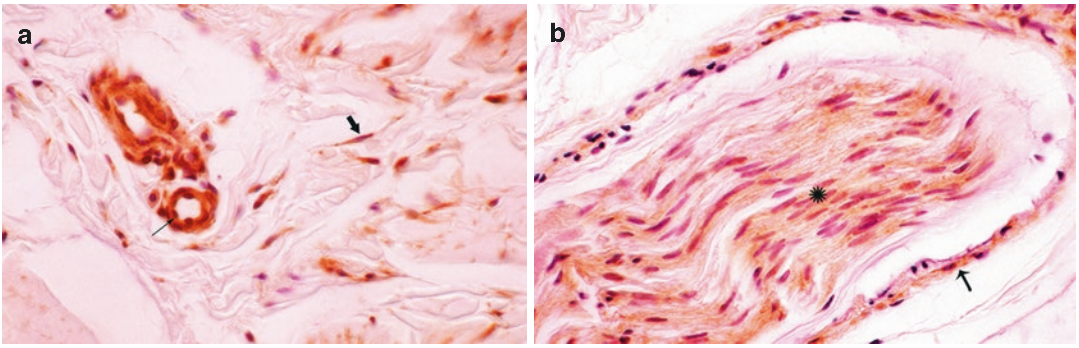


**Fig. 8.9** (**a**) VEGF, the factor promoting vascular proliferation, is present in small vessels (wall and endothelium) and in perivascular fibroblasts. (**b**) Some cases have VEGF expression in the perineural shift and inside the axons (VEGF). (Reused with permission from Springer. From: Neuroanatomical Bases for Anterior Knee Pain in the Young Patient: "Neural Model". In: Sanchis-Alfonso V (Ed) Anterior Knee Pain and Patellar Instability. Springer, 2006)

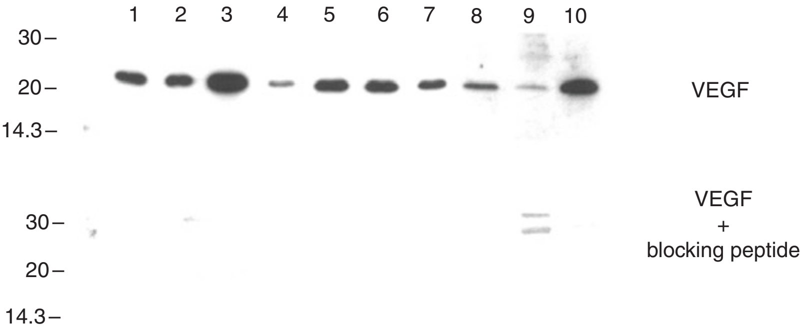


**Fig. 8.10** Immunoblotting detection of VEGF showing a thicker band in cases with AKP (2,3,10) compared with cases with moderate pain (1,5,8) or light pain (4,6,7,9). (Reused with permission from Springer. From: Neuroanatomical Bases for Anterior Knee Pain in the Young Patient: "Neural Model". In: Sanchis-Alfonso V (Ed) Anterior Knee Pain and Patellar Instability. Springer, 2006)

Sandow and Goodfellow [87] investigated the natural history of AKP in adolescents. In a study sample of 54 adolescent girls, the researchers observed that 9 out of 54 (16.7%) had pain that was aggravated by cold weather. According to Selfe and colleagues [88], the proximal part of the rete patellae is very superficial and is therefore vulnerable to thermal environmental stress, resulting in greater hypoxia during cold weather. More recently, Selfe and colleagues [89] studied clinical outcomes in a sample of AKP patients categorized as hypoxic, that is to say, with “cold knees” (his or her legs felt cold even in warm surroundings). Fourteen out of 77 (18.2%) of the patients were categorized as “cold sufferers,” a percentage very similar to that reported by Sandow and Goodfellow [87]. Selfe and colleagues [89] studied local hypothermia by means of infrared thermography and concluded that patients categorized as hypoxic reported greater pain levels and had poorer response to an exercise-based treatment than non-hypoxic patients. Gelfer and colleagues [90], using single photon emission computed tomography (SPECT), also found a relationship between transient patellar ischemia after total knee replacement and the clinical symptoms of AKP. Similarly, using photoplethysmography, which is a reliable technique for estimating blood flow in bone tissue, Naslund also observed that an ischemic mechanism (decreased blood flow in the patellar bone) is involved in the pathogenesis of AKP [91]. Moreover, in half of the AKP studied patients, Naslund observed accelerated bone remodeling in bony compartments of the knee joint, which may have been due to a dysfunctioning sympathetic nervous system and caused intermittent ischemia and pain. Selfe and colleagues [88] classified AKP patients into three groups: hypoxic, inflammatory, and mechanical. However, ischemia may be the pain-provoking factor in all three groups, given that inflammatory changes can develop not only after ischemia but also after mechanical damage to the vascular system. Ischemia could be caused by higher intraosseous pressure, redundant axial loading, or decreased arterial blood flow.

## 8.7 A Pain Neuromatrix Approach to AKP Patients: MR Resting State Functional Connectivity in AKP

Currently, the subjectivity of pain can be captured by objective markers of brain activity, but no single brain area manifests the perceived pain experience [92]. Functional MRI (fMRI) has been used to identify many pain centers in the brain that work together as a network [93]. In particular, fMRI and computational processing allow us to study the structural and dynamic connectivity of brain networks by measuring neuronal activity through the BOLD (blood oxygenation level-dependent) phenomenon [94]. Brain activity mechanism introduces subtle changes in the MR image signal that depend on the level of endogenous oxygenation of the blood in the capillaries near the functionally active brain areas. In patients with chronic pain, an increase brain connectivity, which refers to temporally synchronous neuronal activity in functionally related but anatomically distinct regions of the brain, has been demonstrated [94, 95].

Sanchis-Alfonso and colleagues, in a pilot study (unpublished data), have investigated the impact of AKP on brain dynamics at rest. Age, handedness, and scholarship were considered as covariates in data analysis in order to avoid the effect of these factors on the changes observed in the connectome (i.e., in the map of the neural connections in the brain). All the abovementioned covariates have an influence in functional connectivity [96, 97]. Therefore, to confirm that the observed changes are due only to the presence of AKP, we have to introduce these covariates in the analysis. Significant resting state fMRI connectivity differences between AKP patients and matched healthy controls were found. For example, a positive significant correlation between the cingulate gyrus anterior division (AC-Salience Network -SN-) and the left lateral parietal lobule (LP- Default Mode Network -DMN-) was demonstrated in the AKP patients. AC is a subregion of the anterior cingulate cortex (ACC). This means that both regions are activated simultaneously although the connection between them is weak. This weakness can be interpreted as a loss of the inhibitory capacity of SN against DMN. However, in the control group a signifi-

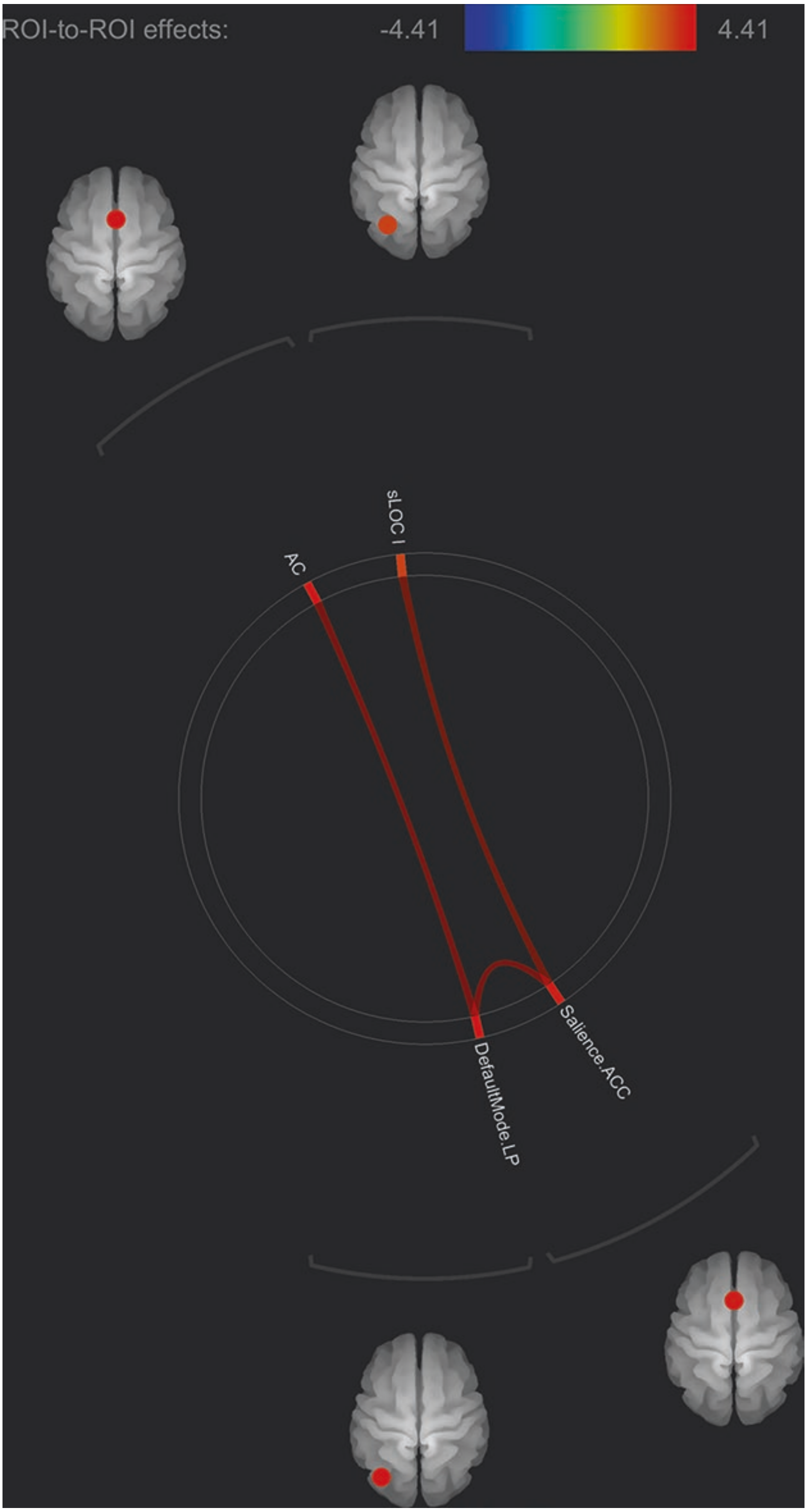


**Fig. 8.11** Functional connectivity analysis with fMRI. Connectome ring showing brain areas that have significant differences in connectivity between AKP patients and control group. A significant region-to-region connectivity between the anterior cingulate cortex (ACC-Salience Network [SN]) and the left lateral parietal lobule (LP- Default Mode Network –[DMN]), between the lateral occipital cortex superior division left (sLOC I) and ACC-SN, and between the cingulate gyrus anterior division (AC) and LP-DMN was demonstrated in AKP patients

cant negative correlation between the AC-SN and the LP-DMN has been found. That is, when the DMN is active the SN is inactive and vice-versa (Fig. 8.11). ACC, which is activated by noxious stimuli, is involved in pain processing, especially in the affective-emotional component of pain, rather than in the sensory component [98]. Moreover, ACC has been also involved in pain anticipation, contributing to patient's pain and disability [99]. The ACC is not only necessary but also sufficient to explain pain-related negative emotions [98]. Furthermore, it has been suggested that the development of neuropathic pain is associated with increased activity in the ACC [100]. At this point, it is important to note that 72% of the patients in our AKP series had neuropathic pain (unpublished data). The left LP cortex is linked to diverse cognitive processes such as attention and social cognition [101, 102]. The lateral occipital cortex and the parietal cortex may be viewed as an extended integration area of different corporal sensations in this particular setting. The insular regions have not gained significance as a functional hub for these AKP patients in our series. This could be due to a difference in the statistical treatment of the data acknowledging significance at a p value $< 0.002$ [103]. In this way, we diminish the sensitivity but increase the consistency and robustness of the participating areas. The abovementioned findings can account for the multidimensional experience of AKP. That is, chronic AKP is not only a temporary extension of acute pain. It is a multidimensional experience with sensitive, cognitive, and affective domains. Moreover, connectome differences between different subsets of AKP

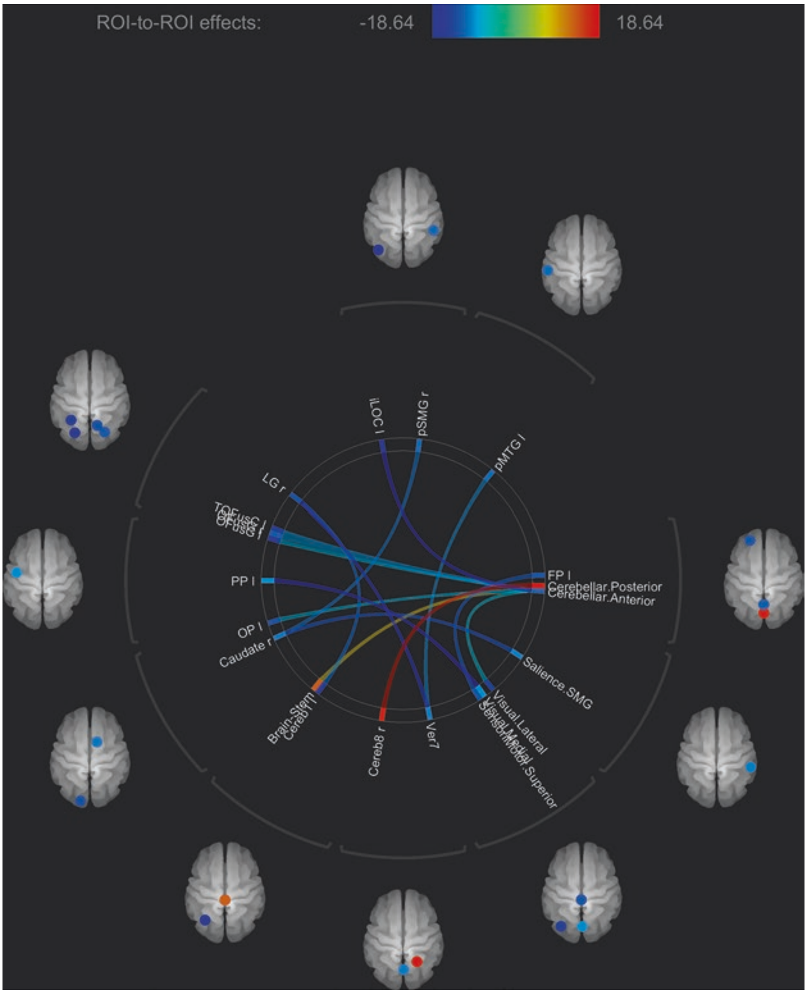


**Fig. 8.12** Functional connectivity analysis with fMRI. Connectome ring showing brain areas that have significant differences in connectivity between AKP patients with catastrophizing ideas and AKP patients without catastrophizing ideas

patients (catastrophizing vs. non-catastrophizing, neuropathic pain vs. non-neuropathic, kinesiophobia vs. non-kinesiophobia, depression vs. non-depression) has been demonstrated (Fig. 8.12). This could explain the great variability in the pain experience among different AKP patients.

This pain neuromatrix can account for the multidimensional experience of pain [92]. Interestingly, Damasio and colleagues [104] observed an overlap between the cerebral activity areas related to chronic pain and those related to cognition and emotions. This finding suggests that chronic pain, cognition, and emotions are interrelated.

The etiology of AKP is multifactorial, with several subgroups of patients presenting different characteristics and prognoses [1, 3, 4]. In many patients there is a poor correlation between pain and structural alterations. There are many patients with lateral patellar subluxation, patellar tilt, severe patellofemoral chondropathies, or torsional deformities that present few painful symptoms and, on the contrary, patients with severe pain and few biomechanical abnormalities. In many cases structural abnormalities are treated, and the patient does not improve or even get worse. Therefore, there must be other factors responsible for pain. Impaired "conditioned pain modulation," defined as the endogenous pain inhibition ability of a subject, has been demonstrated in young women with long-standing AKP [105]. In addition, a subset of AKP patients experience allodynia or hyperalgesia. In these patients, there is "central sensitization," that is, an increased responsiveness of the central nervous system to a variety of stimuli [106–108]. Rathleff and colleagues [107] suggested that adolescent females with AKP have both localized and distal hyperalgesia (reduced pressure pain threshold), which can be determined through pressure algometry. This hyperalgesia may signal altered central processing of nociceptive information. In other words, the central processing of nociceptive input has been altered. Central sensitization is associated with the development and maintenance of chronic pain. Jensen and colleagues [51] have shown that some patients with unilateral AKP have neuropathic pain, which suggests damage in the peripheral and/or central nervous system that causes pain signals without specific cause. In this way, many AKP patients have alterations in the central nervous system that could play an important role both in the magnitude and persistence of pain after an adequate conservative or surgical treatment. Lefaucheur and colleagues [109] found a link between chronic neuropathic pain and motor cortex disinhibition. Current data suggest that repetitive transcranial magnetic stimulation of the motor cortex corresponding to the patient's site of pain could be a complementary treatment modality for patients with chronic neuropathic AKP [110]. Motor cortex stimulation may produce analgesic effects by restoring missing or impaired intracortical inhibitory processes [109].

Pain is a multidimensional phenomenon composed by sensitive, cognitive-evaluative, and affective-motivational domains. Patients with AKP have a high incidence of anxiety, depression, kinesophobia (the belief that movement will create additional injury or reinjury and pain), and catastrophizing (the belief that pain will get worse and one is helpless to deal with it) [111–113]. However, it is also true that these psychological disorders are the result of the pain severity but not the cause of the pain and disability. Psychological factors play an important role as pain modulators. Even in cases with clear structural findings, psychological factors influence and modify pain sensation as well as subsequent impairment and, therefore, can be barriers to recovery. Catastrophizing not only is responsible for the chronification of pain due to a psychological mechanism but also could influence the neurophysiology of pain modulation. In a functional MRI study, Gracely and colleagues [114] showed that for patients with chronic pain, catastrophizing ideas were associated with a higher degree of brain activity not only in the pain regions but also in the cortical regions associated with attention, anticipation of pain, and emotional aspects of pain. Catastrophizing could play a role as a facilitator of the pain perception process. It also has been suggested that pain catastrophizing may interfere with descending pain-inhibitory systems and may facilitate neuroplastic changes in the spinal cord during repeated painful stimulation, subsequently promoting sensitization in the central nervous system.

In short, the neuromatrix model is based on the fact that the central nervous system, both brain and spinal cord, is where pain is produced and modulated. Multiple brain and spinal cord areas work together in response to corporal stimuli to create the multidimensional experience of pain. In essence, the central nervous system, not the tissue damage, produces the pain.

## 8.8 Authors' Proposed AKP Pathophysiology

A subgroup of patients with AKP have a skeletal malalignment of the limb, especially in the transverse plane (femoral and/or tibial rotational malalignment) [34, 35]. This malalignment of the lower limb could provoke pain due to the abnormal stress on tissue which is not of sufficient magnitude or direction to result in instability. It is likely that nerve changes or ischemia may be due to chronic repetitive stretch of soft tissue (retinaculum). Moreover, skeletal malalignment could provoke patellofemoral instability due to a failure of the ligaments that stabilize the PFJ, and it will also lead to the development of patellofemoral cartilage lesions due to the increased patellofemoral compression forces (Figs. 8.13 and 8.14). However, in most cases, the abnormal femoral rotation is functional due to a deficit of the proximal control [115]. This situation will lead to a patellofemoral imbalance as it occurs in the structural skeletal malalignment of the lower limb.

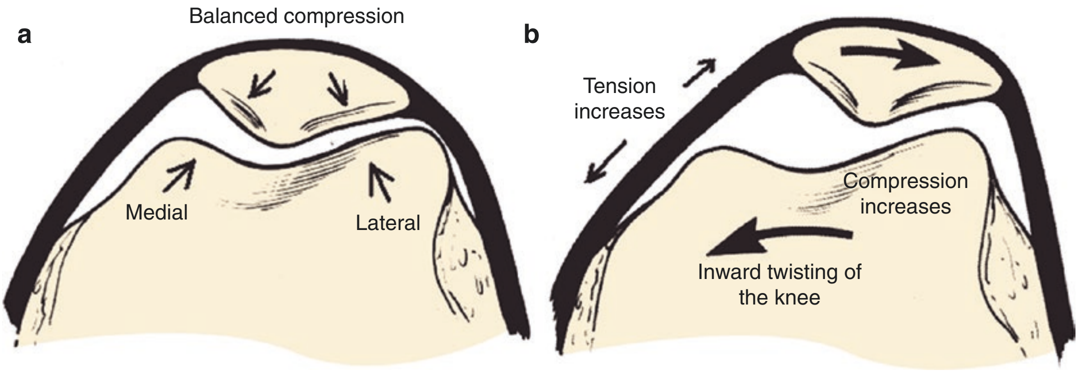
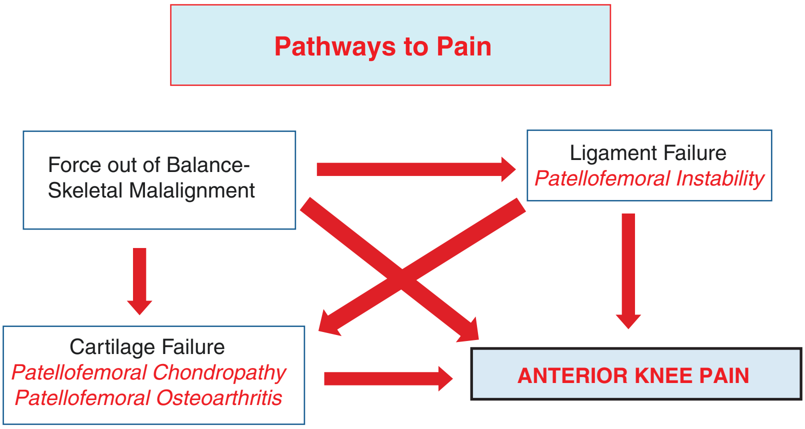


**Fig. 8.13** Twist produces an imbalance. (**a**) Balanced compression in a normal knee. (**b**) If the knee joint twists inward from beneath the patella, the MPFL is placed under increased tension, the compression beneath the lateral facet increases, and the compression beneath the medial facet decreases. It is the twist which creates an imbalance. The twist may be functional (at the hip joint) or structural because of torsion anywhere in the skeleton. (Reused with permission from Elsevier. From Teitge RA. Patellofemoral Disorders Correction of Rotational Malalignment of the Lower Extremity. In: Noyes's Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes, 2017)

**Fig. 8.14** Pathways to pain. Force out of balance is the culprit, and force out of the balance is due to the limb out of alignment



We hypothesize that short and repetitive episodes of tissular ischemia, potentially due vascular torsion or vascular bending induced by a patellofemoral imbalance, could trigger release of NGF and VEGF in the peripatellar soft tissues. Once NGF is present in the tissues, it induces hyperinnervation, attracts mastocytes, and triggers substance P release by free nerve endings (Fig. 8.15) [72]. In addition, VEGF induces hypervascularization and plays a role in increasing neural proliferation.

Free nerve endings, slowly adapting receptors that mediate nociception, are activated in response to deformation of tissues. In the knee, such deformation results from abnormal tensile and compressive forces generated during flexo-extension of the joint or in response to chemical agents such as histamine, bradykinin, prostaglandins, and leukotrienes [59, 116, 117]. Therefore, SP is released from peripheral endings of nociceptive afferents as a result of noxious chemical or mechanical stimulation. The nociceptive information relayed by these free nerve endings is responsible, at least in part, for the pain.

Once SP is liberated in the connective tissue, it induces the release of prostaglandin E2, one of the biochemical agents known to stimulate nociceptors (Fig. 8.15) [52]. The activation of nociceptive pathways by prostaglandins could be one of the many mechanisms involved in the transmission of pain in AKP patients. Moreover, SP stimulates mast cells, facilitating a degranulation process that can liberate histamine, another nonneurogenic pain mediator (Fig. 8.15) [58]. Numerous mast cells have been identified in the LR of AKP patients [21]. Mast cells are also associated with the release of NGF [41, 118], contributing to the hyperinnervation and indirectly provoking more pain. Furthermore, SP has been shown to induce the release of collagenase, interleukin-1, and tumor necrosis factor-alpha (TNF-α) from synoviocytes, fibroblasts, and macrophages (Fig. 8.15) [52, 54]. These factors could contribute to the genesis of patellar

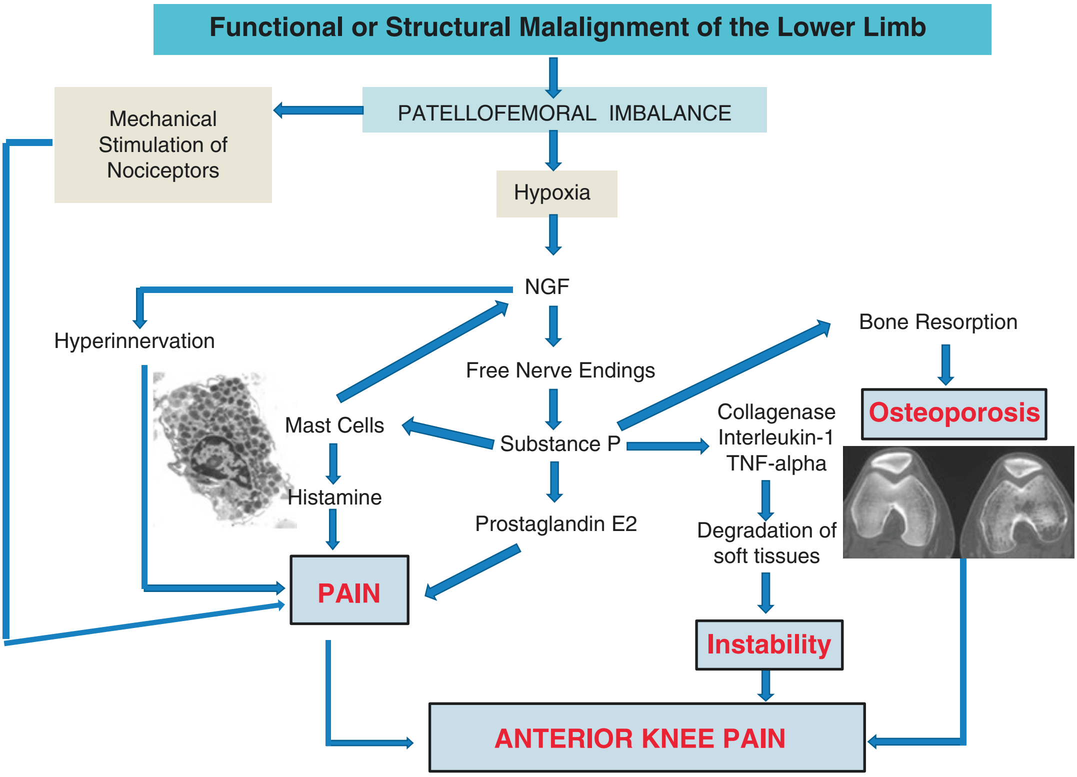


**Fig. 8.15** Pathophysiology of AKP

instability through degradation of soft tissues. SP, NGF, and mast cells have also recently been implicated in bone resorption in both in vitro and in vivo experiments, which could explain, at least in part, the osteoporosis found in many cases of AKP [119]. Finally, SP and VEGF stimulate endothelial cell proliferation and migration [55], which are essential to the development of a new vascular network that may promote tissue repair, but indirectly maintain a vicious cycle.

Woolf [120] described four types of pain from a clinical point of view: (1) nociceptive pain, which is transient pain in response to noxious stimulus; (2) homeostatic pain, which is pain that promotes the healing of injured tissue (i.e., the cascade of events toward re-establishing homeostasis); (3) neuropathic pain, which is spontaneous pain and hypersensitivity to stimulus in association with damage to the nervous system; and (4) functional pain, which is pain resulting from abnormal central processing of normal input. Homeostatic pain may include specific symptoms such as allodynia (i.e., pain due to stimulus that does not normally provoke pain) and hyperalgesia (i.e., a heightened response to a stimulus that is normally painful). All these mechanisms appear to be involved in the pathophysiology of pain in AKP patients.

## 8.9 Conclusions

- Currently, much remains to be learned about the cause of AKP. Our understanding is limited. AKP is one of the most intriguing orthopedic pathologies from a clinical point of view because it obliges us to “think out of the box,” to look deeper into the anatomy, biomechanics, biology, anatomic pathology, physiopathology, and psychology. AKP is a great stimulus for orthopedic intellectual development.
- Chondromalacia patellae is not synonymous with AKP. It is not the underlying problem.
- Very often, patellofemoral malalignment (patellar tilt/lateral patellar subluxation) is not the problem.
- In a subgroup of AKP patients, skeletal malalignment of the limb is responsible for disabling AKP due to both patellofemoral overload and patellofemoral imbalance. Understanding the biomechanics is crucial—orthopedic surgery is very much a mechanical engineering discipline. At this time, from the biomechanical viewpoint, the most powerful treatment effect in treating AKP comes from limb realignment.
- In the vast majority of AKP cases, the loss of both soft tissue (peripatellar synovitis and others soft tissue impingements such as synovial hypertrophy around the inferior pole of the patella) and osseous (intraosseous edema, osseous hypertension) homeostasis is more important in the genesis of AKP than local structural anomalies (patellar till, lateral patellar displacement, and patellofemoral chondropathy). However, we do not know how often is AKP present in a structurally perfect limb, except for overtraining. It is likely that the loss of homeostasis can be mechanical with an as yet unrecognized structural anomaly.
- There is a neuroanatomical basis for AKP in the young patient. A dysfunction of the peripheral and/or the central nervous system may cause neuropathic pain in some individuals with AKP.
- Periodic short episodes of ischemia, secondary to a mechanical stimulus, could be implicated in the pathogenesis of AKP by triggering neural proliferation of nociceptive axons (SP-positive nerves), mainly in a perivascular location. These findings are in line with the homeostasis perspective. Loss of vascular homeostasis in the knee region (e.g., hypervascularity, ischemia, osseous hypertension) may be associated with AKP.
- It is possible that all of the neuroanatomical factors involved in the genesis of AKP and the loss of vascular homeostasis are due to an excess of force that would be the precipitating event.
- Chronic pain is a multidimensional phenomenon composed by sensitive, cognitive-evaluative, and affective-motivational domains. The neuroma-

trix model can explain the multidimensional pain experience in AKP patients.

- We hypothesize that it is the force (magnitude or direction) which determines whether one is in or out of Dye's envelope. In short, the diagnostic challenge is determining the source of excess force which overcomes tissue homeostasis. We are a long way from determining why excess force is excess.

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# 9

# Patellofemoral Pain Syndrome: The Value of Single Photon Emission Computerized Tomography and Conventional Computerized Tomography (SPECT/CT)

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## 9.1 Introduction

Patellofemoral joint pain is the most common problem involving the knee, affecting 25% of the general population [1–8]. Many cases of anterior knee pain are diagnosed as patellofemoral pain syndrome, a largely idiopathic chronic pain disorder characterized by a gradual onset of poorly localized pain in the anterior aspect of the knee aggravated by activities such as squatting, stair climbing and descent or prolonged sitting with the knee bent [9]. The causes of patellofemoral joint pain are versatile including chondral lesions of the patellofemoral joint, patellofemoral malalignment, medial patellar plica, patellar and/or quadriceps tendinopathy, supra- and infra-patellar fat pad lesions or postoperative conditions [4–6, 10, 11]. The diagnosis is based on the clinical history and the exclusion of other causes of anterior knee pain [1, 12]. Therefore, patellofemoral pain syndrome is a diagnosis of exclusion and can present a great diagnostic challenge to the orthopaedic surgeon [8].

The orthopaedic surgeon has various radiological imaging modalities at his disposal such as radiographs, computerized tomography (CT), magnetic resonance imaging (MRI) and single photon emission computerized tomography and conventional computerized tomography (SPECT/CT). Whereas conventional radiographs show a poor correlation between radiographic abnormalities and patellofemoral pain [13, 14] and low sensitivity and specificity to detect grade 1 and 2 chondral abnormalities [15], CT provides a more precise and comprehensive anatomical and mechanical view of the patellofemoral joint, but its informative value is limited to osseous structures [14]. Tears of menisci, osteoarthritis changes, osteochondral lesions or synovial abnormalities may be detected by MRI. In the patellofemoral joint however, the correlation between patient's symptoms and abnormal findings is low, and the sensitivity to detect chondral lesions varies widely [14, 16]. SPECT/CT overcomes the aforementioned limitations and represents a valuable tool in patients with persist-

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ing and unexplained pain as a complementary, sensitive diagnostic instrument. Over the past decade, the clinical value of SPECT/CT has been well established in patients with knee problems [17–20]. Improved diagnostics has been reported not only in patients with patellofemoral joint pain but also in patients after total knee arthroplasty, patients with chondral or osteochondral lesions and patients before and after high tibial osteotomy and after ACL reconstruction [17–29]. With its most commonly used tracer 99 m-technetium-hydroxymethylene-diphosphonate (HDP), which targets active osteoblasts, it allows a window into the bone remodelling process as well as in vivo loading of the joint [30, 31]. Bone remodelling is a physiological cellular process of bone resorption by osteoclasts and formation by osteoblasts allowing for skeletal adaption to biomechanical stress. It begins during foetal development and continues throughout life. Remodelling takes place along the lines of force produced by mechanical stress, resulting in a stronger configuration. Bone responds to stress according to Wolff's law [32]. As the amount of stress applied increases, there is progressive deformity throughout the elastic range with return to its original state if the stress ceases. This principle is being introduced in the assessment of in vivo loading and remodelling processes of the native or post-operative joint.

A thorough understanding of the normal patterns of bone tracer uptake and of normal physiological and anatomical variants is a prerequisite for interpretation of bone scans. Most pathological processes affecting bone provoke a reparative osteoblastic response and will therefore manifest as an increase in bone tracer uptake [33].

A comprehensive clinical history and knowledge of the relevant clinical findings are crucial to the interpretation of the bone scan. Information regarding trauma, infection, arthritis, Paget's disease, metabolic bone disease, orthopaedic surgery (implants), biomechanics, malignancy and previous radio- or chemotherapy is of particular importance. With regard to the knee joint, increased uptake in the patella is a commonly encountered finding on the bone scan. A wide variety of pathological processes may account for this appearance, including osteoarthritic degenerative disease, fracture, metastatic disease, bursitis, Paget's disease and osteomyelitis [34]. Fogelman et al. demonstrated increased patellar uptake in prospective and retrospective patient series with a frequency of 26–31%, concluding that this finding is so common that it cannot be considered of diagnostic significance. It should, however, be considered in light of symptoms and the clinical history [35].

In contrast to SPECT, SPECT/CT as a hybrid imaging technology gives valuable information on alignment, joint homeostasis and structural bone changes [19]. Thus, SPECT/CT allows combined assessment of structural, mechanical and functional information [27, 36].

### 9.1.1 SPECT/CT Imaging

The patient gets injected with a commercial 500–700 MBq, 99 m-technetium(Tc)-HDP (hydroxymethylene diphosphonate) intravenous injection (Mallinckrodt, Wollerau, Switzerland). 99mTc-HDP-SPECT/CT is performed using a Symbia T16 (Siemens, Erlangen, Germany), which is a system that consists of a pair of low-energy, high-resolution collimators, a dual-head gamma camera and an integrated 16-slice CT scanner (collimation of 16 × 0.75 mm). Two-plane scintigraphic images are taken in the perfusion phase (immediately after injection), the soft tissue phase (1–5 min after injection) and the delayed metabolic phase (2 h after injection). SPECT/CT is performed with a matrix size of 128 × 128, an angle step of 32 and a time per frame of 25 s 2 h after injection. Reconstructed data is displayed in transaxial, coronal and sagittal planes. The intensity of the radioisotope uptake is semi-quantitatively colour-coded graded 0–10 (0, normal, 10, severe) compared with the uptake of the proximal femur shaft. BTU on SPECT/CT is analysed using specialized software allowing 3D volumetric quantitative analysis of SPECT data as previously published [20]. The measurement method has been validated and shows near perfect inter- and intra-observer reliability [37].

*Using this scanning protocol, SPECT/CT can assist our diagnosis and management in the following clinical scenarios:*

- *Assessment of* in vivo *loading of the patellofemoral joint*: The intensity and distribution of BTU in SPECT/CT correlate significantly with patella baja ($p < 0.001$) in native painful knees. A higher lateral patellar tilt correlates significantly with higher tracer uptake in the superior lateral femoral parts and the tibial tubercle ($p < 0.01$). Varus-aligned knees show significantly higher SPECT/CT bone tracer uptake on the medial and in valgus-aligned knee in the lateral part of the patellofemoral joint ($p < 0.05$) [29]. In those patients SPECT/CT reflects the in vivo loading within the patellofemoral joint and helps to evaluate patellofemoral disorders and can be used in the follow-up of patients after patellofemoral realignment procedures.
  - A 30-year-old male patient presented over years increasing left medial and anterior knee pain without history of trauma. Examination revealed medial patellar and medial joint line tenderness. Radiographs demonstrated a varus alignment with a proximal tibial varus angle of 7°. In order to localize the in vivo loading of the joint, SPECT/CT was performed and displayed increased bone tracer uptake in the medial compartment of the femorotibial joint as well as on the medial part of the patellofemoral joint (Fig. 9.1). Medial opening wedge high tibial osteotomy was performed. The patient recovers from patellofemoral and medial knee joint pain.
- *Prediction of responsiveness to conservative treatment in middle-aged patients (40–65 years) with chronic anterior knee pain*: Ro et al. could demonstrate that a higher degree of subchondral metabolism in the patellofemoral joint assessed by SPECT/CT in patients with chronic anterior knee pain, particularly the patella, is predictive of a poorer response to conservative management [38]. The PPV of non-response for grade 2 or 3 patella uptake (grade 0, no uptake; grade 1, higher uptake than normal cancellous bone; grade 2, same uptake as the articular surface; grade 3, higher uptake than the articular surface) is 62–67%. In contrast, only 24–25% of patients with

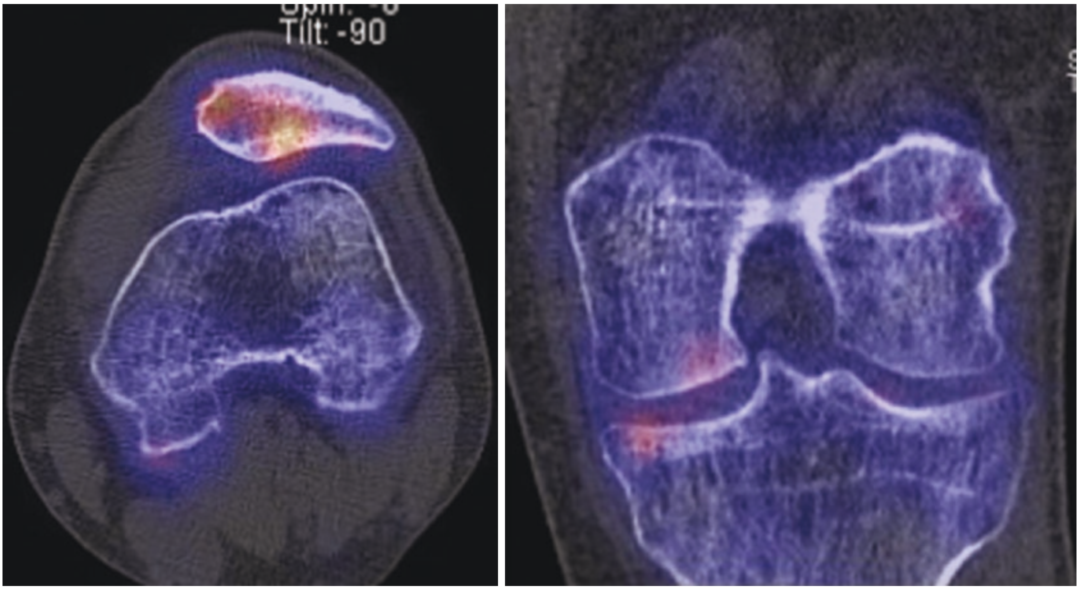

**Fig. 9.1** Combined single photon emission computerized tomography with conventional computerized tomography (SPECT/CT) images of a left knee of a 30-year-old male patient showing an increased bone tracer uptake in the medial compartment of the femorotibial joint as well as on the medial part of the patellofemoral joint

grade 0 or 1 patella uptake do not respond to treatment. These findings suggest that SPECT/CT can aid clinicians in predicting treatment response from conservative management in patients between 40 and 65 years with isolated atraumatic unilateral anterior knee pain.

- A 39-year-old female patient suffered a rupture of the posterior cruciate ligament (PCL) and an injury of the bursa prepatellaris of the left knee in a motorbike accident. The MRI confirmed a complete rupture of the PCL and showed a grade 2 cartilage damage of the medial patella facet (Fig. 9.2a). The conservative treatment with a PCL brace and physiotherapy was initiated. After 8 weeks the patient reported

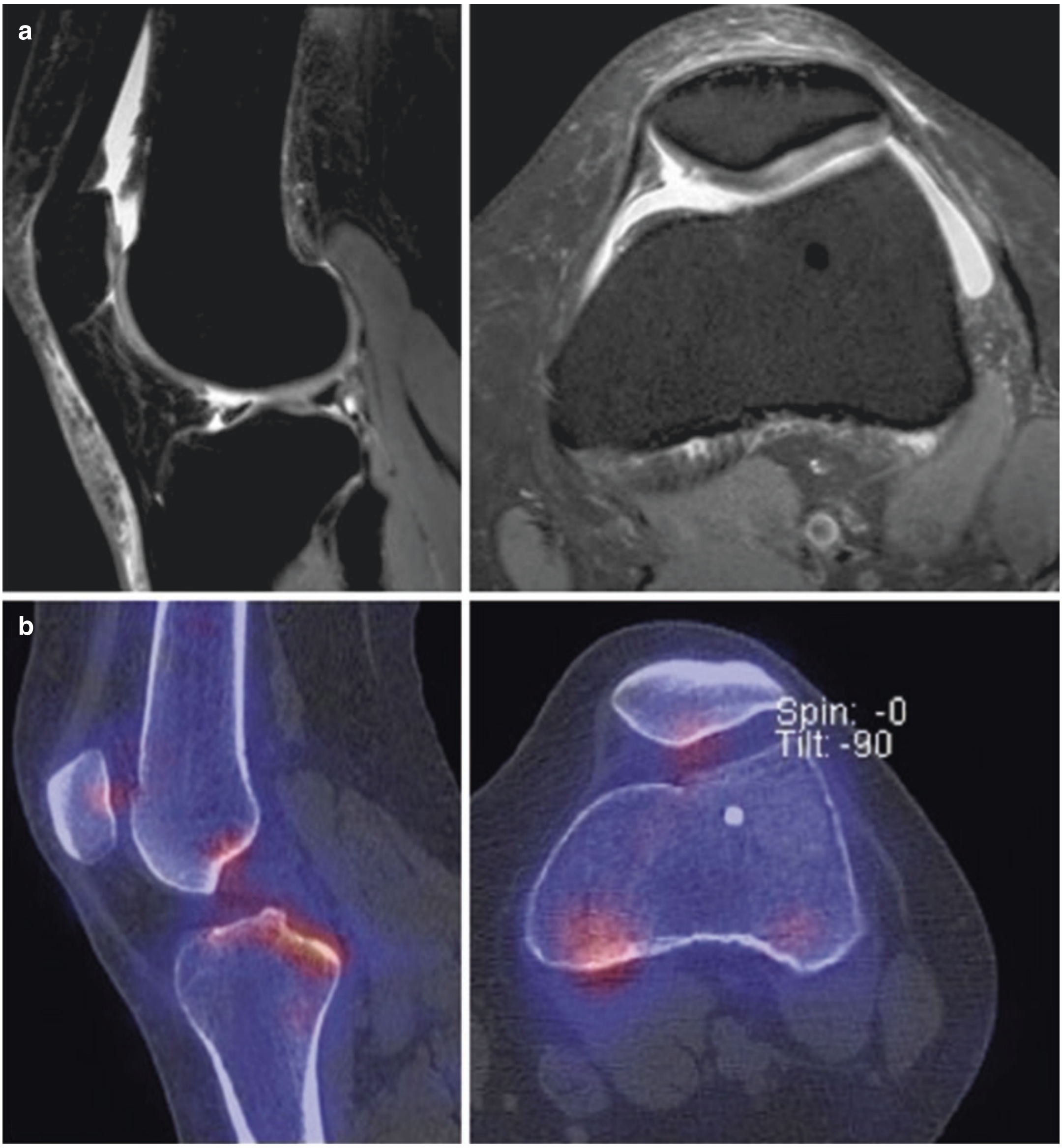

**Fig. 9.2** The MRI (**a**) of the left knee of a 39-year-old female patient confirmed a complete rupture of the PCL and showed a grade 2 cartilage damage of the medial patella facet. SPECT/CT (**b**) was performed and revealed increased bone tracer uptake on the medial patella facet, which indicated a grade 4 damage and in the area of the PCL

noticeably less instability; however more anterior knee pain during weight-bearing was indicated. Clinical examination showed no increase of posterior translation but retropatellar pain on palpation. In order to determine if the chondral lesion on the medial patella facet was metabolically active, SPECT/CT was performed. Increased bone tracer uptake was revealed on the medial patella facet, which indicated a grade 4 damage, and in the area of the PCL, which was interpreted in the context of the healing process (remodelling) (Fig. 9.2b). The patient was treated by an open cartilage reconstruction using three-dimensional collagen matrix.

Considering the study of Ro et al. cited above, it can be speculated that the grade 3 SPECT/CT bone tracer uptake in this patient was predictive for poorer response to conservative management.

- A 60-year-old female patient presented with bilateral knee pain, more severe on the left. There was no history of trauma. The knee was noted to swell and be most painful on walking and climbing stairs. Clinically, the left knee had a mild effusion and peripatellar tenderness. The AP and lateral weight-bearing radiographs showed isolated lateral patellofemoral osteoarthritis of both knees, with largely preserved femorotibial joints. The radiographic changes appeared symmetrical. The SPECT/CT demonstrated activity to both patellofemoral joints. Images corresponded with the patient's symptoms with signal intensity greatest from the lateral femoral condyle and patellofemoral joint (Fig. 9.3). The patient underwent patellofemoral arthroplasty with a resulting abatement in symptoms.
- A 26-year-old male patient sustained a grade 3 cartilage lesion (ICRS) of the size 1.5 × 1.5 cm in the area of the femoral trochlea of the right knee during tackling in a soccer game. The diagnosis was confirmed by MRI. The patient complained of persistent anterior knee pain. Clinically, the right knee showed a swelling and isolated peripatellar tenderness with full range of motion. In order to differentiate chondral from osteochondral lesion, which has a therapeutic consequence, artho-SPECT/CT was performed. A chondral lesion grade 3 (ICRS) without involvement of the subchondral bone (with little formation of cysts) was seen (Fig. 9.4). Therefore, autologous chondrocyte transplantation (ACT) was recommended to the patient.
- A 35-year-old female patient presented with acute left anterior knee pain and swelling, worse after episodes of running. Examination revealed palpable patellofemoral crepitus, with lateral parapatellar and joint line tenderness. Twenty years earlier, she had undergone microfracture of the retropatellar surface for osteochondritis dissecans. She had made a successful recovery and was able to perform to a high level of activity. Radiographs demonstrated disruption of the lateral patella facet with a possible osteochondral defect, which we postulated was a chronic injury from the time of previous microfracture and underlying osteochondritis dissecans. MRI confirmed damage to the lateral patella facet, a grade 3–4 patellofemoral joint chondromalacia with a lateral meniscal lesion (Fig. 9.5a). The SPECT/CT study displayed increased bone tracer uptake in the lateral patella facet (Fig. 9.5b). The patient underwent arthroscopic debridement and partial resection of her lateral patella. She made a full recovery from her symptoms and was able to return to running.

- *Evaluation of painful knees after total knee arthroplasty (TKA)*: Approximately 20–30% of patients after total knee arthroplasty are not pain-free or satisfied [39]. The most common reasons for persistent, recurrent or new-onset pain after TKA are aseptic loosening of a TKA component, malposition or malalignment leading to polyethylene wear, instability, recurrent hemarthrosis, stiffness, periprosthetic fracture, tendon rupture, infection and patellofemoral maltracking. Based on

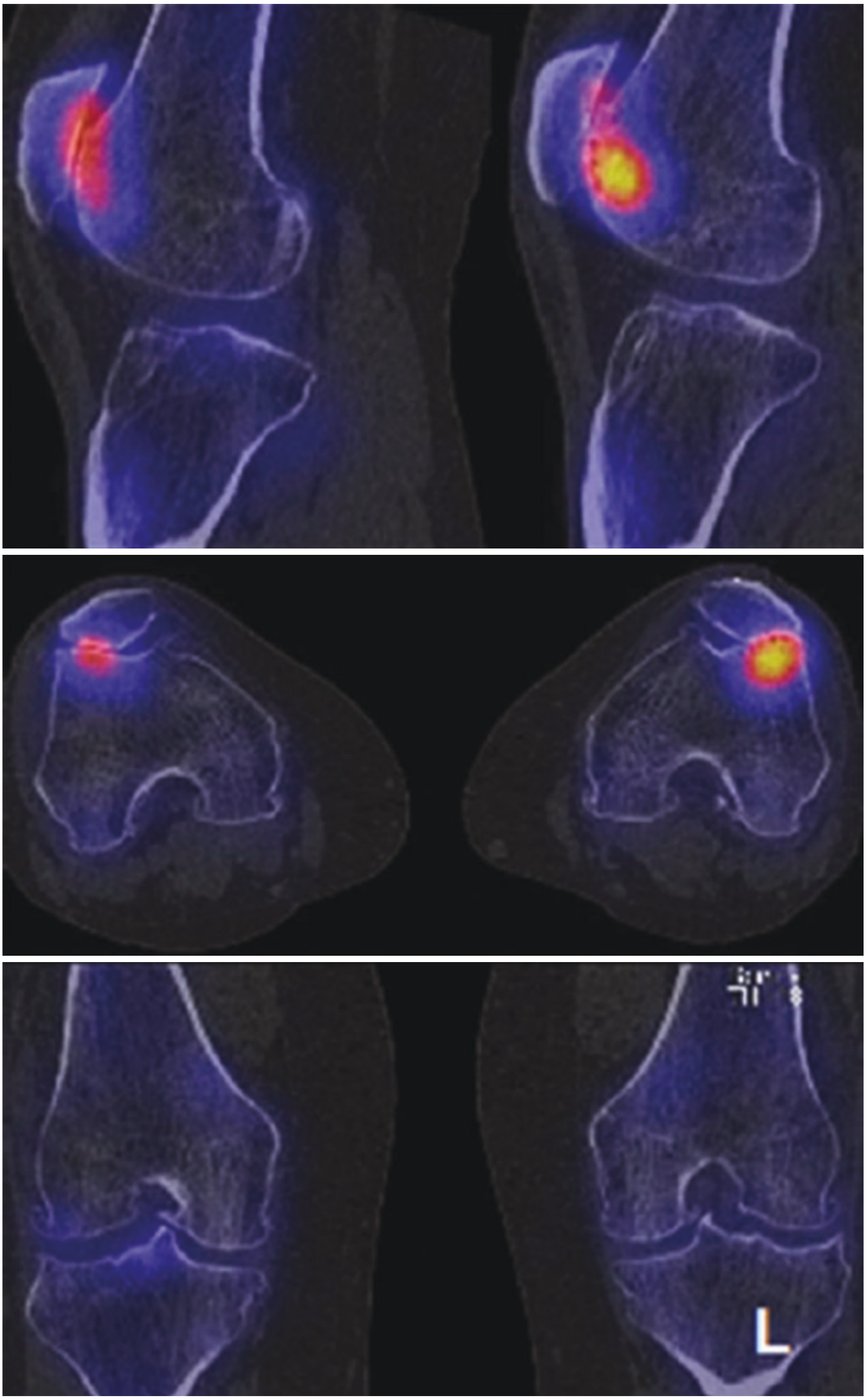

**Fig. 9.3** Combined single photon emission computerized tomography with conventional computerized tomography (SPECT/CT) images of both knees of a 60-year-old female patient showing a localized area of increased tracer uptake to the lateral femoral condyle and patellofemoral joint. The intensity is greatest on the left knee, corresponding with the patient's symptoms

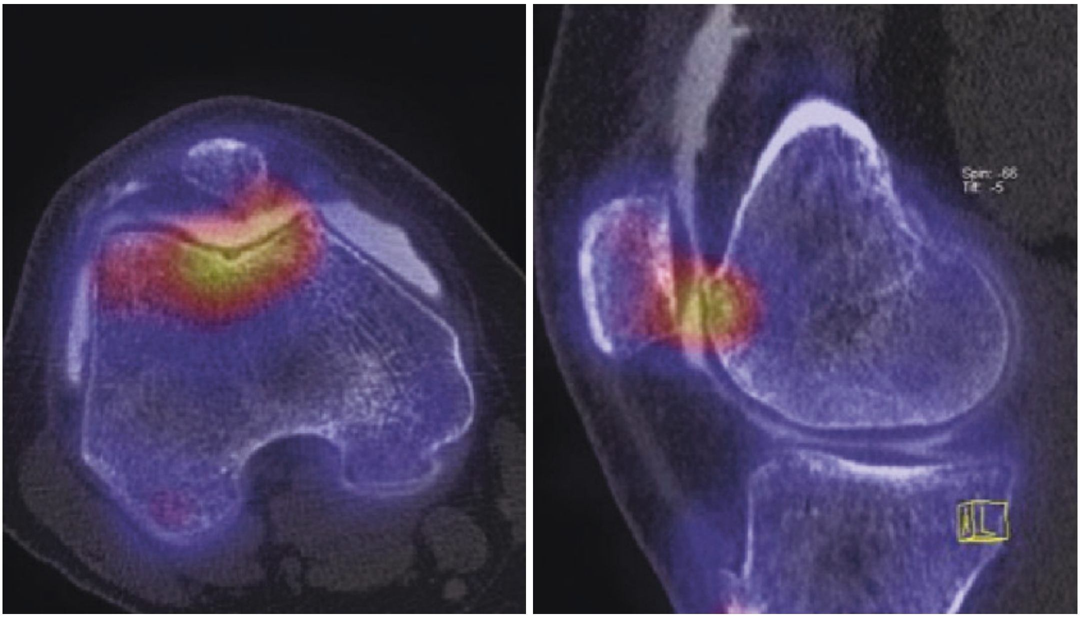

**Fig. 9.4** A 26-year-old male patient sustained a grade 3 cartilage lesion (ICRS) of the size 1.5 × 1.5 cm in the area of the femoral trochlea of the right knee during tackling in a soccer game. The diagnosis was confirmed by MRI. In order to differentiate chondral from osteochondral lesion, which has a therapeutic consequence, artho-SPECT/CT was performed. A chondral lesion grade 3 (ICRS) without involvement of the subchondral bone (with little formation of cysts) was seen

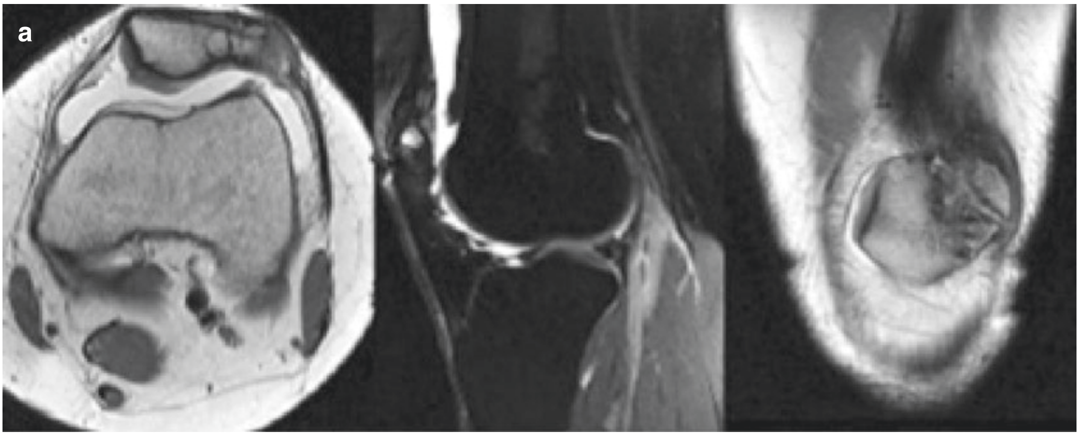

**Fig. 9.5** (**a**–**b**) Combined single photon emission computerized tomography with conventional computerized tomography (SPECT/CT) images of the right knee of a 50-year-old male patient showing a focal increased activity at the retropatellar surface with otherwise unsuspicious knee after total knee arthroplasty

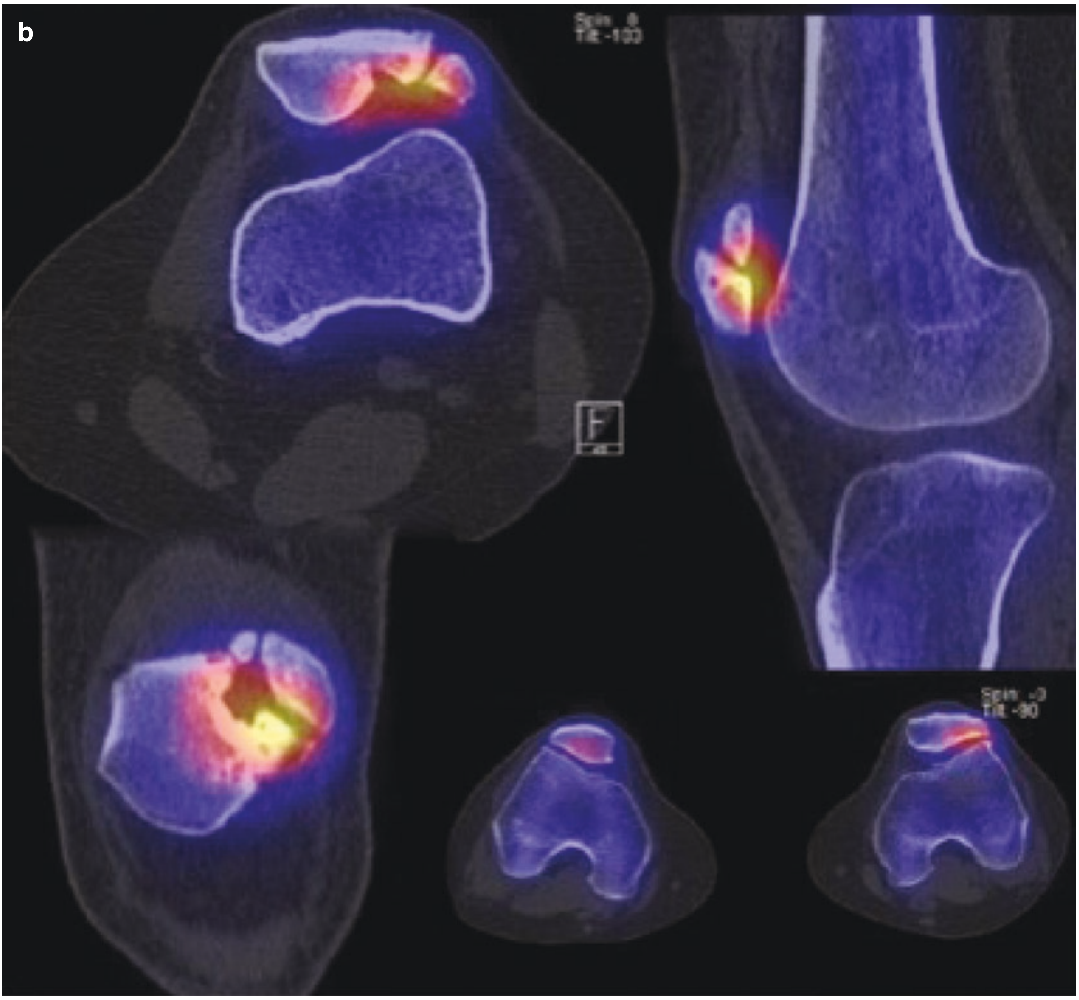

**Fig. 9.5** (continued)

literature, the latter is considered to be the reason for postoperative pain 12 months after TKA in 5% [39–41]. The role of SPECT/CT in those painful patients after TKA has been highlighted in a landmark article by Hirschmann et al. in 2015 [27]. It was shown that SPECT/CT changes the clinical diagnosis and final treatment in 85% of the knees. In 97% the preoperative SPECT/CT diagnosis was confirmed intraoperatively. With regard to patellofemoral peculiarities, patellofemoral osteoarthritis and loosening of tibial or femoral components were diagnosed correctly in 100% of the patients. Typical patterns of BTU for specific pathologies have been identified and the clinical relevance of increased BTU at specific sites described (Table 9.1).

Another pioneering study demonstrating the clinical relevance of SPECT/CT in patients after TKA has been published in 2017 by Slevin et al. [42]. The authors evaluated 62 consecutive patients who underwent primary TKA without patellar resurfacing and analysed rotational, sag-

**Table 9.1** Typical SPECT/CT appearance for patellofemoral overloading and femoral malrotation and loosening

| Pathology | SPECT/CT BTU findings | SPECT/CT findings | Pitfalls |
|---|---|---|---|
| Patellofemoral overloading | Increased BTU at medial or lateral or superior or inferior patellar facet | Sclerotic or cystic changes of patellar facet | Increased BTU at entire patellar facet represents more likely bone remodelling |
| Femoral internal malrotation | Increased BTU at lateral patellar facet | Sclerotic or cystic changes of patellar facet | – |
| Femoral external malrotation | Increased BTU at medial patellar facet | Sclerotic or cystic changes of patellar facet | – |
| Femoral loosening | Increased BTU at lateral and/or medial posterior femur | Radiolucent lines around pegs or around entire femoral interface | – |
| Tibial loosening | Increased BTU below tibial TKA, around tibial pegs and stem | Radiolucent lines around pegs and stem or around entire tibial interface | In TKA with posterior slope increased BTU at posterior tibia represents bone remodelling |

ittal and coronal position of the tibial and femoral components as well as the patellar height, thickness, tilt and TT-TG. Correlations between SPECT/CT BTU and TKA component position and patellar measurements were identified. The strongest correlation was found between valgus alignment of the femoral TKA component and increased BTU at the lateral patellar regions ($p < 0.05$). External rotation of the tibial TKA correlated with increased BTU at the lateral superior joint adjacent part ($p < 0.05$). This allows the conclusion that SPECT/CT reveals clinically relevant postoperative patellar maltracking due to femoral TKA position in the coronal plane and very likely explains anterior knee pain in the majority of TKA patients with femoral valgus alignment [39, 42].

The same authors have also compared the in vivo patellofemoral loading between patients after TKA with resurfaced patellae and without resurfaced patellae using SPECT/CT and assessed the knee society score (KSS) [43]. They have found significantly higher BTU in the anterior, non-articular areas of the patella in patients who underwent patellar resurfacing and the mean postoperative KSS was significantly higher in the unresurfaced group after 12 months. In the light of these results, routine patellar resurfacing as part of a primary TKA should be discussed critically.

- A 50-year-old male patient had undergone a patella sparing primary total knee arthroplasty (Natural Knee®, Zimmer Ltd., Münsingen, Switzerland) for post-traumatic bicompartmental osteoarthritis. Two and a half years after surgery, the patient presented with activity-related anterior right knee pain. Clinical examination and blood tests, including infection screening, were normal. Radiographs showed an unchanged position of the total knee prosthesis but with some notching of the femur. The patella was well seated in the trochlea with neither tilting or subluxation nor degenerative changes. There appeared to be minor osteolysis underneath the tibial base plate (Fig. 9.6a). With the suspicion of tibial component loosening, SPECT/CT was performed. To the surprise of the clinicians, the patellofemoral joint was shown to be the source of the patient's symptoms. There was no evidence of prosthesis loosening or infection (Fig. 9.6b). Following patella resurfacing, the patient made a full recovery.
- A 61-year-old female patient complained of persisting knee pain 1 year after total knee arthroplasty (BalanSys CR rotating platform without patella resurfacing). The character of pain was described differently than before primary TKA ('vice-like'). Clinically, the left knee showed tenderness around the patella

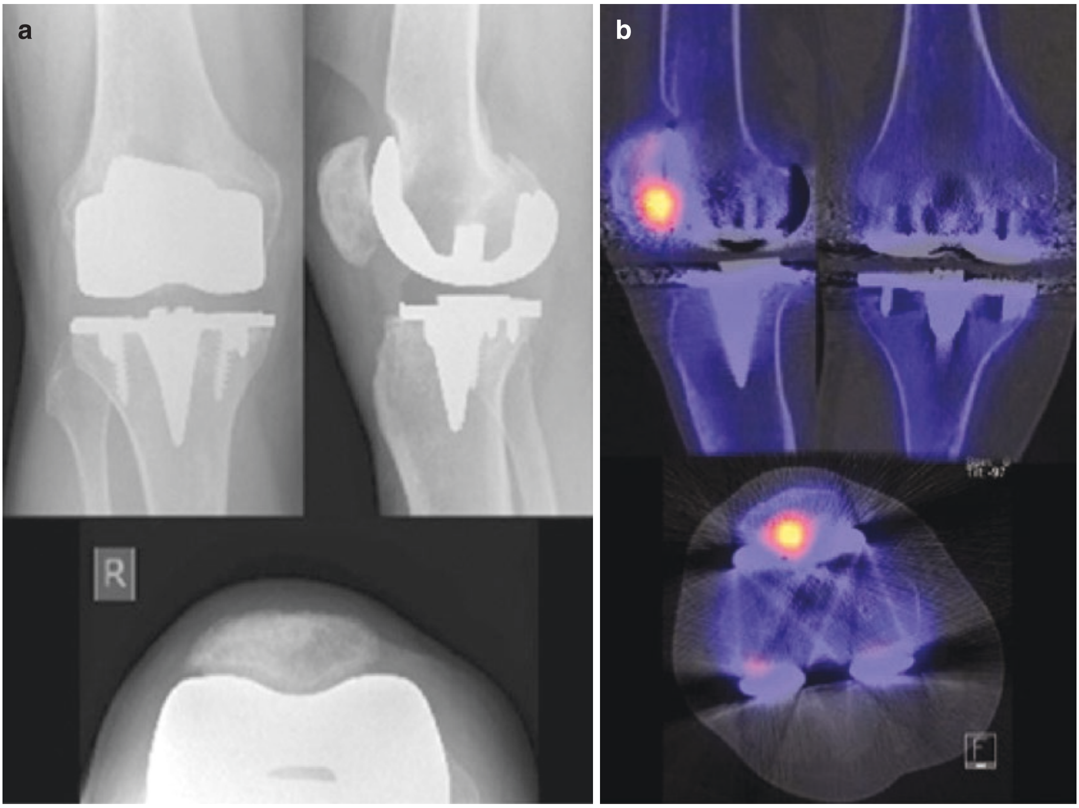

**Fig. 9.6** A 50-year-old male patient had undergone a patella sparing primary total knee arthroplasty (Natural Knee®, Zimmer Ltd., Münsingen, Switzerland) for post-traumatic bicompartmental osteoarthritis. Two and a half years after surgery, the patient presented with activity-related anterior right knee pain. Radiographs showed an unchanged position of the total knee prosthesis but with some notching of the femur. There appeared to be minor osteolysis underneath the tibial base plate (**a**). With the suspicion of tibial component loosening, SPECT/CT was performed, and the patellofemoral joint was shown to be the source of the patient's symptoms. There was no evidence of prosthesis loosening or infection (**b**)

and retropatellar crepitus during flexion. The AP and lateral weight-bearing radiographs showed a patella baja situation, however, no indications of loosening of the implants but a vague assumption of malalignment of the femoral component. With that suspicion 3D-SPECT/CT was performed and showed 3° internal rotation and 8° flexion of the femoral component (Fig. 9.7a) with increased bone tracer uptake in the whole patella (Fig. 9.7b). The patient underwent secondary patella resurfacing, proximalize osteotomy of tibial tubercle and revision of the femoral TKA component. A few months later, the patient was fully recovered from her symptoms.

– A 78-year-old female patient suffered ¾ year after primary total knee arthroplasty a periprosthetic distal femur fracture of the right knee (Rorabeck type II), which was fixed with a NCB plating system. In the postoperative course, however, the patients complained of increasing anterolateral knee pain. Clinical

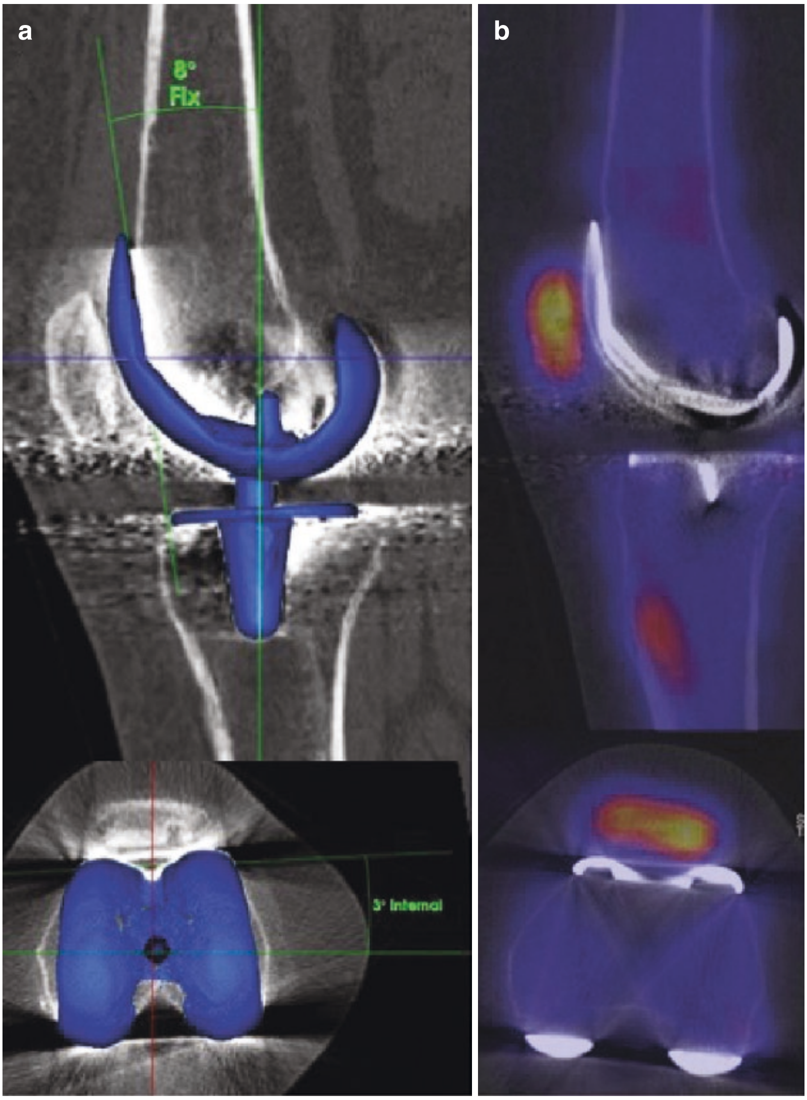

**Fig. 9.7** Measurement of femoral TKA component position in 3D reconstructed CT images using a customized software of a 61-year-old female patient complaining of persisting knee pain 1 year after TKA (BalanSys CR rotating platform without patella resurfacing) showing 3° internal rotation and 8° flexion of the femoral component (**a**) with increased bone tracer uptake in the whole patella (**b**)

examination revealed lateral parapatellar tenderness and retropatellar pain during flexion. There were no signs of an infection. In order to exclude a pathology associated with the TKA (loosening, periprosthetic fracture, malalignment), SPECT/CT was performed. By this means an impingement of the lateral patella facet and the distal femur plate was demonstrated (Fig. 9.8). Due to the persisting symptoms, the plate was removed after 12 months. The patient had a full resolution of pain.

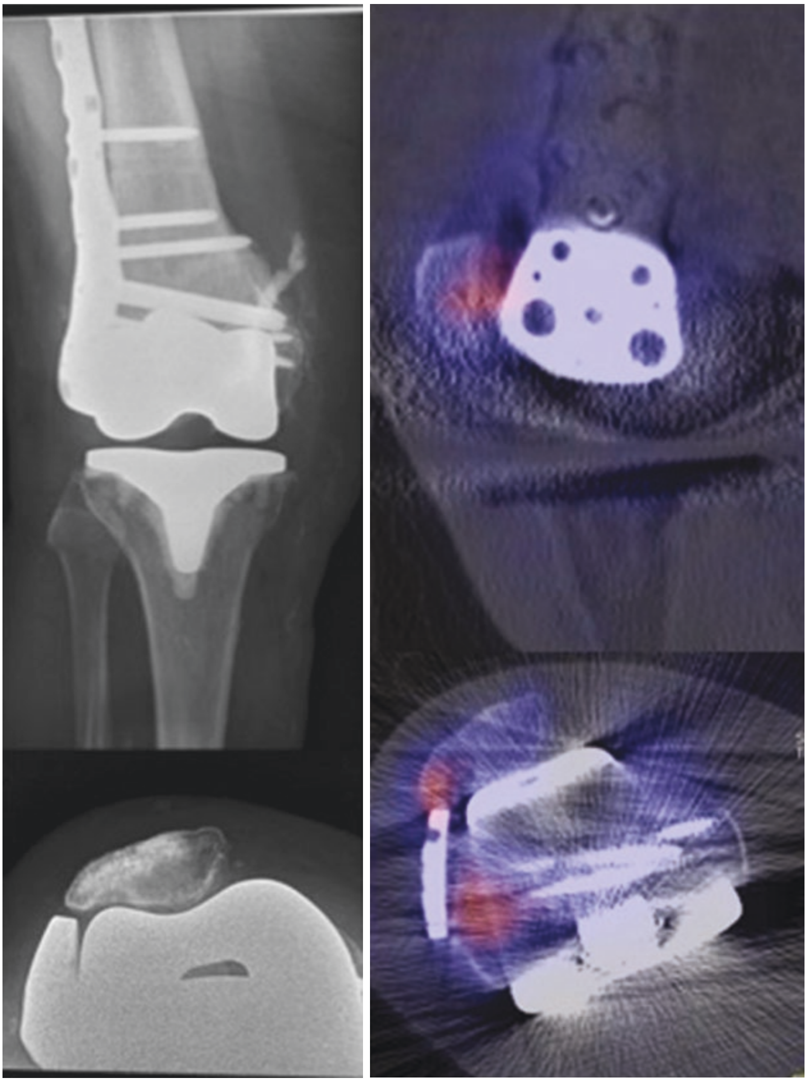

**Fig. 9.8** A 78-year-old female patient presented anterolateral knee pain after a periprosthetic distal femur fracture of the right knee, which was fixed with a NCB plating system. In order to exclude a pathology associated with the TKA, combined single photon emission computerized tomography with conventional computerized tomography (SPECT/CT) was performed. By this means an impingement of the lateral patella facet and the distal femur plate was demonstrated

## 9.2 Conclusions

Although the clinical value of SPECT/CT is established in orthopaedic surgery, there are still many open questions [20, 44, 45]. Among them is the question of what the difference of BTU in normal and symptomatic knees is. How does a pathological BTU differ from a physiological BTU? What does an increased BTU reflect, and how it is influenced by mechanical alignment, the subchondral bone plate or the patient's specific biology [17–19, 25, 27]?

Already two decades ago, the observation has been made that the osseous remodelling often occurs despite the demonstration of normal findings by diagnostic methods, such as radiography, computed tomography and magnetic resonance imaging. In a pioneering article in 1994, Dye et al. described increased osseous metabolic activity of bone that is detectable with scintigraphic methods associated with early stages of stress fractures causing osteoclastic activity and tear of intra-articular soft tissues triggering the biological cascade of increased remodelling

[31]. Fritschy et al. underlined these findings by reporting an unexpectedly high percentage of abnormal findings on bone scans and degenerative changes in patients following reconstruction of the anterior cruciate ligament, despite restoration of normal laxity parameters. The authors emphasized the importance of physiological as well as structural criteria in the assessment of such patients [46].

The following additional factors make the interpretation of SPECT/CT bone trace uptake in patients with knee pain challenging [47]:

- Pain is normal in the postoperative period (TKA 6–12 months) and is usually imprecisely described.
- Differentiation of complication of the prosthesis from other problems or pathologies near to the joint.
- Periprosthetic bone tracer uptake can physiologically persist for several years: heterogeneous uptake that can persist up to 4 years after TKA (it is more evident at the tibia medial compartment [47]).
- There are a variety of types of prosthesis.

Therefore it is essential that the nuclear medicine physician has a broad understanding of the surgical procedures and components of the prosthesis and cooperates closely with the orthopaedic surgeon.

In clinical practice the interpretation of BTU values is currently dependent from examiner's experience. Over the last decade, several authors have introduced methods of quantification of SPECT data to minimize subjectivity in BTU interpretation [48–50]. However, Hirschmann et al. established a clinically neutral reference region in the proximal femur; its BTU intensities were then used as a baseline distribution which functions to normalize other values [20]. Until now, the clinical relationship between the reference region, regions of altered BTU in SPECT/CT and clinical outcomes remains an open research question [17, 18, 25, 44].

To our knowledge, the only studies dealing with thresholds of BTU in orthopaedic surgery are three recent publications of Awengen, Schweizer and Mathis et al. [28, 51, 52]. Awengen and Schweizer et al. identified thresholds for asymptomatic knees and hips after total arthroplasty. However, these thresholds were assessed in knees and hips after total arthroplasty and do not represent an asymptomatic non-operated healthy population. In 2018 Mathis et al. defined for the first time an absolute BTU threshold, which is quantified in the asymptomatic non-operated knee joint [52]. This threshold was defined as the median + 1 SD of the asymptomatic non-operated knee. Values above this threshold most likely represent a pathology in the symptomatic knee after ACL reconstruction, and values below the threshold indicate most likely a physiologic patient-specific BTU.

The literature about greater BTU in the patella than in the ipsilateral distal femur or proximal tibia, known as the 'hot patella' sign, is controversial [34]. Some authors stated that the 'hot patella' is an important abnormal finding indicating overloading of the patellofemoral joint; others did not see any clinical value in reporting a 'hot patella' sign as it includes both the normal remodelling of an unresurfaced patella and abnormal loading of the patella [42]. In a recent retrospective study, Ahmad et al. found a significant correlation between the 'hot patella' sign and postoperative patellofemoral problems in patients after TKA [53]. The authors concluded that patients with a 'hot patella' sign are more likely to benefit from a secondary patellar resurfacing. Based on our data, the 'hot patella' sign is not useful for assessment of patellar loading since it is not very differentiated. However, when the patella is divided into several different areas, BTU evaluation in 3D might be helpful for guidance of treatment. This was demonstrated by Awengen et al. in 2016 finding significantly higher BTU intensity in symptomatic TKA in all eight different anatomical regions in the patella using a SPECT/CT anatomical localization algorithm [28].

In summary, SPECT/CT enables a precise localization of the BTU and shows benefits in establishing the correct diagnosis and therefore might be considered as the ideal imaging modality for evaluation and investigation of patellofemoral problems in general but in particular after TKA.

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# 10

# Non-operative Treatments for Patellofemoral Arthritis

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and Sabrina Strickland

## 10.1 Introduction

Anterior knee pain, also known as patellofemoral pain (PFP), affects approximately 22% of the general population, with increased prevalence in the adolescent community, as high as 28% [1]. It is twice as common among females (29.2%) than males (15.5%) [1]. The predominant demographics for PFP includes adolescents, young active adults, military recruits, and elite athletes, particularly runners, cyclists, and basketball players [2–5].

PFP is characterized by the presence of non-traumatic anterior knee pain, with and without structural damage to the patellofemoral joint [6]. In the absence of structural changes to the patellofemoral joint, such as in young patients, the presence of PFP is considered “patellofemoral pain syndrome” (PFPS), defined by retropatellar pain with actions that increase load across the joint such as ascending or descending stairs, hopping, jogging, prolonged sitting, and squatting [7]. Patients with PFPS do not typically have positive findings on examination of the knee bursa, ligaments, menisci, or plica [7]. Common causes of patellofemoral pain not due to patellofemoral pain syndrome include patellar and quadriceps tendinopathy, iliotibial band syndrome, lateral patellofemoral compression, and plica syndrome, which will be discussed later in the chapter. The presence of structural damage to the patellofemoral joint is considered patellofemoral osteoarthritis (PFOA), affecting predominantly older adults [6, 8].

It was previously believed that PFPS is a benign, self-limiting condition. This notion has been discredited, however, upon the grounds of prospective studies that have shown that patients with PFPS are more likely to decrease or stop their sports activities over a 2-year period [9, 10] and consistently report poorer scores on patient-reported outcomes for knee-specific and quality of life measures [11]. Young patients with PFPS have similar morbidity to patients with ACL injuries, without the resolution of symptoms with surgery or rest [12]. Though symptoms may improve with maturity from adolescents into adulthood, the pain usually persists. In a study by Sandow and Goodfellow, 63 patients with PFPS were followed for 16 years after initial presentation; 78% of patients reported persistent pain, with 71% of patients reporting some improvement of symptoms with age likely due to cessation of pain-inducing activities [13, 14]. Consequently, recognizing and understanding PFPS, and treating it appropriately, is critical for sports medicine physicians.

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This chapter will primarily address the etiology, history, clinical evaluation, and treatment of PFPS and its associated conditions, with a brief discussion of PFPS as a precursor to PFOA.

## 10.2 Patellofemoral Pain Syndrome

### 10.2.1 Anatomy of the Patellofemoral Joint (PFJ)

The PFJ is a diarthrodial joint with its articulation consisting of the posterior aspect of the patella and the trochlear surface of the distal femur. The proximal portion of the patella is termed the base, while the distal point is termed the apex. It is approximately 35–40 mm in length, 40 mm in width, and 20–25 mm thick [15, 16]. The articulating surface of the patella is covered in up to 7 mm of cartilage, essential to the dissipation of joint reaction forces generated with contraction of the quadriceps [15, 17].

The distal femur consists of an intercondylar groove, or trochlear sulcus, upon which the patella engages. Its lateral facet is larger than its medial facet to improve patellar stability [15]. The sulcus angle, measured at the intersection of the medial and lateral sulcus lines, is used to evaluate for trochlear dysplasia. A normal angle is approximately 138 ± 6°; a larger angle, or shallower groove, suggests dysplasia [17].

The soft tissue surrounding the PFJ helps prevent lateral translation of the patella. Static structures include ligaments about the knee, while dynamic structures include muscular attachments. The most important static stabilizer is the medial patellofemoral ligament, which has been reported to provide 60% of total lateral restraint at 20 degrees of knee flexion [18, 19]. Key lateral structures include the iliotibial band, lateral patellofemoral ligament, and joint capsule, which help to provide stability during less than 20–30 degrees of flexion due to absence of bony stability [15].

Dynamic stabilizers include the pes anserine, the biceps femoris, and, most importantly, the vastus medialis oblique (VMO). The oblique angle of the VMO creates a strong medializing force on the patella, thereby resisting lateral translation [15]. Additional soft tissue components key to PFJ stability include hip abductors, in particular the gluteus medius and minimus, and external rotators [20]. Weakness of such muscles allows for increased hip adduction and internal rotation, which together increase the Q-angle and cause increased lateral contact pressure on the PFJ and subsequent wearing of the articular cartilage [21].

### 10.2.2 Biomechanics and Kinematics of PFJ

The function of the patella is to serve as a mechanical pulley for the quadriceps muscle, increasing quadriceps power by 33–50% (it is most important during the last 30 degrees of knee extension).

When considering static alignment of the patella in PFPS, the frontal plane is most important as the patella has the most minimal contact with the femur in this position, allowing the patella to be most mobile and, therefore, least stable [15]. In this plane, the patella sits midway between the two femoral condyles with the knee in full extension. This is also the plane in which the Q-angle is measured, using the angle between the line extending from the anterior-superior iliac spine to the mid-patella and the line extending from mid-patella to tibial tuberosity. Normal Q-angle is 15–17° for females and 10–13° for males, with the gender difference being the results of a wider pelvis in women [22]. Increases in the Q-angle are associated with increased lateral forces on the patella and therefore increased contact stress [15]. Abnormal frontal plane motion, particularly during squatting, step-down, and jogging, is most commonly associated with PFPS [23].

In the sagittal plane, with the knee in partial flexion, the Caton-Deschamps index is measured. This is used to evaluate patella atla and patella baja. In the axial plane, the patella sits horizontally with the medial and lateral borders equidistant between the medial and femoral condyles.

Patellar tilt and tibial tubercle-trochlear groove distance are evaluated in this plane. The mean TT-TG distance is 10–13 mm, with greater values associated with increased risk for patellofemoral maltracking and instability [22].

Dynamic movement of the patella is evaluated in multiple planes including superior and inferior glide, medial and lateral glide, medial and lateral tilt, and medial and lateral rotation [15]. As the knee flexes and extends, the patella glides inferiorly and superiorly, respectively. Contact area between the patella and trochlea increases with knee flexion in order to distribute force over a greater surface area, thereby decreasing point contact pressure [15]. This is essential to preventing excessive wear on the articular cartilage that occurs with increased joint pressures in the setting of decreased contact areas.

### 10.2.3 Etiology of PFPS

In the absence of a single structural defect to account for the pain experienced in PFPS, its etiology is considered multifactorial. It is largely attributed to patellar maltracking, but has also been ascribed to aberrant pain pathways and psychological catastrophizing. As it is considered to be an overuse syndrome, its risk factors should be characterized. Such risk factors are generally classified as extrinsic or intrinsic risk factors, where extrinsic factors include the type of sport played, equipment used, and environment played in [24]. Intrinsic risk factors include all other components contributing to the clinical presentation of PFPS, such as quadriceps imbalance and abnormal trochlear groove. While osseous risk factors are not modifiable without surgery, all other intrinsic and extrinsic risk factors may be considered modifiable, as discussed in the treatment section of this chapter.

While such intrinsic and extrinsic risk factors contribute to the development of PFPS, it is the combination of such components in the setting of acute increases in load across the joint that likely causes the pain described in PFPS. According to Dr. Scott Dye, the typical function of the patellofemoral joint, without pain, should be viewed as within the limits of tissue homeostasis, also referred to as an “envelope of function” [25, 26]. This envelope is established by exposure of chronic loads to the PFJ and its surrounding structures, with subsequent adaptation of the joint to such loads. With the accumulation of acute increases in loading across the joint, the envelope of function may be exceeded, thereby disrupting the joint’s homeostasis. This results in excessive load transfer to subchondral bone causing micro-damage and inflammation that excites nociceptive fibers, resulting in pain [27]. Though intrinsic factors themselves do not result in a painful joint, the presence of extrinsic factors, such as temporary overuse or increase in physical activity level, creating acute increases in load in the setting of pathological kinematics, results in pain. This section will discuss the intrinsic factors contributing to the envelope of function of the PFJ, as well as the extrinsic factors that result in a disruption of homeostasis and resultant pain.

#### 10.2.3.1 Patellar Maltracking

Patellar maltracking, an intrinsic risk factor for PFJ, is typically characterized by static and/or dynamic malalignment resulting in irregular tracking of patella within the trochlear groove. Recent literature has also suggested that atypical patellar shape may also contribute to maltracking [1]. This maltracking results in abnormal contact pressures across joint, which, in the setting of acute load, can cause pain.

Static malalignment is typically characterized by osseous and ligamentous abnormalities including trochlear dysplasia, patella alta, MPFL laxity, and lateral retinacular tightness. Trochlear dysplasia, or a sulcus angle greater than 138 ± 6°, results in an increased tibial tubercle-trochlear groove distance [28], causing lateralization of the patella within the groove. Similarly, a high-riding patella, or patella alta, has been associated with maltracking due to a greater distance for the patella to travel before engaging with the trochlea. “Alta” is determined by an Caton-Deschamps ratio greater than 1.2. This ratio is determined by dividing the distance from the inferior aspect of the patellar articular surface to the tibial plateau by the length of the patellar articular surface [15]. Such static components, when combined with dynamic valgus, result in pathological kinematics that prime the PFJ for inability to tolerate increased loads.

Dynamic malalignment is characterized by disproportionate lateral pull on patella due to vastus medialis oblique (VMO) deficiency and excessive internal rotation of the femur and tibia due to soft tissue imbalance and rear-foot eversion. Weakness of hip abductors and external rotators and iliotibial band tightness are commonly identified as causes for internal rotation of the femur, while rear-foot eversion results in internal rotation of tibia.

#### VMO Deficiency

Deficiency of the VMO weakens the medial quadriceps vector, thereby allowing greater pull of the lateral quadriceps vector with a resultant increase in the dynamic Q-angle. Due to this loss of the medial force, the patella is pulled laterally, out of its normal tracking. Additionally, studies have shown delayed activation of the VMO as compared to the vastus lateralis, at 15, 30, and 45 degrees of knee extension, using electromyography [29]. Such delayed activation contributes to VMO dysfunction relative to vastus lateralis function, with subsequent further lateralization of the patella.

#### Hip Abductor and External Rotator Weakness

The gluteus medius and minimus, two primary hip abductors, are frequently weak in the setting of PFPS. While not directly related to PFJ kinematics, weakness of such muscles allows the femur to adduct/internally rotate more than normal, thereby increasing lateral patellar contact pressure causing subsequent increased pain [30]. Ireland et al. reported that female patients with PFPS had 26% less hip abduction strength and 36% less hip external rotation strength than their non-painful counterparts [30, 31]. Such pathomechanics result in a greater portion of the absorption load to be transferred to passive lower limb structures, with subsequent “out-of-plane” loading with greater control on the frontal and transverse planes [32]. As a result, the patella is forced to dissipate higher levels of force via less efficient control mechanisms [32].

#### Iliotibial Band Tightness

The IT band has been associated with PFPS due to its attachment to the lateral retinaculum and patella. In the setting of such connections, a tight IT band will increase the lateral force vector on the patella, increasing joint stress [33].

#### Rear-Foot Eversion

Patients with PFPS have been shown to have reduced range of rear-foot eversion, increased rear-foot eversion during heel strike, and delayed timing of peak rear-foot eversion, compared to controls [6, 34]. Such foot abnormalities contribute to internal rotation of the tibia in PFPS, with resultant increased lower extremity valgus.

Hamstring tightness is also commonly seen in patients with PFPS, with resultant co-contraction of the quadriceps and hamstrings relatively to controls [6, 35]. This co-contraction results in increased joint forces on the PFJ, contributing to greater contact stress. Additionally, the lateral hamstrings of patients with PFPS have been shown to contact earlier than medial hamstrings during isometric exercises, increasing patellar maltracking [6, 36].

### 10.2.3.2 Overuse

While patellar maltracking may “prime” a knee for PFPS, overuse of the knee is essential to the development of the syndrome, as it is this acute stress that results in surpassing its envelope of function and presentation of pain. Patients with PFPS are classically athletes participating in sports that repetitively load the knee, such as running, cycling, and basketball. Fairbank et al. evaluated involvement in competitive sports in female patients with PFPS and found that those with PFPS were more likely to be involved as compared to age-matched controls [30, 37]. He noted that the patient’s associated pain onset was correlated with an increase in activity level.

### 10.2.3.3 Aberrant Pain Pathways

Neurodynamic causes of PFPS have gain popularity in the last two decades. This theory suggests that minor nerve damage, or altered mechanosensitivity of nerves about the knee, contributes to PFPS. For example, Sanchis-Alfonso and Rosello-Sastre have demonstrated that excessive pressure on the patella causes periodic episodes of ischemia that trigger neural proliferation and cause pain [38, 39]. This group also observed that patients with PFPS often possess hyperinnervation in the lateral retinaculum, which may also contribute to the patients' pain experience [40]. Such hyperinnervation the lateral retinaculum has been corroborated by additional studies that examined the incidence of free nerve endings in the soft tissue structures of the knee and found the highest amounts of afferent nerve fibers type IVa in the retinacula, as well as the patellar ligament, pes anserinus, and ligaments of Wrisberg and Humphrey [41].

The femoral nerve which gives rise to the medial and lateral patellar nerves has also been shown to play a key role in PFPS symptoms. Blocking of the femoral nerve with local anesthetics significantly reduced pain intensity among 20 patients with PFPS, in a study by Maralcan et al. [42]. Further support for the importance of the femoral nerve is demonstrated in a study by Lin et al., in which patients with and without PFPS were subjected to the femoral slump test (FST), the neurodynamic test used to assess mechanosensitivity of the femoral component of the nervous system [39]. The research revealed that patients with PFPS had a smaller hip extension angle during the FST as compared to the control group, suggesting that mechanosensitivity of the femoral nerve may play a role in the development of anterior knee pain.

#### 10.2.3.4 Psychological Impact: Catastrophizing and Fear Aversion

Many patients with PFPS experience psychological distress due to their chronic knee pain [6]. Thomee et al. demonstrated that patients with PFPS cope and experience pain similarly to other chronic pain patients; however those with PFPS tend to catastrophize more than other chronic pain patients [43]. Such catastrophizing likely contributes to perpetuation of pain and cessation of sports activities. This fear-avoidance belief regarding physical activity has been shown to be a psychological risk factor for pain and function in those with PFPS [44].

### 10.2.4 History

Patients with PFPS typically report pain around or behind the patella that is worse with activities that load the patellofemoral joint, including ascending and descending stairs, squatting, running, and jumping. Patients may also describe pain after prolonged sitting, called the "theater sign" [25, 45]. Additional symptoms include crepitus within the patellofemoral joint during knee flexion, tenderness to palpation around the patella, and the presence of a small effusion [46]. Pain is often bilateral, though it is typically worse on one side than the other. Patients often have trouble localizing their pain at a precise location on the patella and therefore typically place their hand on the knee or circumscribe the patella, known as the "circle sign" [45].

Important to note, a history of dislocation or subluxation is exclusion criteria for the diagnosis of PFPS.

### 10.2.5 Clinical Evaluation

As patellofemoral pain syndrome is considered a diagnosis of exclusion, clinical evaluation of anterior knee pain should be systematically approached and should include inspection, palpation, gait, and special tests for anterior knee pain.

#### 10.2.5.1 Inspection

The general appearance of each knee should be considered, taking into account any erythema, swelling, or additional skin changes that may be present. Significant swelling with or without contusion, in the setting of patellar injury, may suggest a patellar dislocation or fracture, both of which are separate entities to PFPS. Any bony abnormalities should be noted, as well as the presence of genu varum or genu valgum. Obvious muscular deformities should be appreciated as well, such as a bulge in the anterior thigh suggesting quadriceps tendon rupture.

#### 10.2.5.2 Palpation

Each knee should be palpated for tenderness around the four poles of the patella, as well as the medial and lateral joint lines, tibial tubercle, pes anserine, patellar and quadriceps tendons, and pre-patellar and supra-patellar bursas. Patients with patellofemoral pain syndrome may present with pain at the superior or inferior poles; however tenderness along the joint lines, tibial tubercle, pes anserine, and supra-patellar bursa typically suggest alternative etiologies for anterior knee pain such as meniscal pathology, patellar tendinitis, pre-patellar bursitis, or apophysitis.

#### 10.2.5.3 Gait

Due to pain and altered biomechanics, patients with PFPS often present with an abnormal gait. Fox et al. examined gait kinematics in patients with acute (<3 months of symptoms) and chronic (>3 months of symptoms) PFPS and found that both groups had greater knee flexion across stance and greater ankle dorsiflexion during early stance as compared to age-matched controls [47]. Interestingly, patients with acute PFPS exhibited greater transverse plane hip motion across stance, while chronic PFPS patients demonstrated greater frontal plane hip motion. Patients with chronic PFPS also exhibited greater knee abduction, and reduced ankle eversion, as compared to acute PFPS and age-matched controls [47].

#### 10.2.5.4 Special Tests

Merchant et al. describe five physical exam maneuvers, and two radiographic measurements, to evaluate anterior knee pain. The physical exam tests will be discussed here:

1. *VMO deficiency*: This is assessed by having the patient actively maintain an unsupported leg at 30° flexion while sitting. Deficiency is observed when the VMO inserts higher into the medial edge of the quadriceps tendon.
2. *MPFL ligament laxity*: This is assessed using the lateral glide test, where quadriceps are relaxed and the leg is supported at 30° flexion, while sitting. The physician then pushes the patella laterally, allowing the patella to translate approximately 1 fingerbreadth. The lateral glide test is positive if the patient demonstrates apprehension during this motion.
3. *Lateral retinacular tightness*: This is assessed by attempting to centralize the patella in the trochlear groove and everting the patella to neutral. If this cannot be completed, excessive tightness is likely present.
4. *Q-angle measurement*: The patient should be supine with their leg in neutral rotation and the knee in full extension.
5. *Hip abductor weakness*: This is assessed with the step-down test, in which the patient stands on a stool/stair and slowly steps down with the opposite limb, allowing their heel to touch the ground, before slowly rising up. The test is considered positive if a Trendelenburg sign is seen.

Additionally, the iliotibial band may be examined for tightness, as a possible contributor to PFPS, by using Ober's test [48]. This test is performed with the patient in the decubitus position with the non-affected lower leg flexed to 45° to maintain a neutral spine [48]. The knee of interest is flexed to 90° with the upper leg brought into abduction and extension. The physician then lowers the leg into adduction, observing for abnormal hip rotation [48].

#### 10.2.5.5 Radiographic Evaluation

##### Plain Radiographs

While PFPS can typically be diagnosed without imaging, plain radiographs are often useful in diagnosing osseous abnormalities, including patella alta and trochlear dysplasia, and in excluding other items in the differential diagnosis for anterior knee pain such as meniscal pathology and plica syndrome.

Bilateral AP views are useful for evaluating the tibiofemoral joint, but may also show patellar abnormalities such as gross patella alta, and lateromedial subluxation. Lateral views are used to evaluate patellar height, and the presence of patella alta or baja, using the Caton-Deschamps ratio.

Merchant view, particularly the standing loaded Merchant, has been shown to be the gold standard for representing joint kinematics. Axial views are preferable for measuring patellar translation or the lateral or medial displacement of the patella with respect to the trochlear groove where >2 mm is considered abnormal [45]. Similarly, the sulcus angle at the intersection of the lines drawn from the medial and lateral femoral condyles is used to evaluate degree of trochlear dysplasia, using axial radiographs. The normal range is 138 ± 6°, where >144° is considered diagnostic of trochlear dysplasia.

#### Advanced Imaging: CT and MRI

The primary advantage of CT and MRI over plain radiographs is the ability to evaluate soft tissue abnormalities that may be contributing to anterior knee pain such as chondral defects, patellar and quadriceps tendinopathy/tendinitis, bursitis, plica, and integrity of the MPFL. Additionally, certain measurements such as the tibial tubercle-trochlear groove distance are better measured on MRI or CT. Furthermore, dynamic MR imaging allows for assessment of patellofemoral kinematics with real-time tracking of patellar movement and surrounding muscle function [45].

Drew et al. conducted a systematic review investigating which PFJ imaging features are associated with PFPS as compared to asymptomatic controls [49]. MRI bisect offset at 0-degree knee flexion under load and CT-derived congruence angle at 15-degree knee flexion with and without load were shown to both be strongly associated with PFP. Increased patellar tilt and decreased patellofemoral contact area were also shown to be suggestive of PFP radiographically [49].

## 10.2.6 Treatment

### 10.2.6.1 Non-operative

The mainstay of treatment for PFPS is currently strengthening and gait retraining. Additional non-operative measures include cortisone injection, hyaluronic acid injection, orthobiologics such as platelet-rich plasma or stem cell injections, and passive correction of patellar maltracking with bracing and taping.

#### Strengthening

Strengthening exercises for PFPS management originally focused on strengthening the knee via quadriceps strengthening as VMO weakness is a known factor in the etiology of PFPS. In recent years, however, the importance of hip strengthening, in particular the hip abductors and external rotators, has been identified as a potentially more important treatment for PFPS. Two recent systematic reviews that investigated the importance of hip and knee strengthening as compared to hip strengthening alone found that the combination therapy significantly reduced pain in patients with PFPS as compared to knee strengthening alone [50, 51]. When comparing hip strengthening alone to knee strengthening alone, earlier reduction of pain has been shown in hip strengthening groups as compared to knee strengthening groups [52]. It is believed that the relative importance of hip strengthening over knee strengthening is due to the change in hip and knee biomechanics during functional activities which addresses the underlying cause of PFJ loading, with hip strengthening [52]. Knee strengthening, in comparison, helps to relieve lateral joint stress on the joint, but does not alter the biomechanics of the hip and knee as significantly as hip strengthening.

In addition to strengthening of the hip and knee, core strengthening has been recently discovered to be an important component to add to PFPS treatment regimens [53–55]. As neuromuscular deficits of the core muscles have been associated with greater risk for knee injury, strengthening of these muscles is useful in the treatment of PFPS [56]. Additionally, patients with PFPS have been shown to have impaired trunk postural control as compared to age-matched controls [53]. Furthermore, patients with PFPS have been shown to have abnormal postural control in both static and dynamic balance positions, as well as core muscle contraction with voluntary heel raise [54]. Such weakness of core musculature contributing to postural imbalances likely contributes to the altered biomechanics and resultant pain seen in patients with PFPS. Therefore, strengthening of the core musculature should improve posture and reduce pain in patients with PFPS. In a recent study by Foroughi et al., patients with PFPS were treated with either hip, knee, and core strengthening or hip and knee strengthening alone [54]. While both groups demonstrated reduced pain after 4 weeks of treatment, those that received the additional core-strengthening regimen reported greater reduction in pain.

### Gait Retraining

Patients with PFPS have greater incidence of rear-foot foot strike pattern as compared to controls. This pattern of foot strike causes greater shock attenuation, loading rate, and patellofemoral joint stress, thereby contributing to the pain experience. As a result, gait retraining has gained popularity as an adjunct or an alternative to strengthening for treatment of PFPS. In a recent prospective study of Roper et al., PFPS patients with rear-foot strike patterns were retrained to adopt forefoot strike patterns [57]. This gait retraining produced significant reductions in pain according to a visual analog scale. Support for pain reduction with retraining to forefoot strike pattern is corroborated by additional studies that have shown a 10–27% reduction in peak patellofemoral joint stress, as compared to rear-foot strike patterns [58–61]. In addition to retaining strike patterns, increasing the step rate, or number of steps per minute, and increasing forward trunk lean are gait retraining methods that have been associated with reduced patellofemoral joint stress [58, 62, 63]. Dos Santos [64] compared these three methods of gait retraining and found that forefoot strike training most significantly reduced patellofemoral pain in patients with PFPS compared to the other two methods. They attributed this improvement in pain with forefoot running to an increased plantarflexor moment during stance phase, allowing greater control of ankle dorsiflexion from ground reactive forces [58]. Additionally, dos Santos found that forefoot running allows for a reduction in peak knee flexion angle; increased knee flexion has been associated with higher patellofemoral joint stress and subsequent pain.

### Foot Orthotics

Similar to bracing and taping, the use of orthotics in PFPS has been frequently debated. Recent studies have demonstrated some benefit of orthotics over short-term interventions [65]. In a 4-week intervention using semi-custom orthotics in runners with PFPS, reduction in pain due to decreased patellofemoral loading was observed [66]. This study attributed the reduction in loading to reduction in knee flexion via proprioceptive effects produced by shock attenuating properties of the orthotics. Similarly, foot orthoses have also been shown to improve joint stability and reduce work by dorsiflexors such as the abductor hallucis and tibialis anterior [67]. Such altered biomechanics improves stability of the knee and reduces pain-producing components seen in PFJS. Important to note, the usefulness of foot orthoses may be limited to those who have greater peak rear-foot eversion during walking and greater midfoot flexibility [65, 68, 69]. Additionally, strong evidence suggests that foot orthoses do not improve outcomes by 12 or 52 weeks compared to placebo, but may improve outcomes in the short term, over 6 weeks [65].

### Bracing and Taping

Both bracing and taping to passively correct patellar malalignment have been explored extensively; however, the literature remains inconclusive regarding long-term benefit of such interventions [70, 71]. Patellar bracing has shown some short-term benefit in small studies evaluating the effect of knee bracing in PFPS [66]. According to a systematic review by Saltychev [71], however, of the 37 studies included in their review, 30 did not demonstrate a significant benefit with patellar bracing. Kinesio taping of the VMO has been shown to decrease pain and improve function of the quadriceps in athletes with PFPS [72]; however these results were among only 15 patients with PFPS, limiting the power of the results. In a systematic review by Logan et al., five studies were evaluated for the effect of taping on patellofemoral pain syndrome [73]. The review found that knee taping may be beneficial in reducing PFPS but only as an adjunct to strengthening therapy.

#### 10.2.6.2 Operative

Surgical treatment for PFPS is uncommon and is reserved for cases due to severe osseous and ligamentous abnormalities that prevent normal patellar tracking despite non-operative treatment programs. Arthroscopic lateral retinacular release may be performed in those with excessive lateral retinacular release; however we do not recommend this treatment. The release has been shown by some authors to relieve lateral tension and decrease surface pressure, as well as denervate the hyperinnervated lateral retinaculum which is believed to contribute to the etiology of PFPS [74]. More typically, lateral release procedures may also be combined with a tibial tubercle osteotomy to unload the lateral aspect of the patellofemoral joint or in dislocators with a medial patellofemoral ligament reconstruction as part of general soft tissue balancing [6, 75].

## 10.3 Additional Causes of Anterior Knee Pain

### 10.3.1 Patellar Tendinopathy

#### 10.3.1.1 Pathology

Patellar tendinopathy, commonly referred to as jumper's knee, is an overuse injury affecting the patella tendon. This condition can be very painful and often affects young patients, particularly athletes. Athletes who participate in sports that involve a lot of jumping, such as basketball and volleyball, are more likely to present with patellar tendinopathy [76]. The other common name for this condition, patella tendinitis, is misleading as it refers to an inflammatory disorder, when tendinopathy actually describes a degenerative disorder. However, studies involving more modern research tools have shown evidence that inflammatory responses may be an important component to chronic tendinopathy [77]. There is no consensus on the pathogenesis of tendinopathy, which is a main reason there is no consensus on an effective treatment for this disease. The most widely accepted theory for pathogenesis of tendinopathy describes cellular and mechanical property changes as a result of repetitive microtrauma to the tendon [78]. An alternative theory is the neural theory, which describes the release of pain-generating neurotransmitters and substance B due to cellular changes within the nerves themselves [78]. The last major theory is the vascular theory, which is studied more in regard to other tendons rather than the patella tendon. This theory blames the degeneration and substandard healing of tendons to the poor blood supply tendons receive [79].

#### 10.3.1.2 Diagnosis

Patellar tendinopathy presents itself as localized anterior knee pain at the inferior pole of the patella, as consistent with the origin of the patella tendon. When magnetic resonance imaging is performed, there tends to be an increase of signal intensity at this location [80]. It is important to note that there are patients who have imaging that reads abnormal, but who have no pain. Onset of pain is often gradual. Studies show that the following characteristics are related to increased risk of patellar tendinopathy: male gender, increased weight, decreased upper leg flexibility, decreased upper leg strength, increased fat pad size, decreased foot arch height, and increased leg length differences [81]. Extrinsically, increased training—both volume and frequency—is a risk factor for patellar tendinopathy [81]. A macroscopic look at the histopathologic changes shows that tendinopathic tendons are gray/brown instead of white and fragile instead of firm [82].

#### 10.3.1.3 Treatment

Similarly to the lack of consensus on the pathogenesis of patella tendinopathy, there is little consensus on the most effective treatment plan for this disease. The majority of treatments for patella tendinopathy are non-operative. Physical therapy, in particular eccentric training with the addition of decline squats, is the most frequent treatment [83]. Extracorporeal shock wave therapy (ESWT), which involves using high-energy acoustic waves to deliver pressure to the symptomatic area, is also a possible treatment [84]. A variety of injections are used to treat patellar tendinopathy. Platelet-rich plasma (PRP), aprotinin, sclerosing polidocanol, and steroid injections all show promising results—however, steroids have been shown to be harmful to the tendon in the long run. Operative options include both arthroscopic surgery, involving shaving of the tendon and tendon debridement, and open knee surgery, involving excising the abnormal tissue and drilling the inferior pole of the patella [85]. With no agreement on the correct pathogenesis nor effective treatment plan for this condition, there is much progress to be made in the study of patellar tendinopathy.

## 10.3.2 Iliotibial Band Syndrome (ITBS)

### 10.3.2.1 Pathology

Iliotibial band syndrome (ITBS) is a painful condition involving the inflammation of the iliotibial band (IT band) or deep to the IT band. It is typically inflamed by activity that incorporates recurring flexion and extension of the knee and is especially prevalent in long-distance runners. This motion causes friction which can bring about inflammation. The IT band is a band of connective tissue that runs from the proximal end of the tendons of the tensor fasciae latae and gluteus maximus muscles, across the knee joint, and into the patella, tibia, and biceps femoris tendon [86]. When magnetic resonance imaging is done, fluid is often seen in between the IT band and femoral epicondyle. In addition, the distal portion of the IT band appears thicker on an MRI [86]. The reason why some athletes are affected by ITBS and other athletes are not is still unclear. Studies have shown some internal risk factors may be muscle weakness around the knee and hip abductor weakness [87].

### 10.3.2.2 Diagnosis

Patients with iliotibial band syndrome present with pain along the distal portion of the lateral femoral epicondyle and/or lateral tibial tubercle. Patients are often unable to pinpoint a specific area of discomfort and describe pain spread out over the lateral knee. Pain is present while working out and after working out for most patients. As ITBS worsens, pain can become constant, even while the patient is not being active [86]. Ober’s test is used to diagnose ITBS. As the patient lies on their unaffected side with their hips and shoulders in line, the bottom knee and hip are bent to 90°. The affected leg is then lowered, adducting the hip until motion is limited. A positive Ober’s test occurs when the patient describes lateral knee pain and cannot fully adduct their hip, which indicates ITBS [88].

### 10.3.2.3 Treatment

The vast majority of treatments for ITBS are non-operative and aim to reduce friction between the IT band and the femoral condyle. This is done by minimizing activities that involve repeated extension and flexion of the knee and stretching the iliotibial band, plantar flexors, and hip flexors. Anti-inflammatory medications also help in alleviating pain. If pain and inflammation continue, local corticosteroid injections to the greatest point of discomfort are an option. Once inflammation is reduced, patients begin strengthening the knee and hip extensors and flexors and can progress back toward normal activity. If pain persists, surgery to release the posterior aspect of the IT band over the lateral femoral epicondyle is an option [86].

## 10.3.3 Lateral Patellofemoral Compression Syndrome (LPCS)

### 10.3.3.1 Pathology

Lateral patellofemoral compression syndrome (LPCS), also known as patellar compression syndrome or excessive lateral pressure syndrome, is a condition in which overload to the lateral facet of the patella causes pressure and pain in the knee. This is exacerbated by patellofemoral malalignment, which results in a higher Q-angle. Malalignment of the patella causes increased contact between the patella and lateral femoral condyle and increased pressure on the lateral patellar facet when the knee is flexed. A tight lateral retinaculum contributes to lateral pressure in flexion [89].

#### 10.3.3.2 Diagnosis

Patients with LPCS present with localized pain to the inferolateral patella and anterolateral joint line and describe anterior knee pain during both activity and rest. Patients may have limited knee extension and test positive for the “theater sign” of worsened knee pain by prolonged flexion while seated [90]. A clinical exam to diagnose LPCS involves the seated patient attempting to extend and flex their knee. Extension is often limited, and pain heightens as the knee reaches 90 degrees of flexion. If the patella is moved medially and manually centered in the trochlea by the clinician, the patient is frequently relieved of pain and instantly may show a larger pain-free range of motion [89].

#### 10.3.3.3 Treatment

Conservative treatment for LPCS consists of closed-chain strengthening of the muscles of the upper leg, specifically the quadriceps [91]. Open-chain strengthening exercises should be limited to after 30 degrees of knee flexion [92]. Stretching should be done to improve flexibility of the quadriceps, IT band, and hip flexors. Taping the patella medially is an additional technique that can be done. The surgical treatment of LPCS would consist of a simple lateral release to correct excessive patellar tilt; however some patients may also receive a tibial tubercle osteotomy [93].

### 10.3.4 Plica Syndrome

#### 10.3.4.1 Pathology

Plica syndrome occurs when synovial plica of the knee, most commonly the medial patellar plica, becomes inflamed and thus symptomatic. The mediopatellar plica runs from a supra-patellar origin to the Hoffa fat pad [94]. Plicae are very common and are thought to be the result of mesenchymal tissue from embryological development that is not fully reabsorbed after birth [95]. While most people with plicae are asymptomatic, plica can become aggravated by repetitive knee flexion and extension, blunt trauma, fat pat irritation, twisting injuries, or meniscal injuries [96]. When inflamed, plica thickens and can cause impingement on the femoral condyle. Rarely this can cause chondromalacia by abrading the far medial aspect of the trochlea [97].

#### 10.3.4.2 Diagnosis

Patients with plica syndrome are usually young and present with dull anterior knee pain in the area anterior and medial to the patella. This pain is worsened with knee flexion and increased activity level [94]. Popping can rarely be heard with both extension and flexion [95]. When a clinical examination is performed, patients may express tenderness at the location of the plica, and clinicians may be able to feel the thickened plica as the patient extends and flexes the knee. Imaging is usually done to rule out other causes of anterior knee pain. Arthroscopy may rarely be used to provide a conclusive diagnosis [98].

#### 10.3.4.3 Treatment

Conservative treatment for plica syndrome involves strengthening the quadriceps and stretching the muscles of the upper leg. Lowering activity levels, NSAIDs, and corticosteroid injections also may help in reducing inflammation and pain levels. When non-operative treatment fails, arthroscopy with resection of the entire plica is done.

### 10.3.5 Chondral Lesions

#### 10.3.5.1 Pathology

Chondral lesions of the patella are the second most common location of cartilage lesions found during knee arthroscopy [99]. Chondral lesions of the patellofemoral joint are caused by acute trauma such as traumatic dislocation or subluxation, impaction such as a dashboard injury microtrauma due to abnormal joint loading, or osteochondritis dissecans [100]. If not treated, such defects affect the normal distribution of PFJ stress and can predispose the patient to the development of PFOA [101]. Of note, the chondral lesion itself is not pain-generating as cartilage is aneural. Rather, the pain experienced by patients is likely due to subchondral bone overload and synovial and capsular inflammation [102].

#### 10.3.5.2 Diagnosis

Patients typically present with anterior knee pain worsened by activity, occasional swelling, and intermittent locking or catching with knee flexion. Activities that exacerbate pain include prolonged sitting, ascending or descending stair, squatting, and running. Like the physical exam for other causes of anterior knee pain, the patient should first be evaluated for overall varus or valgus alignment and patellar position, as a large Q-angle and patella alta are risk factors for the development of chondral lesions [101]. Tibial torsion, VMO atrophy, patellar tracking, and medial and lateral stability should also be assessed. Crepitus and pain in early flexion may also be appreciated.

While initial radiographic evaluation should begin with plane radiographs, to assess for osteoarthritis, fracture, or other lesions, MRI is considered the gold standard in evaluating chondral pathology.

#### 10.3.5.3 Treatment

Nonsurgical treatment for chondral lesions includes NSAIDs and intra-articular corticosteroid injections, platelet-rich plasma injections, as well as possible hyaluronic acid injections. All such treatment options aim to reduce pain and inflammation. Additional non-operative management includes weight loss, avoidance of painful activities, and strengthening the supporting musculature about the knee.

If patients fail nonsurgical treatment, surgical options to be considered include osteochondral autograft transplantation, autologous chondrocyte implantation, or particulated juvenile cartilage allograft. Restoring cartilage defects in the patella is particularly challenging due to the high loads seen by the PFJ, heterogeneous morphology between patients, and thickness of the patellar cartilage as compared to other articular surfaces in the body. Contraindications to cartilage restoration include PFOA, inflammatory joint disease, and low-grade lesions. If patients also have concurrent patellar malalignment or instability, such abnormalities should be surgically addressed before or during the cartilage restoration procedure. Patellofemoral arthroplasty is an additional surgical option for patients with bipolar chondral defects, but should only be considered as a salvage procedure for those who have failed cartilage restoration procedures.

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# 11

# Is There a Surgical Treatment of Patellofemoral Pain?

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## 11.1 Background

It is widely accepted that the vast majority of patients with anterior knee pain (AKP) do not need a surgery; they only need conservative treatment [1–3]. In more cases than desirable, the AKP patient worsens after surgical treatment [4]. In fact, many surgeries in AKP patients are undertaken to address complications from previous poorly performed or badly indicated surgeries intended to treat AKP [4]. The patellofemoral joint (PFJ) does not really tolerate surgical procedures that do not respect its unique anatomical, biological, and biomechanical characteristics [5, 6]. That is why AKP surgery is not performed frequently. However, the results of conservative treatment for AKP are often frustrating—40% of AKP patients have an unfavorable recovery with conservative treatment at 12 months after the initial diagnosis [7]. This high percentage of unfavorable results may be due to some of these patients actually needing surgical treatment but not receiving it because their doctor lacks adequate knowledge to make a precise diagnosis.

Poor results of surgery in AKP patients may arise either because the diagnoses are inaccurate or because physiopathological premises (i.e., "pathologic" tibial tuberosity-trochlear groove [TT-TG] distance) on which surgery is based are incorrect and therefore treatment is also incorrect. Currently, the TT-TG distance is widely used as an indicator for medialization of the tibial tubercle in the AKP patient. However, Tensho and colleagues [8] have proved that knee rotation affects the TT-TG distance more than tubercle malposition does. For this reason, it should not be used for tibial tubercle transfer as an indicator. Unfortunately, many orthopedic surgeons operate on what computed tomography (CT) or magnetic resonance imaging (MRI) shows, that is, chondropathy, lateral patellar subluxation, patellar tilt, or increment of the TT-TG distance. Using this information as the basis for surgery is a critical error—and it is responsible for the poor reputation of AKP surgery. The patient with AKP is at high risk of receiving surgical treatment with little or no scientific basis simply because AKP is a musculoskeletal pathologic entity with a poorly understood etiopathogenesis [9].

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For AKP patients who could benefit from surgery, a knowledgeable surgeon and a correct diagnosis are crucial. Required factors include a careful history, close attention to what the patient reports, physical examination, and use of imaging. Unfortunately, many orthopedic surgeons base their surgical indications on an MRI or CT alone—it seems they are operating on an image instead of a person. Speaking with a patient and physical examination are fundamental, but neglected too often. This, in turn, triggers a failed patellofemoral surgery. One of the most powerful causes of AKP that both doctors and the literature forget to mention is the pain resulting from torsional alterations of the lower limb. However, tibiofemoral rotation has yet to be integrated into our thinking. If we carry out a search on PubMed, we see that there are few papers on torsional alterations of the lower limbs in patellofemoral disorders [10–30]. Furthermore, most of them are recent and published by the same group of researchers. In fact, most of the current literature discusses patellar alignment in association with AKP as a problem of the patella itself (increased tilt or increased shift of the patella). However, in many cases the problem is not in the patella but in the femur. Then, it is of a vital importance to assess the rotational profiles of the femur and tibia in an AKP patient. As far back as in 1995, Flandry and Hughston [31] showed that the most frequent cause of failure of an extensor mechanism realignment surgery was the existence of an underlying torsional alteration not diagnosed and therefore not treated. Stevens and colleagues [26] have demonstrated clinical improvement after osteotomies of femur and/or tibia in patients with a previous failed surgery (tibial tubercle osteotomy, LRR or arthroscopic debridement) to treat AKP in whom torsional abnormalities of the lower limb were unnoticed. These authors state that many orthopedic surgeons focus only on the knee when they see an AKP patient. Torsional abnormalities are often unrecognized.

This chapter focuses on the patient with AKP without patellofemoral chondropathy or osteoarthritis as the cause of pain. Consequently, techniques such as the anteromedialization of the tibial tubercle (Fulkerson's osteotomy) and the patellofemoral arthroplasty are not analyzed in-depth here. This chapter analyzes the current state of knowledge of surgical treatment of AKP patients, emphasizing the importance of the diagnosis and treatment of torsional alterations of the lower limb. Surgical techniques include minimally invasive procedures, such as peripatellar synovectomy or resection of synovial hypertrophy around the inferior pole of the patella, and major surgical techniques such as rotational osteotomies. Indeed, limb osteotomy should be seriously considered as a part of the armamentarium for treating AKP patients.

## 11.2 When Surgery Is Needed: General Principles

AKP remains a challenging condition for an orthopedic surgeon. Although surgery is not habitually needed, it is also true that in many cases AKP patients come to an orthopedic surgeon in search of a surgical solution. The surgeon must then determine what surgical procedure, if any, has the potential to improve the patient's condition and, most importantly, do no harm them.

As suggested by Post and Dye "Think of surgery as a tool used to create an environment in which homeostasis may be restored" [2].

A right diagnosis is paramount. To arrive at that diagnosis, answers are needed to the following questions: (1) is AKP secondary to patellar instability, or does it arise from bone rubbing or tension in the soft tissues?; (2) does the patient have a neutral mechanical axis, or is varus or valgus present?; (3) does he or she have abnormal torsion (i.e., considerable external rotation of the tibia or internal rotation of the femur)?; and (4) is the quadriceps too tight? A critical factor to consider when treating AKP patients is whether patellofemoral instability is present concurrently. Treatment of underlying patellar instability in these patients should be undertaken with caution, and the patients must know that surgical patellar stabilization may not relieve AKP. Moreover, a careful assessment of the limb alignment is an essential part of the physical evaluation of the AKP patient.

Many orthopedic surgeons base their surgical indication for patellofemoral surgery on a TT-TG distance greater than 20 mm. Use of this parameter as the deciding factor is a critical mistake because it can be a source of surgical failure and iatrogenia. We must not use imaging numbers to treat a patient. Physical examination is the key part of assessing AKP.

Historically, great importance has been given to the presence of a lateral patellar subluxation, which is attributed to excessive traction of the lateral retinaculum (LR) in the AKP patient. However, the LR does not pull the patella laterally—it prevents it from moving too far medially. Lateral patellar subluxation could be due to inadequate lateral trochlear inclination, genu valgum, or abnormal femoral anteversion. If lateral subluxation of the patella is present, the patellar tendon approaches the tibial tuberosity from a more lateral direction. Specifically, when the quadriceps contracts, more of its force through the patellar tendon is diverted into pulling the tuberosity laterally, causing the tibia to rotate more externally on the femur. Therefore, using a lateral retinaculum release (LRR) to correct a lateral patellar subluxation is inappropriate. We must treat the underlying cause, for example, an excessive femoral anteversion.

A key step in surgical decision-making is to identify whether AKP is related to patellofemoral overload. Pain related to it is generally localized and worsened or improved depending on the load applied to the PFJ. Patients with localized, load-related pain may be more amenable to successful surgical treatment, while diffuse, constant pain generally does not improve with surgery.

A true skeletal malalignment of the lower limb could be responsible for focal overload in the PFJ [6, 28–30, 32–34]. In these cases, imaging studies such as single-photon emission computed tomography (SPECT)-CT can document overloaded areas (Fig. 11.1). Rotational osteotomies may be used to unload bone and peripatellar soft tissues and create an adequate environment for return to homeostasis. Addressing the involved structures (trochlea, cartilage, and ligaments) does not address the cause of the abnormal force that produces focal overload; however, osteotomy is strongly able to change the direction of the force. This ability is particularly important when an abnormal limb alignment (transverse or coronal plane or combination) is present. If the cartilage is repaired, but the mechanics that caused its failure are ignored, failure is the likely outcome. It appears to be adequate to place the trochlear groove under the patella instead of forcing the

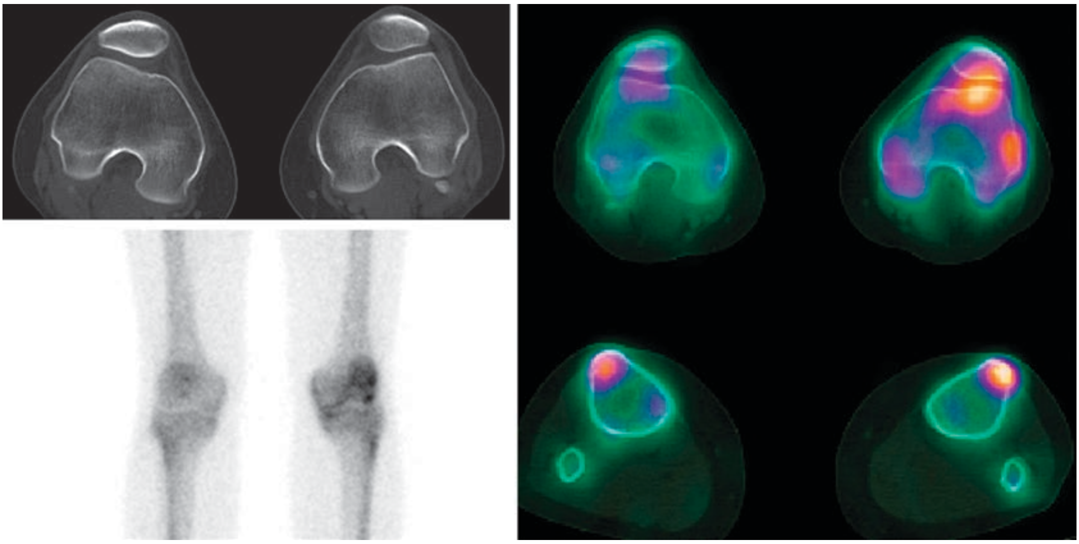

**Fig. 11.1** SPECT-CT in an AKP patient with 40° of external tibial rotation. External tibial rotation increases pressure on the lateral side of the PFJ

latter over the trochlear groove. In short, think about limb alignment, not patellar alignment. Paulos and colleagues [25] compared 2 surgical techniques in 25 patients with patellar instability and significant lower leg deformities. Group 1 underwent a rotational high tibial osteotomy, and Group 2 underwent an Elmslie-Trillat-Fulkerson proximal-distal realignment. Results in Group 1 were significantly better than those in Group 2.

In short, we must always evaluate the following: (1) skeletal alignment (i.e., geometry, including the trochlea); (2) ligaments (i.e., the presence of hypermobility and its cause and location); (3) articular cartilage (i.e., complete or partial loss, location of the loss, possibility to shift contact to intact cartilage); and (4) muscle (i.e., symmetrical atrophy versus gross imbalance).

## 11.3 Minimally Invasive Surgical Procedures

LRR has a long history, and it has often been used to treat AKP recalcitrant to conservative treatment in very selected patients with a patellar tilt and a tight LR, which is demonstrated by an inability to evert the lateral patella to a neutral position on physical examination [35]. In a systematic review of literature, Lattermann and colleagues [36] demonstrated that the isolated LRR for AKP yielded 76% of good results with no significant difference between open or arthroscopic procedures. They showed a need for revision surgery in 12% of the cases after a 52-month follow-up, but they emphasized that the surgical procedure is necessary in less than 15% of AKP patients. Nevertheless, the authors drew attention to the need for randomized clinical trials to assess the advantages of this procedure when treating AKP. Currently, however, experienced knee surgeons with a special interest in the patellofemoral joint rarely perform isolated LRR [37]. Iatrogenic medial patellar instability has been described after excessive LRR or in the setting of LRR performed in cases of patellar tilt without a tight LR or in patients with a severe trochlear dysplasia [38]. Lateral retinacular lengthening has been reported as an alternative to LRR in order to avoid eventual complications of itself [37]. Moreover, releasing the painful retinaculum in a limited way in a very selected group of AKP patients may relieve pain [39]. Finally, arthroscopic LRR of a symptomatic type III bipartite patella without excision of the accessory bone fragment is related to excellent AKP relief and early return to sport activities [40].

When a focal soft tissue source of AKP refractory to an adequate conservative treatment can be identified, arthroscopic debridement of this pathologic tissue can relieve the pain [41, 42]. The most frequent sources of pain would be synovial hypertrophy around the inferior pole of the patella, Hoffa fat pad impingement, or peripatellar synovitis. Use of a superomedial portal could help to avoid potential errors arising from viewing the anterior compartment from a peripatellar tendon portal [2]. These minimally invasive surgical procedures should not be approached lightly. It is imperative to avoid postoperative hemarthrosis, which can be very painful and set back restoration of homeostasis [1, 2]. Therefore, intraoperative hemostasis must be meticulous, and a 24-hour drain through one of the arthroscopic portals of the patient's knee is advised. Other patients may require removal of a chronically tender synovial band of tissue or plica. Moreover, it has been suggested that the ligamentum mucosum (i.e., infrapatellar plica) could potentially play a role in the pathogenesis of AKP [43]. Release or resection of the infrapatellar plica, which tethers the Hoffa fat pad, significantly improves AKP in these patients [44]. In patients with AKP recalcitrant to conservative treatment for more than 6 months and with no associated structural anomalies, patellar denervation could be an option [45].

Soft tissue impingement can also be associated with osseous hypertension, which can produce transitory ischemia and mechanical stimulation of nociceptors and therefore pain. Patients with an intraosseous hypertension of the patella with a positive pain provocation test (i.e., pain reproduced by raising infrapatellar pressure) could be good candidates for extra-articular arthroscopic patellar decompression [46].

## 11.4 Major Surgical Procedures: Osteotomies

In the setting of patella alta, excessive load of the distal patella can occur due to decreased engagement of the patella in the trochlea, concentrating load on a smaller than normal area of cartilage with a resultant increase in cartilage load which may provoke cartilage wear [47]. These patients may respond positively to treatment with a distalizing tibial tubercle osteotomy that increases contact area with triggered decrease in PF pressure. In case of a lateralized tibial tubercle with a visible patellofemoral maltracking and a correct alignment of the limb, a tibial tubercle osteotomy can be considered. Anteromedialization of the tubercle can effectively unload the lateral and distal aspects of the patella in these situations and yield excellent pain relief [48–50]. This procedure is especially attractive in the face of concurrent lateral patellofemoral osteoarthritis.

In cases when all of the following are present: (1) diffuse disproportionate patellar cartilage softening, (2) disabling AKP, (3) failure of adequate physical therapy treatment, and (4) normal patellofemoral tracking, a fresh patellar allograft transplantation could be a good option [51].

### 11.4.1 Torsional Malalignment of the Lower Limb

A not infrequent cause of intractable AKP is the torsional malalignment of the lower limb [10, 11, 13–19, 21, 22, 24, 26]. It is very often missed, despite being easy to detect, but more common than generally appreciated.

#### 11.4.1.1 Rationale

Limb alignment appears to have a very powerful influence on the quadriceps vector [30]. If an abnormal quadriceps vector is an important contributor to AKP and skeletal malalignment of the lower limb explains the offending quadriceps vector, then any torsion or coronal correction is important [30]. It is important to note that small alterations in skeletal alignment of the lower limb can result in significant alterations in PFJ stresses. Osteotomy has a strong ability to change the direction of the force and therefore treat these patients.

Lee and colleagues [33] have demonstrated that femoral rotation results in an increase in PFJ contact pressures on the contralateral facet of the patella (i.e., lateral PFJ during internal rotation of the femur and vice versa) and tibial rotation results in an increase in PFJ contact pressures on the ipsilateral facet of the patella. Lee and colleagues have demonstrated that tibial rotation has an influence not only on PFJ contact pressures and areas but also on strain in the peripatellar retinaculum [6]. More recently, Passmore and colleagues [34] have shown that idiopathic lower limb torsional deformities of the femur and tibia in children and adolescents are associated with gait impairments as well as a loading increment of the hip and PFJ. Thus, idiopathic lower limb torsional deformities are not a purely cosmetic issue. Using a finite element model, Liao and colleagues [52] have demonstrated that internal rotation of the femur provokes and increment of the PFJ stress.

#### 11.4.1.2 Clinical Evaluation

Two types of torsional alteration of the lower limb are possible: (1) excessive external tibial torsion (Fig. 11.2) and (2) excessive femoral anteversion associated with an increased external tibial torsion (Fig. 11.3). One of the questions yet to be answered, biomechanically, is “Are excess tibial torsion and excess of femoral anteversion of equal mechanical importance?” or “Does tibial or femoral torsion have a greater negative mechanical influence?”. The importance

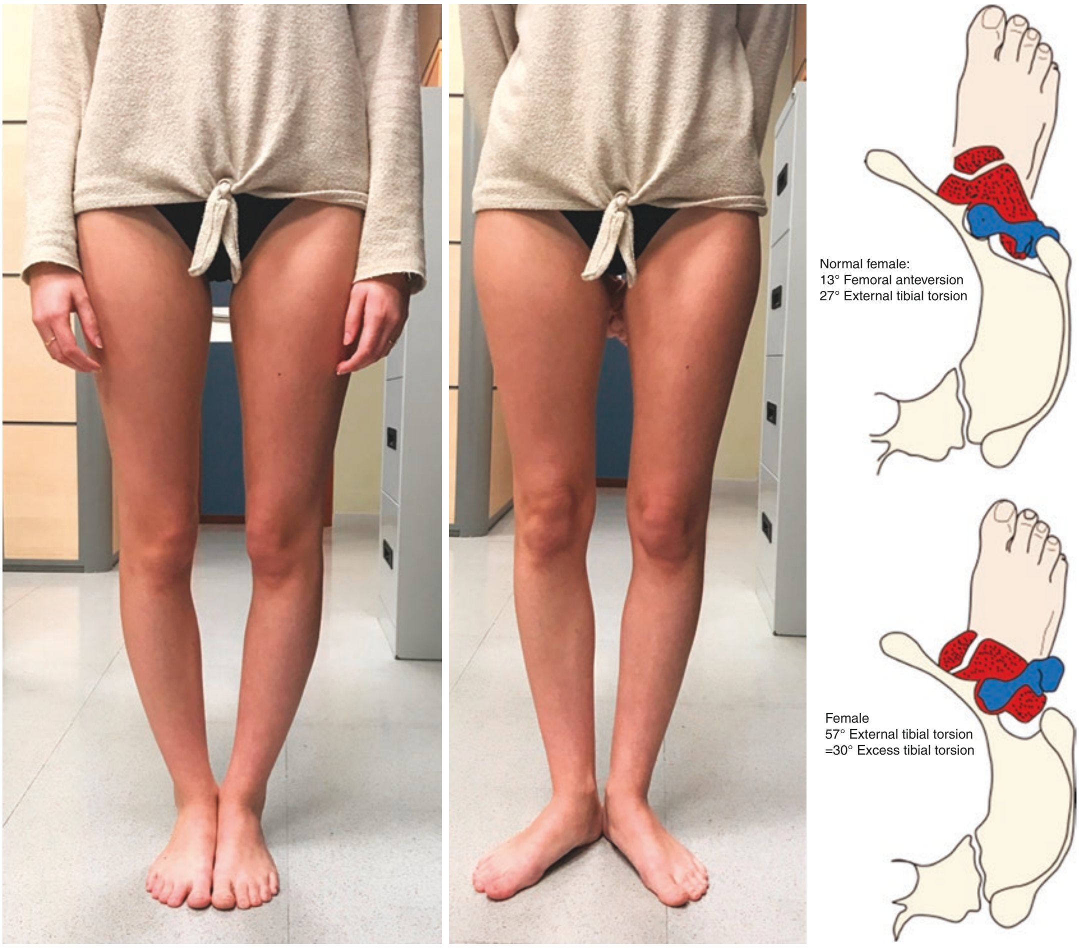

**Fig. 11.2** Squinting patella in a patient with excessive external tibial torsion. (Photographs: Reused with permission from AME Publishing Company. From Sanchis-Alfonso V et al. Ann Joint 2018; 3:26. Graphics: Reused with permission from Elsevier. From Teitge RA. Patellofemoral Disorders Correction of Rotational Malalignment of the Lower Extremity. In: Noyess Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes, 2017)

of different maltorsions is unclear. In theory, we should operate on the level with the greatest deformity, recognizing that it may be necessary to operate on the other level in a second surgery. When we must perform both femoral and tibial rotational osteotomy, we recommend performing the two procedures simultaneously. Osteotomy may be placed anywhere between the reference lines used to measure a torsional deformity.

Coronal deformities must not be overlooked because both torsional deformities and coronal plane deformities are associated in many cases. The most common multiplanar deformity in AKP patients is internal femoral torsion and valgus, and in these cases, both deformities must be corrected [30].

When the patient stands with their feet parallel, the patella should be facing forward. In patients with excessive external tibial torsion, we can see a squinting patella and a genu varum (Fig. 11.2). The combination of increased femoral anteversion and increased external tibial torsion has

**Fig. 11.3** Miserable malalignment syndrome. (Graphics: Reused with permission from Elsevier. From Teitge RA. Patellofemoral Disorders Correction of Rotational Malalignment of the Lower Extremity. In: Noyess Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes, 2017)

been termed miserable malalignment syndrome that includes squinting patella, genu varum, genu recurvatum, and pronated foot (Fig. 11.3).

In prone position we must measure the proportion of internal to external rotations of the hips in extension [53]. If internal rotation exceeds external rotation in more than 30 degrees, there is an increased femoral anteversion (Fig. 11.4). In cases with isolated excessive external tibial torsion, internal and external rotations are similar (Fig. 11.5).

What is more, it is important to evaluate the foot progression angle. The "foot progression angle" should be neutral when walking [54, 55]. An excessive femoral anteversion is manifested by a gait pattern with an internal foot progression angle (in-toeing) and external tibial torsion by out-toeing (Fig. 11.6) [26]. However, if an excessive femoral anteversion is associated to excessive external tibial torsion (i.e., pan genu torsion or miserable malalignment), the foot progression angle will be neutral, and this combined long bone deformity may be concealed to the unwary observer [11, 26]. It is therefore important to have a patient appropriately unclad and note that the knee progression angle is inward [11, 26].

### 11.4.1.3 Measuring Torsion

Measuring torsion may be accomplished with either CT or MRI, although controversy exists about which method is the most accurate and reproducible [56, 57]. However, CT and MRI are not interchangeable when they are used to evaluate femoral anteversion [58]. Moreover, CT has higher interobserver reliability than MRI [58]. Excessive femoral anteversion has different thresholds according to MRI and CT measurements [58]. According to Parikh and Noyes, MRI has an advantage over CT because femoral anteversion measurements are more accurate and ionizing radiation is avoided [57]. In addition, measured values vary greatly in the literature. CT

**Fig. 11.4** Evaluation in prone position in a patient with excessive right femoral anteversion

is crucial to accurately analyze rotational lower limb alignment (Figs. 11.7 and 11.8). Kaiser and colleagues [56] showed that femoral torsion measurements can differ by more than 10 degrees, depending on the measurement technique used.

In our clinical practice, we use the technique described by Murphy and colleagues [59] in 1987 because we find that it is the most anatomic, accurate, and reproducible—high intra- (ICC: 0.95–0.98) and interobserver agreement (ICC: 0.93) has been reported for this method [56]. Murphy and colleagues reported that the common method of running a line along the femoral neck on a CT image underestimated the actual anteversion by a mean of 13° [59]. The line that is used as the axis of the femoral neck is not the true axis of the femoral neck (Fig. 11.7). Our reference normal values are femoral anteversion 13° and external tibial torsion 21° in males and 27° in females [28, 29, 60].

#### 11.4.1.4 Surgical Tips in Rotational Osteotomies

Rotational osteotomies are often performed according to the experience of the surgeon. There is no evidence to support decisions regarding sur-

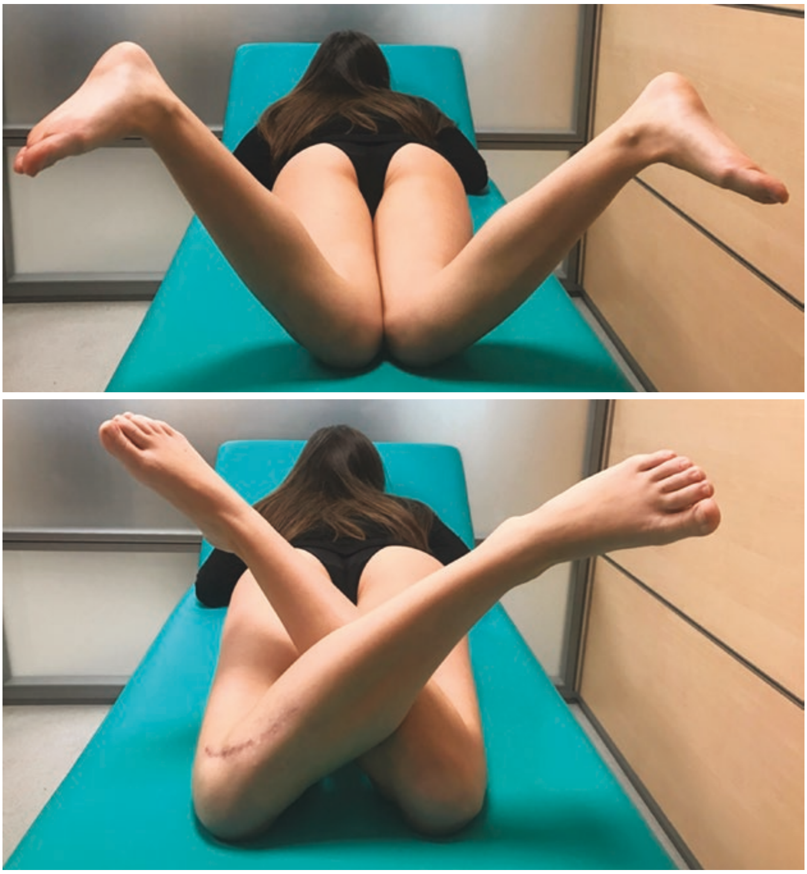

**Fig. 11.5** Evaluation in prone position in a patient with near normal hip motion (femoral anteversion). This patient had an excessive external tibial torsion measured with CT

gical technique or level of osteotomy. We do not know if maltorsion exists at a particular location since we are only measuring torsion as the angle between the proximal and distal joint axis. The objective is to create the proper angular relationship in the transverse plane between the two axes. We can accomplish this at any location between the two axes in question.

In preparation for a rotational osteotomy, the patient is placed in supine position on a radiolucent table. The entire limb is exposed. The foot is in a sterile transparent bag and the drape rests above the hip joint so the entire limb is visible after correction. A tourniquet is not used, and the C-arm is placed on the opposite side to the operated limb. Femoral rotational osteotomy can also be performed using a fracture table.

Undercorrecting is better than overcorrecting. The objective is a correction that is slightly less than what a torsion measurement might indicate. For example, if a patient has a femoral anteversion of 49°, the aim should be an external femoral rotation of 30° but not more (49 − 30 = 19). For an external tibial torsion of 56°, we would propose an internal rotational osteotomy of 30° (56 − 30 = 26). But we do not know what the minimum correction is necessary for the surgery to be successful (Fig. 11.9). According to Lerat and Raguet [21], the risk of neurovascular complications increases significantly above 30° of correction in the tibia.

Rotational osteotomy of the femur may be made anywhere between the hip joint and the knee joint. There is no evidence that proximal,

**Fig. 11.6** Foot progression angle in a patient with excessive external tibial torsion. In this case the foot is externally rotated during the swing phase of gait, then internal rotation osteotomy of the tibia should result in a neutral foot progression angle during stance phase; and this is something considered as correct. If the foot is neutral during the swing phase of gait, then internal rotation of the tibia can result in an in-toeing gait during stance phase. And this, on the other hand, is not correct. (Reused with permission from AME Publishing Company. From Sanchis-Alfonso et al. Ann Joint 2018; 3:26)

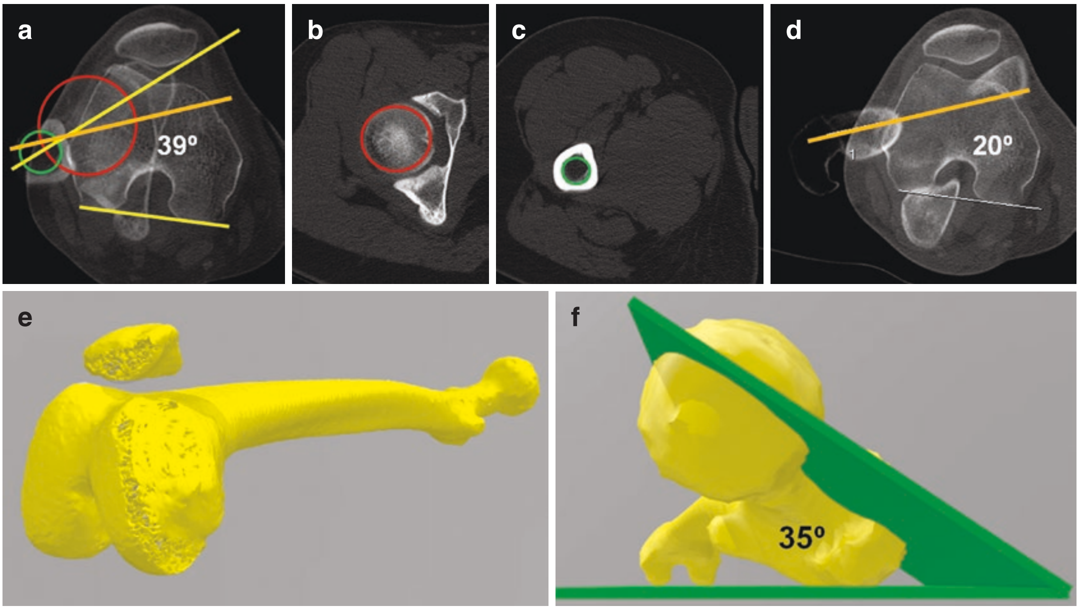

**Fig. 11.7** Measurement of femoral anteversion. (**a**) Technique described by Murphy and colleagues. Draw a circle on the femoral head (**b**) and another circle centered in the femoral shaft below to the lesser trochanter (**c**). Then draw a line connecting the center of these two circles. This line defines the femoral neck axis in the transverse plane. Then draw a line tangent to the posterior aspect of the femoral condyles (posterior condylar line). The angle between these two lines represents the femoral anteversion. (**d**) Method commonly used to measure femoral anteversion. The line that is used as the axis of the femoral neck (orange line) is not the true axis of the femoral neck. (**e**) Whole femur 3D reconstruction. (**f**) Femoral anteversion of the same patient measured on 3D reconstruction of the whole femur

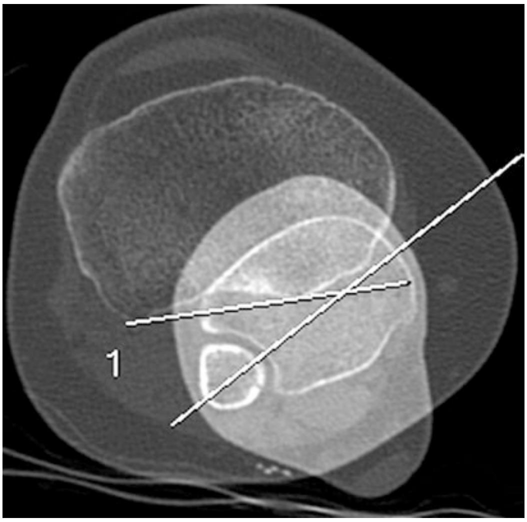

**Fig. 11.8** Measurement of external tibial torsion. It is measured as the angle between the posterior aspect of the tibial metaphysis and the ankle joint line

mid-shaft, or distal location of the osteotomy is preferable. We have most often performed femoral rotational osteotomy at the intertrochanteric level to avoid any scarring to the quadriceps muscle in the region of the knee. It is more straightforward to control the varus-valgus and flexion-extension at this particular level as the femur is more cylindrical. However, in case of the deformity of knee varus or valgus, the correction must be made closer to the knee joint, and usually it would be in the supracondylar region. After marking the osteotomy level with a K-wire, we insert two K-wires at an angle equal to the desired rotational correction, one proximal and one distal to the osteotomy site. The osteotomy is completed using an oscillating saw while protecting soft tissues with two Hohmann retractors. After the osteotomy is complete, external rotation of the

**Fig. 11.9** Bilateral severe external tibial torsion (CT measurement: 72°). Patient operated on both legs by tibial osteotomy of internal rotation with an excellent result in both limbs despite the undercorrection of the left side

distal fragment is performed until both K-wires are parallel, which indicates that the planned correction has been achieved (Figs. 11.10 and 11.11). We then perform the osteosynthesis. In cases of proximal osteotomy, we can use a 95° angled blade plate (DePuy Synthes) as the insertion of a blade into the proximal fragment gives an excellent proximal fixation, the distal shaft fragment is easily aligned to the plate, and a lateral plate under tension counters the normal varus bending stress in the proximal femur. When the 95° angled blade plate is selected, the track for blade is created in the center of the femoral neck before the osteotomy is performed. The blade of the blade plate is inserted into the femoral neck after the osteotomy is complete. This provides accurate control of the location of the proximal fragment. Another option would be a proximal femoral locking compression plate (LCP) 4.5/5.0 (DePuy Synthes) [23].

As with the femoral osteotomy, tibial rotational osteotomy has also been performed at any level. Our preference is below tibial tuberosity. Kuroda and colleagues have demonstrated that medial tuberosity transfer from the nor-

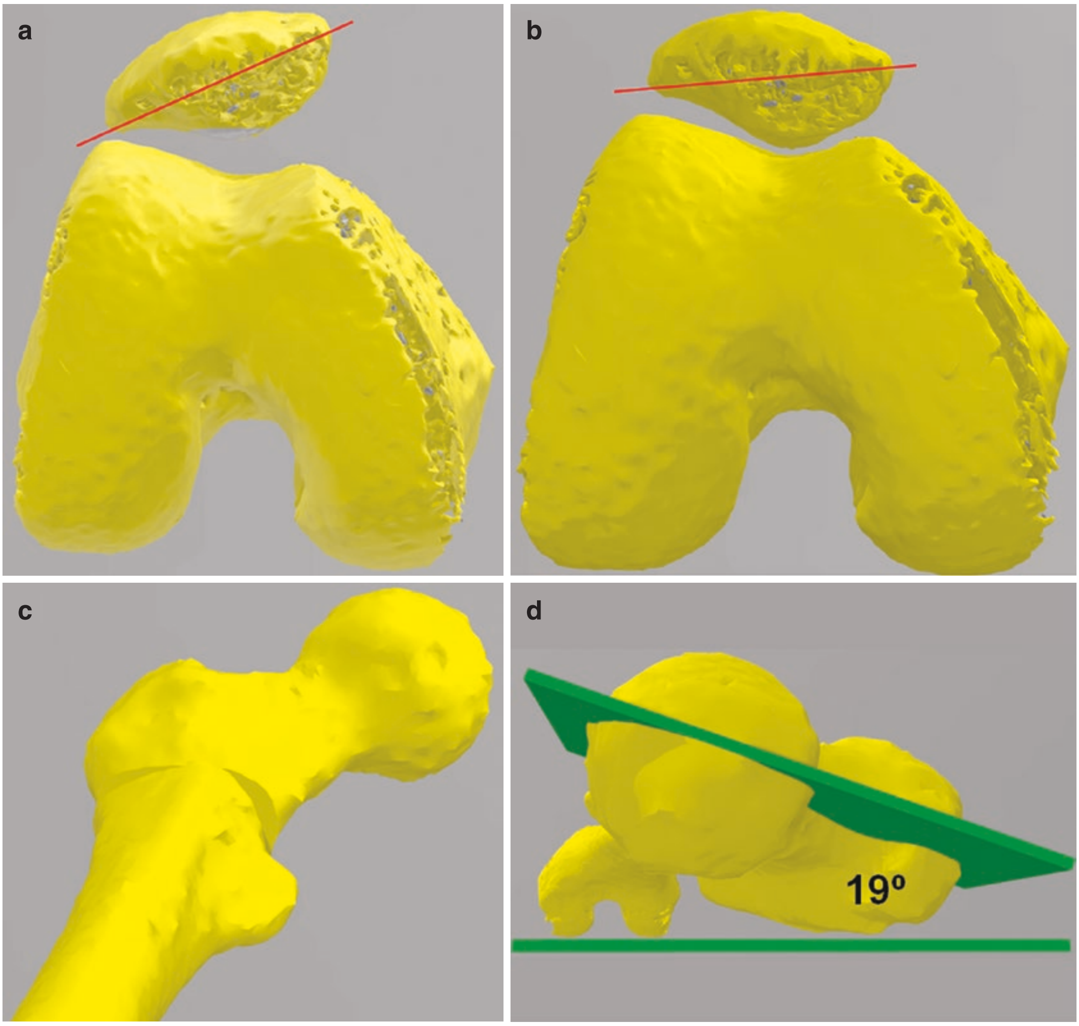

**Fig. 11.10** Think about limb alignment, not patellar alignment. (**a**) Preoperative position of the patella with respect to the femur with the knee in extension. (**b**, **c**) Position of the patella with respect to the femur with the knee in extension after proximal femoral osteotomy. The distal fragment has been rotated externally 20°. You can observe a correct patellofemoral congruence. (**d**) The femoral anteversion of the femur measured on a 3D reconstruction is 19°. In the contralateral asymptomatic hip, the femoral anteversion is 15°

mal position will provoke an increment of the medial tibiofemoral compartment pressure and medial patellofemoral pressure and a decrease of the lateral tibiofemoral pressure that theoretically leads to medial compartment osteoarthritis, degenerative tears of the medial meniscus, and medial patellofemoral osteoarthritis [61]. If we place the osteotomy above the tubercle, we will move it medially which will create joint imbalance. We always perform a peroneal nerve release. Moreover, fibular osteotomy is recommended before making the tibial rotation because (1) the fibula provides some degree of resistance to prevent rotation of the tibia and (2) the fibula must pull on the proximal and distal tibiofibular capsule, which could be painful. A proximal long oblique cut is recommended because it provides a larger surface area of contact between the bones, making healing easier. With a transverse osteotomy, enough rotation is present to prevent

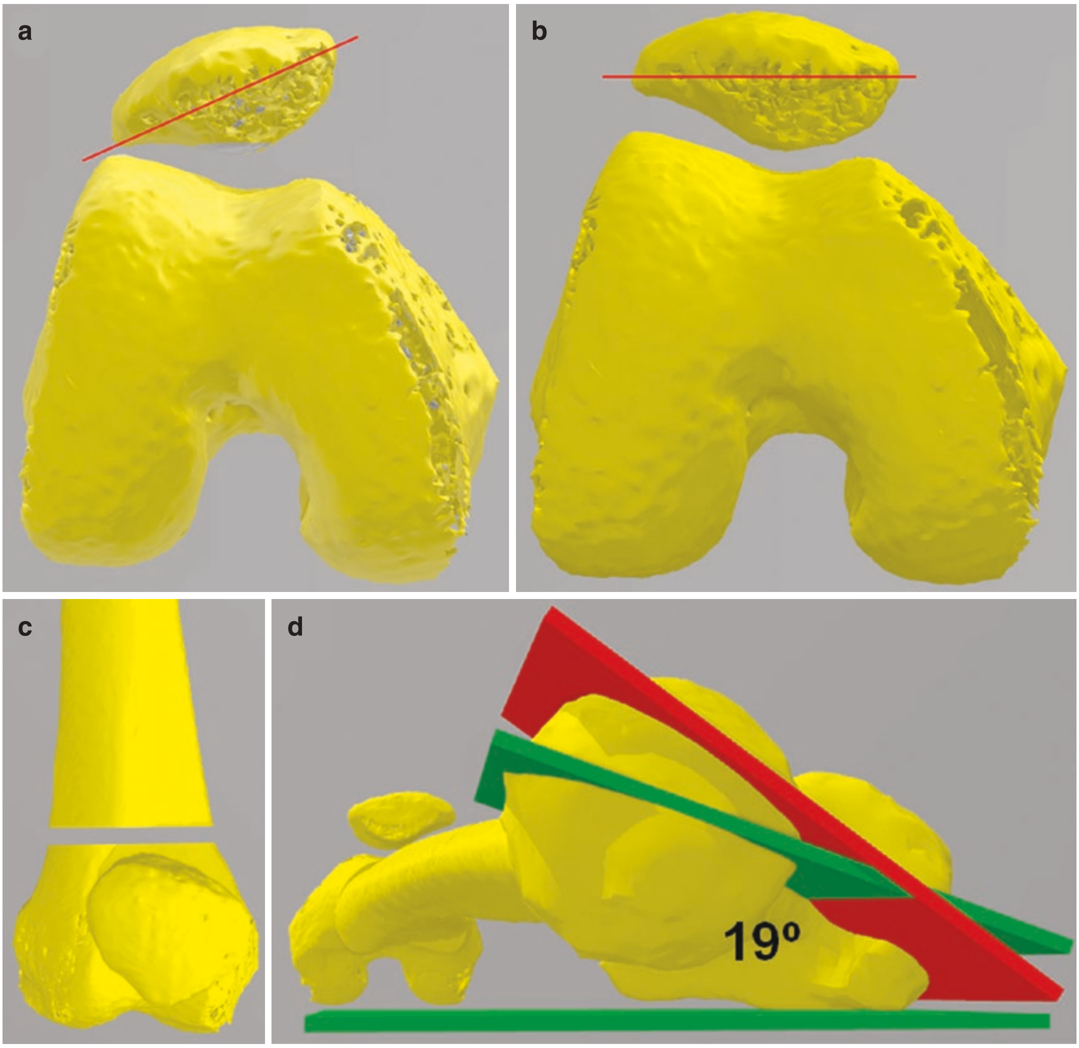

**Fig. 11.11** Think about limb alignment, not patellar alignment. (**a**) Preoperative position of the patella with respect to the femur with the knee in extension. (**b**, **c**) Position of the patella with respect to the femur with the knee in extension after distal femoral osteotomy. The distal fragment has been rotated externally 20°. You can observe a correct patellofemoral congruence. (**d**) The femoral anteversion of the femur measured on a 3D reconstruction is 19°. In the contralateral asymptomatic hip, the femoral anteversion is 15°. In red, the preoperative femoral anteversion

two fragments from being in contact, and healing can take more than 1 year. To protect the nerve while making the osteotomy with a small saw, we place two hallux retractors around the neck of the fibula.

Prior to tibial osteotomy, we mark the osteotomy level with a K-wire. We then place two K-wires at the desired correction angle, perform the osteotomy below the tibial tuberosity, derotate the tibia, and check.

The varus in patients with external tibial rotation may be real, or it may be a reflection of the tibial torsion (thus pseudo-varus) (Fig. 11.12). In Fig. 11.13 we can observe a varus correction after isolated internal tibial rotation osteotomy. Therefore, it is very important to check whether there is a neutral coronal plane alignment after rotation, before fixation. We use the alignment rod from the center of the femoral head to the center of the talus to make sure the mechanical

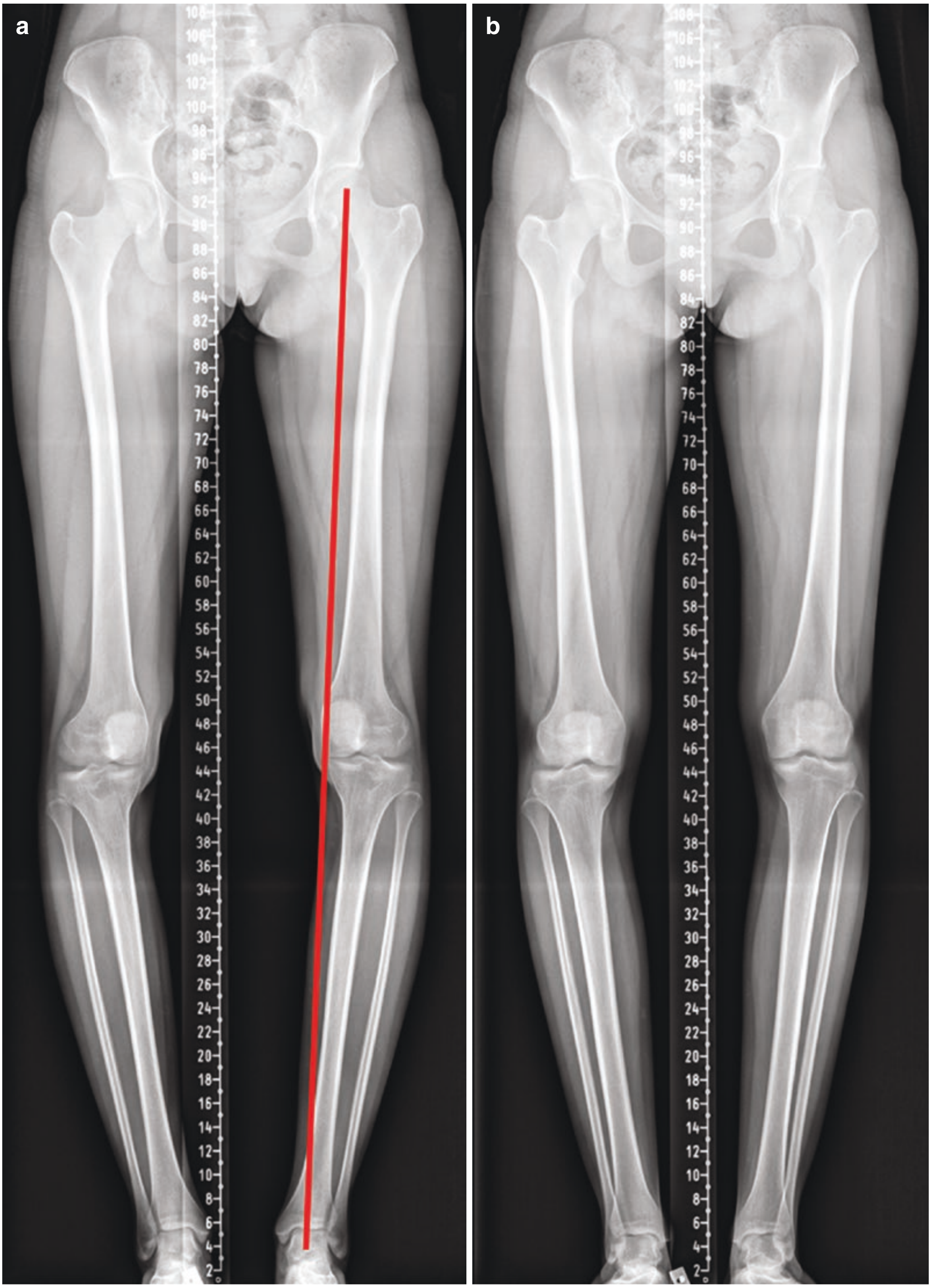

**Fig. 11.12** An example of skeletal malalignment of the lower limb: excessive external tibial torsion associated to excessive femoral anteversion. Anteroposterior weight-bearing radiography of the lower limbs with the feet straight forward (**a**) and with the feet externally rotated (**b**). Mechanical axis—varus deformity (red line). In the coronal plane, the patella should be centered in the middle of the distal femur unless the patella is known to be subluxed laterally. Observe how with the feet straightforward the patella is inward and with the knee joint pointing forward the feet points laterally

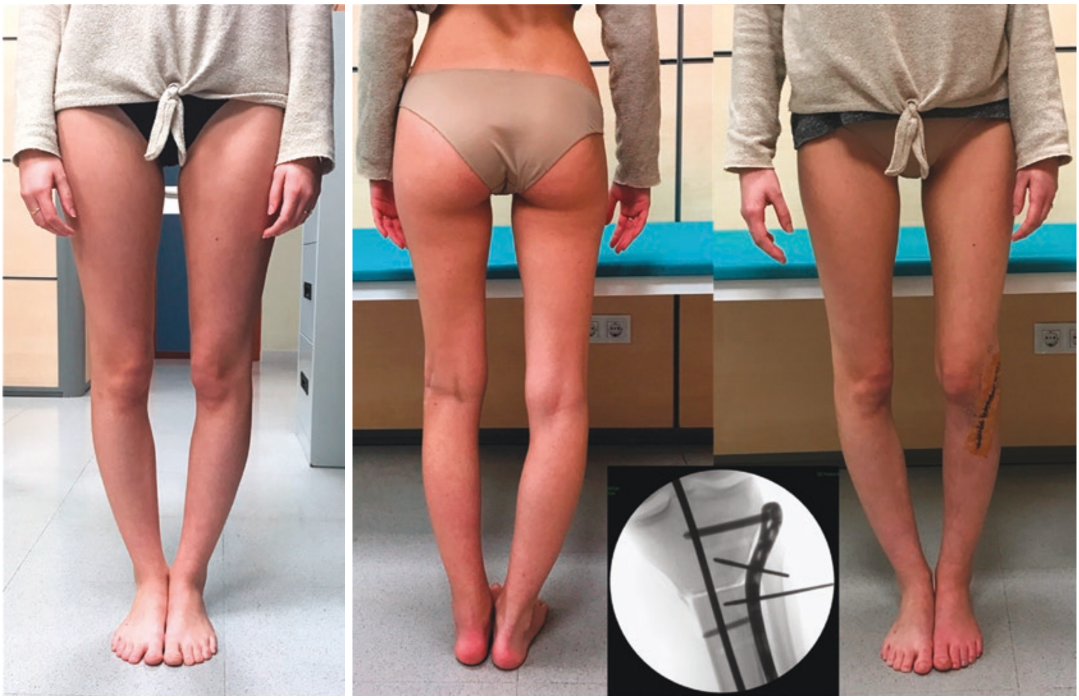

**Fig. 11.13** In most of the cases, the varus is not real, but it is a reflection of the tibial torsion (thus pseudo-varus). A varus correction after isolated internal tibial rotational osteotomy can be observed on the left limb. (Reused with permission from AME Publishing Company. From Sanchis-Alfonso et al. Ann Joint 2018; 3:26)

axis falls near the medial tibial spine. A normal mechanical axis is actually near the medial tibial spine, not in the center of the knee joint. The patella must always be pointing straightforward, and it should also be in the middle of the distal femur on the anteroposterior image. We use a lateral TomoFix plate (DePuy Synthes) for osteotomy fixation.

We always use a drain to reduce risk of hematoma and compartment syndrome. If the anterior compartment is very tight, we leave the fascia open.

We encourage active hip, knee, and ankle motion immediately after surgery. The patient uses crutches to prevent bearing weight with the operated leg. Loading is permitted after 6 weeks.

## 11.5 Conclusion

The gold standard in the treatment of AKP is physical therapy within the patient's envelope of function. Surgery for AKP is a last resort, and very often it is not needed. However, certain surgical procedures in a carefully selected patient can significantly improve AKP resistant to all non-operative alternatives. Surgical treatment must be considered only when well-documented anomalies amenable to a specific targeted intervention are present, especially when there is evidence of focal patellofemoral overload. Every surgical treatment ought to be tailor-made just because every person is different. For example, when focal pathology, such as synovial hypertrophy around the inferior pole of the patella or peripatellar synovitis, can be identified, procedures to debride inflammatory foci in the synovium can be very successful. Finally, in some cases, major surgery, such as osteotomy, to correct abnormal femoral and tibial torsion may be essential for the optimal treatment of AKP. In our experience, AKP patients with an underlying torsional abnormality respond very well to derotational corrective osteotomies.

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# 12

# Anatomic Instability Factors: Principals and Secondary for Patellar Instability

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## 12.1 Introduction

Patellofemoral instability represents a severe problem in young and active patients [1, 2]. Recurrent instability episodes often cause injury to structures within the patellofemoral joint, including soft tissue, cartilage, and the bone, leading to an early-onset degenerative changes and to knee dysfunctions [3, 4].

Patellofemoral instability results from abnormalities of constraint given by passive soft tissue tethers and chondral/bony geometry that, with muscular forces, guide the patella into the trochlear groove and keep it engaged within the trochlear groove as the knee flexes and extends [5].

Anomalies in these factors are often present in combination and can also influence each other, widening the spectrum of clinical presentation and functional limitation.

Central to the development of a rational therapy for these patients is a complete and deep knowledge of the various anatomical and biomechanical abnormalities that can be responsible for patellofemoral instability.

One of the main concept that orthopedic surgeon must consider is the "valgus law." It underlines the prevalence of the lateral structures with respect to the medial ones [6]. The lateral compartment of the patellofemoral joint is normally wider than the medial one. In fact, the lateral condyle is larger than the medial one with an external part of the patellar groove higher and wider with respect to the medial compartment. The lateral patellar facet is larger in respect to the medial facet. At the capsular level presents a prevalence of the lateral retinaculum that is stronger and wider with respect to the medial one. The patella is the largest sesamoid bone in the body and resides within biarticular muscles (the quadriceps and patellar tendons). Biomechanically the patella functions both as a lever and a pulley. As a lever, the patella magnifies the forces exerted by the quadriceps on the knee during extension. As a pulley, the patella redirects the quadriceps force

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as it undergoes normal lateral tracking during flexion. Considering these anatomical features, it is easy to understand how the complex and delicate equilibrium between bony, ligamentous, and capsular structures can be easily compromised altering the forces exerted on the patella, with external forces that overcome the medial forces.

Patellofemoral instability can result from soft tissue abnormalities, such as weakness of dynamic stabilizer like the distal oblique portion of the vastus medialis or laxity of the static stabilizers like the medial patellofemoral ligament. Generalized ligamentous laxity must also be considered as a risk factor, especially in nontraumatic instability. The other fundamental risk factors are the osseous abnormalities such as trochlear and patellar dysplasia, patella alta, abnormal patellar engagement, rotational deformities, and coronal plane malalignment of the lower limb.

## 12.2 Soft Tissue Abnormalities

As active stabilizer of patellofemoral joint, the extensor muscle complex with vastus medialis obliquus (VMO) and vastus lateralis plays a crucial role. These two compartments must work synergistically to provide adequate tracking of the patella in the trochlear groove during knee flexion.

As recently stated by the American Orthopedic Society for Sports Medicine (AOSSM) and the Patellofemoral Foundation (PFF), a “patholaxity” of medial and lateral soft tissue constraints, defined as excessive tightness or laxity, is an important factor contributing to patellar instability [5].

Ficat and Hungerford [6] in the late 1970s have considered lateral patellar compression syndrome as one of the major causes of patellar symptoms and instability as well as a risk for degenerative joint disease of the patellofemoral joint. The augmented tension on the lateral retinacula predisposes to patellar malalignment and instability increasing the stress on the lateral patellar facet, even though no objective data have documented this theory.

Also, iliotibial band with his attachment on patellar and quadriceps tendon can align more laterally the patella predisposing to dislocation [7].

### 12.2.1 Vastus Medialis Obliquus (VMO)

On the medial side, a hypoplasia of vastus medialis and its altered insertions on the patella can lead to patellar maltracking. Insall [8] and Fox [9] were the first in the 1980s to evaluate those factors opening the road to studies in experimental setup by Farahmand [10]. He observed in vitro that the vastus medialis obliquus has a mean orientation that deviates 47° ± 5° medially from the femoral axis and the vastus lateralis has a mean orientation that deviates 35° ± 4° laterally from the axis. He also found a different cross-sectional area between the vastus medialis and lateralis and a higher variation of this in the vastus lateralis. Therefore, an imbalance in strength caused by different cross sections or different fiber orientations may lead to instability. Vastus medialis relaxation increases lateral patella displacement at all flexion angles. Goh [11] found lateral stability to be reduced by 30% when the vastus medialis obliquus was relaxed at 20° of knee flexion with a lateral patellar displacement of 4 mm.

A VMO dysplasia does not guarantee the force necessary to compensate the action exerted by the lateral structures and so stabilize the patella in the trochlear groove.

In this type of dysplasia, the absence of the oblique muscle fibers causes a worse lever arm. The consequences are usually an increased patellar tilt or a tendency to patellar subluxation (Fig. 12.1).

Voight [12] also has demonstrated that although the medial and lateral muscle structures are normal, a defect in the muscular coordination can determine an opposite recruitment order between vastus medialis and lateralis originating in patellar instability.

### 12.2.2 Medial Ligaments

The medial patellofemoral ligament (MPFL) is a continuation of the deep retinacular surface of the vastus medialis obliquus (VMO) muscle fibers [13] confirming the intimate synergy between active and passive patellar stabilizer (Fig. 12.2).

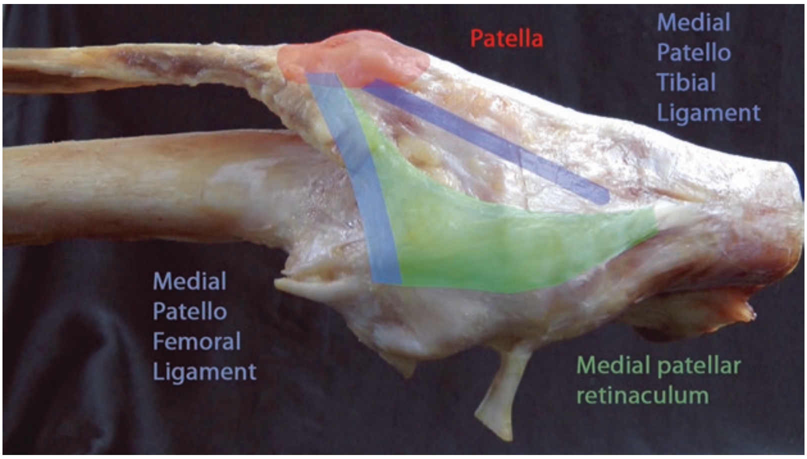
Other passive medial restraints are medial patellotibial ligament (MPTL), medial patellomeniscal ligament (MPML), and medial retinacula.

**Fig. 12.1** The VMO dysplasia, the excessive tension of the lateral structures or the coordination defect between the two, causes a concentration of stress on the lateral patellar facet and at the same time a maltracking with lateral patellar subluxation

Warren and Marshall describe the MPFL as an extracapsular structure which extends from the superior medial border of the patella, and it attaches to the bone just anterior to the MCL on the medial epicondyle [14]. The size and thickness of the ligament varies considerably among individuals, but it is relatively constant within a given person [15]. Reider et al. could not identify the MPFL in some specimens [16], and Arendt et al. [13] did not always identify the ligament as a clear thickening of tissue, but they always distinguished a separate extracapsular layer originating from the medial femoral epicondyle and inserted into the medial border of the patella. The MPFL acts as a static checkrein to resist lateral translation of the patella. Desio [17] reported that the MPFL contributes 60% of the total restraining force against lateral patellar displacement with the patellomeniscal ligament the second most important medial stabilizer contributing an average of 22% of the total restraining force. Senavongse [18] found that 20° of knee flexion was the position when 10 mm displacement occurred at the lowest restraining force. However, the patella was more resistant to medial than lateral 10 mm displacement.

Senavongse and Amis [19] tried to demonstrate the relative effects of various abnormalities on patellar stability. They found that a relaxed VMO reduced by 30% the force to displace the patella laterally in 20°–90° flexion range while only by 14% in extension. If the MPFL was ruptured, the

**Fig. 12.2** Passive medial restrainers of the patella: medial patellofemoral ligament (MPFL), medial patellar retinaculum (MPR), and medial patellotibial ligament



force required to displace the patella laterally was reduced by 50% in the extended knee, decreasing while the knee flexed. Interestingly abnormal trochlear geometry reduced the lateral stability by 70% at 30° of flexion.

In Philippot et al.'s work [20], all the medial ligamentous structures were considered. They confirmed the role of the MPFL in patellar stabilization during the first 30° of knee flexion. The ligament is responsible for 50–60% of medial stabilization forces during patellar engagement in the femoral trochlea. Besides they quantified the contribution of MPML and MPTL against lateral shift of the patella which resulted being 28–48% and 23–71% during knee flexion. Their biomechanical control on patellar kinematic increased gradually throughout knee flexion.

A study in 2018 by Matthew LaPrade et al. [21] confirmed that the MPFL is the strongest of the medially located patellar stabilizers and that MPTL has mechanical properties like those of the MPFL. In addition, it suggests that the mechanical properties of the MPML/MPTL complex indicate a potentially important role in providing patellar stability.

### 12.2.3 Hyperlaxity

General hyperlaxity can also be a cause of patellofemoral instability related to the insufficiency in controlling lateral patellar displacement. Carson and James [22], evaluating lateral patellar displacement in response to applied load at full extension, found a significantly greater lateral patellar mobility in symptomatic and hyperlaxity patient. Fithian [23] performed the same observation at 30° of flexion. Nomura in 2006 [24], in a case series, showed that a hypermobile patella and generalized joint laxity were significantly important in the recurrent patellar dislocation group compared to the control group, with hypermobile patella as a predisposing factor for dislocation.

Christoforakis [25] still in 2006 has shown that release of the lateral retinaculum reduces at 10° and 20° of flexion the force required to displace the patella by 20%. These findings underline the importance of medial structures like the VMO (dynamic) and MPFL (static) firstly and all other restrain secondly.

## 12.3 Bone Abnormalities

Dysplasia of the femoral trochlea, together with patellar height abnormalities, axial and rotational malalignments, and soft tissue imbalances, represents the main feature of the concept of patellofemoral dysplasia [26] and is a major predisposing factor for the instability of the patellofemoral joint [27–31].

### 12.3.1 Trochlear Dysplasia

Anatomical characteristic of trochlear dysplasia has been associated with clinical patellar instability because there is a lack of congruence between the groove and the patella [27]. Recurrent patellar dislocation is associated with a high incidence of the patellofemoral arthrosis [27, 32, 33]. The normal trochlea is concave and strictly correlated to the bony contour and depth of the overlying cartilage [18, 34]. Trochlear dysplasia is defined as a geometrical abnormality of the shape, length, and depth of the trochlear groove mainly at its proximal part, where the patella first engages in early flexion. The groove has a proximal flat articular zone and a distal shallow zone. An inadequate depth of the intercondylar groove can be global or focal, when affecting only the proximal part [35]. Trochlear dysplasia was first descripted in 1802 by Richerand, who wrote about an abnormal lateral condyle in patients with recurrent patellar dislocations [36]. In 2007, a study of Dejour et al., comparing 143 radiographs of patients and 190 control radiographs, showed that 85% of patients with a history of patellar dislocation had evidence of trochlear dysplasia [32]. In the presence of dysplasia, the intercondylar groove may be flattened or even convex [37, 38]. This convexity results the articular cartilage being thicker centrally than laterally and medially [18, 34]. These findings have been confirmed from other authors [39, 40] utilizing standard

X-ray and CT images. In patients with recurrent patellar dislocation, it was found that the mean extent of convexity of the femoral trochlea was twice compared with the control group [41].

Two MRI indexes that correlate trochlear dysplasia and patellar instability are the lateral trochlear inclination and the lateral condyle index. Carillon et al. fixed the diagnostic threshold to define a lateral trochlear inclination pathological at 11°; lower values has shown a sensitivity of 93% and a specificity of 87% for trochlear dysplasia [42]. Biedert et al. described the "lateral condyle index": the ratio of the anterior cartilaginous trochlea to the posterior aspect of articular cartilage of lateral femoral condyle [43]. They found that this index is reduced in patients with patellar dislocation. Moreover, they described the "too short trochlea," an abnormal trochlea which doesn't arrive proximally enough to engage with the patella.

One of the most authoritative methods of evaluating trochlear dysplasia, and the most used in the international literature, is the four-grade classification of the Lyonnese School of Henry and David Dejour [27]. This classification is based on three radiograph signs: "crossing sign," "supratrochlear spur (STS)," and "double-contour sign." Based on the presence of these radiographic features, four grades can be obtained: type A, (fairly shallow trochlea), type B (flat or convex trochlea with a STS), type C (lateral convexity and medial hypoplasia, no STS), and type D (cliff pattern). In 2012 it was also confirmed that this classification can be reproduced with the use of MRI [44] (Fig. 12.3a, b). Trochlear dysplasia represents an important biomechanical component of patella instability that has been recognized for many years. The kinematic behavior of the four different types of patellofemoral dysplasia has been tested in a cadaveric model, simulating the dysplastic trochlea with three-dimensional printed specimens inserted in the human joint [45]. Increased lateral patellar tilt, lateral patellar tracking, and internal patellar rotation were found in the dysplastic models compared with the normal joint, especially for type D dysplasia in open-chain activity simulation. Also, an increased patellofemoral pressure and a reduced patellofemoral contact area were reported in trochlear dysplasia, more pronounced in B and D types. Finally, a 100 M lateral force tended to displace the patella 4 mm more in dysplastic models compared with the normal joint, especially at 20° of flexion. Similar findings were reported in vivo with a combined MRI and fluoroscopic evaluation of patellar tracking during weight-bearing knee flexion [46]. The authors reported a significant correlation between trochlear geometry and lateral patellar shift and tilt.

Flattening of the groove does not allow the patella to fit into the trochlea during range of motion. Imbalance of the patellofemoral joint with risk of patellar dislocation is created by this lack of centration, especially in the first degrees of flexion that allows the lateral structure to overtake easily the medial ones. This important role of stabilizer of the patellofemoral joint increases significantly in importance during the flexion of the knee. When the knee starts to flex, the initial contact is centered at the distal/lateral edge of the patellar articular surface, which bears against the proximal/lateral extremity of the trochlea. Thus, in early flexion, there is a mechanism to "catch" the patella, which shifts medially into the center of the trochlear groove. In the process of flexion, the contact area moves proximally across the patella, which remains in congruent contact with the lateral trochlear facet or the condyle throughout the range of knee flexion. This maintains patellar stability against lateral displacement. Therefore, a flat trochlea, without a prominent lateral facet, lacks an indispensable bony restraint that can predispose the patella to lateral displacement. This has been confirmed by Amis et al. in cadaveric models [47]. In this study the trochlear dysplasia was simulated by elevating the central groove. This condition reduced the force needed to displace the patella laterally up to 50% compared with a normal joint, especially at 30° of flexion. Moreover, flattening the lateral trochlea has been demonstrated to cause a greater loss of patellar stability than dysfunction of vastus medialis obliquus or rupture of the medial retinacula across most of the arc of knee flexion [19].

The importance of the lateral facet of the trochlea in resisting the lateral force is logical and widely accepted [18, 19, 48, 49]. The first author

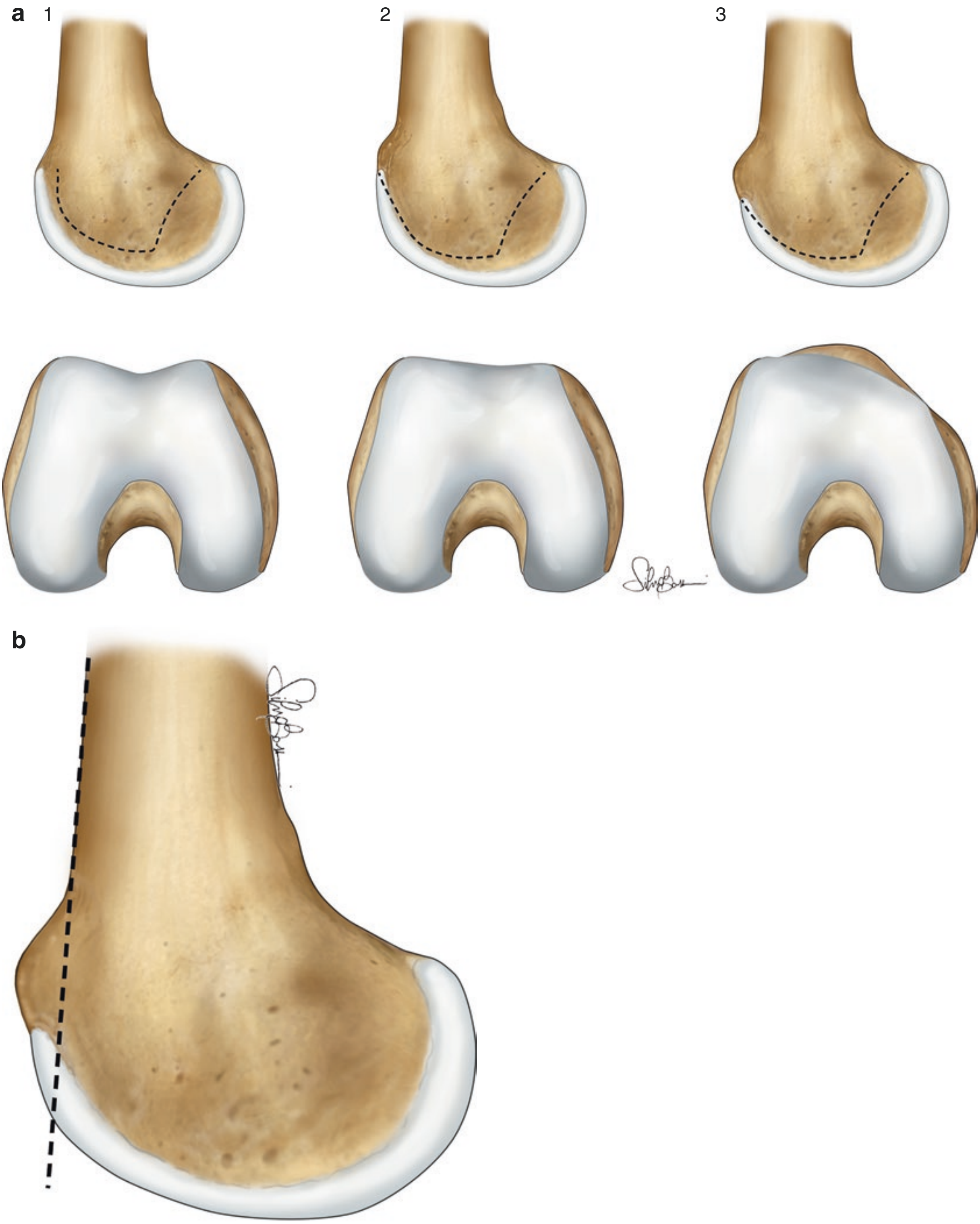


**Fig. 12.3** (**a**) Radiographic features of trochlear dysplasia: (*1*) normal deep trochlea, (*2*) crossing sign with a flat trochlea, (*3*) double contour sign with a convex trochlea. (**b**) Supratrochlear bump or spur is an osseous prominence of the proximal part of the femoral trochlea measured from a reference line along the anterior cortex

who described this concept has been Brattstrom in 1964 [50]. He studied qualitatively and quantitatively the shape of the intercondylar groove describing the trochlear dysplasia as an increase of the sulcus angle in relationship to developing defects of the trochlear profile. He found the lateral condyle to be significantly lower in patients with habitual patellar dislocation.

About the etiology of femoral dysplasia, there is no consensus as to whether patellofemoral dysplasia is genetic in origin, caused by unbalanced forces producing maltracking and remodeling of the trochlea during infancy and growth or due to other unknown and unexplored factors [51, 52]. Some authors suggested that breech presentation is a possible predisposing factor for patellofemoral dysplasia [53]. They reported a 15-fold higher incidence of breech presentation in children with trochlear sulcus angle values greater than 159°. Salzmann et al. [54] imputed the reason for patellar dislocation in a below-knee amputee patient, to be the patellofemoral dysplasia produced by the lack of mechanical stimuli during the developmental years. The patient, who sustained a below-knee amputation at the age of 18 months followed by another 18 months of immobilization, experienced an atraumatic patellar dislocation at the age of 16 years, due to a grade C trochlear dysplasia according to Dejour and Walch [27], compared with a perfectly shaped patellofemoral joint in the contralateral knee. This concept finds some confirmation in animal models, in which an artificially malpositioned patella during growth constrained physiological trochlear sulcus development in terms of depth when compared with controls [55]. Despite these interesting and fascinating theories, the exact etiology of patellofemoral dysplasia remains unknown.

### 12.3.2 Patellar Dysplasia

It has been found that the patellar shape could change in trochlear dysplasia. The distal medial facet in dysplastic knee does not articulate well with the trochlea, becoming smaller than normal [56, 57]. Fucentese et al., in a comparative MRI study, proposed that the patellar morphology may be not only a result of missing medial patellofemoral pressure in trochlear dysplastic knees but a decreased medial patellofemoral traction. They found hypotrophic medial patellofemoral restraints and increased lateral patellar tilt in the dysplastic knees. Wiberg [58] has classified radiographically the shape of the patella determining three types of patellar hypoplasia that can originate from patellar symptoms. Ficat [6] has underlined that the severe dysplasia of the internal facet implies a reduction of the weight-bearing internal area with a surface incongruence and an automatic stress concentration on lateral side that can start the degenerative phenomena.

### 12.3.3 Patellar Height

Patella alta is characterized by a more proximal position of the patella and represents one of the primary factors of patellofemoral joint instability [27, 59, 60]. Abnormal height of the patella is strongly associated with patellar instability: Dejour et al. found patella alta in 24% of patients with objective patellar instability [27]. For the evaluation of patellar height in literature are described several radiological methods. The Insall-Salvati (Fig. 12.4) is the ratio between the patellar tendon length and the length of the patella and defines patella alta with a ratio > 1.2 and patella infera with a ratio < 0.8. Caton-Deschamps index is the ratio between the distance from the lower pole of the patella and the upper limit of the tibia and the length of the patellar joint surface at 30° of flexion. It defines patella alta with a ratio > 1.3 and patella infera with a ratio < 0.6 [61]. New MRI evaluation method has been also introduced in describing the abnormalities of patellar height: patellotrochlear index [62]. Insall [63] and Blackburne [64] have underlined the role of patella alta as a risk factor for lateral patellar instability. When the patellar tendon is longer than normal, during quadriceps contraction, the patella goes proximal and completely above the corresponding femoral surface without any lateral bony support preventing lateral dislocation. During flexion there is a delay in centration of the patella in the trochlea groove. In this condition the lateral structures do not find any bony resistance to lateral traction of the patella, due to the normal prevalence of the lateral structures with respect to the medial ones. Patella alta, modifying the lever arm between quadriceps and patellar tendons, increases the compression forces in patellofemoral joint leading to cartilage damage. In patient with patella alta, Dejour has

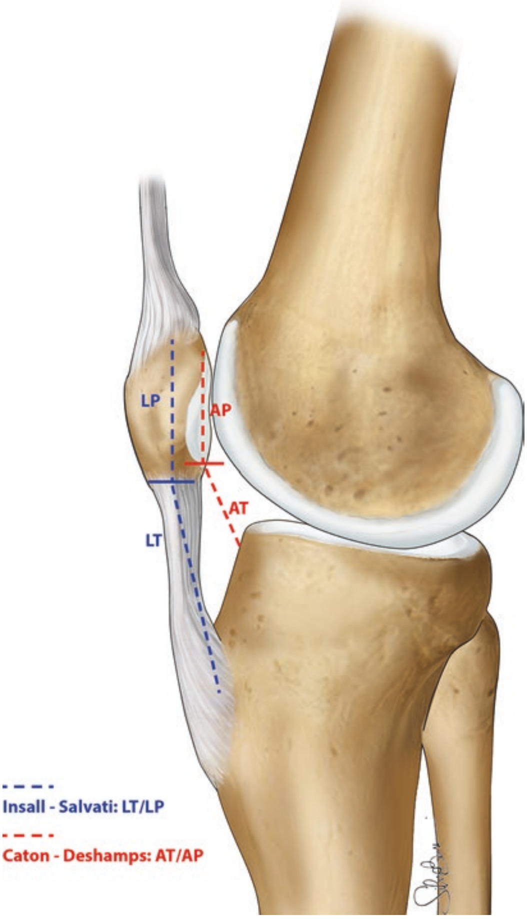


**Fig. 12.4** Insall-Salvati ratio is measured on a true lateral radiograph with the knee at 30° of flexion as the ratio between patellar tendon length and the length of patella. Similarly the Caton-Deschamps ratio is measured as the ratio between the distance from the lower pole of the patella to the upper limit of the tibia and the length of the patellar joint surface

often found stiffness of the rectus femoris, supposing that patella alta may be a rectus femoris dysplasia [27]. Biomechanically the patellofemoral joint is a lever system. The patella is the fulcrum of this system and contributes significantly to the torque in knee extension by increasing the lever arm of the quadriceps and transmitting the forces from the quadriceps tendon to the patellar tendon. In the normal knee, the patellofemoral total contact area increases from extension to flexion and reaches a maximum at 90°, reducing the contact stress in deeper flexion. The cartilage layer is thicker in the high load area of the joint. The cartilage layer is thicker in the high load area of the joint. Although in the literature some authors [65–67] have suggested that patella alta may alter the mechanics of knee extension, there is no consensus on the real effect of patella alta on patellofemoral force, contact area, and contact pressure. Singerman, Davy, and Goldberg [68] reported, in an in vitro study, that the patellofemoral contact force, and its point of application on the patella, depended on patellar height. In a high-riding patella, the magnitude of the PF contact increases with increasing flexion angle. They report also no increases from 0° to 60° of knee flexion and a significant rising at 90° in PFJ reaction force with patella alta. Luyckx [69], using a dynamic knee simulator, reported that the patellofemoral contact force is the sum of the patellar tendon force and the quadriceps tendon forces. In patella alta he showed the lowest PF contact force in initial flexion (35–70°) and a higher contact force in deeper flexion (70–120°) than in normal conditions. In this way he demonstrated a direct association between patellar height and maximal contact force. He also found that patella alta caused the greatest maximal contact force and pressure. In normal conditions the effective moment arm of the quadriceps tendon is greater than that of the patellar tendon because of the distal contact point of the patella during initial flexion [70, 71]. Yamaguchi and Zajac [67], moreover, by a mathematical simulation of patella alta to calculate a quadriceps moment arm, reported that modified lengthening of the patella or patellar tendon caused alteration of force transmission from quadriceps to patellar tendon. They showed a considerable increasing of moment arm and joint reaction force at flexion above 25–30°, with the patella alta condition. It seems that patella alta creates a more efficient knee extensor mechanism by a more distal contact point in initial flexion (0–60°), whereas, in deeper flexion, it is considered a biomechanical disadvantage [69]. Ward et al. [66, 72] demonstrated in two MRI studies that patella alta is correlated with a significantly larger quadriceps and smaller patellar ligament moment arm than in normal condition, with a greater transmission force from quadriceps to patellar ligament. They showed 19% less contact area than normal between 0° and 60° of flexion, with lateral displacement and lateral tilt of the patella at 0° of flexion. Patients with patella alta and pain have elevated PFJ stress because of smaller PFJ contact areas and interrelate with patellofemoral cartilaginous breakdown and degeneration, dysfunction, and subsequent pain [60, 73]. No correlation could be found between malalignment and the reduced contact areas [69].

In those cases where there is no assessment of a patella alta, it is important to evaluate the patellar engagement. This is a functional parameter that describes the overlap or the lack of it between patellar and trochlear articular surfaces [59]. It is composed by an evaluation on sagittal plane (sagittal patellar engagement index) and on axial plane (axial engagement index) [74]. The normal value is close to 1, while lower values indicate more severe forms of objective patellar instability and are correlated with trochlear dysplasia with increased trochlear prominence.

### 12.3.4 Rotational Deformities and Coronal Plane Malalignment

Rotational and axial deformity of the entire leg can play a role in patellar instability. An increased femoral anteversion and an increased tibial torsion can determine patellofemoral disorders and symptoms [75]. Femoral torsion is the measure of the angle formed between a line running through the center of the femoral head and the center of the femoral neck at its junction with the diaphysis and the posterior bicondylar line (Fig. 12.5). The mean value of this angle measured using these landmarks is 13° of femoral anteversion. Weber [76] found a frequent combination of femoral anteversion with chondromalacia and patellar instability. Eckhoff [77] and Lee [78] have demonstrated that increased femoral anteversion determined increased patellar tilt and promoted lateral patellar subluxation. Eckhoff has suggested correction of excessive femoral anteversion in young patients to prevent these phenomena. Takai [79] has documented that patients with increased femoral anteversion have an increased incidence of osteoarthritis. Femoral anteversion increases compression forces on the lateral compartment of the patellofemoral joint by bringing the lower femoral extremity in internal rotation resulting in the clinical appearance of "squinting patellae." In a computational analysis of factors contributing to patellar dislocation, Fitzpatrick et al. found that isolated femoral anteversion is less impactful factor with respect to other characteristics like sulcus angle, patella alta, and tibial tuberosity-trochlear groove length. However, in association with these other risk factors, the patellofemoral constraint was

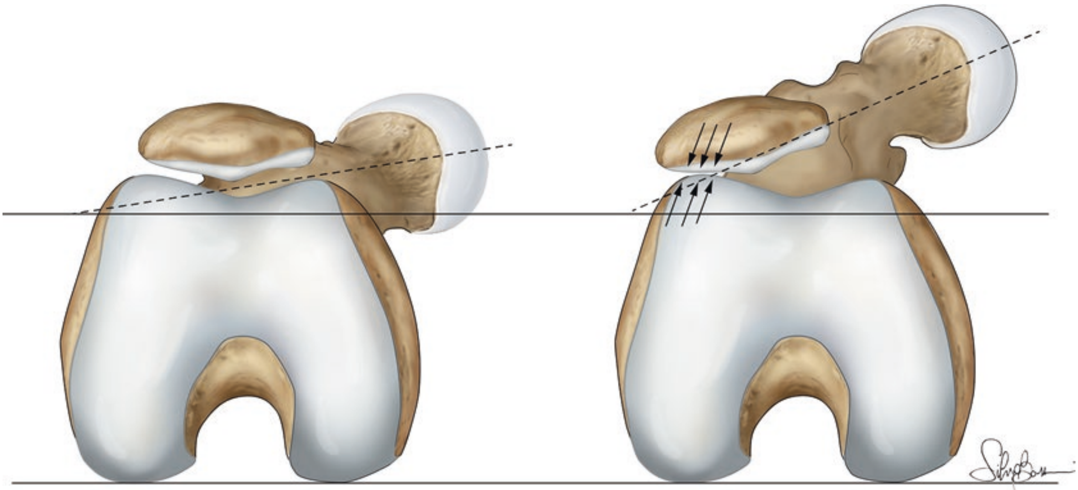


**Fig. 12.5** An increased femoral anteversion increases the patellar tilt and subluxation determining higher compressive forces on external compartment of patellofemoral joint, with increased risk of chondral damage

lowest in the single risk factor model [80]. The association between distal femoral internal rotation and tibial external rotation alters the Q angle (Fig. 12.6). Brattstrom [50] described the Q angle as the angle formed by the line of pull of the quadriceps and that of the patellar tendon as they intersect at the center of the patella. The Q angle is largest in extension in relation to the screw home mechanism of the knee. For this measurement to be accurate, the patella should be centered on the trochlea. In males the Q angle is normally about 8–10° in females 15 plus or minus 5°. It should be noted that the relationship between the Q angle and clinical signs and symptoms has not always been consistent. A possible reason for the lack of association is related to the fact that there has been no consensus with respect to how this measurement should be taken, but more important is the fact that this measurement is taken statically; therefore, the contribution of abnormal segmental motions and muscle activation to the Q angle during dynamic activities may not be appreciated. The Q angle is an expression of patellar kinematic that is guided by the static bony restraints and by dynamic muscle vectors. Therefore, the analysis of the static deformities that can alter the patellar kinematic is better evaluated with CT scan taking into consideration femoral neck anteversion, distal femoral rotation, and tibial rotation.

Patellar centration is more reliably evaluated by the measurement of TT-TG that considers femoral rotation as well as the rotation of tibial tuberosity (Fig. 12.7). The TT-TG distance is used to determine the degree of lateralization of the tibial tubercle in relation to the deepest part of the trochlear groove. A TT-TG distance of more than 20 mm on CT scans is considered pathological and is a significant risk factor for patellar instability [81]. However TT-TG distance measured in full extension seems to be not so accurate in the evaluation of the dynamic lateral displacement of the patella [82]. Recently Mistovich et al. described a novel measure, the

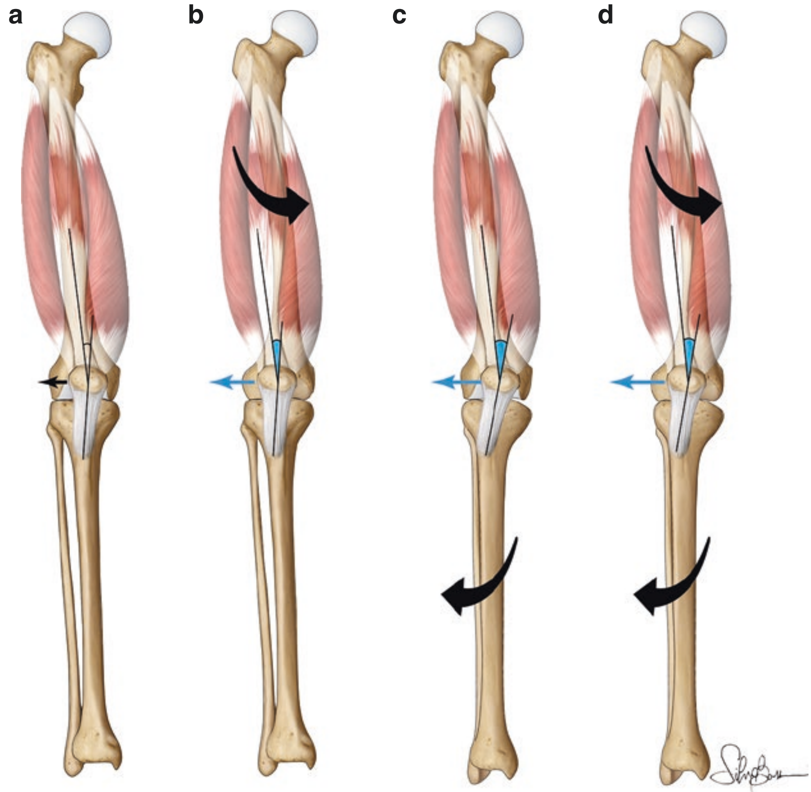


**Fig. 12.6** Alteration of lower limb and patellar instability. (**a**) Normal limb alignment. (**b**) Increased femoral anteversion with internal rotation of femoral condyle causes high patellar stress and instability. (**c**) External tibial torsion promotes increased compressive forces on lateral patellar facet with subluxation. (**d**) Limb alteration could be combined in a same patient with, consequently, a severe clinical picture and a technically demanding solution

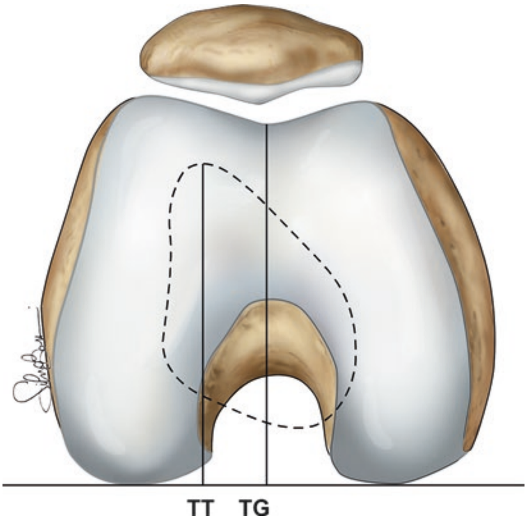


**Fig. 12.7** Patellar centration evaluation with measurement of TT (tibial tuberosity)-TG (trochlear groove) displacement: the deepest point of the trochlear groove is obtained in the axial cut and superimposed in a second axial cut where the anterior tibial tuberosity is marked. The distance between these two points is measured

patellar tendon-lateral trochlear ridge distance (PT-LTR): comparing PT-LTR distance with TT-TG distance, they found that this new measure is reliable, predictable, and discriminative in predisposing pediatric and adolescent patient populations to patellofemoral instability and dislocations [83]. Lee in 1994 [78] has demonstrated in vitro that fixed rotational deformities of the distal femur increase patellofemoral contact pressure with higher risk of joint degeneration and patellar dislocation. Powers [84] and Tennant [85] have shown that femoral internal rotation influences patellar alignment and kinematic. Powers, using dynamic MRI in patient with patellar instability, demonstrated that the primary contributor to patellar tilt and displacement was femoral internal rotation and not patellar motion. This phenomenon was more pronounced in the last 10° of extension. Many authors have suggested that patellofemoral symptoms are often associated with excessive primary or secondary tibial torsion [9, 77, 86]. Tibial torsion is measured between the knee flexion-extension axis and the ankle joint axis. Turner [87] has demonstrated that an excessive external tibial torsion determines a modification of the Q angle and that tibial external rotation was significantly different in patient with patellar instability. This alteration creates a less favorable lever arm for quadriceps muscle that during contraction moves the patella laterally increasing instability. Van Kampen and Huiskes [88], Nagamine [89], and Sakai [90] examined the effect of tibial rotation on patellar three-dimensional movement. Hefzy [91] also studied the change of patellofemoral contact area with tibial rotation.

Coronal plane malalignment can also influence patellofemoral joint stability.

Fujikawa et al. [92] observed that in varus deformity the patella displaces laterally and the lateral facet is hyperstressed with the increased risk of patellar instability. They also observed an association of proximal tibial rotation with varus deformity. The association between a combination of varus alignment and external tibial torsion and an increased risk of patellar instability has been described by Coscia in 1983 [93]. Moreover, in these conditions, the screw home mechanism is reduced or missed, and this can originate in degenerative changes of the medial femorotibial compartment and of the lateral patellofemoral joint. Worlicek et al. in an exploratory cadaver study showed that varus stress leads to significantly higher external rotation than valgus stress and to a significantly higher lateral patellar tilt than both neutral position and valgus stress [94].

A valgus knee alters the Q angle and can be responsible for dynamic patellar instability [6]. Coscia [93] has also observed that in a valgus knee, it is difficult to achieve knee extension stability due to excessive internal rotation. In severe valgus deformity, articular stability is lacking due to the difficulties in controlling external rotation and the screw home mechanism. As underlined by Powers [84], a valgus knee is not only determined by static osseous abnormalities but also dynamically during certain activities as a result of femoral, tibial, or combined adduction moment. This can result from muscle weakness or imbalance or abnormalities at the level of the hip and pelvis as well as of the foot. Torsional defect of the lower extremity can be found often together with different patient penetration originating in a wide variety of clinical aspects that are difficult to be globally understand.

## 12.4 Conclusion

Anatomical alterations present with different penetration in each patient are various and complex and create several clinical scenarios. Treatment options should be individualized in relation to the etiologic factors responsible for clinical symptoms in each patient. A rational treatment of these disorders must foresee the execution of different surgical procedures in the same patient when the symptoms have a multifactorial origin in a manner to completely modify the joint physiology and kinematic. Even if the surgical procedure acts mostly on passive and static stabilizers of the patella, it is fundamental during surgery to achieve a dynamic patellar equilibrium with correct patellar tracking during the whole range of motion. Hughston [95] in 1989 has underlined the importance of dynamic stability of patellofemoral joint.

## 12.5 Summary

There are many anatomic alterations that place a patient at increased risk for patellar instability.

These include:

**Soft tissue abnormalities:**

- Extensor muscle dysplasia.
- Hypoplasia of the vastus medialis.
- Patellofemoral, patellotibial, and patellomeniscal ligament disorders.
- General hyperlaxity.

**Osseous abnormalities:**

- Trochlear and patellar dysplasia.
- Patella alta and patella engagement.
- Rotational deformity of lower limb.
- Coronal plane malalignment of lower limb.

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# 13

# Influence of Risk Factors in the Natural History

Elizabeth A. Arendt

Understanding the natural history of lateral patellar dislocations (LPD) is to understand the risk of reinjury. There are many elements that may factor in evaluating a “risk equation,” among them sport, age, and level of fitness. However, at the core of evaluating risk is understanding the unique role of one’s own anatomy in the risk of reinjury. This chapter will be a brief review of the present state of the influence of anatomic risk factors in the risk of reinjury after a primary LPD.

The rate of lateral patellar dislocation (LPD) is reported to be 6–12% per 100,000 people [1–5], with LPD being the most common serious knee injury among children aged 14 years and under who present with acute knee hemarthrosis [6]. When a decision is made to treat primary LPD nonoperatively, some patients will experience redislocation. Estimates on the number of redislocations vary between 20% and 40% [7–9]. Additional morbidity to the patellofemoral (PF) compartment, in the form of cartilage damage and increased ligamentous laxity, can occur with each episode of instability [10]. Identifying those patients most at risk would lend clarity to those who might benefit from early surgical intervention and has been a focus of many recent studies.

The seminal work by Dejour et al. [11] identified a number of imaging risk factors associated with recurrent LPD. These include a high quadricep vector as measured by tibial tubercle-trochlear groove [TT-TG] distance and excessive lateral patella tilt measured on axial CT, patella alta, and trochlear dysplasia determined by a true lateral radiograph. With the increased use of magnetic resonance (MR) as the imaging tool, a number of other measurements in both primary and recurrent LPD have populated our literature. Most specifically additional measurements of the trochlea including trochlear sulcus angle, trochlear facet asymmetry, and trochlear depth (Fig. 13.1) have been chronicled in populations of both primary and recurrent LPD dislocations. To these imaging factors, a number of demographic factors have been explored including age, sex, and physeal status and injury variables including ligament injury pattern and mechanism of injury [9, 11–18]. Literature to date has been limited in helping to define coronal (varus/valgus) and axial (torsion) plane alignment and their role in primary and recurrent instability [19–26].

Studies looking at reinjury risk were done in hopes of better understanding the natural history of first-time patellar dislocations and in hopes of creating a better algorithm for treatment of primary LPD patients. By understanding risk factors, knowledge can be obtained of which patients are most likely to experience redislocation and how significant is that risk.

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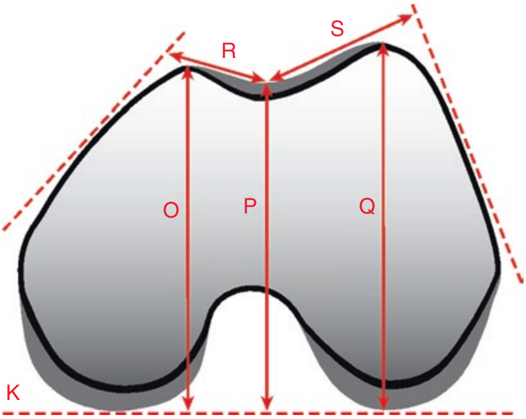

**Fig. 13.1** *Sulcus angle (°),* Measure cartilage surface, beginning at the deepest part of the trochlear groove and extending to the highest points of the lateral and medial cartilage. Measure angle between the slopes of the medial (*R*) and lateral (*S*) trochlea; *Trochlear facet asymmetry*, Measure on full articular cartilage across anterior femur from the groove to the edge of the subchondral bone. Calculate the ratio of the medial trochlear facet length (*R*) to the lateral trochlear facet length (*S*): FA = $R \div S$; *Trochlear depth (mm)*∗, Drop lines at 90° to the baseline (*K*) along posterior condyles at the most inferior level of the full posterior articular cartilage (may need to visualize on >1 axial slice, as the full cartilage may not correlate over the anterior and posterior femur). Average the lengths of the medial (*O*) and lateral (*Q*) trochlear facets, and subtract the length of the trochlear groove (*P*): TD = $[(O + Q) \div 2] - P$; *Trochlear condyle asymmetry,* Drop lines at 90° to the baseline (*K*) along posterior condyles at the most inferior level of the full posterior articular cartilage (may need to visualize on >1 axial slice, as the full cartilage may not correlate over the anterior and posterior femur). Divide the length of the lateral (*Q*) by the medial (*O*) trochlear facet, as a percentage: CA = $Q \div O \times 100\%$

Balcarek et al. [27] developed a patellar instability severity score based on a retrospective case-control model with 5-year follow-up, where 40 (65%) of 61 patients had redislocation, all within 24 months of the index injury. Anatomic variables were measured on MR. Of the variables measured, the ones of statistical significance between the injured and reinjured groups were mean chronologic age (15 vs 22 years), trochlear dysplasia (mild vs severe), and lateral patellar tilt (20° vs 17°).

Arendt et al. [28] examined a larger cohort, and age was not a significant predictor; however, skeletal immaturity was a significant risk predictor. The anatomic measurement of lateral patellar tilt was not a risk factor in their analysis; however, in the Balcarek analysis, the difference between 20° and 17°, though statically significant, is likely not clinically relevant.

A reinjury risk equation was developed by Jaquith and Parikh [29] in a pediatric population (average age 13.7 ± 2.3 years, range from 8 to 18) over an 11-year period. Their retrospective cohort included 222 patients, with 34.7% ($n = 77$) recurrence rate. Significant anatomic risk factors, based on radiographic measurements without slice imaging measurements, included trochlear dysplasia (defined by a modified 2-grade Dejour criteria), skeletal immaturity, and patella alta (defined by C/D index > 1.45) as well as demographic factors, including a history of contralateral patellar dislocation. The authors defined patella alta cut point based on an ROC curve as C/D index 1.45, which is an extreme measurement.

Skeletal maturity status was found to have an effect on the risk of patellar instability [15]. In many series, chronologic age was used as a proxy for skeletal maturity status [27, 30, 31].

Sex has often been thought to be a predictor of a patellar instability risk [2, 30, 32, 33]. Generally, it has been held that females are more at risk than males, although this is not consistent across studies [16–18, 34].

When reviewing the combined effect of multiple risk factors, recent studies have shown that the risk of redislocation increases as the number of risk factors increases (Table 13.1). More recently, Hevesi et al. [35] reported a recurrent instability of the patella (RIP) score based on the presence of skeletal immaturity, trochlear dysplasia, TT-TG/PL ≥ 0.5, and age < 25 [36]. This study categorized patients into low/intermediate risk and high risk finding that patients in the low-risk group had a 100% instability free survival up to 10 years [35]. This contrasted with patients with high risk having a 20.8 ± 9.6% chance of not having a recurrent instability event at 10 years [35].

A recent systematic review and meta-analysis looking at factors associated with an increased risk of recurrence after first-time patellar dislocation found 17 studies met the criteria for inclusion. The overall rate of recurrent dislocation following first-time lateral patellar dislocation

**Table 13.1** Summary of studies reporting the risk of recurrence with multiple concurrent risk factors

| Number of risk factors | Risk of recurrence (%) | | | | |
|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 |
| Arendt [28] | 7.7 | 22.7 | 50.9 | 78.5 | – |
| Jaquith and Parikh [29] | 13.8 | 30.1 | 53.6 | 74.8 | 88.4 |
| Lewallen (2015) [37] | 8.6 | 11.1–26.6 | 29.6–60.2 | 70.4 | – |

Risk factors for Lewallen (2015) [37] were patella alta, trochlear dysplasia, and chronological age < 25

Risk factors for Arendt [28] were open growth plates, sulcus angle >154°, and Insall-Salvati index >1.3

Risk factors for Jaquith and Parikh [29] were trochlear dysplasia, past contralateral history, skeletal immaturity, and a Caton-Deschamps index >1.45

*(Adapted from Factors associated with increased risk of recurrence after first-time patella dislocation: A systematic review and meta-analysis., Feller, AJSM, accepted 2019)*

*Depending on risk variable

was 33.6%. Multiple risk factors were included; not all studies reported on the same risk factors. However, in studies which reported on the presence of multiple risk factors, recurrence rates were 7–14% when no risk factors were present increasing to 50.9–60.2% when two risk factors were present and to 70.4–78.5% when three risk factors were present [38].

The authors found an increased risk of recurrence was reported in patients with younger chronological age, open physes, trochlear dysplasia, elevated TT-TG distance, and patella alta, though precise thresholds could not be ascertained.

Sex, patterns of medial patellofemoral ligament (MPFL) injury, and past history of contralateral dislocation were not found to be associated with an increased recurrence rate in this meta-analysis [38].

## 13.1 Conclusion

There is mounting evidence in our literature that there are key risk factors influencing the rate of recurrent dislocation after first-time patellar dislocation. These include trochlear dysplasia, younger age/open physes, radiographic patella alta, and an elevated TT-TG.

Additive factors impose an additive risk of reinjury. Though we can characterize these risk factors, we cannot say when we should surgically correct these and at what numerical threshold to obtain the most consistent high-level outcomes. Currently, clinicians should consider the impact of the presence of the above-established risk factors on the risk of recurrence when advising the patient with first-time patellar dislocation.

The role of these risk factors in creating a clinical algorithm continues to be explored.

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# 14

# History and Clinical Examination of Patellofemoral Instability

Simon Donell and Iain McNamara

## 14.1 Clinical Symptoms

### 14.1.1 Background

To understand the mechanism of injury in patellar dislocation requires knowledge of the pathoanatomy of the patellofemoral joint. The key points are that:

- The trochlea may be normal or dysplastic
- The extensor mechanism may be normal or abnormal

The patella is the marker in the three-dimensional space that indicates which soft tissues within the extensor mechanism are abnormal, typically:

| Abnormal anatomy | Findings |
|---|---|
| Long patellar tendon | Patella alta |
| Long or ruptured MPFL | Lateral displacement of the patella |
| Ligamentous laxity | Excessive mediolateral patellar glide |

Patellofemoral instability is the "symptomatic deficiency of the .... passive constraint (patholaxity) such that the patella may escape partially or completely from its asymptomatic position with respect to the femoral trochlea under the influence of displacing force. Such displacing force could be generated by muscle tension, movement, and/or externally applied forces" [1].

The aim of taking the history is to define a likely diagnosis or differential diagnosis and how to manage the patient. The differential diagnosis includes identifying important or serious conditions that require urgent treatment. It is also important to understand the patient, which includes what they think the problem may be and how this affects them, any worries that they have, and what it is that they are expecting from the consultation. This is summarised by the acronym "ICE": ideas, concerns, expectations. It is also important to ascertain how motivated the patient is to get better. If a surgical intervention is considered, then fitness for anaesthesia needs to be confirmed.

Patients usually present with complaints of knee instability and may state that the kneecap (patella) itself is unstable. An actual complaint that the kneecap has dislocated is unusual, even when it is the true diagnosis. It can be difficult to decide whether an instability episode was a dislocation of the patella with spontaneous reduction or a subluxation. Patients may also have instability secondary to poor muscle control and

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proprioception, particularly of the hip rotators which control femoral rotation. Notably, weakness of the *gluteus maximus* muscle (the hip external rotator) results in an internal rotation of the femur with adduction of the knee on single-leg squat. If this is uncontrolled and sudden, the patient may complain of three problems: a feeling the knee is dislocating inwards, a feeling that the kneecap is dislocating outwards, and/or anteromedial knee pain due to stretching of the medial retinaculum. All patellofemoral disorders present with a combination of instability and anterior knee pain. Pure pain is unusual as it typically results in poor rehabilitation and therefore muscle weakness and instability. Pure dislocation without pain is typically seen in patients with Down syndrome.

The term "patellar dislocation" is used when the patella moves completely out of the trochlea. It may reduce spontaneously or need formal reduction. There may or may not be a background of prior patellofemoral symptoms (anterior knee pain and/or instability). The age at first-time patellar dislocation (FTPD) is useful to know since, if it is prepubertal, it is associated with significant trochlear dysplasia. The term "acute" patellar dislocation can cause some confusion since if it has occurred on more than one occasion, then the patient has recurrent patellar dislocation. With this in mind, it is worth considering the patient who presents to the expert for the first time separate from those who present on further occasions.

The consensus statement from the American Orthopaedic Society for Sports Medicine (AOSSM) and the Patellofemoral Foundation (PFF) Patellofemoral Instability Workshop agreed on the key questions that are relevant to taking the history when a patient presents with possible patellofemoral instability (PFI) [1].

### 14.1.2 Key Questions for Patients with an Initial Injury

- History of injury: high or low energy?
- How much swelling was present soon after the initial injury?
- Description of sensation: what did it feel like at the time of injury?
- Did you see your kneecap out of place?
- Reduction needed?
- Family history of patellar instability and/or systemic hypermobility?

It is worth noting that there are essentially three typical pathoanatomical scenarios for a patellar dislocation:

1. Dysplastic
2. Normal anatomy
3. Normal radiological anatomy with hyperlaxity

The dysplastic group may also have hyperlaxity, but the group with normal radiological anatomy are the hypermobility syndromes, of which Ehlers-Danlos is the commonest.

Typical histories for each of these are:

**Dysplastic**
- A 15-year-old girl presents with an injury to her left knee whilst dancing when the kneecap popped out as she turned to the right on the planted left foot.

**Normal Anatomy**
- A 17-year-old soccer player sustained an injury to his right knee when an opponent performed a slide tackle whose foot struck his knee on the inside, dislocating the kneecap.

**Normal Radiological Anatomy with Hyperlaxity**
- A 16-year-old girl presents with an episode where her kneecap came out whilst getting up from a chair that spontaneously reduced as she fell to the ground. She describes spontaneous shoulder dislocations in the past.

For the dysplastic and hyperlax groups, one would expect a relatively low-energy injury without severe swelling, a feeling that the kneecap slipped out of joint and typically relocated without reduction. There may be a positive family history which increases the chances of a significant trochlear dysplasia, and/or there may be a family history of hyperlaxity or hypermobility syndrome.

For the normal anatomy group without hyperlaxity, one would expect a high-energy injury with significant swelling, severe pain, and spontaneous reduction especially if there is an osteochondral fracture and without a family history of patellar dislocation or hyperlaxity. A dislocation with normal anatomy implies significant external lateral force to the patella and is therefore a serious injury. Besides the significant risk of an osteochondral fracture, if the medial retinaculum is ruptured, then the haemarthrosis may not be contained in the joint, and so no effusion may be present.

### 14.1.3 Key Questions for Patients with a Recurrent Injury

The same questions should be asked as for the initial injury, plus the following:

- What activities have provoked recurrent symptoms?
- Response to prior treatment?
- How severe were pain and swelling this time?
- Number of episodes of instability?
- Was knee function normal between episodes (pain and/or perceived instability)?
- Review history of initial event: high or low energy?
- Age at onset?
- Bilateral?
- Pain or instability more of a problem?
- Patient/family goals and expectations?
- Family enabling or supportive?

There are two typical presentations of recurrent patellar dislocation:

**Sports and Exercise Active**

- A 17-year-old male, with dislocations affecting one knee but instability symptoms in the other, who dislocates his kneecap while playing sports (soccer or rugby or another depending on the local majority sport) twisting on the flexed knee. There may be a crack heard, they fall to the ground, the knee swells up, and they cannot continue playing. They often know that their patella can dislocate. There may be a positive family history, and they have coped in the past by self-treating. The differential diagnosis is an anterior cruciate ligament rupture. They may sustain both at the same time.

**Non-sports or Exercise Active**

- A 16-year-old female has a long-standing history of recurrent instability symptoms with the kneecap coming out and spontaneously reducing. She has controlled this by avoiding sports. She presents because the kneecap came out after she knocked (e.g. against a table) and the pain has been more severe and the result more disabling.

Both these types may be dysplastic and/or hyperlax; the initial questions should help define this. Patients with a positive family history of patellar dislocation and early age of onset (prepubertal) are more likely to have significant trochlear dysplasia. The sporty patients and those with enabling carers are more likely to successfully rehabilitate after a surgical intervention.

### 14.1.4 Goals of History Taking in Patellofemoral Instability

Patients with recurrent patellar instability have either dysplastic knees or hypermobility or both. Both knees tend to be affected, but only one may have significant symptoms. The aim of the history, with respect to making a diagnosis and management plan, is to:

- Confirm that the kneecap is unstable *is* the diagnosis
- Define whether there is likely to be significant trochlear dysplasia and/or hypermobility
- Verify that they have an important functional loss
- Check that they are motivated and that they are keen to consider an operative intervention

They may have had various interventions in the past, including a variety of operations, but beware of the patient with multiple operations that have been made functionally worse each time. It is worth emphasising that almost invariably these are patients with Ehlers-Danlos syndrome or similar where they are hyperlax and have normal trochleae.

The subsequent examination and investigations with imaging will confirm the anatomy and pathoanatomy.

### 14.1.5 Paediatric Patients

Children presenting with patellofemoral instability with open physes, before the onset of puberty, require special handling as their treatment is driven by the parents' concerns and wishes as well. Experience with managing paediatric patients is essential before considering their management.

### 14.1.6 Older Patients

Less common are patients presenting in later years. These patients have often coped with patellar instability over many years. When they are in their 30s or 40s, their muscle function naturally deteriorates with age-related changes, and they become more symptomatic. Pain is often more of a problem. The results of operative corrections are therefore less predictable. Patient motivation to rehabilitate is therefore very important to consider.

In our experience, patients over 50 years old presenting with patellofemoral instability are mothers of young adults treated with a successful deepening trochleoplasty. They realise that the knee function is much better than they expected and want the same for themselves.

### 14.1.7 Medial Patellar Subluxation/Dislocation

Finally, medial subluxation/dislocation of the patella occurs when an overzealous lateral retinacular release is performed, especially in hyperlax patients. Patients without having had a lateral retinacular release may report their kneecap moving medially. If the foot is planted on the ground, then the femur internally rotates. If the patella does not move in space then, although it dislocates laterally with respect to the femoral groove, the patient feels an inward (medial) instability of the femur and can report this as a medial dislocation of the patella. Clinical examination and the pattern of bone bruising on the MRI scan confirm the lateral patellar dislocation.

## 14.2 Clinical Examination

### 14.2.1 Background

Examination of a patient follows the taking of a detailed history and is a part of the clinical workup of a patient. Its purpose is to confirm the working diagnosis concluded from the history, to exclude important adverse diagnoses, and, in surgery, to provide information important to the conduct or technique used should an operation be considered as part of the patient's management. Since anterior knee pain per se is typically managed conservatively, more work has been done on examination tests and signs for patellofemoral instability (PFI). A systematic review of tests for PFI [2, 3] reviewed 17 tests and signs (see Table 14.1). This was followed up by a study looking at the reliability of these tests (and other used in clinical examination) when performed by internationally recognised experts in the management of PFI [15]. Most tests had a very poor inter-observer reliability, with only patellofemoral crepitus, the J-sign, and foot arch position having fair to moderate agreement. Intra-observer reliability showed moderate to substantial agreement between first and second tests with the assessment of tibial torsion, popliteal angle, and Bassett's sign having the strongest agreement. It was noted that the inter-observer reliability improved if a qualitative assessment was made (normal or abnormal) rather than a quantitative one. Of note, in a PFI population, the Q-angle was more reliably measured at 30° flexion, than 0°. This is different to an anterior knee pain population [2, 3]. At the moment there is no

**Table 14.1** Clinical examination tests and signs [2]

| | Test | Indication | Procedure |
|---|---|---|---|
| Patient specific | Hypermobility [4,5] | Generalised ligamentous laxity | Beighton hypermobility score |
| | Gait pattern | Lower limb biomechanical abnormities may functionally place adverse forces on the patella | Observation of functional biomechanical abnormalities particularly for evidence of foot pronation and persistent heel valgus during step-off, indicating a fixed hind foot deformity or Achilles tendon contracture. Leg length discrepancy should also be noted |
| | Evaluation of lower limb alignment | Lower limb abnormalities may predispose the patient to increase patella torque | Patient standing. Observation of femoral anteversion, external tibial torsion, standing visual mechanical axis for varus/valgus orientation and the extent to which these may be corrected by core stability of the lower extremity, degree of genu valgum, hind foot valgus, and forefoot pronation |
| Knee-specific: *inspection* | Q-angle [6] | Increased Q-angle may increase the laterally directed force on the extensor mechanism, predisposing the patella to malpositioning and instability | Patient supine. A line is drawn from the anterior superior iliac spine to the centre of the patella. A second line is then drawn from the centre of the patella to the tibial tubercle. The angle this makes is the Q-angle.<br>Normal value is 10–15° for men and 15–20° for women |
| | Tibial tubercle to trochlear groove (TTTG) assessment [7] | The TTTG suggests the position of the tibial tubercle relative to the patella. This may indicate whether the tubercle is lateralised which could increase the lateral force on the patella | Patient in semi-recumbent position. Mid-point of the symphysis pubis and the anterior superior iliac spine is marked. This is the proximal reference point. Knee in 90° flexion, a calliper is applied across the epicondyles. One end of a piece of string is held by the patient over the reference point, and where the calliper and string meet is the centre of the trochlear groove. The string is then positioned over the front of the knee and confirmed to be straight by visual inspection. The horizontal distance is then measured between the string and the centre of the tibial tubercle. The knee is then fully extended, whilst the string is pulled taught in line with the proximal reference point. Once the knee is in full extension, the horizontal distance between the string and the tibial tubercle is measured with a ruler. A displacement lateral to the string is a positive and medial is a negative score. The score is the displacement of the tubercle in extension from the flexion measurement |
| Knee-specific: *palpation* | Quadriceps definition [8] | Reduced quadriceps definition may indicate atrophy of the quadriceps, which may alter the quadriceps stability on patella biomechanics | Not described |

(continued)

**Table 14.1** (continued)

| | Test | Indication | Procedure |
|---|---|---|---|
| | Apprehension test [9] | Reduced medial stability allows excessive lateral glide to mimic a recurrent dislocation | Patient supine, knee relaxed in 30° flexion. Examiner uses one hand to push the patella laterally. A positive sign is when it reproduces the patient's pain or causes fear that the patella will dislocate. Apprehension can either be from verbal expression of anxiety or involuntary quadriceps muscle contraction |
| | Modified apprehension test [10] | This force would reduce the tension of the distally based medial patellomeniscal ligament to isolate the MPFL. In addition, a distal force would prevent the anterior prominence of the proximal lateral femoral sulcus from inhibiting lateral translation to isolate a disruption of the MPFL | Displacement of the patella in a distal lateral direction |
| | Bassett's sign [11] | Tenderness on palpation may indicate a rupture or disruption of the MPFL contributing to reduced medial stability of the patella | Tenderness on palpation of the adductor tubercle and medial epicondyle |
| | Palpation of the medial retinaculum [12] | This may indicate a disruption of the MPFL or medial retinaculum following patellar dislocation | Careful palpation of the medial aspect of the patellar and medial retinaculum investigating for pain or a palpable defect the medial retinaculum |
| | Patellar glide test [12] | Excessive glide suggests reduced restraint from the medial structures or tightness of the lateral retinaculum | Patient spine, knee relaxed in 30° flexion. Patella manually glided medially and laterally. The patella is divided into 4 quadrants. A glide ≥3 quadrants (or more than half the patellar width) represents reduced patella restraint |
| | Patellar tilt test [12] | Limited upwards movement would indicate excessively tight lateral retinaculum, as normally the patella can be tilted upwards above horizontal | Patient spine, knee relaxed in 20° flexion. Examiner holds the patella between their thumb and forefinger and pushes the patella down in an attempt to flip the lateral edge of the patella upwards. Elevation of the lateral patella to less than neutral suggests an abnormal result, where 0°–20° elevation is normal |
| | Gravity subluxation test [13] | Inappropriate or overzealous lateral release surgery may cause iatrogenic medial subluxation as lateral retinaculum and vastus lateralis are insufficient to prevent medial displacement and therefore are unable to relocate the patellar into the trochlear groove | Patient in lateral decubitus position, affected leg superior, knee in full extension. Patient relaxes whilst the examiner abducts the leg. In patients with medial patella subluxation, the patella visibly shifts medially. The patient then isometrically contracts the quadriceps; if the patella remains medially subluxated, then this suggests a complete dissociation of the vastus lateralis from the patella. If the patella relocates laterally on contraction, the vastus lateralis is intact |
| Knee-specific: *motion* | VMO[a] capability [8] | The VMO may exhibit atrophy or hypotrophy in patella instability patients, to possibly suggest a reduction in dynamic medial stability | Patient sits on edge of bed. Examiner observes for a concavity on the medial aspect of the distal thigh when the leg is activity extended against gravity at 15°–45° |

**Table 14.1** (continued)

| | Test | Indication | Procedure |
|---|---|---|---|
| | Quadriceps pull test | A higher result indicates a greater force on the patella from lateral forces of the lateral retinaculum than the medial structure (vastus medialis, MPFL, trochlear groove) can restraint, indicting a biomechanical abnormality | Patient supine, knee relaxed in full extension. The central point of the patella is marked, and a line is drawn from this point to the centre of the tibial tubercle. This is the reference line. Patient told to perform an isometric quadriceps contraction. The centre of the patella is then determined, and its horizontal deviation from the reference line is measured. This measure gives the test result. Results > 15 mm horizontal movement indicate a marked imbalance of forces on the patella |
| | Patellar positioning | Patella infera and alta may indicate abnormal patellar engagement in the trochlear. Patellar tilt may indicate reduced medial retinaculum stability or possible tightness of the lateral retinaculum | Patient initially supine, but retested in sitting. Knee initially relaxed in full extension. Examiner observes for patellar tilt, lateralised position, patellar infera, and patellar alta whilst knee actively moves from full extension to full flexion |
| | J-sign [12, 14] | This may suggest excessively tight lateral retinaculum, causing the patella to shift laterally in terminal knee extension as it disengages from the femoral intertrochlear groove | Patient sits on the edge of the plinth, knee in full extension. Patient then actively moves the knee into full flexion. Examiner observes for an exaggerated lateral to medial translation of the patella into the trochlear groove in early flexion |

[a] VMO *vastus medialis obliquus* muscle

standardisation of the physical examination tests, and so a numerical value for the tests cannot be used for decision-making. It is thought that with standardisation of how to perform the tests, then the level of agreement would improve.

The consensus statement from the AOSSM/PFF PFI Workshop produced key points in the clinical examination depending on the presentation [1].

### 14.2.2 Key Points for Patients with Suspected Acute Patellar Instability: First Time or Recurrent

- Patellar glide in extension and various degrees of early flexion (if tolerated) evaluating amount of displacement and endpoint (in response to force) (Fig. 14.1, Movie 14.1).
- Apprehension test at 30° if tolerated: does displacement produce an apprehension reaction (subjective response) (Movie 14.2)?
- Tenderness along medial patella and/or medial patellofemoral ligaments.
- Effusion (large effusion may raise suspicion of osteochondral fracture).
- Rotational alignment, including femoral anteversion, tibial torsion, and hyperpronation.
- Hypermobility (Beighton score), emphasising the presence of knee hyperextension (Movie 14.3).
- Do not forget anterior cruciate ligament and medial collateral ligament examination.
- Include general examination for range of motion of the ligament, meniscal pathology, referred pain, and neurological compromise.
- If patient is experiencing too much acute pain and swelling for meaningful examination, a repeat evaluation should be planned within several weeks.
- Compare all with contralateral leg.

**Dysplastic**

- In the dysplastic patient, abnormal signs should be expected bilaterally. The mediolat-

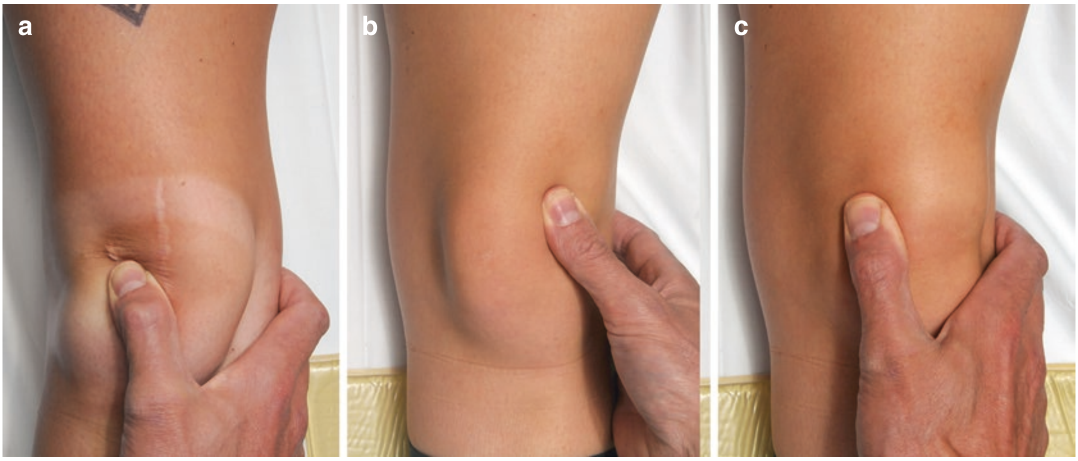

**Fig. 14.1** Photograph of knees in the examination of a patient with excessive medial glide following an overzealous lateral retinacular release. (**a**) Affected knee with increased medial patellar displacement. (**b**) Normal contralateral knee showing medial patellar displacement. (**c**) Normal contralateral knee showing lateral patellar displacement

eral glide will be increased. In the absence of hyperlaxity, then the symptomatic side usually has greater displacement than the asymptomatic contralateral side. The apprehension test may not be positive. Rotational malalignment can be part of an overall dysplasia.

**Normal Anatomy**

- The key here is that the patient's injured knee may be too painful and swollen at the initial consultation, and therefore the contralateral knee should be examined carefully and confirmed to be normal.

**Normal Radiological Anatomy with Hyperlaxity**

- With hyperlaxity the Beighton score is ≥4 out of 9 (Table 14.2) [4, 5]. If 9/9 then look for syndromes such as Ehlers-Danlos (extensible skin and bruising) or Marfan's (high-arched palate and arachnodactyly).

**Table 14.2** Beighton score

| Description | Bilateral test | Score |
|---|---|---|
| Passive dorsiflexion of 5th MCP joint to ≥90° | Yes | 2 |
| Passive apposition of the thumb to the flexor side of the forearm, whilst shoulder is flexed 90°, elbow is extended, and hand is pronated | Yes | 2 |
| Passive hyperextension of the elbow ≥10° | Yes | 2 |
| Passive hyperextension of the knee ≥10° | Yes | 2 |
| Forward flexion of the trunk, knees straight, so that the hand palms rest easily on the floor | No | 1 |
| | **Total** | **9** |

### 14.2.3 Key Points for Patients with Suspected Recurrent Instability: Non-acute Visit Examination

- Standing alignment, gait (watching especially for valgus and rotational abnormalities).
- Single-leg stance, squat, or step-down as tolerated (screening evaluation of hip strength and core control) (Movie 14.4).
- Patellar glide in extension and various degrees of flexion evaluating amount of displacement (laxity) and endpoint.
- Apprehension test for lateral instability: does displacement produce an apprehension reaction and at what degree of flexion?
- J-sign with active knee extension/flexion (Movie 14.5).
- Fixed lateral tracking, when patella fails to centre with increasing flexion (may be dif-

ficult to confirm on physical examination alone).
- Effusion.
- Rotational alignment, including prone femoral anteversion, tibial torsion, and hyperpronation.
- Hypermobility (Beighton score).
- Hyperalgesia.
- Include general examination for range of motion of the ligament (especially anterior cruciate ligament and medial collateral ligament), meniscal pathology, referred pain, and neurologic compromise.
- Compare all with contralateral leg.

From the point of view of sports- and exercise-active versus non-sports- and exercise-active patients, the key points of the clinical examination are the same. The distinction is most useful in deciding whether an operative intervention is more or less likely to be considered. The clinical examination should run to a repeated standard (see below) with a useful format being a general examination as the patient moves about, noting dysmorphic features and overall lower limb alignment. It is worth doing the Beighton score before the patient lies down; this is because it tends to be forgotten if left till the end.

With the patient semi-recumbent and the knees in extension, the rotational alignment and any recurvatum can be measured. An effusion is looked for, and the quadriceps bulk noted. The extensor mechanism is then examined using the specific tests listed above: patellar glide, apprehension, as well as local tenderness. Both knees should be examined.

Knee range of motion is then noted: passive extension, active extension, and active flexion – recorded as 0°/0°/140° in normal knees but could be −15°/0°/150° in a hypermobile patient with poor rehabilitation following an injury episode. This finding indicates quadriceps lag of 15°.

With the knee at 90°, a standard examination of the tibiofemoral joint is then performed to confirm that this is normal and especially that the anterior cruciate ligament is intact. With the knee fully flexed, the anterior distal femur is palpated through the quadriceps tendon to assess its shape. Loss of a groove or a dome shape indicated significant trochlear dysplasia.

The patient is then sat over the edge of the couch and each knee actively flexed and extended from 0° to 90° to assess the tracking. A J-sign indicates that the medial restraints (medial patellofemoral and medial patellotibial ligaments) are deficient (stretched or ruptured) and is seen as a movement laterally in extension. The more flexed the knee is when this lateral patellar movement occurs, the more severe the underlying trochlear dysplasia. There is a special group where the dislocation appears in flexion. Here there is significant trochlear dysplasia plus a tight lateral retinaculum.

The couch is then put flat. A passive straight-leg raise will indicate if there is hamstrings' tightness. The patient's core strength is also tested. This is performed by flexing the knees to 90° and lifting the buttocks off the couch. With strong core muscles, the patient can straight-leg raise each leg and hold it in line with the spine for 30 s.

Finally the patient stands and hip rotator muscle function and proprioception are tested. In all cases the patient is asked to stand on each leg (normal or asymptomatic side first) and lift the opposite side so that the hip and knee are at right angles. They should be able to hold this steady for 10 s. They are then asked to semi-squat and hold for a further 20 s. The clinician looks for adduction and internal rotation of the femur indicating weakness of the *gluteus maximus* muscle and unsteady balance suggesting poor proprioception. In more sports-active patients, the same information can be obtained from a step-down test.

### 14.2.4 Key Points for Complex Situations or Patients with Previous Surgery

- Gravity subluxation test: gravity-provoked medial subluxation in lateral decubitus position.
- Medial apprehension test: displace the patella medially from the trochlea, observing for apprehension reaction.

- Relocation test: displace the patella medially, then flex the knee quickly, and see if this reproduces the symptom of the patella moving from too far medially back to the trochlear groove.

Patients who have undergone previous multiple procedures typically fall into four groups:

1. Missed or untreated significant trochlear dysplasia
2. Missed hypermobility syndrome
3. Inadequate or excessive extensor mechanism correction
4. Overzealous lateral release

The overzealous lateral release requires examination of the lateral retinaculum, and three key points itemised above assess this [13, 16, 17]. An excessive medial patellar displacement can be noted (see Fig. 14.1).

### 14.2.5 The Standard Clinical Examination for Patellofemoral Instability

The standard examination for PFI allows rapid and efficient assessment of the patient. Depending on the working diagnosis after taking the history, more detailed examination may be needed for parts of it. The examination can be broken down into:

(1) *General view*

    As the patient enters the examination room, or whilst walking to the couch, observe the overall limb alignment and gait. Note the body posture and consider the morphotype.

    Check the Beighton score.

(2) *Lying supine*

    Examining the knee is more comfortable, and therefore more effective, if the couch backrest is inclined at around 45°. Examine both knees.

    (a) *Knees extended*
        - Hip version and tibial torsion
        - Presence of an effusion
        - Bulk of *vastus medialis obliquus* muscle
        - Patellar apprehension
        - Mediolateral glide

    (b) *Range of knee motion*
        - Passive extension
        - Active extension
        - Active flexion

    (c) *Knees flexed at 90°*
        - Tibiofemoral joint.
        - Trochlear groove: palpate anterior distal femur with knee fully flexed.

(3) *Sitting on edge of couch*
    (a) J-sign

(4) *Couch lain flat*
    (a) *Lying supine*
        - Core control
        - Hamstrings' tightness

    (b) *Lying prone*
        - Hip version
        - Quadriceps tightness

(5) *Standing* (screening evaluation of hip strength and core control)
    (a) Single-leg stance
    (b) Squat or step-down as tolerated

### 14.2.6 Goals of the Clinical Examination in Patellofemoral Instability

In summary, the goals of the clinical examination are to confirm the working diagnosis of the history and exclude any important alternative diagnoses. The hip strength and core control tests also are important in educating the patient (and observed by their carers) that poor muscle control and proprioception can cause feelings of instability around the kneecap, independent of the anatomy of the patellofemoral joint.

Having examined the patient, the clinician should have a clear expectation of the results of any investigations that are ordered. Validated scoring systems should also be assessed as part of the clinic workup and prior to discussing with the patient their diagnosis and treatment options.

## 14.3 Conclusion

Although common things occur commonly, there are so many rare diagnoses that a clinician in a tertiary referral practice will regularly see rare things. These are more obvious to spot if a detailed history is taken first, to provide the working diagnosis, and then confirmed by the examination. If the examination does not match the history, or the investigations do not confirm the expected findings, then the chances are that the correct diagnosis has not been made, e.g. an ACL rupture rather than a patellar dislocation (although both diagnoses may be present in one patient as the mechanism of injury is similar). The history then has to be retaken, a new examination performed, and further investigations have to be undertaken. A rare diagnosis may be then identified.

It should also be stressed that the management of the patient is indicated by the history and not the examination findings or the imaging. As Sir William Osler stated “It is more important to know the patient that has the diagnosis than the diagnosis the patient has.”

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# First-Time Dislocation: How to Deal with It

# 15

Petri Sillanpää

## 15.1 Introduction

First-time (primary) patellar dislocation commonly occurs in the young physically active population and is associated with a high rate of recurrent patellar instability [1–3]. Previous studies have demonstrated that the incidence of primary patellar dislocation is between 30 and 70 per 100,000 among children and teenagers [1, 4–7]. Primary patellar dislocation results in medial patellofemoral ligament (MPFL) injury [8–10], the major soft tissue stabilizer of the patella [9], which may lead to recurrent patellar instability. Recurrent patellar dislocation may require surgical correction. Acute patellar dislocation occasionally has concomitant osteochondral fracture, which requires surgery [8, 10–12]. The variation in location of injury of the MPFL and the varying presence of predisposing factors for recurrent patellar dislocation, such as trochlear dysplasia and patella alta, makes challenges in clinical decision-making between nonoperative and operative treatment [3, 12–14]. Although nonoperative management for primary patellar dislocation without osteochondral fracture is generally favored, current evidence suggests that not all primary dislocations should undergo the same treatment. Whereas MPFL reconstruction has been established as the golden standard for a soft tissue surgical procedure, the need to perform additional bony corrections is not yet known. Individualized analysis of risk for recurrence is advocated including meticulous physical examination and sufficient imaging modalities to recognize the first-time dislocators with high risk of recurrence.

## 15.2 Diagnosis and Assessment of Risk Factors for Recurrence

Patellar dislocation diagnosis is typically based on patient history and physical examination. Usually dislocated patella relocates by itself but sometimes may need to be reduced manually. Medial side tenderness and acutely swollen knee are the most common clinical findings, and knee aspiration might be necessary if heavily swollen. Patellar dislocation is the most common reason for knee hemarthrosis in adolescents [2, 15].

When the patella dislocates laterally, the medial patellar restraints are injured, particularly the MPFL [1, 3, 10, 11, 16–19]. The external force required to dislocate the patella most likely depends on the individual patellofemoral morphology. When the femur rotates internally and the tibia externally, with the foot fixed on the ground, the patella may dislocate without any pathologic structures in the patellofemoral joint

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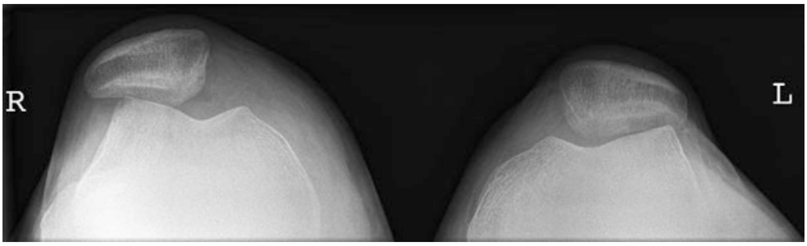

**Fig. 15.1** Axial view of both knees. Acute patellar dislocation on right knee, the patella is lateralized if compared with the contralateral knee

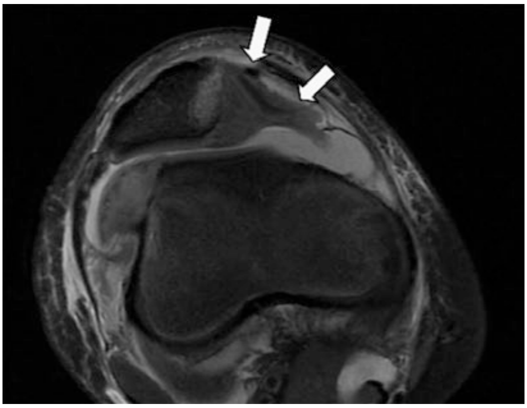

**Fig. 15.2** Axial MRI of acute patellar dislocation with a large osteochondral fracture (arrows) and medial patellofemoral ligament injury. Large ostechondral fracture requires surgical fixation

[1, 15]. Quite often, however, patellar dislocation occurs in a knee that has predisposing anatomic factors for patellar instability. These include trochlear dysplasia, patella alta, increased femoral antetorsion, increased external tibial torsion, and valgus alignment of the lower limb, and sometimes generalized ligamentous laxity can be present [13, 20]. In pediatric primary patellar dislocation, population predisposing anatomical factors are more common, and first-time dislocation may present without extensive soft tissue damage [6, 15]. In adults who sustain a primary dislocation without prior knee complaints, medial restraint injury results in acute hemarthrosis indicating more extensive external force to dislocate the patella [1, 2, 21]. Due to varying clinical presentations of primary dislocation, radiographs are required to confirm the diagnosis.

From plain radiographs, axial view of the patella is particularly important, and both patellae should be included in this view. The patella may be lateralized if compared with the contralateral side (Fig. 15.1), and an avulsion fragment of the medial patella, or a loose osteochondral fragment, may be observed (Fig. 15.2) [8, 10]. Because of the high prevalence of osteochondral fractures, MRI is recommended to assess the cartilage more precisely [10, 22]. Without MRI, osteochondral flake fractures can easily be missed, and therefore MRI should be performed quite soon after the injury. In addition, MPFL injury and its location can be assessed reliably by MRI, to confirm the diagnosis of acute patellar dislocation [8]. MPFL injuries are classified in three categories based on location: at the level of the MPFL patellar insertion, at the midsubstance of the MPFL, and at the femoral origin of the MPFL (Table 15.1) [8, 23]. In summary, MRI is necessary in a case of suspected primary patellar dislocation to verify the diagnosis, to evaluate concomitant cartilage injuries, and, importantly, for assessment of the patellofemoral joint anatomy [8, 10, 11, 17–19].

Each patellofemoral joint has unique anatomy. The abnormalities in bony structure that predispose recurrent patellar instability include trochlear dysplasia, patella alta, elevated TT-TG or TT-PCL distance, increased femoral antetorsion, increased external tibial torsion, and valgus alignment of the lower limb [3, 6, 13, 14, 20, 24–26]. These factors are discussed in detail in other chapters of the book. When primary dislocation has occurred, essential part of the treatment is to recognize these factors. Therefore, sufficient imaging modalities are necessary. In addition to plain radiographs, MRI is mandatory to confirm the diagnosis, to assess concomitant

**Table 15.1** Medial patellofemoral injury location in primary patellar dislocation [8, 10, 11, 17–19]

| MPFL injury classification | Anatomic description | Proportion in primary dislocations | Mean reported incidence (%) |
|---|---|---|---|
| Patellar | MPFL patellar attachment | 13–76% | 54 |
| Midsubstance | MPFL mid substance (region between patellar and femoral attachments) | 0–30% | 12 |
| Kernoral | MPFL femoral attachment | 12–66% | 34 |

MPFL indicates medial patellofemoral ligament

injuries, and for evaluating patellofemoral joint anatomy. If suspected in physical examination, long leg standing x-rays might be necessary to evaluate coronal plain alignment in a case of genu valgum. If rotational abnormality is present, rotational CT or MRI is used to assess rotational alignment. In younger individuals, MRI is preferred to avoid radiation exposure.

## 15.3 Nonoperative Management of First-Time Patellar Dislocation

The standard of care for a primary patellar dislocation without osteochondral fracture has been nonoperative treatment. A short immobilization period is used for patient comfort and is followed by formal physiotherapy. A systematic review regarding the clinical outcomes of rehabilitation for patients after lateral patellar dislocation concluded that no randomized controlled clinical trials had been published that assessed different physiotherapy interventions [27]. Therefore, the optimal conservative management has yet to be established. Longer immobilization period than required for pain relief is most likely unnecessary and is not supported by the literature either. The immobilization period has varied widely between 0 and 6 weeks in studies [27–30]. A report of preliminary results of a prospective randomized study in which immediate mobilization was compared with flexion restriction with a patellar brace found no difference at 2 years [31]. A feasibility study for a pragmatic randomized controlled trial comparing cast immobilization versus no immobilization for patients after first-time patellar dislocation suggested better short-term functional result for those not immobilized, but the reported preliminary sample was too small to make any conclusions [32].

Usually a period of physiotherapy is prescribed to encourage patients to return in their daily activities. Furthermore, the aims of physiotherapy are to restore knee range of motion and to strengthen the quadriceps muscles to restore the dynamic part of the patellar soft tissue stabilizers [27]. Patients should activate the quadriceps as tolerated by pain, and after 2–3 weeks, when pain and swelling are nearly disappeared, more strenuous exercises should be started aimed at normalizing quadriceps strength and lower body proprioceptics. At 4–6 weeks, by which point walking and knee range of motion have been normalized, exercises continue with more extensive extension raises, proprioceptive activities, and core stability training. Return to full activity can be suggested at 2–3 months. Regaining muscle strength and avoiding restrictions in daily physical activities are the main rehabilitation goal.

## 15.4 Surgical Management of First-Time Patellar Dislocation

Decision for surgical treatment for first-time patellar dislocation is made on an individual basis and may vary according to a number of factors. Factors that may contraindicate nonoperative treatment include osteochondral lesions and high risk of recurrent instability [3, 12–14, 26]. In these cases, surgery is considered. Acute osteochondral fracture can be considered an indication for surgery, and cartilage defects should be repaired by reduction and fixation of the fragment (Fig. 15.3) [10, 33, 34]. In particular, fractures located in a high-pressure area, central or lateral

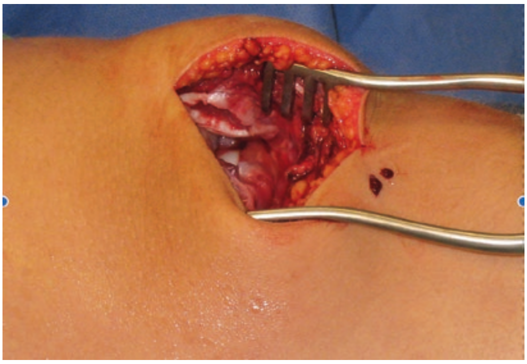

**Fig. 15.3** Acute osteochondral fracture can be considered as an indication for surgery – large cartilage defects should be repaired by reduction and fixation of the fragment

patellar cartilage, or lateral trochlear wall, should be repaired if possible. A fragment size >5 to 10 mm can be fixated, and based on the experience of the author, large fragments heal well if fixation is performed within 2–3 weeks from the injury. Fragment fixation can be performed with bioabsorbable nails, pins, small screws, or sutures. Small osteochondral fractures can be managed nonsurgically, especially in cases when the fracture is located in a low-pressure area, the distal lateral margin in the lateral condyle of the femur, which normally does not carry weight or articulate with the patella. In such cases, a small fracture may be arthroscopically removed if it acts as a loose body and produces symptoms [10, 34].

In primary patellar dislocation, the MPFL is the injured as a part of the medial patellar stabilizing complex, whereas limb alignment and patellofemoral joint morphology are individual persistent factors. Theoretically, repair of the injured MPFL or medial stabilizing complex should be the primary surgical option. Surgical stabilization of the patella can be performed with MPFL repair or reconstruction. Surgical repair can be performed if the injury location is known [10]. Some patients, however, may have remarkable underlying pathology that critically affects patellar stability, although the decision to operate on patients with a first-time dislocation remains controversial. Additional procedures involving osseous anatomy should be selected on an individual basis.

MPFL patellar or femoral attachment injury can be surgically reinserted with satisfying results and may lead to a better outcome than nonsurgical treatment [29], although some controversy exists in the results of prospective studies [21, 28, 35, 36]. MPFL midsubstance injuries seem to not benefit from acute repairs [10, 21, 28]. MPFL injury at the femoral or patellar attachment can be repaired with sutures or suture anchors [29]. Midsubstance MPFL injury is difficult to repair adequately and is therefore not recommended [21, 23, 28, 35].

Patellar attachment MPFL injury can be classified as a ligamentous or bony avulsion from the medial margin of the patella [10]. A third type includes an osteochondral fragment with articular cartilage involvement from the medial patella (Fig. 15.2). Similar lesions might be seen at the medial patellotibial ligament (MPTL) attachment at the lower third of the medial patella. According to a retrospective study, femoral MPFL injury is associated with an increased rate of recurrent instability compared with patellar MPFL avulsion injury with similar nonsurgical management [10].

Multiple injury locations of medial patellar stabilizing complex have been reported to be found in MRI [37], indicating that certain MPFL or MPTL injury location repair is unreliable to fully restore patellar stability. Given the variety of injury location and the reported less favorable clinical outcomes for repair, MPFL repair is generally not recommended as surgical solution, whereas MPFL reconstruction is recommended [23, 28, 38].

The higher the risk for recurrent patellar dislocation, the more predisposing factors the first-time dislocator has [3, 12–14, 24]. Pediatric population is also at higher risk of recurrence than adults. Recent studies have documented low rate of return to preinjury physical activities after primary dislocation, despite not having recurrent dislocation [13, 30]. Algorithm to assess risk factors for recurrent dislocation has been proposed by Balcarek et al. [12] to help clinical decision whether surgery would be necessary already after primary dislocation. Their "patellar instability severity score" (ISS) includes six risk factors: age (<16 years of age), bilateral instability, trochlear dysplasia (none, mild, severe), patellar height

**Table 15.2** Patellar instability severity score

| Risk factors (odds ratio) | | Points |
|---|---|---|
| Age (11.2) | >16 years | 0 |
| | ≤16 years | 1 |
| Bilateral instability (3.2) | No | 0 |
| | Yes | 1 |
| Trochlear dysplasia (4.2) | None | 0 |
| | Mild | 1 |
| | Severe | 2 |
| Patellar height (1.4) | ≤12 | 0 |
| | >1.2 | 1 |
| TT-TG (1.5) | <16 mm | 0 |
| | ≥16 mm | 1 |
| Patellar tilt (1.9) | ≤20° | 0 |
| | >20 | 1 |
| | Total score range | 0–7 |

Odds for recurrence are five times higher when total score ≥ 4 points

**Table 15.3** Prediction model for recurrence after first-time patellar dislocation based on number of risk factors

| Risk factors | Average predicted risk of recurrence | Treatment recommendation |
|---|---|---|
| 0 | 13.8% | Conservative treatment |
| 1 | 30.1% | Conservative treatment |
| 2 | 53.6% | Surgery optional |
| 3 | 74.8% | Surgical treatment |
| 4 | 88.4% | Surgical treatment |

The four risk factors include trochlear dysplasia, history of contralateral dislocation, skeletal immaturity, patella alta (C-D ratio > 1.45)

(IS > 1.2), TT-TG distance (>16 mm), and patellar tilt (>20°). They reported almost five times higher patellar redislocation rate if ISS scores 4 or higher, if compared to 3 or less points. Surgical treatment for primary dislocation should therefore be aimed for those who score 4 points or more (Table 15.2).

Another prediction model for recurrent instability has been proposed, by Parikh et al. [13], who evaluated multiple risk factors to develop a tool to help estimate the recurrence rate after primary patellar dislocation in less than 18-year-old population (Table 15.3). They recommended surgical treatment after primary dislocation if three or more risk factors are present (trochlear dysplasia, history of contralateral dislocations, skeletal immaturity or Caton-Deschamps ratio more than 1.45).

## 15.5 Review of the Current Clinical Evidence

The complexity of patellar instability leads to challenges in decision-making between different treatment modalities. Most cases are suitable for initial nonsurgical management with physiotherapy, although recurrent instability is very common [21, 39, 40]. Osteochondral fragments amenable for surgical fixation are an indication for surgery, and MPFL reconstruction is a more reliable method of stabilizing the patella than MPFL repair, which has limitations related to the MPFL injury location [10, 37]. Osseous surgery is usually not needed if surgery is planned after primary dislocation, but corrections are needed in cases with severe bony abnormalities [40].

Studies report variable results after surgical treatment for primary patellar dislocation [4, 28, 40–43]. Studies initiated >10 years ago mainly utilized surgical techniques that were nonanatomic and are no longer used [21, 28, 35]. Therefore, those results are considered less reliable than modern surgical techniques [40]. MPFL repair by sutures is not better than nonsurgical treatment and does not decrease recurrent instability rate in skeletally immature children and does not improve subjective results in adults [21, 28, 35]. Acute arthroscopic MPFL repair is also not superior to nonsurgical management [23, 38]. Arthroscopic repair is likely an insufficient method to approach the MPFL injury locations. Delayed repair is usually not targeted to the previous injury location and is therefore not useful [36, 38, 44].

Eight prospective randomized studies have been published, some of them described better patellar stability after MPFL repair compared with conservative treatment [28, 29, 41, 42]. However, only one study described clinically significant improvement in subjective outcome [29]. The more recent the prospective randomized study, the more favorable the result toward operative treatment [40]. All of the prospective randomized studies utilized different kinds of MPFL repair [21, 28, 29, 35, 36, 41–43]. To date, no study has compared MPFL reconstruction to nonoperative treatment in a prospective and randomized study setting. Whether some of the patients with primary patellar dislocation and predisposing anatomical factors would benefit for additional osseous surgery has not been studied in prospective, randomized study setting. Because of the insufficient amount of evidence in the literature, there is currently no universally accepted, optimal strategy for primary patellar dislocation available [40]. Despite systematic reviews and meta-analyses, the ideal management of first-time lateral patellar dislocation (LPD) has not yet been established but should be individually tailored.

## 15.6 Pearls How to Deal with First-Time Patellar Dislocation

| |
|---|
| First-time patellar dislocation diagnosis includes radiographic studies and MRI |
| Immobilize primary dislocation only for a short period of time for patient comfort (<2 weeks), followed by active physiotherapy |
| Osteochondral fracture amenable for fixation is an indication for surgery – if fragment is fixated, simultaneous MPFL reconstruction is recommended |
| MPFL repair alone is insufficient method for stabilizing surgery |
| Patellar instability severity score 4 or more indicates consideration of surgical approach after first-time patellar dislocation |
| Additional procedures involving osseous anatomy should be selected on an individual basis; based on patellofemoral joint anatomy, no uniform method is available |

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# 16

# Medial Patellofemoral Anatomy: Surgical Implications in Patellofemoral Instability

Miho J. Tanaka and Jorge A. Chahla

## 16.1 Introduction

The soft tissue anatomy of the medial patellofemoral stabilizers is an important topic in the surgical treatment of patellar instability. Of these, the medial patellofemoral ligament (MPFL) is most well-known as the primary static stabilizer to lateral patellar translation. Reconstruction of the MPFL has become popularized over the last 15 years, with outcomes showing improved functional scores and low rates of recurrent instability and postoperative apprehension at 36.8 months [1].

The anatomy of the ligament and our ability to reconstruct this ligament has increasingly come into focus, as the complications of this procedure have become more apparent. Parikh et al. [2] demonstrated a 16.2% rate of complications after MPFL reconstruction in a series of 179 adolescent knees with patellar instability, including recurrent instability, flexion deficits, patellar fractures, and patellofemoral arthrosis or pain. Of these 38 patients with complications, the authors reported that 18 (47%) were secondary to technical factors [2]. Of these 12/18 demonstrated recurrent instability, patellofemoral pain, or limitation in motion which were associated with a malpositioned femoral tunnel, and 5 of 6 patellar fractures occurred through the newly created bony tunnels.

Proper understanding of the anatomy of medial patellar restraints has been shown to be critical in reconstruction outcomes. Elias and Cosgarea [3] demonstrated in a computational modeling study using simulated procedures that proximal malpositioning of the femoral attachment site by 5 mm increased tension on the MPFL graft and led to statistically significant decreases in lateral graft force and patellar tilt. When proximal malpositioning of the femoral tunnel was combined with a graft that had a shortened resting length by 3 mm, these changes were even more prominent, with increased compressive forces on the medial patellofemoral cartilage. The importance of recreating the anatomy of the MPFL in order to maintain good outcomes and prevent complications highlights the need for an improved understanding of the native anatomy.

Furthermore, recent advances in anatomical studies have changed the understanding of medial patellofemoral anatomy. While several early studies had commented on the presence of the proximal fibers of the MPFL that attach onto the quadriceps tendon, more recent anatomic studies have identified the consistent presence of these proximal fibers indicating their potential dynamic role in limiting

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lateral patellar translation. Biomechanical and anatomic studies have also revisited the role of the distal patellar stabilizers, including the medial patellotibial ligament (MPTL) and medial patellomeniscal ligament (MPML), particularly with regard to their roles in greater degrees of knee flexion and in active terminal extension of the knee. This chapter will review the current understanding of the medial patellofemoral anatomy and the implications for soft tissue reconstruction.

## 16.2 Terminology

The main static stabilizer to lateral patellar translation is known as the MPFL, a fan-shaped ligament that extends from the medial femur to the medial patella. More recently, the anatomical insertion of these fibers on the extensor mechanism has been found to include attachments to the quadriceps tendon, which can vary in the location of the primary attachment [4–8]. Fulkerson and Edgar [4] described these fibers as a distinct ligament, which they termed the medial quadriceps tendon femoral ligament (MQTFL). This term describes the specific fibers that attach to the quadriceps tendon. Others have included these fibers as variable components of the MPFL that do not necessarily form a distinct ligament [6, 9]. Because of this, the entire ligament has also been referred to as the medial patellofemoral complex (MPFC), to allow for its variability in attachment sites on the extensor mechanism. Together, these ligaments comprise the proximal medial patellar restraints.

The distal medial patellar restraints are comprised of the MPTL and the MPML. These originate on the medial tibia and medial meniscus, respectively, and attach to the distal patella. An illustration of this terminology is shown in Fig. 16.1.

## 16.3 Proximal Medial Patellar Restraints

As summarized above, the proximal medial patellar restraints consist of the MPFL and MQTFL, which can be referred to as a single entity called the MPFC due to the common origin of the fibers on the medial femur. This ligament courses along the undersurface of the distal border of the VMO between layers 2 and 3 and expands into a broad attachment on the patella and/or quadriceps tendon (Fig. 16.2).

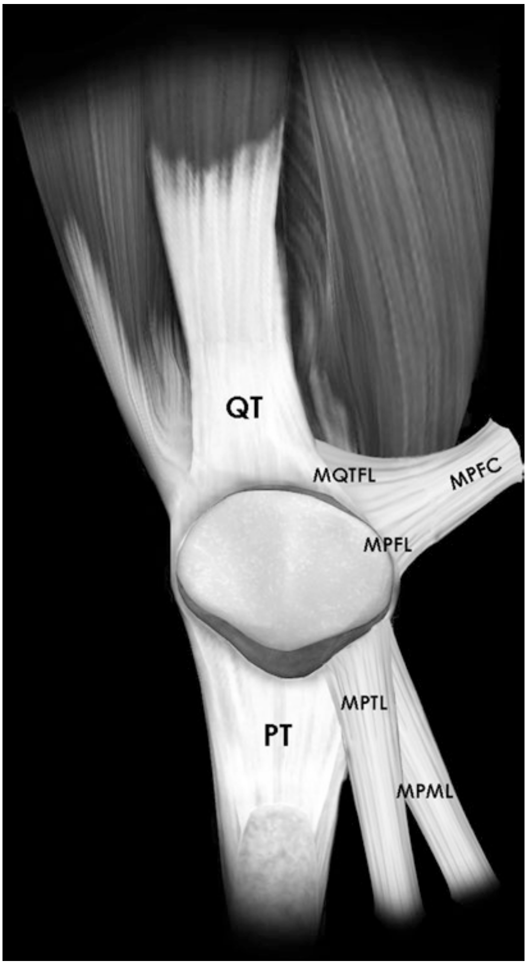


**Fig. 16.1** Illustration of the structures comprising the medial patellar restraints showing the terminology used in this chapter. *MQTFL* medial quadriceps tendon femoral ligament; *MPFL* medial patellofemoral ligament; *MPFC* medial patellofemoral complex; *MPML* medial patellomeniscal ligament; *MPTL* medial patellotibial ligament

The ligament originates on the medial femur as a ribbon-shaped or oblong footprint with a range of 9–17 mm in length [9–15], with a surface area of 26 mm$^2$ [16]. The thickness of the footprint is not well described in most studies but appears to correspond with the thin ligament, which has been reported to be 0.44 ± 0.19 mm [17].

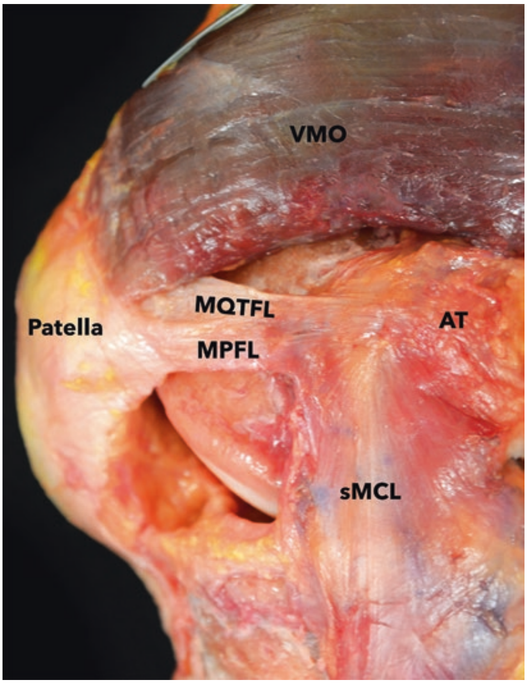


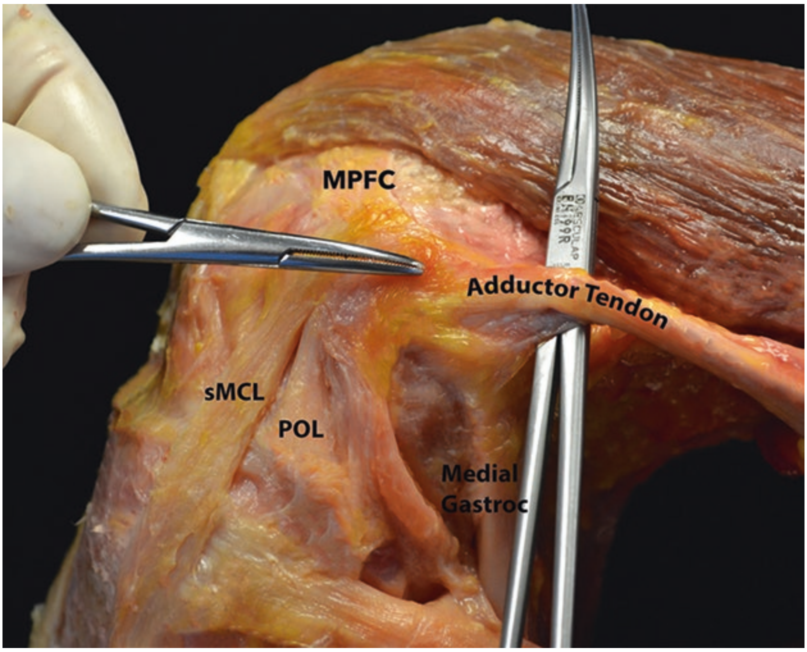
**Fig. 16.2** Anatomic dissection of a right knee demonstrating the attachments of the medial patellofemoral complex demonstrating the course of the medial patellofemoral complex (MPFC) and the more proximal medial quadriceps tendon femoral ligament (MQTFL). *AT* adductor tendon; *sMCL* superficial medial collateral ligament

## 16.4 Femoral Origin

The femoral origin can be identified most commonly in the "saddle" between the medial epicondyle and the adductor tubercle [8, 18–21]. Relative to the adductor tubercle, authors have confirmed its presence as within 1 cm distal to the adductor tubercle [22–25]. Expansions to the medial collateral ligament and/or the adductor tendon have been described as well [10, 26, 27] (Fig. 16.3).

Overall, variability in these reports on the femoral origin of the MPFL exists, and authors have suggested that the dysplastic morphology that exists in symptomatic patients may account for some variability within these patients [28, 29]. This variability has been shown in the pediatric population as well. Shea et al. [30] measured in 15 cadavers aged 7–11 the distance from the MPFL midpoint to the most medial aspect of the distal femoral physis. They found the midpoint to be distal to the physis in 11 specimens and proximal in 4 specimens. For these reasons, authors have recommended individualizing the femoral fixation point based on individual anatomy [31].

**Fig. 16.3** Dissection of a right knee demonstrating the relationship between the adductor tendon (and tubercle) and the medial structures [medial patellofemoral complex (MPFC), superficial medial collateral ligament (sMCL), and posterior oblique ligament (POL)]



The femoral origin on the MPFL has gained considerable attention due to the sensitivity of graft function to malpositioning of the femoral tunnel. Cosgarea and Elias have demonstrated in a computational modeling study that even 5 mm of proximal malpositioning can lead to abnormal graft forces [3]. In a similar modeling study, 5 mm of posterior malpositioning error led to overcorrection of patellar shift and tilt, as evidenced by increases of maximum medial patellofemoral compartment pressures [32]. Stephen et al. [33] demonstrated similar findings in a cadaveric model, in which they reported that femoral tunnels that were positioned proximal to the native origin resulted in significant increases in medial patellofemoral compartment pressures and increased medial patellar tilt with knee flexion, while distal malpositioning of the tunnels resulted in similarly increased pressures and tilt with knee flexion.

Despite an understanding of medial anatomy, the intraoperative identification of the appropriate femoral tunnel site may not always be easily achieved. Servien et al. [29] reported on 29 MPFL reconstruction with radiographic analysis of femoral tunnel positioning at 1 year and found that 20 (69%) were considered to be in good position, while 5 (17.5%) were considered to be too proximal, and 5 (17.5%) were too anterior and/or proximal. The authors reported that the anatomical landmarks of the medial epicondyle and adductor tubercle may be difficult to locate and that the use of anatomical landmarks alone may not be effective. Redfern et al. [34] also noted that intraoperative identification of the anatomic landmarks may be complicated by the presence of tissue injury or scar formation after the injury itself.

Because of this, the use of intraoperative fluoroscopy can be helpful in identifying the optimal location for femoral tunnel placement. Schottle [35] identified the MPFL origin on eight cadaveric knees and described the mean radiographic correlation to this point on lateral views. They described this point as 1.3 mm anterior to the posterior cortical line, 2.5 mm distal to the proximal origin of the posterior medial femoral condyle, and proximal to Blumensaat's line.

Ziegler et al. [36] demonstrated in a cadaveric study that the native origin of the MPFL was a mean of 4.1 mm from the point described by Schottle, and furthermore that MPFL tunnel malposition exceeded 5 mm with only 2.5 degrees of malrotation on lateral radiographs. 5 degrees of malrotation in the anterior-posterior direction corresponded to a malposition of 7.5 mm, whereas 5 degrees of posterior-anterior rotation lead to a difference of 9.2 mm. With 5 degrees cephalad malrotation, this led to 8.1 mm difference.

Stephen et al. [37] also described the native MPFL origin on lateral radiographs and reported its position relative to the size of the femur. They noted that if the anterior-posterior dimension was 100%, the origin is 40% from the posterior surface and 60% from the anterior surface, as well as 50% from the distal condylar surface. The authors emphasized that fixed measurements do not account for size variability in knees and recommended the use of percentages to approximate the MPFL origin based on the individual's size.

## 16.5 Anterior Attachment

The MPFC has a broad attachment on the patella and the quadriceps tendon, which has been described to range from 14 to 39 mm [5, 7–9, 11, 18, 21, 22, 26, 38]. Early anatomical descriptions of the patellar attachment included extensions of fibers proximal to the patella [23]. Smirk noted that in 48% of cases, there were attachments to the quadriceps tendon and that in 20% of cases, "almost the entire ligament extended proximal to the patella" [10, 23]. However, for many years, the primary fibers were described to attach to the superomedial patella for purposes of reconstruction. More recently, the proximal portion of the MPFL has been highlighted, leading to the multiple options for terminology as described above.

While graft function after MPFL reconstruction has been shown to be less sensitive to patellar position than femoral tunnel position [37], fixation on the patella, particularly as it relates to large or multiple tunnels or those traversing the entire width of the patella, has been associated with the catastrophic complication of patella fracture [2, 39].

Anatomical studies of the MPFL had primarily utilized an outside-in exposure to identify the MPFL fibers deep to the distal border of the VMO. In 2013, Mochizuki et al. introduced and described a new approach to expose the MPFL, by exposing the ligament from the articular surface and removing the synovium. This allows for direct visualization of the ligament's attachments to the VMO aponeurosis, as well as the broad attachment to the patella and the vastus intermedius (Fig. 16.4). In this study, the authors noted attachments to the vastus intermedius in all cases [7]. Another study utilizing the same technique described extension to the quadriceps in 7 out of 20 cases [8]. Tanaka [5] demonstrated the variability of the attachment site of this ligament in a series of 28 cadaveric knee dissections, in which one knee had 100% of fibers attaching to the patella, while another had 100% of fibers attaching to the quadriceps tendon. Overall, a mean of 57% ± 20% were found to attach to the patella, with the remaining fibers attaching to the quadriceps tendon.

Kang [9] described this broad attachment as two separate bundles within one ligament with a common origin. The authors utilized the term "inferior-straight bundle" to describe the fibers attaching to the medial border of the patella and the "superior-oblique bundle" as the fibers attaching to the quadriceps tendon. The authors reported the differential functions of these fibers in having static and dynamic roles in patellar stabilization.

Given the broad attachment of the ligament to the extensor mechanism, some authors have aimed to identify the midpoint of its insertion, in order to guide graft placement in single-bundle reconstruction of the proximal stabilizers. Tanaka et al. [6] determined by analyzing digital images of 31 cadaveric knee dissections that the midpoint of this complex was 2.3% ± 15.8% of the patellar articular length distal to the superior pole. The authors also identified a reproducible anatomic reference point at the junction of the medial quadriceps tendon and the superior articular border of the patella, where the MPFC midpoint was found at or proximal to this point in all knees.

Radiographically, the midpoint of the MPFL has been described to be 27% ± 10% from the upper end of the patella [17]. Based on the increased understanding of the proximal attachment site of the MPFC, a recent reanalysis of the radiographic correlate to the midpoint was determined to be 19% of the articular surface from the

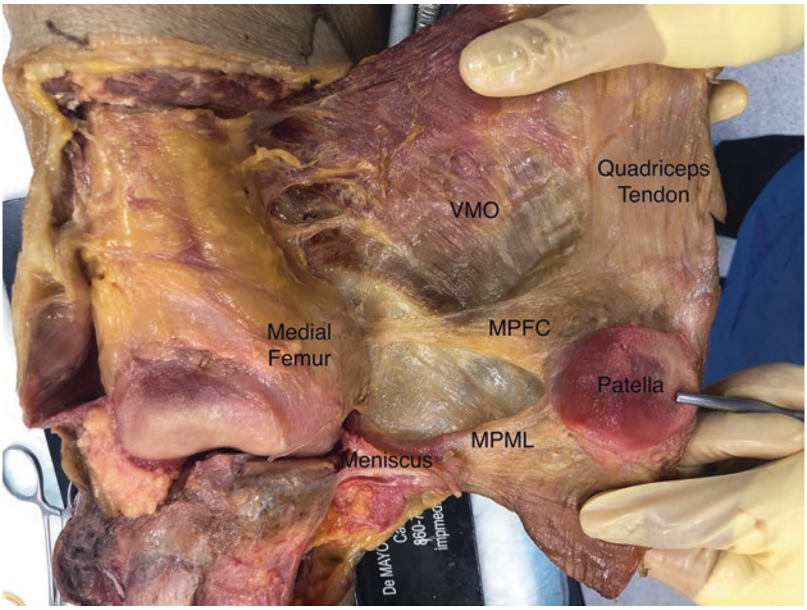


**Fig. 16.4** Articular-sided view of the medial knee allows for direct visualization of the MPFC fibers extending from the medial femur to the quadriceps tendon and patella, with adherence to the vastus medialis obliquus aponeurosis. *VMO* vastus medialis obliquus; *MPFC* medial patellofemoral complex; *MPML* medial patellomeniscal ligament

superior pole [40]. The authors reported that the use of this point can indicate the anatomic point at the junction of the medial quadriceps tendon and the articular surface of the patella, which can be used to localize graft position as a tunnel on the patella or to confirm that the insertion on the quadriceps tendon is appropriately distal.

Fulkerson and Edgar [4] described a technique to reconstruct the MQTFL by suturing the graft onto the quadriceps tendon at its insertion site on the patella, which they noted had the benefit of avoiding patellar tunnels and the subsequent risk of fracture. They reported on a small series of 17 patients with minimum 1 year follow-up, with no recurrence of instability.

The wide attachment of the MPFC fibers has several implications for reconstruction procedures. The length of the most proximal and most distal fibers has been shown to have a length difference of 2–7 mm [5, 9], indicating varying isometry between the most proximal and distal fibers. Furthermore, the differential role static versus dynamic roles of the patellar and quadriceps tendon attachments have been discussed and require further study. A recent reconstruction technique described by Spang et al. [41] aimed to recreate the wide attachment of the ligament with double-bundle fixation on both the quadriceps tendon and patella. The authors reported improved functional scores at 2-year follow-up and a 77% return to sport rate at 5.8 ± 3.9 months. In contrast, other authors have described the use of a single bundle, flat, and wide graft using quadriceps tendon autograft [42, 43], to recreate the appearance and function of the proximal stabilizers. Given the evolving understanding of the anatomy of the proximal medial patellar restraints, further biomechanical studies are needed to understand the optimal technique for reconstruction.

## 16.6 Distal Medial Patellar Restraints

Although the vast majority of the literature on medial patellar restraints focuses on the MPFL [10, 21, 38, 44, 45], recent evidence [21] suggests that the distal restraints including the MPTL and MPML have an important role in active terminal extension of the knee [46] and they directly counteract quadriceps contraction and restrict lateral patellar translation, patellar tilt, and patellar rotation at higher degrees of knee flexion [21]. Nonetheless, the role of the trochlea in patella stabilization in deep flexion is a well-recognized factor that prevents lateral patellar motion; therefore further understanding of the distal complex is required, specifically in non-dysplastic patients where they could potentially aid in avoiding patellar tilt/rotation. The contribution of these secondary stabilizers varies among studies, ranging from 0 to 24% for the MPTL and from 8 to 38% for the MPML [13]. Of note, imaging studies suggested that the MPTL is torn in most primary lateral patella dislocations [22], which highlights the potential clinical importance of the distal, medial-sided ligaments that attach to the patella. Furthermore, there are reports of symptomatic knee dysfunction with isolated MPML injury [47]. In this study, patients complained of anterior knee pain and instability that worsened during terminal extension. Additionally, after a failed trial of conservative measures and rehabilitation, the patients underwent repair of the MPML with good clinical outcomes.

The distal medial patellar restraints originate on the medial aspect of the distal patella and include the MPTL and MPML [2–5, 7–14, 16, 23, 27, 33, 36–39, 48–60] (Fig. 16.5). The distal medial patellar complex attaches through a common insertion (MPTL and MPML), over an area of 27.4 $mm^2$ [16]. The center of the patellar attachment is in close proximity to the patellar tendon (3.5 mm medial and 3.5 mm proximal to the medial border of the patellar tendon attachment). Hinckel et al. [12] reported that there could exist variability of the attachment on the patella (common attachment and individual attachments of the MPTL and MPML), with five of the nine knees in their study having a combined MPML and MPTL on the patella, whereas the MPML was proximal in three and distal in one. They noted that in two cases, the MPML extended also to the tibia, indicating that the MPML and MPTL may have some interrelated

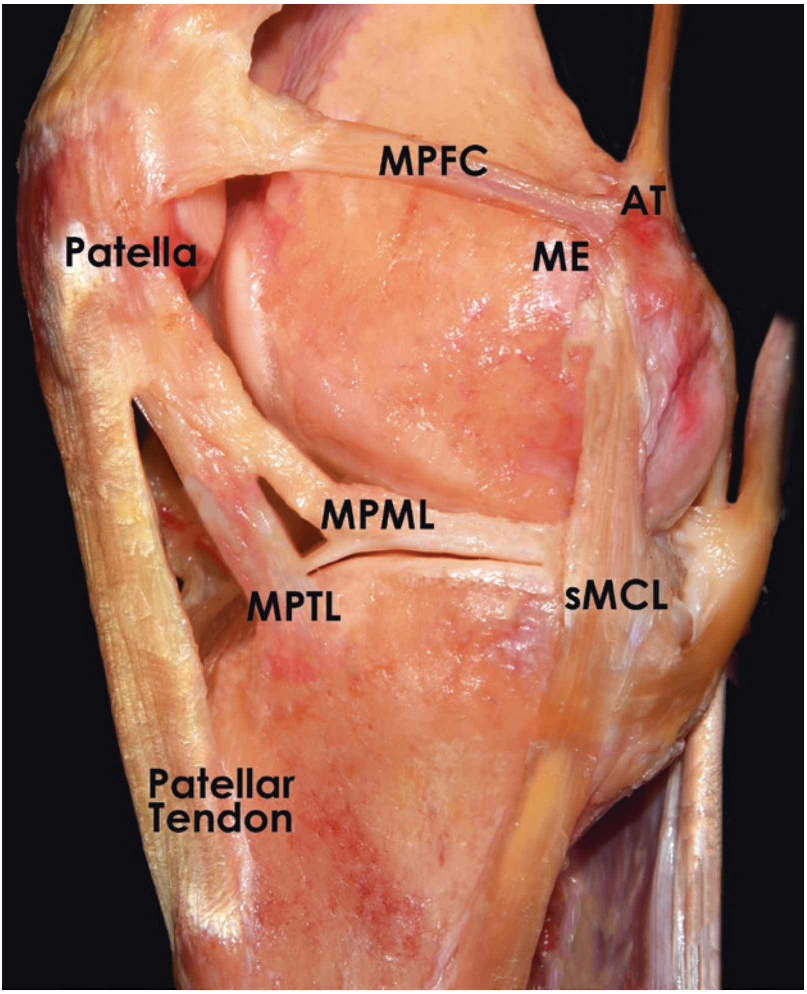


**Fig. 16.5** Anatomic dissection of a right knee demonstrating the attachments of the medial patellar restrains. The relationship of the medial patellar ligament's attachment sites to other medial knee structures can also be appreciated. The arrows indicate the direct and indirect arms of the semimembranosus. *MPFC* medial patellofemoral complex; *MPTL* medial patellotibial ligament; *MPML* medial patellomeniscal ligament; *AT* adductor tendon; *MGT* medial gastrocnemius tendon; *ME* medial epicondyle; *SM* semimembranosus; *sMCL* superficial medial collateral ligament; *MM* medial meniscus; *PT* patellar tendon

functions. From its proximal attachment, there is consensus that both ligaments run deep to the patellar tendon and superficial to the knee joint capsule. The MPTL extends medially and the MPML laterally, with orientations relative to the patellar tendon being 8.3° and 22.7°, respectively [61].

Besides being relatively small structures, the MPML and MPTL can be identified on MRI. Similar to the abovementioned anatomical descriptions, Thawait et al. [62] described the MPML within layer III as a hypointense taut band. Dirim et al. [63] described its course in a more comprehensive manner, stating that the MPML extended from the medial margin of the inferior pole of the patella obliquely and inferiorly and attached to the anterior horn of the medial meniscus and coronary ligament on MR images of all specimens. Additionally, the MPTL was identified as a very thin structure within layer III, distal to the tibial plateau level. This ligament was attached to the medial aspect of the tibia immediately below the joint line. Interestingly, its patellar attachment was not only described at the lower part of the patella but also to the proximal aspect of the patellar tendon.

Outcomes of combined MPFL and MPTL reconstruction are limited in the literature; however, good overall outcomes with low complications rates were achieved in the majority of the studies [46, 64–66]. Described techniques in the literature are based (with modifications) on the technique described by Galeazzi in 1922 [semitendinosus (ST) patellar tenodesis (mimicking an

MPTL reconstruction)]. Reported techniques utilize ST or gracilis (G) autografts, preserving their tibial insertion (simulating the MPTL tibial insertion).

### 16.6.1 MPTL

The MPTL was first described by Terry in 1989, who observed a condensation of the medial retinaculum that originated inferiorly and medially in the patella and inserted 1.5 cm distal from the joint line into the anteromedial tibia [67]. The MPTL is the thinner and most medial of the medial patellar ligaments that attaches 15 mm distal from the joint line on the anteromedial tibia [12, 67]. Extensive analysis of the tibial bony anatomy [16] allowed for the identification of a bony prominence in this area, termed the medial tibial tubercle, on which the MPTL is reported to consistently insert. The MPTL dimensions have been reported with a wide range of values, 35–50 mm long and 4–22 mm wide according to different authors, which highlights the challenges of the identification and proper dissection of this structure [12–14, 21, 38]. These fibers are more vertically oriented than the MPML and course in a more superficial plane [16, 48]. Radiographic analysis has also been previously performed and becomes an important consideration when reconstructing these structures. On the anteroposterior (AP) radiographs, the center of the tibial insertion of the MPTL was found to be 5 mm distal to the tibiofemoral joint line. On the lateral radiographs, the center of the tibial insertion of the MPTL was 9.3 mm distal to the tibial slope line.

Biomechanical data suggested that the MPFL and MPTL had similar mean stiffness and failure loads. The authors suggested that the MPTL might therefore also have an important functional role for medial patellar stabilization [68]. Although being described as the thinner component of the distal medial patellar stabilizers, the mean failure load of the MPTL was higher than the MPML (147 N vs 105 N). In contrast, another biomechanical study[11] found lower biomechanical strength of the MPTL, probably due to the increased mean age (67.4 years versus 56.4 years) of their specimens (MPTL had a lower force energy at maximal tensile strength of 85.5 N).

A systematic review by Baumann and Cols [69] identified 19 articles detailing the clinical outcomes of 403 knees. Several surgical procedures were described including hamstrings tenodesis, medial transfer of the medial patellar tendon, and the reconstruction of the MPTL in association with the MPFL. When pooling outcomes from these studies, good to excellent outcomes were achieved in more than 75% of the patients, and the redislocation rate was less than 10%, with or without the association of the MPFL (with the exception of one study that reported a high failure rate of 82%) [70]. Recently, Hestroni et al. [71] reported on combined MPFL and MPTL reconstruction in 16 patients (20 knees) with a minimum follow-up of 2 years. The authors concluded that significant improvement in subjective knee function can be achieved with minimal risks. They reported that associated factors of improved outcomes included higher preoperative knee scores and activity levels, decreased Beighton scores, and male sex. However, they also warned that preinjury activity levels are not consistently restored.

### 16.6.2 MPML

The MPML is a round, cord-like ligament superficial and adherent to the medial capsule. It is thought to contribute more to patellar stability than the MPTL, with forces accounting for 22% of the total restraint against lateral patellar translation [10, 14]. It can be identified in layer 3, within the deep capsular layer [16, 48]. It is 20–40 mm long and 3–10 mm wide [13, 14, 21, 38].

The MPML has a narrow origin of 3–5 mm on the inferomedial patella, at a point described as 5.7 mm proximal to the distal border of the patella [12, 27, 48]. It has a “close relation to the infrapatellar fat pad” [27] and a wide attachment to the anterior horn of the medial meniscus. Hinckel et al. [12] noted that this meniscal attachment was variable. In seven of nine cases, the MPML attached to the anterior horn, whereas in two cases, it attached to the area between the anterior horn and body. Others have reported attachments distal to the coronary ligament on the tibia. The MPML is thought to have more horizontally oriented fibers than the MPTL, and it courses more posterior than the MPTL [14, 16, 38].

## 16.7 Conclusion

The medial patellar stabilizers consist of the proximal restraints, which include the MPFL and MQTFL, and the distal restraints, including the MPTL and MPML. While MPFL reconstruction has been popularized due to its role as the primary static stabilizer, the contributions of these other ligamentous restraints are becoming increasingly recognized for their roles in stabilizing the patella. As anatomic accuracy is critical in avoiding surgical complications, the evolving understanding of medial patellar anatomy continues to influence our reconstructive techniques in the treatment of patellofemoral instability.

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# 17

# Medial Retinaculum Reefing for Patellar Instability

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## 17.1 Introduction

Patellofemoral instability occurs commonly in young and active patients. A spectrum of clinical entities can be identified according to the Dejour classification [1]: objective patellar instability (OPI), potential patellar instability (PPI), and the painful patellar syndrome (PPS). OPI is defined by the observation of at least one patellar dislocation in patients with one or more predisposing factors for patellar instability: excessive patellar height, excessive tibial tuberosity-trochlear groove distance (TT-TG), vastus medialis obliquus (VMO) dysplasia, and trochlear dysplasia. The PPS group is characterized by anterior knee pain, subjective instability, and popping, with no objective evidence of patellar dislocation or predisposing factors. The PPI group is a mix of the previous two groups: symptoms like the painful patellar group with one or more predisposing factors but without evidence of patellar dislocation. This condition may evolve to a true objective instability. Generally, non-operative treatment is suggested as the first-line therapy in patients with PPI and PPS conditions, whereas surgery is indicated in case of OPI. Sometimes in patients with PPI surgery could be indicated in case of failure of conservative treatment. Several studies investigated the anatomy and biomechanics of the medial stabilizers of the patella [2–4]. The medial retinaculum (MR), formed by fibers of the deep transverse layers, consists of a strong fibrous structure formed by important ligaments: the medial patellofemoral ligament (MPFL), the medial patellotibial ligament (MPTL), and the medial patellomeniscal ligament (MPML). These ligaments offer a medial restraint to lateral patellar dislocation. Some authors [5] investigated the contribution of these structures to the patellar stabilization, proving that the role of passive stabilizers is more important than dynamic ones and this condition is more evident in case of patella alta or patellofemoral dysplasia. In patients with PPI or PPS, conservative treatment remains the first option, in absence of important predisposing factors for patellar instability. In these particular patients, in case of failure of the conservative approach for at least 6 months, medial reefing might be considered.

## 17.2 Materials and Methods

Between 2001 and 2006, 36 medial reefing in 36 patients with PPI or PPS were performed at our institution. Twelve patients were male and 24 female. Right knee was involved in 20 cases and left knee in 16 cases. Mean age at the time of

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surgery was 26.6 years. Surgery was indexed after an unsuccessful conservative treatment. All patients were evaluated both preoperatively and postoperatively through a physical examination and a complete imaging study. This latter consisted of AP and LL weight-bearing X-ray views, the Merchant view (to assess patellar height and trochlear dysplasia), and a CT scan. The CT scan was performed to assess the TT-TG distance and the patellar tilt in static conditions. Finally, Kujala, Fulkerson, Larsen, and Tegner questionnaires were administered to all patients.

## 17.3 Surgical Technique

The procedure can be performed under locoregional anesthesia. Under anesthesia before incision, an accurate knee exam is performed: passive ROM, patellar tilt, and medial/lateral patellar glide are recorded. After that, the tourniquet is inflated, and an arthroscopic look is performed. During this first look, the patellar tracking is evaluated, and chondral damages are investigated and eventually treated. The deep surface of (MR) is then inspected. Three medial sutures are thus percutaneously passed through the MR using a spinal needle. The first needle is positioned into the most distal aspect of the MR, just adjacent to the patella. A No. 1 PDS suture is passed through the needle and then retrieved from a more lateral approach (Fig. 17.1). Other two sutures are then passed proximally at a 1.5 cm distance each other. The more tissue is included into the loop, the greater could be the re-centering effect on the patella (Figs. 17.2 and 17.3). The two edges of each suture are finally retrieved from the posterior access, and the knots are tied at 60°–70° of flexion under arthroscopic control to avoid any hypercorrection. The tourniquet is deflated, and washout is performed. No skin suture is used. Postoperative protocol consists of elastic compressive knee brace in extension for 3 weeks, immediate passive motion from 0° to 50° of flexion, and complete weight-bearing 4 weeks after the surgery. During this time, quadriceps and VMO strengthening are performed.

## 17.4 Results

Twenty patients were available for complete clinical and imaging examination (Fig. 17.4). After a mean of 14 years of FU, the average Kujala score was 90.0 (pre-op 72.9), the Larsen score was 17.0 (pre-op 15.0), the Lysholm score was 90.0

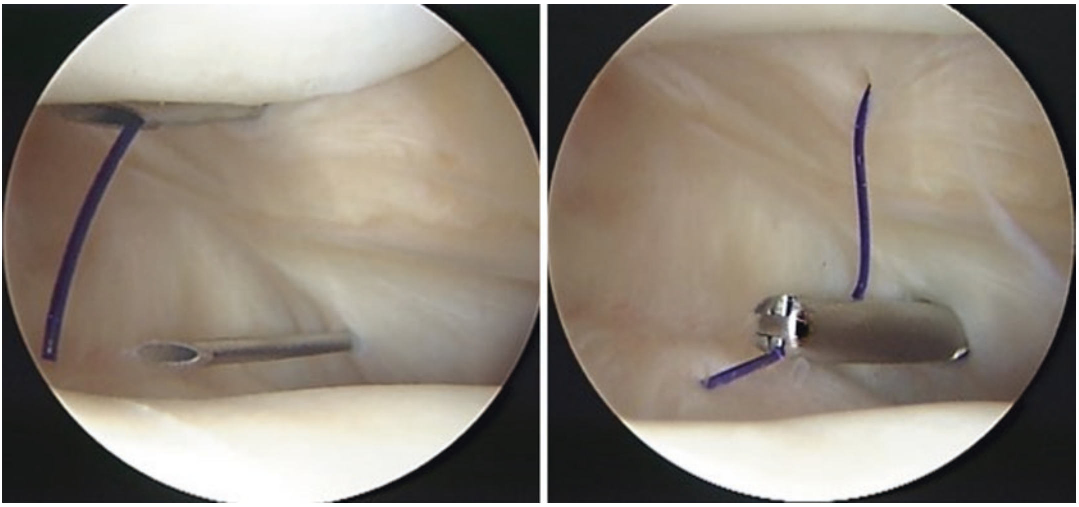

**Fig. 17.1** A N°1 PDS suture is passed percutaneously through a spinal needle at the distal third of the patella and retrieved more posteriorly

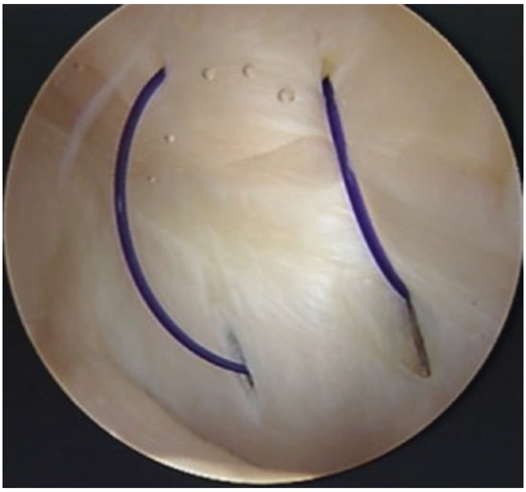

**Fig. 17.2** A second vertical stitch is passed at 1.5 cm distance from the other stitch

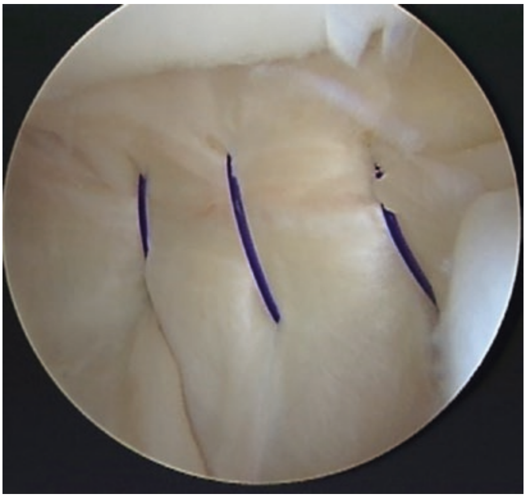

**Fig. 17.3** Three vertical stitches including wider tissue are enough to correct patellar tilt and to obtain patellar recentering

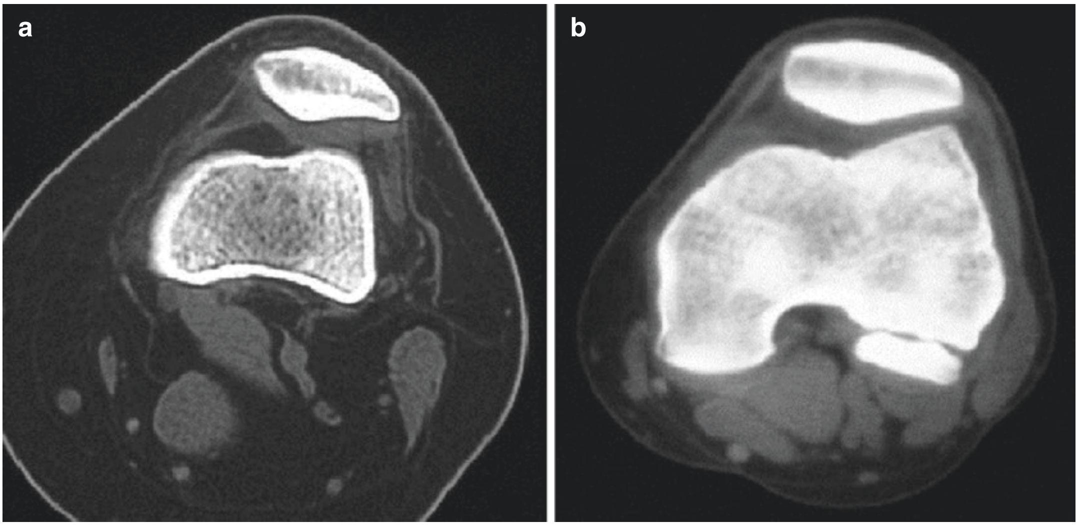

**Fig. 17.4** Pre-op CT scan (**a**) with patellar subluxation in a 16 years old female. Fiftheen-years late post-op CT scan view (**b**)

(pre-op 63.8), and the Fulkerson was 89.0 (pre-op 69.5). No intraoperative complications were observed. No difference in patellar height was observed on postoperative X-rays. Patellar tilt decreased from 12° preoperatively to 8° postoperatively. Twelve patients out of 20 (60%) were very satisfied with their functional result, and 5 (25%) were satisfied, while 3 (15%) were not satisfied with their result.

## 17.5 Discussion

Patellar instability is a complex issue, and several factors may contribute to its development. According to Dejour classification, three groups are identified: the OPI, the PPI, and the PPS. In addition to classic risk factors (increased TT-TG dysplasia, patella alta, trochlear dysplasia, and VMO dysplasia), the role of the medial stabilizers must be also considered. MR with the its structure MPFL, the MPTL, and the MPML strongly contribute to medial patellar stability preventing lateral dislocation [6–9]. It was observed a high incidence of medial structure damage just after the first patellar dislocation, with the MPFL involved in more than 90% [6–10]. Therefore, MPFL reconstruction is always recommended in case of patellar dislocation. It could be performed as an isolated treatment or in association with other procedures to correct any other predisposing factors. Medial reefing could be considered a surgical option in patients with patellofemoral instability without any previous dislocation. Most authors suggest this procedure in case of patellar instability (patellar subluxation or dislocation) that has failed after a period of 3–6 months of conservative treatment [11–13]. Nam et al. reported the results of a mini-open medial reefing associated with lateral release in the treatment of recurrent patellar dislocation showing 91% good or excellent results, with only 4% of patients with recurrent dislocation or subluxation [14]. Schiavone Panni et al., associating the surgical procedure with a specific rehabilitation protocol in a cohort of patients with patellofemoral instability, without patellar dislocation, reported good functional outcomes in 90% of cases after 120 months of follow-up [11]. Miller using this technique in patients with a previous dislocation or subluxation and a failed conservative treatment observed that 96% of patients were satisfied with the result and no recurrent dislocation occurred. Moreover, an improvement in congruence angle, lateral patellar displacement, and lateral patellofemoral angle was reported [15]. Halbrecht described an all-inside arthroscopic medial reefing in patients with patellar dislocation or subluxation. Ninety-three percent of patients showed significant subjective and X-ray improvement without reporting any complications [16]. Coons [17] reported the results of his arthroscopic technique consisting in a thermal medial capsule shrinkage and a lateral release in patients with recurrent instability. He performed this procedure in patients without medial retinacular tenderness or in whom the dislocation occurred at least 6 weeks before the indexed procedure, assuming the complete healing of medial stabilizers in these conditions. The author reported 90% of good or excellent results at 53 months of FU with a 9% of dislocation recurrence.

Anyway, analyzing these studies, two controversial issues can be identified: the degree of knee flexion for knot tying and the postoperative rehabilitation protocol. Nam [14] proposed to tie the knots in full extension. In the postoperative period, the reefing was protected with a knee brace in full extension while allowing weight-bearing as tolerated. At 2–3 weeks gradual passive and active ROM exercises as well as quadriceps strengthening were started [14]. Schiavone Panni tied the knot at 60°–70° of flexion under arthroscopic control to avoid hypercorrection. The postoperative protocol was based on the use of a knee brace in extension for 3 weeks with immediate passive motion from 0° to 50° of flexion and complete weight-bearing 4 weeks after the surgery [11]. Halbrecht [16] did not give any information about the degree of knee flexion; he suggested the brace blocked in full extension. Weight-bearing was immediately allowed. The brace was unlocked after the first week to start ROM exercises (below 90°) and maintained for 3–4 weeks. Miller [15] suggested tying the knots at 20° of flexion. A knee immobilizer was used allowing weight-bearing as tolerated. ROM exercises start at 1 week after the procedure, while strengthening exercises at 4 weeks. Despite the excellent results reported, we still have some concerns. The first one refers to the terminology: the term subluxation is rather unclear. In fact, it could be referred as a subjective sensation of knee instability or an objective abnormal patellar lateral glide. In both cases, it seems a concept difficult to define for both the patient and surgeon. Therefore we still prefer the classification proposed by Dejour [1] in which three precise groups may be easily identified. The second concern is about the indication for medial reefing. We believe that the ideal indication of medial reefing is PPS or PPI with nearly normal predisposing factors. In case of patellar dislocation, the MPFL rupture has to be reconstructed, considering its predominant role as passive medial stabilizer [6, 9, 18]. On the contrary, medial reefing alone does not address this lesion with no restoration of its essential role. Additionally, we believe that the role of a lateral release alone or in association with medial reefing is very limited, and that should be proposed to the (few) patients with persistent patellar tilt after tying the knots of the medial reefing.

## 17.6 Conclusion

The literature evidence led to a great interest for MPFL reconstruction in cases of OPI and for medial reefing in cases of PPI and PPS. Medial reefing represents a safe and reproducible procedure. In our opinion medial reefing should not be performed in case of previous dislocation, because in this case the MPFL is constantly lesioned and reefing alone does not allow to treat it, thus exposing the patient to the risk of dislocation recurrence. Therefore, the use of medial reefing should be limited to the cases of PPI and PPS without important predisposing factors for patellar instability and after the failure of the conservative treatment. The most important finding of this paper is that the results remain almost the same in a very long follow-up (average of 14 years). Probably the reason is that the indications for this procedure are very strict and not frequent. This procedure is then indicated in potential instability and not in patellar dislocation in which it is necessary to reconstruct the primary stabilizers of patella (MPFL).

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# 18

# Medial Patellofemoral Ligament (MPFL) Reconstruction

Andrew P. Hurvitz, Najeeb Khan,
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## 18.1 Introduction

Stability of the patellofemoral joint (PFJ) is multifactorial. Risk of dislocation depends on limb alignment, interaction of the surrounding muscles, osseous architecture of the patella and the trochlea, and integrity of the medial soft tissue constraints of which the medial patellofemoral ligament (MPFL) is the main component [1, 2]. Of the many factors contributing to PFJ stability, the MPFL is the primary ligamentous restraint against lateral patellar displacement, with the MPFL reported to provide between 50% and 60% of the medial soft tissue resistance to lateral dislocation of the patella [3, 4]. Consequently, first-time patellar dislocation often results in injury to the medial retinacular ligaments, including the MPFL, leading to increased lateral patellar mobility. Competency of the MPFL is both necessary and sufficient to restore lateral patellar mobility to a normal range; consequently, surgical treatment should aim for restoration of a functional MPFL.

## 18.2 Anatomy of the MPFL

The MPFL is an extra-articular ligament that lies in layer 2, between the medial retinaculum superficially and the joint capsule on its deep surface. The vastus medialis obliquus (VMO) tendon lies superficially anteriorly and inserts onto the anterior third of the MPFL. The MPFL is approximately 58 mm in length, with a width and thickness of 12 mm and 0.44 mm, respectively, at its midpoint [5]. The MPFL fans out anteriorly, inserting on the proximal two-thirds of the patella with extension of fibers onto the quadriceps tendon, which some authors independently term the medial quadriceps tendon femoral ligament (MQTFL) [6]. The femoral attachment of the MPFL is posterosuperior to the medial femoral epicondyle and just distal to the adductor tubercle with the knee fully extended. The center of the anterior edge of the femoral attachment is located 9.5 mm proximal and 5.0 mm posterior to the center of the medial femoral epicondyle (Fig. 18.1) [5]. Other medial stabilizers of the patella have been identified, namely, the medial patellotibial ligament (MPTL) and medial patellomeniscal ligament (MPML) [4, 6, 7]. While their role in medial restraint is still evolving, they have been shown to contribute to stability at terminal extension and greater degrees of knee flexion [4]. As of this writing, the MPFL still remains the primary soft tissue medial stabilizer of the patella [4, 6].

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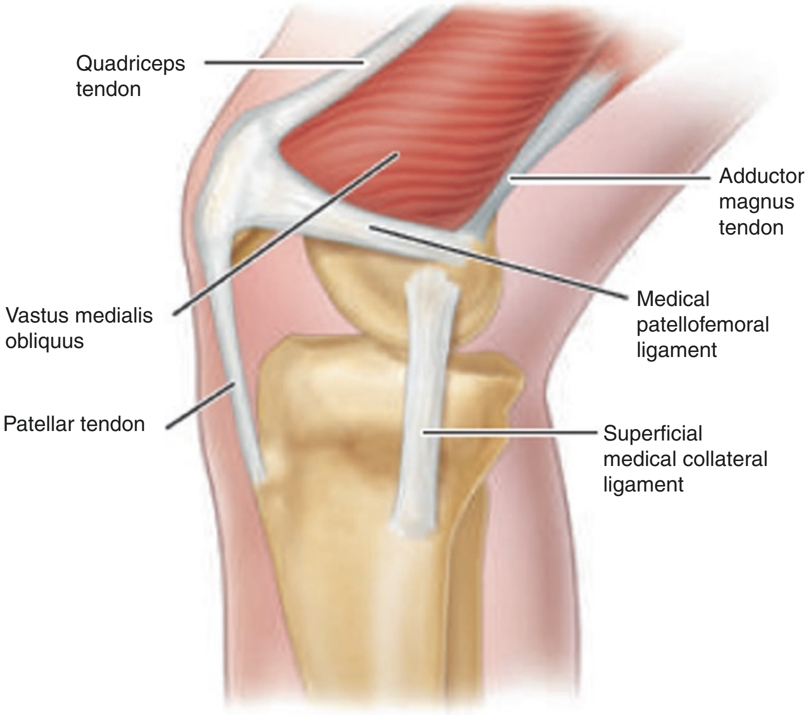

**Fig. 18.1** Schematic diagram of the medial knee. The MPFL arises between the adductor tubercle and medial epicondyle then runs forward just deep to the distal VMO to attach to the superior two-thirds of the medial patellar margin

## 18.3 Natural History

Fithian et al. [8] reported a 17% incidence of redislocation in a cohort of first-time dislocators followed over 2–5 years. Conversely, patients presenting with recurrent patellar instability are much more likely to continue experiencing additional dislocations than patients who present with their first dislocation. The risk of a repeat dislocation in patients presenting with a history of prior patellar dislocation is about 50% over a 2- to 5-year period [8]. The strongest risk factor for recurrent patellar instability is a history of prior patellar subluxation or dislocation [8]. Other risk factors include female gender and younger age (younger than 18 years old) [8, 9].

Lewallen et al. revealed a 62% success rate with nonoperative management of first-time patellar dislocators in the pediatric and adolescent population. Risk factors for recurrent instability included skeletal immaturity and trochlear dysplasia [10].

Balcarek et al. defined a patellar instability severity score incorporating age, bilateral instability, trochlear dysplasia, patella height, TT-TG distance, and patella tilt, with a maximum score of 7. They found that a score of 4 or greater resulted in a nearly fivefold increased risk of recurrent patellar instability within the first 2 years following an initial dislocation [11].

Jaquith et al. determined that trochlear dysplasia, skeletal immaturity, contralateral patellar instability, and a Caton-Deschamps ratio of >1.45 were all significant risk factors for recurrence in young patients with first-time patellar dislocations [12].

More recently, Christensen et al. demonstrated a 36% incidence of ipsilateral patellar dislocation with a 20-year follow-up. Trochlear dysplasia, elevated TT-TG distance, patella alta, age < 18 years at the time of the first dislocation, and female sex were significantly associated with ipsilateral recurrence. Furthermore, trochlear dysplasia, elevated TT-TG distance, patella alta, and age < 18 years at the time of the first dislocation were predictive of a statistically significant decrease in time to recurrence [13].

The association between patellar dislocation and arthritis is evolving. Crosby and Insall [14] reported that degenerative changes were uncommon after patellar dislocation. In a more recent study, however, Sanders et al. revealed that patients who had experienced a patella dislocation had a significantly higher risk of developing arthritis when compared against a control. Specifically, osteochondral injury, recurrent patellar instability, and trochlear dysplasia were associated with arthritis after patellar dislocation [15].

Although the aforementioned studies demonstrate modest rates of recurrence with certain patient characteristics, the authors advise against using this data to support early operative management for first-time patellar dislocators. Rather, the authors find these studies helpful in guiding appropriate discussion and expectations with patients and family.

## 18.4 Patient History and Physical Findings

A closed workshop was undertaken to reach a consensus on the aspects of history, examination, workup, and management [2]. A careful history should include the total number of dislocation events, age at first dislocation, mechanism, whether a reduction was required, and symptomatology between instability episodes.

Elements of the history can influence the treatment plans. A history of contralateral patellar dislocation significantly increases the risk of recurrence. Noncontact and episodic instability is more likely to require surgical stabilization than a first-time traumatic dislocation. Locking or catching symptoms may correlate with osteochondral loose bodies, which may require removal for small fragments and fixation for larger fragments. A history of prior surgery can greatly influence our understanding of the pathology. In particular, a history of prior lateral release can reduce resistance to lateral displacement and increase the risk of iatrogenic medial dislocations.

Physical examination should include the following:

- Standing alignment and gait.
- Patellar translation. Evaluate for amount of displacement and endpoint. Increased laxity is signified by more than two quadrants of translation, 10 mm or more of lateral translation, or the absence of an endpoint.
- Apprehension test at 30 degrees of knee flexion. Inability to fully translate the patella laterally because of patient guarding.
- J sign. The patella abruptly translates laterally as the knee is fully extended, moving in an upside-down “J” pattern.
- Patellar facet palpation. Tenderness may indicate an osteochondral or avulsion injury.
- Effusion. A tense effusion or hemarthrosis on aspiration after acute dislocation should raise suspicion for an osteochondral fracture. Magnetic resonance imaging (MRI) or arthroscopy should be considered.
- Rotational alignment (including femoral anteversion), tibial torsion, and hyperpronation.
- Hypermobility (Beighton score).
- General examination of the knee including range of motion, meniscal and ligamentous evaluation, and strength testing.
- Compare all with the contralateral knee/leg.

## 18.5 Imaging

AP, lateral, and merchant radiographs are used to confirm patellar position, the presence of osteochondral fracture, and patellofemoral relationships. An osteochondral fracture that is visible on conventional radiographs is likely a significant lesion that should be followed by an MRI and possible surgical excision or fixation. The lateral view with the knee flexed 30° can help determine patella height. A Caton-Deschamps ratio of more than 1.2 implies patella alta, which predisposes to lateral instability as the medial patellar facet is not captured by the lateral femoral condyle in early flexion. A perfect lateral view (with the posterior condyles aligned) can evaluate trochlear dysplasia. The "crossing" sign, where the curve of the trochlear floor crosses the anterior contour of the lateral femoral condyle, represents flattening of the trochlear groove and absence of trochlear constraint against patellar displacement [16]. Trochlear prominence (also called a trochlear "boss," "bump," or "eminence") is represented by the distance between the most anterior point of the trochlear floor and a line drawn along the distal 10 cm of the anterior femoral cortex. The degree of trochlear prominence on a lateral radiograph correlates with severity of dysplasia. Although MPFL reconstruction does not directly address trochlear dysplasia, it is helpful to understand the forces contributing to patellar instability when performing the procedure.

We advocate for an MRI examination for all recurrent dislocators and, at times, for first-time dislocators with the primary objective of assessing for osteochondral or chondral injuries that are amenable to surgical intervention. The secondary objective of the MRI is to ascertain the location of the MPFL lesion, which has possible prognostic value. An MPFL avulsion at the femoral attachment in primary traumatic patellar dislocations predicts subsequent patellar instability [17, 18]. Axial MRI images are also used to determine tibial tubercle-trochlear groove (TT-TG) or tibial tubercle-posterior cruciate ligament (TT-PCL) offset, which may influence whether to perform a tibial tubercle osteotomy in addition to the MPFL reconstruction.

## 18.6 Indications and Contraindications

MPFL reconstruction is best used to treat recurrent lateral patellar instability due to excessive laxity of medial retinacular patellar stabilizers. The ideal candidate has minimal pain between episodes of patellar instability and seeks medical care primarily to address the occasional dislocation or subluxation. It is imperative that the surgeon documents MPFL laxity by physical examination, stress radiography, and/or arthrometry before committing to an MPFL reconstruction. Frequently, an examination under anesthesia is necessary to confirm laxity of the medial retinacular structures due to patient apprehension and discomfort in the clinic.

First-time dislocators are better served with a nonoperative approach, barring any associated unstable osteochondral injuries. Several level 1 and 2 prospective studies have shown no benefit of operative compared with nonoperative treatment after initial patellar dislocation [9, 19–21].

MPFL reconstruction should not be done for isolated patellofemoral pain. There is little in the literature to support this approach, and there is ample evidence that stabilization of the patella is unlikely to result in reduced pain even if performed successfully [22]. Pre-existing arthritis is also a relative contraindication to MPFL reconstruction because the operation will increase patellar constraint and may actually increase loading on damaged patellofemoral surfaces.

As noted in prior sections, patients with patellar instability should also be examined for other clinical and radiographic findings that include malrotation and/or malalignment of the lower extremity, patella alta, trochlear dysplasia, increased tibial tubercle to trochlear groove (TT-TG) distance, and generalized ligamentous laxity. Failure to address some or all of these features may decrease operative success after an isolated MPFL reconstruction [23].

## 18.7 Preoperative Preparation

It is important to have a thorough preoperative discussion with the patient regarding the potential risks, benefits, goals, and postoperative course. Patients should have realistic expectations regarding their postoperative pain and the need for active participation in their healing, rehabilitation, and return to sport. Passively receiving surgery and then awaiting a desired result can lead to failure of the graft and delay, if not preclude, return to activities of daily living and sports.

Patients should make appropriate activity restriction arrangements with their place of employment. Return to sedentary work is usually possible 5–7 days after surgery, once pain is controlled and narcotic usage is minimal. Family and/or friends should also be recruited to help during the postoperative period. Driving can be considered once off narcotics, weight bearing is comfortable, and distal neuromuscular control allows for normalized reaction time. Ideally, the operative knee should be clinically "quiet" prior to surgery.

## 18.8 Graft Options

Although it is the author's preference to use semitendinosus autograft for MPFL reconstruction, allograft and synthetic options have shown acceptable results. McNeilan et al. recently published a meta-analysis demonstrating that autograft is not superior to allograft or synthetic grafts for isolated reconstruction of the MPFL and rates of recurrent instability are generally low. They conclude that while caution should be used in making definitive recommendations secondary to the small number of allograft and synthetic studies, selection of graft type based on surgeon preference, comfort, and prior experience remains appropriate [24].

## 18.9 Surgical Objectives

In performing MPFL reconstruction at our institution, we have two specific surgical objectives. First, we re-establish the natural checkrein against lateral patellar motion [19]. This checkrein, which is a palpable, firm stop when the patella is passively displaced in a lateral direction, represents the tethering of the patella by the intact MPFL. Our second objective is to re-establish normal limits of passive lateral patellar motion. Prior studies have shown that the patella is free to glide laterally up to 9 mm, at which time the MPFL will engage in order to prevent further displacement [25, 26].

## 18.10 Authors' Preferred Technique

### 18.10.1 Setup

This procedure typically requires 1 h of operative time. We use general anesthesia with the option for regional anesthesia, a tourniquet, and an adjustable knee support that can be used to adjust knee flexion during the procedure. The setup includes a fluoroscopy machine, standard arthroscopy tower and instruments, instruments for hamstring harvesting, a drill set (usually 3.2, 3.5, and 4.5 mm drills are sufficient), small curved curettes, and a curved suture passing device such as a doubled #18 or #20 gauge wire. One length of #5 braided polyester suture will be used as a pullout suture, and several lengths of #0 absorbable suture material on a taper needle are used for whipstitching the free graft ends and the looped end of the graft. The patient is positioned supine on the table. It is often helpful to use an image intensifier to confirm femoral tunnel placement, and this should be taken into consideration when positioning the patient.

### 18.10.2 EUA

Patellar mobility is evaluated. If the patella cannot be dislocated, the diagnosis must be questioned. The diagnosis of patellar instability requires that there be a soft endpoint or no endpoint to lateral patellar displacement either at full knee extension or at 30 degrees of flexion and that the patella be mobile enough to displace it more than 10 mm laterally from the centered position with the knee at 30 degrees flexion.

### 18.10.3 Arthroscopy

May be used in select cases but not mandated per our technique unless loose body, osteochondral lesion, or other intraarticular pathology is suspected.

### 18.10.4 Semitendinosus Tendon Harvest

The skin incisions are shown in Fig. 18.2. Semitendinosus (semi-T) harvest follows the technique described by Brown et al. [27]. The graft is prepared and sized on the back table. The doubled, or looped, graft should be at least 120 mm after trimming (240 mm total graft length). Due to this length requirement, the gracilis is generally not sufficient for this technique. The graft is sized to 240–260 mm and then folded in half. A pullout suture of #5 polyester or similar material is placed through the loop to be used for pulling the doubled graft into the blind femoral tunnel. A baseball stitch 20 mm in length is placed in the looped end of the graft, similar to technique for ACL and other looped tendon graft applications. The two free ends are appropriately tapered and baseball-stitched with absorbable suture in preparation for their passage through the two patellar tunnels (Fig. 18.3). The looped end will be anchored in the blind femoral tunnel (Fig. 18.4), while the two free ends will pass through individual tunnels in the medial patella (Fig. 18.5). In this way the two ends “fan out” slightly on the patella to reproduce the normal insertion of the MPFL onto the patella (Fig. 18.6).

**Fig. 18.2** Right knee. Incisions shown with the two patellar tunnels exposed. Medial femoral epicondyle and adductor tubercle are marked

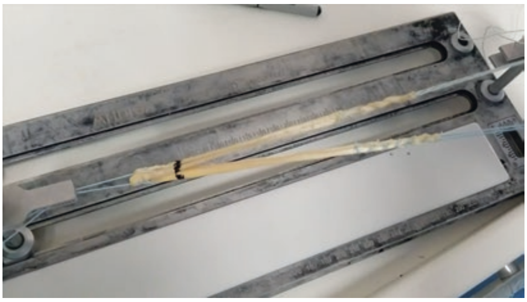

**Fig. 18.3** A prepared graft consisting of a doubled semitendinosis autograft that is whip-stitched for 20 mm with #0 absorbable suture at the doubled end and on each individual limb

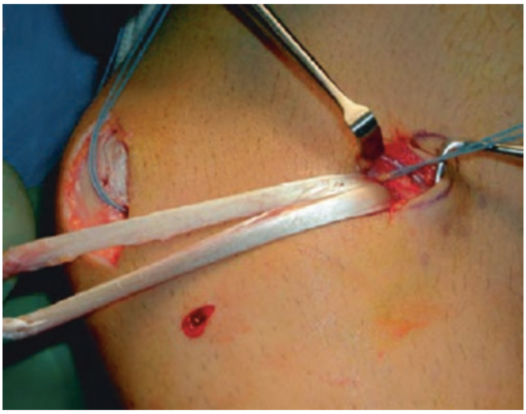

**Fig. 18.4** Graft fixed in femur, isometry stitch now used to pass the graft through retinaculum

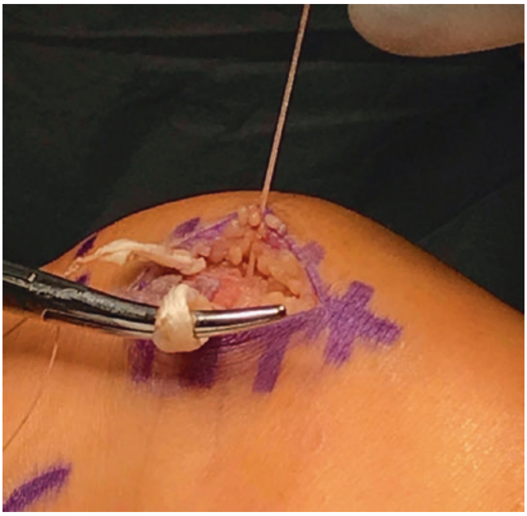

**Fig. 18.5** Passing graft arms through patellar tunnels

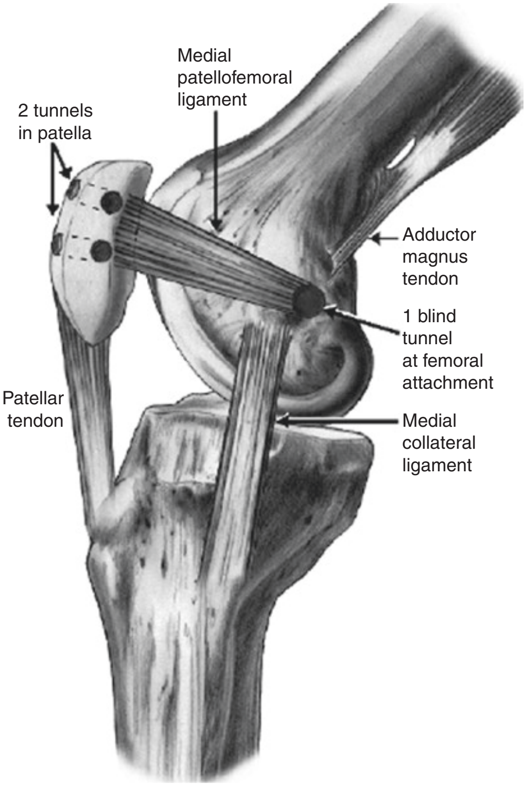

**Fig. 18.6** Anteromedial schematic view of a right knee. The MPFL is shown, along with the MCL and adductor magnus tendon attachments to the medial femur. The MPFL originates from a ridge connecting the adductor tubercle and epicondyle. The MPFL fans out as it runs anteriorly and laterally, to insert on the proximal two thirds of the medial patellar border. The MPFL is reconstructed by making one blind tunnel at the femoral attachment, and two tunnels on the patella which enter at the medial articular margin and exit on the anterior (ventral) patellar surface

### 18.10.5 Patellar Exposure and Patellar Tunnels

Make an incision the length of the patella, centered over the junction of the medial and middle thirds of the patella (in line with the medial border of the expansion of the patellar tendon at the distal patellar pole). The medial quarter, or 8–10 mm, of the patella is exposed by subperiosteal dissection with a scalpel. The dissection extends medially around the patella, through layers 1 and 2 (longitudinal retinaculum and MPFL), stopping after the transverse fibers of the native MPFL have been cut (Fig. 18.7). At this level, only layer 3 (the capsular layer) remains intact. Placing the graft between layers 2 and 3 is preferred for two reasons. First, the vastus medialis inserts superficially into the anterior 3 cm of the MPFL [28], so blind dissection superficial to the MPFL may cause unnecessary trauma to this insertion. Second, if the graft is placed deep to the MPFL, the native MPFL may be repaired to the graft during wound closure. The graft should not be deeper than layer 3 so that it remains extra-articular in order to avoid graft abrasion and to allow healing in the extra-articular environment. Using a long curved clamp, develop the selected soft tissue interval all the way to the medial femoral epicondyle. Fig. 18.8 shows an axial schematic view of the graft in place. The looped end is fixed in the femur with an absorbable screw. The graft passes between the capsular layer (layer 3) and the native MPFL (layer 2). Each free arm enters the medial border of the patella, exits anteriorly, and is sutured to itself with a #2 braided nonabsorbable suture. Use a 3.2-mm drill to create the two tunnels in the proximal 2/3 of patella (Fig. 18.4). Care should be taken to avoid inserting the graft distal to the native insertion of the MPFL, in order to avoid constraint of the distal patellar pole. Enter with the drill bit at the medial patellar border of the patella, adjacent to the articular margin, to a depth of 8–10 mm. Leave a distance between the two tunnels, and keep them parallel to avoid fracturing the bone bridge between them. Then create exit holes on the anterior surface of the patella, at the lateral edge of

**Fig. 18.7** Image of the transverse fibers of the MPFL after subperiosteal dissection through layers 1 and 2 in a cadaveric specimen

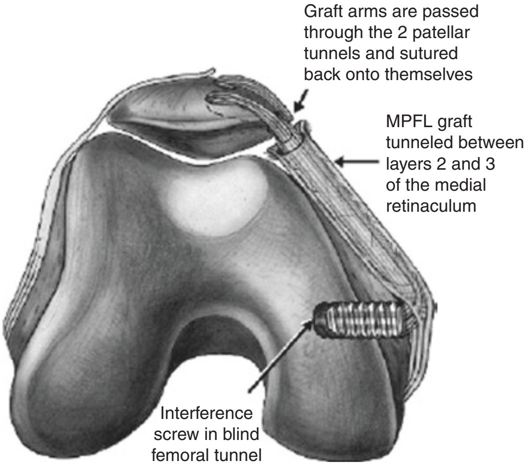

**Fig. 18.8** Axial schematic view of a right knee, from below. The MPFL graft is shown, fixed in the blind femoral tunnel with an interference screw. The graft passes outside the capsular layer (layer 3) so that it remains extra-articular. The two free arms of the graft are passed into the patellar tunnels from the medial patellar border, exiting anteriorly, and the free ends are sewn back onto themselves with two figure-eight stitches of #2 nonabsorbable suture. All slack is removed from the graft before suturing, but the grafts should be under no tension when the patella is centered in the groove. Excess graft length is removed after tension and patellar mobility are confirmed to be satisfactory

the original retinacular dissection about 8 mm from the medial patellar border. A small angled curette is used to complete the connection between the anterior and medial holes to create the tunnels. Note that the semitendinosus is sometimes thicker than 3.2 mm diameter. If the grafts are too thick for the tunnel, you may enlarge the drill holes slightly up to 4.5 mm as needed. The graft ends may also be tapered to accommodate the desired diameter. The baseball stitches in the two free ends of the graft should not thicken the ends of the graft, and the sutures need not be stout: they should be just strong enough to pull the ends through the patellar tunnels. The excess length on the free ends will be discarded after final fixation, so permanent suture is not needed. We recommend using a graft sizer to ensure easy passage of the graft prior to any fixation.

### 18.10.6 Femoral Exposure and Femoral Tunnel

Make an incision just anterior to the palpable ridge connecting the femoral epicondyle to the adductor tubercle (Fig. 18.1). If this landmark is difficult to palpate, flex the knee slightly. This maneuver shifts the medial hamstrings posteriorly away from the epicondyle so that the epicondyle is easier to locate. If obesity still makes exact localization of medial landmarks difficult, make a small incision and use digital palpation through the wound, and redirect the incision as needed. When the epicondyle and adductor tubercle have been localized with confidence, reintroduce the long curved clamp into the retinacular interval from the patellar end of the medial retinaculum, and with the tip of the clamp overlying the ridge between the epicondyle and tubercle, incise layers 1 and 2 of the retinaculum using a scalpel blade. Place the tip of a Beath guide pin at a point midway between the adductor tubercle and the epicondyle. Pass the pin toward the broad lateral (nonarticular) surface of femur. Pass a loop of #5 braided polyethylene suture around the pin, through the dissected retinacular layers and then through the patellar tunnels. Hold the suture in place with a clamp on the superficial surface of the patella, and range the knee to evaluate length change behavior (isometry). This suture is then left in the retinacular tunnel for later graft passing. Placement of the femoral attachment is one of the most critical steps in the operation. It is often helpful to use fluoroscopy to confirm the placement of the Beath pin just proximal to the junction of Blumensaat's line and the posterior femoral cortex, along a line extending down from the posterior cortex of the femoral shaft [29]. The native MPFL originates on the ridge between the adductor tubercle and the medial femoral epicondyle (Fig. 18.6). Once the femoral pin site is accepted, ream a blind tunnel into the femur of the size needed to receive the doubled end of the graft, rarely more than 7 mm. Ream to a depth of at least 25 mm or to a depth appropriate for the choice of fixation. If bone is of poor quality, ream small and dilate up to desired tunnel diameter. Fixation to femur may be achieved reliably with a 20-mm absorbable interference screw. The graft makes a turn of approximately 110° exiting the femoral tunnel (Fig. 18.8) and does not require extreme measures in order to be fixed securely. The looped isometry suture, which was removed from the Beath needle prior to reaming but which was not removed from the retinaculum, can be used to lead the free graft ends through the space created within the retinaculum. After delivering the free ends through the retinaculum, pass the free graft arms individually through their respective patellar tunnels using doubled #18 or #20 gauge stainless steel wire or other curved suture passer such as a #5 Mayo needle. The graft arms enter the medial patellar border and exit anteriorly (Fig. 18.8). The surgeon takes all slack out of the graft, but there should be no tension on the graft with the patella centered in the groove. Each free end of the graft is doubled back and sutured to itself just medial to the patella using two figure-eight mattress sutures of #2 nonabsorbable suture on a tapered needle (Fig. 18.9a, b). Patellar mobility is checked after the first suture is placed. There should be a good endpoint, or checkrein, with the knee in full extension and at 30 degrees of knee flexion, knee range of motion should be full, and lateral patellar displacement from the centered position at 30 degrees of flexion should be between 7 mm and 9 mm. Sharply remove excess graft, and then close the retinaculum over the graft. Close wounds in standard fashion. No drains are used.

### 18.10.7 Postoperative Care

Perioperative pain management is generally easier than that for other knee reconstructive surgery, possibly because the synovium is not disturbed. Outpatient management is the norm, usually with oral narcotics after discharge home. Immediate motion is critical. Our protocol closely mirrors the ACL reconstruction protocol. A drop lock or knee extension brace is used for up to 6 weeks to prevent falls. Immediate full weight bearing is allowed, and gait training may be progressed as soon as good muscular control has been re-established. Physical therapy is used to restore quadriceps control and range of motion as quickly as possible. If the patient does not have at least 90 degrees of flexion by 6 weeks, the intensity of the therapy program must be increased; manipulation under anesthesia (MUA) may be needed between 9 and 12 weeks postoperatively if stiffness does not resolve with therapy alone.

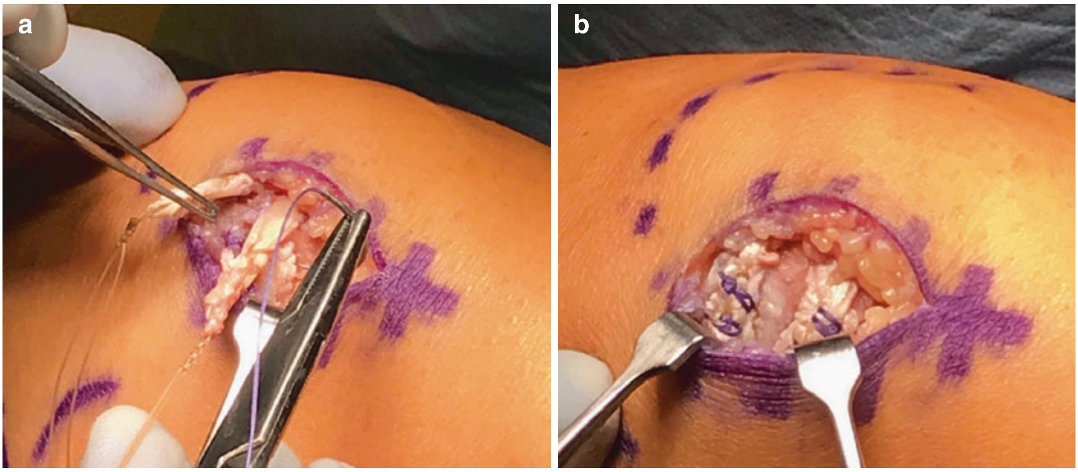

**Fig. 18.9** (**a**) Limbs of graft have been passed through the patellar tunnels and doubled back on themselves in preparation for final suture fixation. (**b**) Final suture fixation with excess graft cut short

## 18.11 Results and Complications

In a series of 92 knees treated with MPFL reconstruction, Fithian and Gupta [16] reported only 7 failures or reoperations (7.6%) and only 1 case of frank patellar redislocation (1.1%). Most of the reoperations were for stiffness and were treated successfully with MUA.

Kita et al. [30] published a 4.5% redislocation rate following MPFL reconstruction with a mean follow-up of 3.2 years. Failures were found to occur predominantly in those patients with high-grade trochlear dysplasia and elevated TT-TG distance [30].

A systematic review by Schneider et al. involving 14 studies was performed to determine outcomes after isolated medial patellofemoral ligament (MPFL) reconstruction. Of the 510 knees in this study, the pooled total risk of recurrent instability was only 1.2% with a mean follow-up of 36.8 months [31].

Despite the documented success of MPFL reconstruction, potential complications surrounding this procedure should not be discounted. Parikh et al. reported a 16.2% complication rate in their cohort of 179 knees. Major complications included recurrent lateral instability (eight patients), knee stiffness with flexion deficits (eight patients), patella fractures (six patients), and patellofemoral arthrosis/pain (five patients). Eighteen of the 38 complications (47%) were secondary to technical factors the authors considered preventable [32].

Shah et al. revealed a 26.1% complication rate in their meta-analysis of 629 knees [33]. Adverse events in this study, in decreasing order of frequency, included recurrent instability, loss of knee flexion, painful hardware, and patella fracture. Twenty-six patients underwent reoperation. Risks for redislocation included poor surgical technique as well as predisposing factors, such as patella alta, trochlear dysplasia, lateralization of the tibial tuberosity, or overall malalignment of the limb.

Overall, MPFL reconstruction is a reliable and effective procedure for the treatment of patellar instability when performed for the appropriate indications. However, the procedure does require technical skill and attention to detail because the complication profile is not trivial.

### 18.11.1 Pearls/Pitfalls

**Indications:**

- Perform an examination under anesthesia to confirm excessive lateral patellar mobility.
- Consider arthroscopy to stage articular cartilage lesions and rule out pre-existing arthritis, a contraindication to MPFL reconstruction.

**Graft Preparation:**

- The semitendinosus graft is prepared such that the limbs will fit and easily pass through the patellar tunnels. The terminal 20 mm of each limb is tapered and then secured with an 0 vicryl suture. We recommend using a graft sizer to confirm easy passage of the limbs prior to fixation into the femur.

**Patellar Tunnel Preparation:**

- For each tunnel, the medial to lateral portion is drilled first. A mark is placed on the drill bit to ensure that the bit is not drilled more than 1-cm deep. A free drill bit is kept in the medial to lateral tunnel, and the anterior to posterior tunnel is drilled toward the tip of the medial/lateral tunnel. The drill bit is used only to broach the anterior cortex.
- Straight and curved curettes are used to prepare the tunnel edges and to clear the 90-degree tunnel of any bony debris. This attention to detail will make graft passage much smoother.
- Breakage of patellar bone bridge may occur during preparation of the two patellar tunnels or during passage of an oversized graft through a tight patellar tunnel. If this occurs, then drill a second exit hole more laterally on the anterior patellar surface.
- Avoid drilling a tunnel across the patella, as this carries a risk of patellar fracture [33].

**Femoral Tunnel Placement:**

- Multiple studies have demonstrated that small errors in femoral tunnel position can substantially increase the force and pressure applied to the medial facet of the patella [34, 35].
- The position of the femoral socket is critical to determining graft behavior during knee function. If the graft is too tight, the patella will be captured and lead to patellofemoral arthrosis. A femoral tunnel that is placed too proximally will cause the graft to tighten in flexion, and the converse is true with a graft that is placed too distally. A femoral tunnel that is too anterior may capture the knee in all flexion angles.
- Adjust the tunnel placement to ensure appropriate graft behavior during flexion and extension, recreating isometry.
- Check for accurate tunnel placement using fluoroscopy. We find it more accurate to use the large image intensifier with an attendant technician rather than the mini c-arm. Koenen et al. published a study that revealed intraoperative fluoroscopy leads to more accurate tunnel positioning than gross anatomic landmarks [36].

**Setting MPFL Graft Length Without Tension:**

- Center the patella in the patellar groove, and ensure that the MPFL graft is lax throughout an ROM, becoming tight only when the patella is displaced laterally from its centered position.
- The patella should enter the trochlea from the lateral side as the knee is flexed.
- The graft should not be tensioned as it serves as a checkrein. It should be set to a length that allows no excessive slack and no tension. An overtightened graft results in excessive medial constraint.
- If the patella enters the trochlea from the medial side as the knee is flexed or if there is less than 5 mm of lateral patellar glide with gentle manual force at 30° of knee flexion, then the graft is overtensioned. The sutures should be removed and the graft length set again.

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# 19

# Medial Patellotibial Ligament: Clinical Application and Surgical Reconstruction for Patellar Stabilization

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## 19.1 Introduction

To better understand the patellofemoral joint's complex anatomy, and perhaps improve surgical outcomes, focus on the distal medial patellar restraints (medial patellotibial ligament (MPTL) and patellomeniscal ligament (MPML)) has been recently scrutinized for their (potential) role in injury and surgery [3, 9, 11–13, 19, 24, 25, 32, 34, 36, 38]. The anatomy of the medial patellar restraints has been previously detailed [24, 35], and described in a companion chapter in this publication. Therefore, it is not included in this chapter.

## 19.2 Biomechanics

A brief review of biomechanics of the distal medial patellar restraints is helpful in understanding possible surgical applications.

The first biomechanical study of medial sided patellar ligaments was by Conlan et al. [6], followed by Desio et al. [7], Hautamaa et al. [16], and Panagiotopoulos et al. [31]. These investigations involved in vitro cutting studies, looking at the difference in lateral patellar translation before and after cutting various medial sided structures. All used a straight lateral force with the knee near full extension. There was agreement by all authors that the MPFL was the primary stabilizer to lateral translation, contributing to 50–60% of restraint. The contribution of the secondary stabilizers was variable, ranging from 0 to 24% (MPTL) and 8 to 38% (MPML), and combined MPTL and MPML 20 to 40% [6, 7, 16, 31].

In 2012, Philippot et al. evaluated patellar tracking in a cadaver model from full extension to 90° of flexion [32]. Acquisitions were made sequentially on a healthy knee, with individual sectioning of the MPFL, and MPTL along with the MPML. The contributions of the MPTL and MPML as a unit against lateral translation increased from 26% in extension to 46% at 90° of flexion. Additionally, the MPTL and MPML at 90° of flexion were responsible for 72% of patellar tilt and 92% of patellar rotation. Isolated contribution of the MPTL and MPML was not evaluated. A comparative description found on these studies is summarized in Table 19.1.

Translating these in vitro studies to the clinical arena, one can surmise that the distal medial patellar complex augments the proximal medial patellar

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**Table 19.1** Restraint to patellar lateral translation and influence on patellar tracking of the medial ligament stabilizers

| Study, year, number of knees, degree of knee flexion | MPFL | MPTL | MPML |
|---|---|---|---|
| Conlan [15], 1993, 25 knees, slight flexion | 53% ± 15 (23–80%) | 5% ± 5.9 (0–21%) | 22% ± 9.5 (8–38%) |
| Desio et al. [17], 1998, 9 knees, 20° of flexion | 60% ± 13 (41–80%) | 3% ± 3 (1–9%) | 13% ± 10 (4–35%) |
| Hautamaa et al. [30], 1998, 17 knees, 30° of flexion | 50–55% | 0–20% | |
| Panagiotopoulos et al. [55], 2006, 8 knees, 20–30° of flexion | 50% | 13% | 24% |
| Philippot et al. [56], 2012, 9 knees, 0–90° of flexion | Patellar translation:<br>Extension: 72%<br>Flexion: 53% | Patellar translation:<br>Extension: 26%<br>Flexion: 46% | |

Adapted from Hinckel et al. [20]

*MPFL* medial patellofemoral ligament, *MPTL* medial patellotibial ligament, *MPML* medial patellomeniscal ligament

complex in resisting lateral patellar translation in early flexion (Fig. 19.1), and is the main soft-tissue restraint in deeper flexion, where typically the bony walls of a normal trochlear are the main constraint against lateral patellar translation. Trochlea dysplasia can change those contributions, and is possible that in that setting, ligamentous stability becomes more important in the whole arc of motion, including in deeper flexion when the patella should be engaged in the trochlea.

## 19.3 Clinical

Clinical correlation for MPTL is derived from articles discussing patella motion parameters associated with injury site [11], imaging correlation with injury [37], and reconstruction of the MPTL ligaments [1, 5, 8, 9, 12, 13, 15, 17, 22, 28, 34, 38].

Isolated clinical reports of MPTL reconstructions and their indications have been previously published. In 1922 Galeazzi [10] described a semitendinosus (ST)-patellar tenodesis for treating patellar instability and, in 1998, Rillmann et al. [33] described a transfer of the medial portion of the patellar tendon (PT) when persistent objective instability despite conservative treatment of at least 6 months was present. Both techniques were analogous to MPTL reconstruction. Myers et al. [28] perform MPTL reconstruction in skeletally mature patients with Q < 25° or skel-

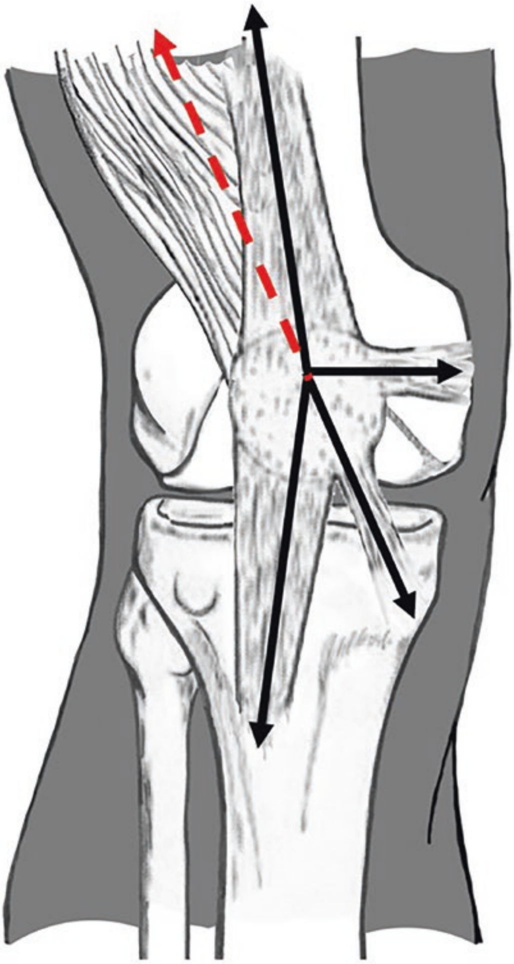

**Fig. 19.1** Schematic depiction of the vectors of the medial patellotibial ligament counteracting on the vectors of quadriceps and vastus lateralis in full extension (red dashed line represents the resultant vector) (Copyright © Regents of the University of Minnesota. All rights reserved)

etally immature patients with any Q value. Marcacci et al. [27] showed MPTL reconstruction to be a good option in case of objective habitual patella dislocation or chronic lateral instability; Zaffagnini et al. [38] (2014) used the same technique in case of dislocation, traumatic or atraumatic, with no resolution of symptoms after at least 3 months of conservative treatment. These reported clinical series were without a MPFL reconstruction.

Hinckel et al. [17] proposed augmenting MPFL reconstruction with MPTL reconstruction if the patient presents lateral patellar subluxation in extension, dislocation in flexion, and knee hyperextension associated with generalized ligamentous hyperlaxity, and in select cases of skeletal immaturity when a bony procedure is precluded.

Individual techniques and their results have been summarized in a recent systematic review and were found to have favorable results for the outcome of no recurrence of lateral patellar dislocations [3].

Current use of MPTL reconstructions can be summarized as:

1. Reconstruction of MPTL as the sole soft-tissue restraint for stabilization of the patella against lateral translation. This is most often accomplished by use of the semitendinosus (ST) or utilization of the medial third of the patella tendon.
   (a) Semitendinosus: From a historical perspective, Galeazzi in 1922 first described a patellar tenodesis (mimicking the MPTL) for treating lateral patellar instability [10]; some authors use a modification of the Galeazzi ST-patellar tenodesis by passing the tendon through a tunnel drilled in the patella (Fig. 19.2) [1, 2, 13, 26]. Most frequent indication was recurrent lateral patellar dislocation in children, with recurrent rate of continued patellar instability ranging from 0% to 82% [1, 2, 13, 15, 26].
   (b) The medial transfer of the medial third of the patellar tendon, which can be likened to a reconstruction of the MPTL.

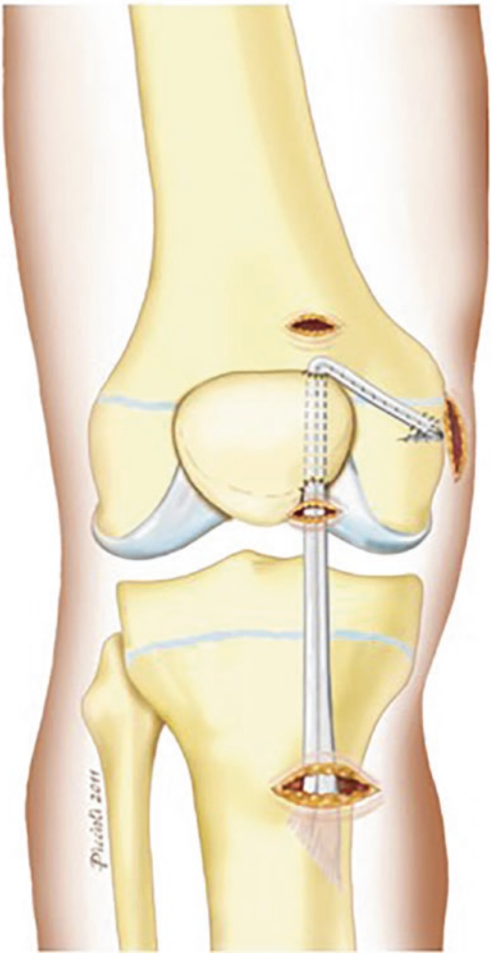

**Fig. 19.2** Reconstruction of the medial patellofemoral ligament and the medial patellotibial ligament with the hamstrings (with permission, Giordano M, Falciglia F, Aulisa AG, Guzzanti V (2012) Patellar dislocation in skeletally immature patients: semitendinosus and gracilis augmentation for combined medial patellofemoral and medial patellotibial ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 20:1594–1598)

   Many of the published series were before the widespread use of MPFL reconstruction as a surgical option.

2. For patellar stabilization in obligate patellar dislocation in flexion (habitual lateral patellar dislocation): To date, there is only one report in the literature to include a type of MPTL reconstruction (Galeazzi procedure), in addition to lateral release, proximal "tube" realignment of the patella, and transfer of the patellar tendon, into the surgical procedure for habit-

ual patella dislocation. This was a small cohort of children <7 years old with severe generalized laxity and trochlear dysplasia [22]. No patients had recurrence of patellar instability.

3. More recently, outcomes of combined MPFL and MPTL reconstruction have been reported by six authors for treatment of recurrent lateral patellar dislocations with varying techniques:
    (a) Use semitendinosus (ST) or gracilis (G) autografts, maintaining their tibial insertion (simulating the MPTL tibial insertion) with extension of the graft proximally to reconstruct the MPFL [5, 9, 12, 34] (Fig. 19.2).
    (b) Independent fixation of the auto- or allografts on the patella, one for the MPTL reconstruction and one for the MPFL reconstruction: This allows better positioning of the two grafts on the patella, as well as independent graft tension at different degrees of knee flexion [34].
    (c) Use of quadriceps (MPFL) and patellar tendon (MPTL) grafts, with retained patella attachments with independent fixation on the femur (MPFL) and tibia (MPTL) (Fig. 19.3) [17, 18]: This also allows better positioning of the two grafts on the patella, as well as independent graft tension at different degrees of knee flexion.

## 19.4 Surgical Considerations

Based on anatomy and biomechanical studies, the distal medial patellar complex (MPTL and MPML) is important in two knee motions: active terminal extension of the knee, where it directly counteracts quadriceps contraction [9, 11] (Fig. 19.1), and deeper knee flexion, when the ligament complex tightens increasing its contribution to lateral patella translation [32] (Fig. 19.4). It also improves kinematics of patellar tilt and rotation throughout range of motion, especially in deep knee flexion [32]. The alignment of the MPML in both extension and flexion helps resist the superior/lateral pull of the patella.

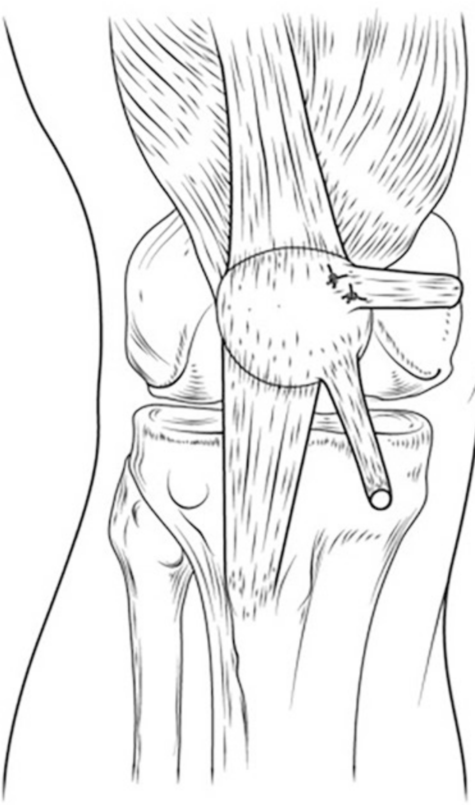

**Fig. 19.3** Reconstruction of the medial patellofemoral ligament with a medial slip of the quadriceps tendon, and of the medial patellotibial ligament with the medial third of the patellar tendon (with permission, Hinckel BB, Gobbi RG, Bonadio MB, Demange MK, Pécora JR, Camanho GL. Reconstrução do ligamento patelofemoral medial com tendão quadricipital combinada com patelotibial medial com tendão patelar: experiência inicial. Revista Brasileira de Ortopedia. 2016;51(1):75–82)

Current reconstructions of the distal medial restraints are called MPTL reconstructions due to its osseous tibial fixation, but its orientation to the patella tendon may be better directed to mimic the direction of the MPML. Recent anatomic studies suggest that our current use of MPTL reconstruction is more in line with the MPML (approx. 25° angled from the patella tendon) than the MPTL (approx. 10° angled from the patella tendon) [23, 24]. Knowledge to date suggests that MPTL and MPML have similar biomechanical roles and act complementarily. The MPML is more horizontal (oblique)

**Fig. 19.4** Schematic depiction of the vectors of the MPTL counteracting on the vectors of quadriceps and vastus lateralis at 90° of knee flexion. Note the near-parallel nature of the MPFL and the MPTL (*MPFL* medial patellofemoral ligament, *MPTL* medial patellotibial ligament) (Copyright © Regents of the University of Minnesota. All rights reserved)

opposing more lateral translation while the MPTL is more vertical, opposing more proximal translation (Fig. 19.5 a, b) [19, 24]. The MPTL and MPML shared a common patellar insertion in many cases [19, 23, 24]. The MPTL inserts on a bony ridge, which was located 5.0 mm distal to the joint line measured on radiographs [24]. By anatomic dissection, the insertion distance from the joint line is 13–14 mm [19, 23].

Biomechanical studies show the MPML and MPTL to have similar strength, with the MPTL being stiffer than the MPML and the MPFL [19, 25].

Recognizing the tibia insertion site is especially important in children, as the graft should ideally be fixed just above the tibial physis, on the proximal epiphysis of the tibia, so tension can be maintained during growth; this is an agreement with MPFL surgical principles of fixation distal to the femoral growth plate [29].

The closer the tibial insertion is to the joint line the more parallel the MPML is to the MPFL in deeper knee flexion, increasing its contribution to the restraint of lateral translation [20]. Future studies are needed to assess the ideal orientation of a distal patellar pulley to help resist proximal-lateral patellar dislocation, and may differ depending on its use (to help augment the patella near extension or in deep flexion).

For MPTL reconstructions that maintain the hamstrings of tibial insertion, one must note that it is not an anatomic reconstruction, with hamstring insertion more distal and more midline than the MPTL. The tibial insertion of the hamstrings is 41 ± 6.6 mm distal from the tibial plateau and 6.88 ± 1 mm medial to the patellar tendon [14], while the MPTL's bony attachment is 5.0 to 10 mm distal to the joint line (measured on radiographs) [19, 24].

Clinical and biomechanical data suggests that the MPTL should be tightened at 90$^o$, which makes it easier to achieve similar tension to the patellar tendon. This permits its normal behavior during flexion, without overtensioning and overloading the patellofemoral joint in extension, which could lead to pain and/or elongation [4].

Graft choices vary depending on the technique chosen. As with MPFL reconstruction, surgical principles are more important than graft choice.

The advantages and disadvantages of the different graft choices and techniques are itemized in Table 19.2.

Due to the heterogeneity among case series, lack of comparative studies, and emerging focused anatomic and biomechanical studies, the indications for the clinical use in patellar stabilization do not allow for authoritative statements on the indication for their role, either isolated or combined, in patellar surgical stabilization. Based on the reviewed literature and on the authors' collective experience, suggested indica-

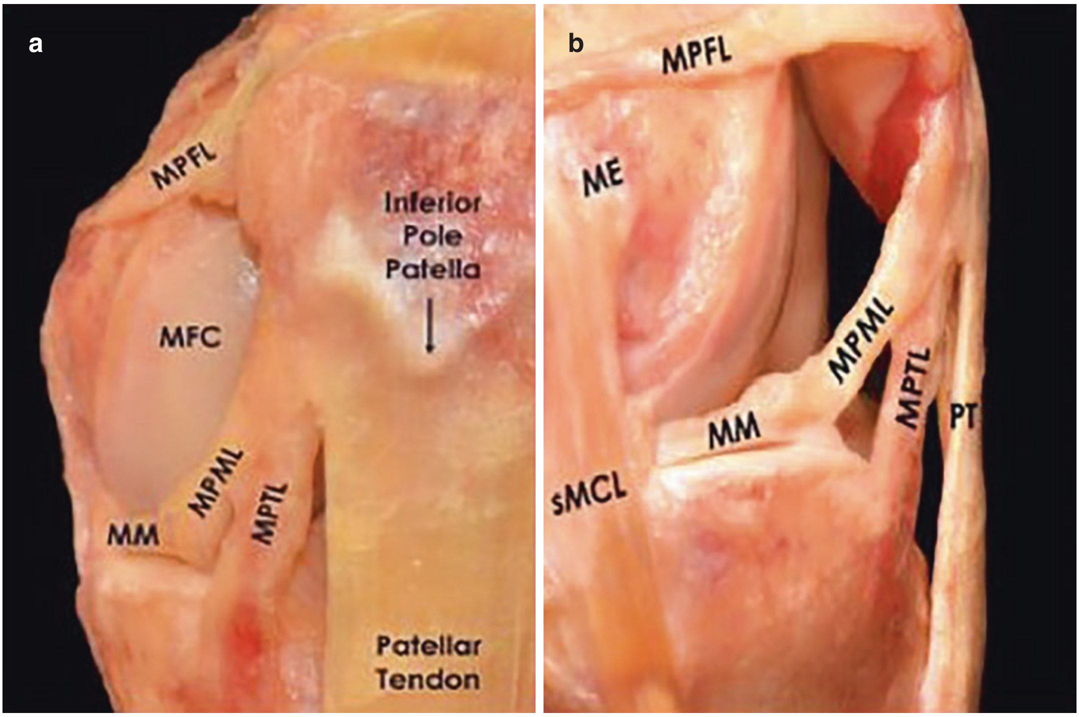

**Fig. 19.5** A cadaveric dissection from the frontal (**a**) and lateral (**b**) views depicting the MPML more horizontal (oblique) opposing more lateral translation while the MPTL is more vertical, opposing more proximal translation (Kruckeberg BM, Chahla J, Moatshe G, et al. Quantitative and Qualitative Analysis of the Medial Patellar Ligaments: An Anatomic and Radiographic Study. Am J Sports Med. 2018;46(1):153–162)

tions for this considering adding MPTL to MPFL procedure are as follows:

- Active extension subluxation (defined by patellar lateral translation during active quadriceps contraction with the knee fully extended): MPTL is combined with MPFL to restrain lateral and superolateral translation, specifically opposing proximal and lateral quadriceps muscle pull [11].
- Flexion instability (obligatory patellar dislocation and lateral glide during flexion): To contribute restraint to lateral translation in higher knee flexion angles, as the MPTL tightens with increasing knee flexion [22, 27, 32].
- Children with excessive number anatomic risk factors (trochlear dysplasia, large quadriceps vector, and patella alta): To add additional support during extension and flexion when there is the risk of complications when doing bony procedures due to open physes [12, 22, 28, 30].
- Knee hyperextension associated with generalized laxity: To add additional support to functional patella alta and large quadriceps vector during hyperextension [21, 22].

### 19.4.1 Surgical Technique of MPTL Reconstruction Using Medial Third of PT

The patient is positioned supine on the table, with an applied tourniquet. A midline incision with the knee in 20° of flexion is performed exposing the entire length of the extensor apparatus (Fig. 19.6). It is possible to perform a lateral release when a tight lateral retinaculum is observed with abnormal patellar tilt. Also, a dissection of the vastus medialis oblique is performed, with the aim of making a clearer evaluation of the patellar tracking in the trochlear groove and checking the status of articular cartilage. Then the tibial tuberosity is isolated and the medial third of the patellar tendon is detached from its distal insertion (Fig. 19.7) and prepared with nonabsorbable suture (Fig. 19.8). The graft is medialized and put

**Table 19.2** Advantages and disadvantages of the different graft choices and techniques

| | Pro | Con |
|---|---|---|
| Attached hamstring | Tissue readily available<br>No tibial fixation needed | Nonanatomic<br>Stiffer than anatomic structures |
| Medial 1/3 patella tendon (PT) | No patella fixation needed<br>Relatively anatomic on the patella and can be anatomic in the tibia<br>Shares biomechanical properties with PT<br>Allows for independent fixation of grafts on patella and tibia | Compromises anatomic PT<br>Nonanatomic on the tibia when the bone block is preserved |
| Free hamstring grafts (ST/G) | Can be anatomic on the patella and tibia<br>Allows for independent fixation of grafts on patella and tibia<br>More (potential) elongation<br>Requires fixation at the patella and tibia | Stiffer than anatomic structures<br>Requires fixation on the tibia and patella |

*PT* patellar tendon, *ST/G* semitendinosus/gracilis

**Fig. 19.6** A midline incision with the knee in 20° of flexion is performed exposing the entire length of the extensor apparatus

**Fig. 19.7** The medial third of the patellar tendon is detached from its distal insertion

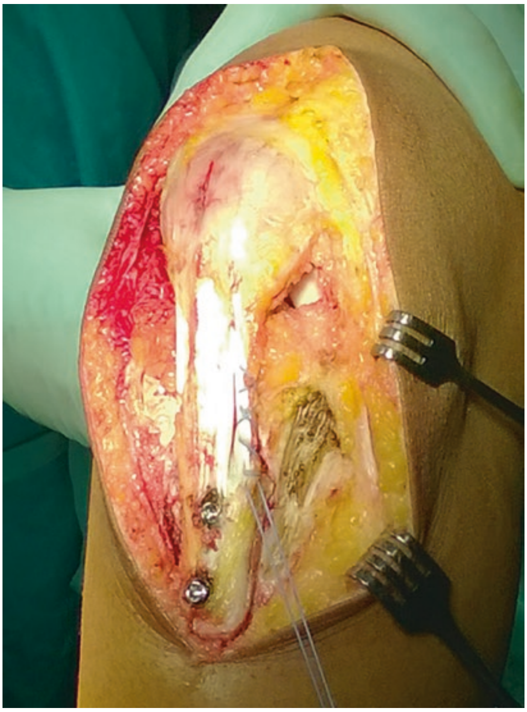

**Fig. 19.8** The medial third of the patellar tendon is prepared with nonabsorbable suture. In this case, a tibial tuberosity transfer was associated to MPTL reconstruction

under tension trying to find a medial insertion location close to the anterior edge of medial collateral ligament. The tourniquet is normally released to avoid any influence on this functional evaluation of patella tracking. Repeated dynamic analysis of patella tracking is carried out to find the precise location where the graft must be fixed with a metal staple (Fig. 19.9). The fixation must lead to patellar stability without creating excessive tension on the ligament band in case of flexed knee. In this position, the patella stability is tested using a finger that tries to pull the patella laterally in the first degrees of flexion. The patella must be stable in every degree of the ROM, without any joint limitation and avoiding any stretching of the ligament structure. It is fundamental to avoid excessive medialization of the patella with the aim of preventing clinical failure. Associated procedures such as tibial tuberosity transfer or trochleoplasty are usually performed before MPTL reconstruction when anatomical abnormalities are present.

**Fig. 19.9** Repeated dynamic tests are performed to find the precise location where the graft must be fixed with a metal staple

### 19.4.2 Surgical Technique of MPTL Reconstruction Using Free Hamstring Graft

Typically, the MPTL reconstruction is an adjunct to patella stabilization with MPFL. The surgical procedure of MPFL is done in the surgeon's usual practice. If using an auto hamstring, oftentimes the length is enough to accommodate a single-strand MPFL and MPTL. Using allograft, a peroneal allograft often offers the width needed to divide the graft into two parts, one longer one for the MPFL and one shorter one for the MPTL. The length of the graft can be estimated by the length of the patella tendon.

**Fig. 19.10** Intraoperative image of the patellar insertion of the medial patellotibial ligament (MPTL)

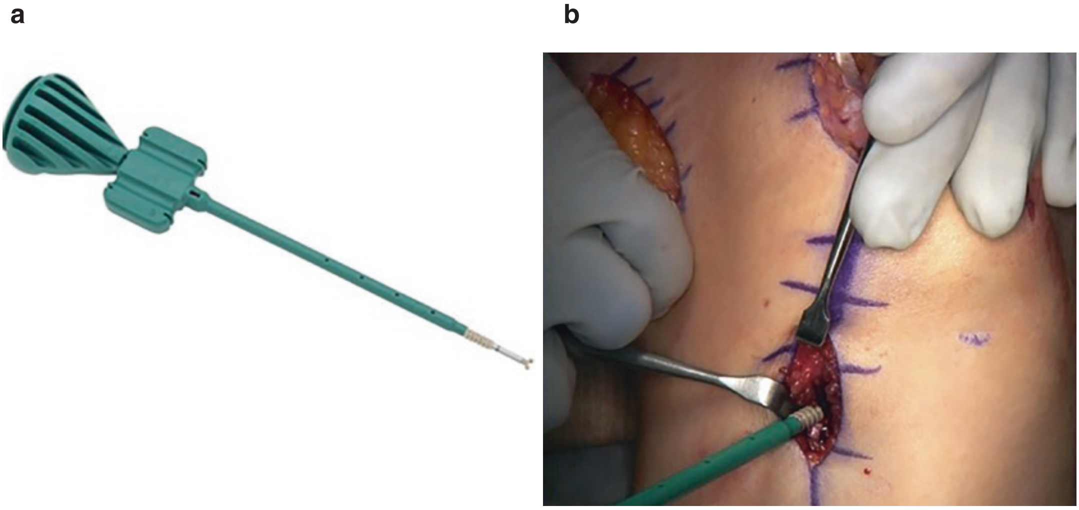

**Fig. 19.11** (**a**) 4.75 “fork-tip” PEEK swivelock (Arthrex™). (**b**) Intraoperative image of the tibial insertion of the medial patellotibial ligament (MPTL)

Fluoroscopy is already in the surgical theater for visualizing MPFL insertion sites.

Keeping the C-arm in the lateral position, one identifies the inferior-medial border of the patella, at the distal end of the cartilage border. Patella fixation can be a bony fixation using a 4 mm tunnel, entering on the medial patellar border and exiting on the dorsal surface. If the patella is small or there are concerns of bone quality, one can undermine the periosteum starting just underneath the patella tendon and periosteum, and exiting on the dorsal patella surface. A leader suture is placed in the tunnel for later use. Turning the C-arm to an AP position, one identifies a place on the anteromedial tibia approx. 5–10 mm from the joint line visualized on imaging, angled 25° from the medial patellar tendon border. One marks this spot for later use of the tibial attachment of the MPTL. Fluoroscopy is no longer needed.

Under separate cover, a peroneal allograft is brought into the room typically 8 mm wide and >200 mm in length. The graft is divided into two grafts, each approximately 4 mm in diameter. We put leader sutures on both ends of the graft, trimming the graft as needed to fit a 4 mm tunnel.

The graft is brought to the surgical table. Using the previously placed suture as a passing guide, we threaded the graft into the patellar tunnel (bony or soft tissue). The graft is then sutured into the soft tissue on the dorsal surface of the patella or on itself (Fig. 19.10).

Once the patella insertion is secured, the knee is flexed to 90°. In the pre-designated spot on the anterior tibia (located), a 5.0 mm drill is made in the tibia for a depth of 20 mm. The graft is placed under the patellar retinaculum, and placed over drilled bony tunnel, with the graft secured to the tibia using a 4.75 PEEK “forked-topped” swivelock anchor (Arthrex™) (Fig. 19.11 a, b).

During fixation, the tension in the MPTL should be similar to the one in the patellar tendon to prevent excessive medial pressure.

Full passive range of motion of the knee and medial and lateral patella translation are checked.

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# 20

# Tibial Tubercle Osteotomies: Indications and Results

Julian A. Feller

## 20.1 Introduction

This chapter will consider the current role of tibial tubercle osteotomy (TTO) in the treatment of patellofemoral problems. There are essentially two scenarios in which one would consider performing a TTO: in the management of recurrent patellar instability (recurrent lateral patellar dislocation) and in the management of pain thought to be due to damage to the patellofemoral articular surfaces. In the first situation, one is trying to restore normal patellar tracking in the trochlear groove and in the latter to unload the damaged articular surface(s). There are of course situations in which one is trying to address a combination of instability and pain at the same time, but for the sake of clarity, the two conditions will be discussed separately.

## 20.2 Recurrent Patellar Instability

### 20.2.1 A Changing Paradigm

The role of TTO in the management of recurrent patellar instability has changed significantly over the past two decades, in no small way due to cross-fertilisation of ideas between continents [1]. Once the basis of many, if not most, surgical procedures for recurrent patellar instability, a paradigm shift has seen TTO performed less frequently and medial patellofemoral ligament (MPFL) reconstruction performed more frequently, such that in many instances a fundamental question for the treating surgeon is whether a TTO needs to be added to a MPFL reconstruction or whether MPFL reconstruction alone will be enough to stabilise the patella in an individual patient [2].

### 20.2.2 Biomechanics

In the management of recurrent patellar instability, the tibial tubercle can be shifted medially or distally or in both directions simultaneously. An anteriorisation component can be added to the osteotomy to reduce the load on the articular surfaces, typically in the management of associated pain. This is considered in more detail later in the chapter. As part of the changing paradigm discussed above, medialisation has, overall, become less frequent, whilst distalisation has perhaps been used more frequently.

The biomechanical effects of medialisation and anteromedialisation of the tibial tubercle have been studied in both cadaveric and computational models. Studies have measured both patellar tracking and displacement, patellofemoral joint contact pressures, and tibiofemoral kinematics.

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Lateralisation of the tibial tubercle or of the vector of the pull of the quadriceps muscle has been shown to increase lateral tracking of the patella as well as lateral patellar tilt and contact pressure in the lateral patellofemoral compartment [3, 4]. On the other hand, medialisation has been shown to reduce lateral tracking of the patella in the trochlear groove and reduce lateral patellar tilt and lateral patellofemoral contact pressure [3–7]. The effect of medialisation on medial patellofemoral contact pressures is less clear, with studies showing either an increase or no change [4, 7, 8]. Anteromedialisation has been shown to reduce lateral patellar tracking, but, again, the effect on medial patellofemoral contact pressure is variable [3, 7]. Importantly, medialisation has been shown to be less effective than MPFL reconstruction in stabilising the patella and did not relieve load in the reconstructed MPFL [9].

There can also be unintended consequences. Medialisation can increase the external rotation of the tibia [6, 10], and anteromedialisation can translate the tibia posteriorly [10]. Furthermore, medialisation has also been shown to significantly increase the contact pressure in the medial tibiofemoral compartment [8].

There is little information about the biomechanical effects of distalisation to address patella alta. However, it is important to recognise that patella alta is the result of a long patellar tendon rather than a more proximal insertion of the tendon on the tibia [11]. In a cadaveric model, shortening of the patellar tendon has been shown to shift the patellofemoral contact area on the patella proximally whilst shifting it distally on the trochlear groove, effectively moving the patella further into the trochlear groove at any given angle of knee flexion [12]. It is a reasonable assumption that this also occurs with distalisation of the tibial tubercle. Interestingly, the change in the location of the patellofemoral contact area was associated with an increase in overall contact area, but not with an increase in patellofemoral stress [12].

In a more recent study of cadaveric knees with normal patella height, distalisation of 10 mm was found to significantly increase patellofemoral contact pressures in early knee flexion [13]. It is, however, important to recognise that the distalisation created patella baja as opposed to correcting patella alta to a normal patellar height. Nonetheless, it is clear that inadvertently creating patella baja when performing a distalisation for patellar instability can have significant negative consequences.

### 20.2.3 Indications

In general, the indication for medialisation of the tibial tubercle is a laterally positioned tibial tubercle and, for distalisation, patella alta.

#### 20.2.3.1 Radiological Assessment of Patellar Height

Lateral radiographs with the knee in 20°–30° flexion have been widely used to assess patellar height. Various indices have been described (Fig. 20.1). The Caton–Deschamps and Blackburne–Peel indices use the length of the patellar articular surface relative either to the distance from the distal end of the patellar articular surface to the line of the tibial plateau or to the anterosuperior corner of the tibia, respectively. The Insall–Salvati index and the modified Insall–Salvati index use the length of the patellar tendon relative to the length of the patella or the articular surface of the patella, respectively. The latter two indices cannot be used following distalisation of the tibial tubercle because the length of the patellar tendon is not changed.

Although satisfactory inter-observer reliability has been reported for individual indices, there is considerable variation between indices in terms of the number of patellae classified as normal, baja or alta [14, 15]. However, indices that use the length of the articular surface as a reference appear to be reasonably similar in terms of classification of patellae as normal, alta and baja. Whichever index is used, it is important that the knee is in enough flexion, typically 20°–30°, to have tension in the patellar tendon. If the patellar tendon is lax, the patella may sit more distal, leading to an underestimation of patellar height (Fig. 20.2a).

With the increasing availability of MRI and concerns about radiation exposure, particularly in what is usually a young patient population, MRI has also been used to assess patellar height. Satisfactory correlation between plain

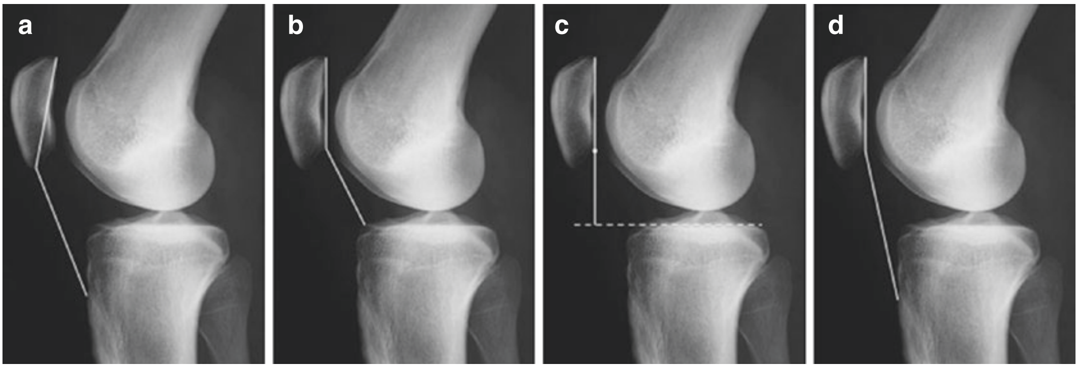

**Fig. 20.1** Patellar height indices based on lateral radiograph; (**a**) Insall–Salvati, (**b**) Caton–Deschamps, (**c**) Blackburne–Peel, (**d**) Modified Insall–Salvati

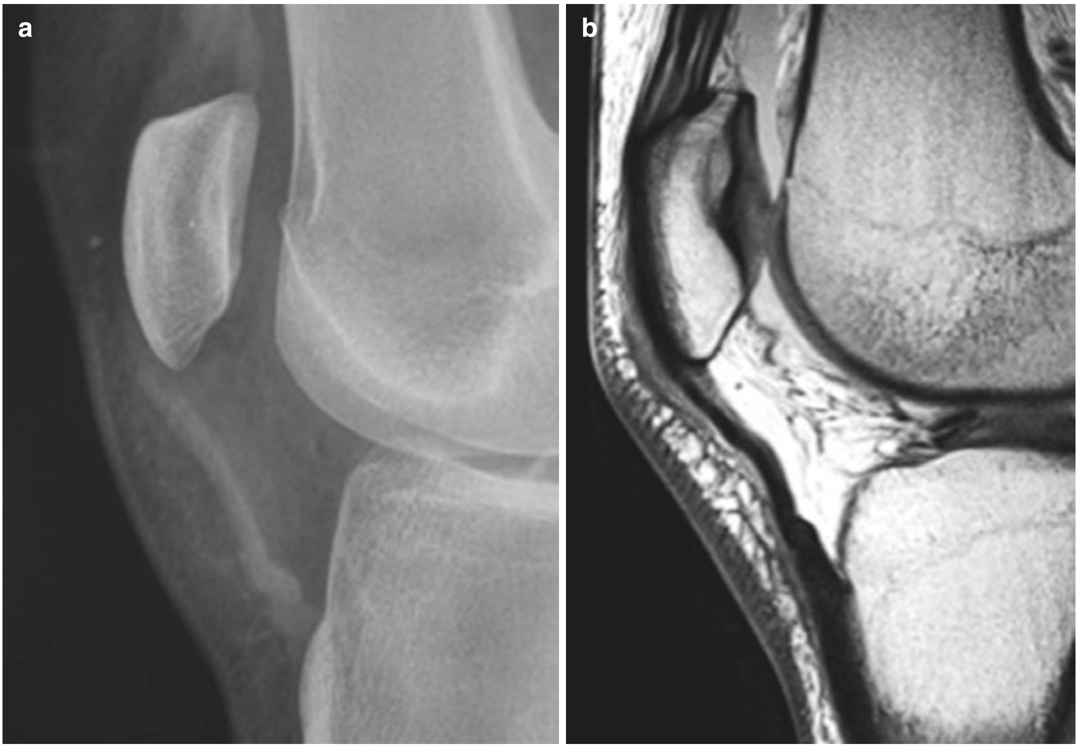

**Fig. 20.2** Effect of a lax patellar tendon on measurement on patellar height. If the patellar tendon is not under some tension, the patella may appear to sit artificially low both on a plain radiograph (**a**) and on MRI (**b**)

radiographic and MRI measurements of the Caton–Deschamps index has been reported [11]. However, when using MRI to assess patellar height, consideration needs to be given to which sagittal slice to use. A slice that is too lateral may give the appearance of a shorter patella and therefore of patella alta (Fig. 20.3a). Thus, the slice that gives the longest length of the patellar articular surface is preferable (Fig. 20.3b). As with plain radiographs, the knee needs to be in enough flexion to ensure that there is adequate tension in the patellar tendon (Fig. 20.2b).

More recently, MRI has been used to evaluate the engagement of the patella in the trochlea in the sagittal plane [16]. There appears to be a group of patients with patellar instability in

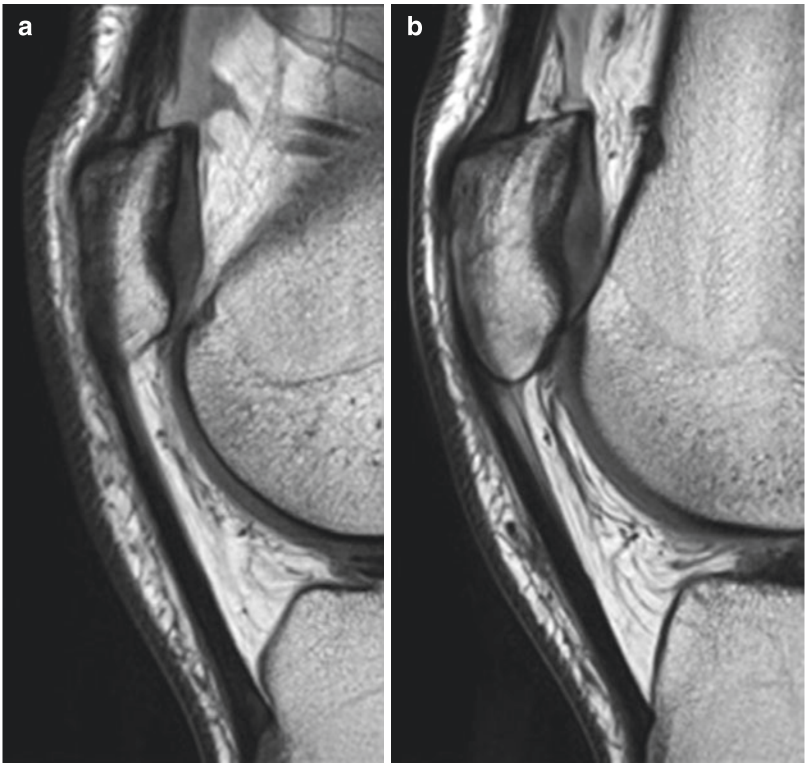

**Fig. 20.3** Effect of slice selection when measuring patellar height on MRI. Selecting a lateral slice (**a**) will give the impression of the patella sitting higher than the slice in which the patella is seen at its longest (**b**)

whom there is reduced engagement of the patella in the trochlea in early knee flexion but without obvious patella alta. However, patellar-trochlear indices are not yet in in widespread clinical use.

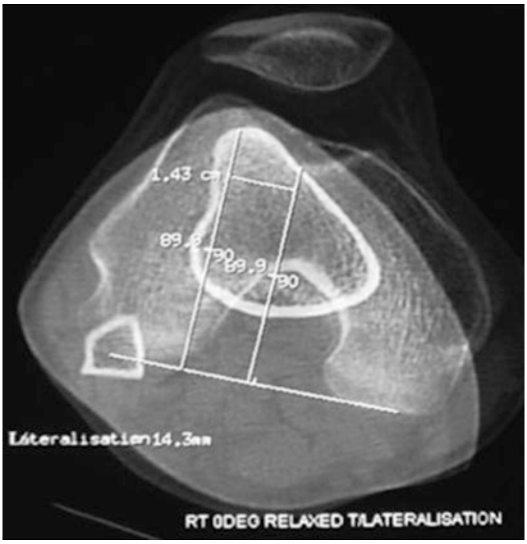

**Fig. 20.4** Tibial tubercle-trochlear groove distance as measured on CT scan with knee in extension. The distance from the centre of the trochlear groove to the centre of the tibial tubercle is measured on two superimposed slices using lines that are perpendicular to a line joining the posterior aspects of the femoral condyles

#### 20.2.3.2 Radiological Assessment of Tibial Tubercle Lateralisation

Lateralisation of the tibial tubercle is measured as the tibial tubercle-trochlea groove (TT-TG) distance. This was originally described using two superimposed slices of a CT scan, with the patient supine, a support under the feet to ensure the knee is in extension, and the feet held in 15° external rotation [17]. The first slice is where the intercondylar notch has the shape of a Roman arch, and this is used to identify the centre of the trochlear groove. The second slice is through the proximal tibial tubercle, and the distance between the centre of the trochlear groove and the centre of the tibial tubercle is measured and corrected for magnification (Fig. 20.4). It is important that the knee is extended. In full extension, the tibia is externally rotated, which effectively shifts the tibial tubercle laterally. If the knee is flexed, the tibia rotates internally with an associated reduction in the TT-TG distance [18]. Despite being widely used for preoperative planning, the TT-TG distance is not a reliable measurement, with measurement errors as high as 6 mm having been reported [19].

As with patellar height, MRI has also been used to measure the TT-TG distance. Although good correlation between CT and MRI measurements of the TT-TG distance has been reported [20], the two may not be interchangeable with MRI measurements being systematically smaller [21]. This may in some instances be partly due to the use of a knee coil in MRI, which can flex the knee. As previously noted, knee flexion will tend to reduce the TT-TG distance. Using the tibial tubercle itself or the patellar tendon insertion may also affect measurements [22].

#### 20.2.3.3 Threshold Values

In a classic paper, Henri Dejour et al. described addressing multiple predisposing factors when treating recurrent patellar instability, but it should be noted that MPFL reconstruction was not part of the surgical armamentarium [17]. Such an approach has frequently been referred to as *le menu à la carte*, and good results using this algorithm have been reported, although it is worth noting that the authors reserved deepening trochleoplasty for only the most severe cases of trochlear dysplasia [23].

Since the rise in popularity of MPFL reconstruction and the reporting of its effectiveness [24, 25], algorithms for which surgical procedures to perform have been modified. If MPFL reconstruction is seen as the basis of surgery for recurrent patellar instability, the issue becomes when to add an additional procedure, typically a TTO. It is probably fair to say that medialisation is now less frequently performed and that, increasingly, distalisation is becoming the main reason to perform a TTO. In the author's practice, for the majority of patients with recurrent patellar instability, MPFL reconstruction in isolation or combined with a distalising TTO will provide satisfactory stability (Fig. 20.5). Other procedures such as trochleoplasty, lateral retinacular lengthening or release and femoral osteotomy are generally only required in more complex situations such as habitual dislocation or chronic dislocation.

**Fig. 20.5** Lateral radiograph following distalisation of the tibial tubercle in association with a medial patellofemoral ligament reconstruction

Dejour et al. suggested threshold values greater than 20 mm for the TT-TG distance (as measured by CT scanning with the knee extended) and greater than or equal to 1.2 for the Caton–Deschamps index of patellar height as indications for medialisation and distalisation of the tibial tubercle, respectively [17]. As noted earlier, these thresholds were used in an algorithm that did not include MPFL reconstruction. Including MPFL reconstruction means that potentially higher thresholds can be used. For example, raising the threshold for

TT-TG distance to greater than 21 mm and the threshold for the Insall–Salvati index to greater than 1.4 has not been associated with higher recurrence rates of patellar instability [26].

It is possible that these thresholds can be further increased such that a MPFL reconstruction is sufficient on its own in even more patients. However, it should be noted that this applies to "typical" cases of recurrent patellar instability and that even in these scenarios, many factors need to be taken into account, such as whether the problem is primarily dislocation or subluxation, the presence and severity of J-tracking on clinical examination and the degree of trochlear dysplasia. When one is dealing with less common and more complex cases such as chronic dislocation or habitual dislocation, centring the patella in the trochlear groove is the first priority, and this determines what procedures need to be employed.

#### 20.2.3.4 Author's Approach

The author's approach is, where possible, to use an isolated MPFL reconstruction as surgery to treat recurrent patellar instability. In determining whether an additional procedure may be required, key clinical features are whether the presenting problem is primarily recurrent subluxation or dislocation, whether J-tracking is present and the degree of patella alta. Recurrent dislocation and the presence of J-tracking in the marked patella alta are relative indications for an additional TTO, usually distalising. J-tracking is in itself regarded as an indication that a bony procedure is likely to be required to achieve patellar stability.

Another way of looking at the place for an additional procedure is to consider both the ideal and the less than ideal, but nonetheless appropriate, patient for an isolated MPFL reconstruction—in other words the patients in whom one can achieve a satisfactory outcome without the need for a TTO.

The ideal patient for an isolated MPFL reconstruction has unilateral recurrent patellar dislocation or subluxation, no J-tracking, normal patellar height, normal trochlear morphology and a normal TT-TG distance. The "less than ideal" patient importantly does not have J-tracking but can have an Insall–Salvati or Caton–Deschamps index up to 1.4 or 1.3, respectively, a TT-TG distance <24 mm (measured with the knee in extension) and almost any degree of trochlear dysplasia with the possible exception of Dejour type D. It should be noted that patients with marked trochlear dysplasia are likely to demonstrate J-tracking and therefore, at least in the author's view, are not candidates for an isolated MPFL reconstruction.

Trochleoplasty as a primary procedure is reserved for marked trochlear dysplasia in more complex settings such as chronic dislocation or habitual dislocation.

### 20.2.4 Results

It is difficult to assess the results of TTO per se in the setting recurrent patellar instability, as TTO is usually performed in conjunction with another procedure. Most studies reporting the results have evaluated the outcomes of specific surgical strategies that include TTO, rather just TTO. Moreover, in recent years TTO has been used less frequently, and when used, it has typically been as an addition to MPFL reconstruction with the latter representing the primary procedure.

#### 20.2.4.1 Results of Tibial Tubercle Osteotomy Without MPFL Reconstruction

**Tibial Tubercle Medialisation**

In 2002 Nakagawa et al. reported long-term outcomes of tibial tubercle medialisation combined with a lateral release and medial plication in 45 knees, 6 of which had habitual patellar dislocation [27]. The overall rate of recurrent instability was 13%, although 39% had persistent patellar apprehension. The authors noted that functional outcomes deteriorated over time, primarily due to the presence of patellofemoral pain. Marcacci et al. reported no re-dislocations in a similar series (i.e. some with habitual patellar dislocation) of 18 knees in which a combination of procedures were used to achieve stability [28]. All included tibial tubercle medialisation, but in more severe cases, the distal attachment of the medial third of the patellar tendon was transferred medially, effectively reconstructing the medial patellotibial ligament.

In a series of 18 knees treated with an isolated tibial tubercle medialisation, Carney et al. reported a 7% rate of recurrent instability and once again noted a deterioration in functional outcomes over time [29]. Using the TT-TG distance as the base for tibial tubercle medialisation (combined with a lateral release), Tecklenburg et al. had a 15% recurrence rate and satisfactory results on patient-reported outcomes. They did, however, note persistent patellar apprehension in 29% of knees.

These series are mostly quite small, as is common in the literature on this subject. This makes recurrence rates difficult to interpret as a single patient with recurrent instability can influence the percentage by a relatively large amount. Nonetheless, the overall recurrence rate for tibial tubercle medialisation seems to be in the order of 10%, although the rate of persistent patellar apprehension is higher, suggesting at least subtle ongoing instability. Studies reporting longer-term follow-up have noted a deterioration in functional outcome over time, mainly due to pain.

#### Tibial Tubercle Anteromedialisation

Barber et al. reported an instability recurrence rate of 9% in 35 knees treated with a TTO that primarily medialised the tibial tubercle but which did include some anteriorisation [30]. The TTO was routinely combined with thermal shrinkage of the medial retinacular structures and a lateral release.

In a small study of 12 knees with significant patella alta, Otsuki et al. used a TTO that combined distalisation with anteromedialisation and reported good functional outcomes at a mean follow-up time of 3 years [31]. There was one traumatic re-dislocation. In a subsequent study from the same group, the authors reported a 3.4% recurrence rate and noted poorer functional outcomes in patients who were older at the time of surgery [32]. Increasing age correlated with greater articular cartilage damage in the patellofemoral compartment.

### 20.2.4.2 Results of Tibial Tubercle Osteotomy Combined with MPFL Reconstruction

Burnham et al. performed a systematic review—published in 2016—of the literature about MPFL reconstruction performed in conjunction with a TTO [33]. At the time, they could only identify five studies for inclusion. Based on these mostly small series, the authors were able to conclude that "reconstruction of the MPFL with concomitant transfer of the tibial tubercle is a safe and effective procedure, with … outcome and risk profile(s) … similar to those of isolated MPFL reconstruction." However, there have been many further studies since that time, and they are summarised in the following paragraphs.

There are essentially two groups of studies exploring the outcomes of TTO combined with MPFL reconstruction. In one, the overall cohort consists of patients who underwent MPFL reconstruction, and this cohort is subdivided into those who had an isolated MPFL reconstruction and those in whom an additional TTO was performed. The results of the two subgroups are typically compared. In the second, a group of patients who were deemed to require both an MPFL reconstruction and a TTO make up the whole cohort, and the results of the case series are reported.

#### Comparative Studies

Watanabe et al. reported on a consecutive series of 42 knees [34]. The first 13 knees had an MPFL reconstruction combined with a tibial tubercle medialisation, and the subsequent 29 had an isolated MPFL reconstruction. The isolated MPFL reconstruction scored higher on a multifaceted functional score, largely due to better outcomes in terms of the "Japanese full sitting" position. There were no other statistically significant differences between the two groups.

Reflecting the changing paradigm for surgery for recurrent patellar instability, Mulliez et al. reported on two groups of patients, one who had been treated with an isolated MPFL reconstruction and the other with an MPFL reconstruction and TTO [35]. The tibial tubercle was medialised if the TT-TG distance was greater than 20 mm and distalised if the Caton–Deschamps index was greater than 1.2. All TTOs were analysed as a single group. The outcomes of the groups were essentially the same with only one re-dislocation in the combined group.

Neri et al. reviewed the outcomes of a similar approach to the previous study (MPFL reconstruction +/− TTO) but distinguished between those patients in whom the tibial tubercle was only medialised and those patients in whom it was medialised and distalised [36]. There were no patients in whom the tibial tubercle was distalised only. The overall re-dislocation rate was 3% with no differences in re-dislocation rates or functional outcomes between the three groups.

Following the trend of less medialisations and more distalisations of the tibial tubercle, Feller et al. compared isolated MPFL reconstruction with MPFL reconstruction combined with tibial tubercle distalisation [26]. The decision to perform a distalisation was based on a combination of recurrent patellar dislocation rather than subluxation, the presence of J-tracking and an Insall–Salvati index greater than 1.2. Once again the recurrence rate was low (one patient with possible subluxation but no patellar apprehension in the isolated MPFL reconstruction group), there were no differences between the groups, and the return to sport rates were high. In both the Mulliez et al. and Feller et al. studies, the severity of trochlear dysplasia did not influence the results.

Damasena et al. reported a different approach, randomising patients to either TTO (with lateral release) or MPFL reconstruction [37]. There were no differences in functional outcomes between the two groups and only one recurrence (in the TTO-only group). Based on CT measurements with the quadriceps muscle contracted, the combined group did, however, have greater improvement in patellar tilt and congruence angle.

Overall, these studies show that isolated MPFL reconstruction can provide good outcomes in selected patients. The addition of a TTO in the remainder gives similar results with little downside, and the degree of trochlear dysplasia does not seem to affect outcomes. What remains unclear is where to set the threshold values for the addition of a TTO and in which direction the tibial tubercle should be shifted.

#### Case Series of Combined Procedures

Two recent studies confirm the findings of the comparative studies described in the previous section. In one, 72 knees had a tibial tubercle medialisation (8 also had anteriorisation) combined with an MPFL reconstruction with a recurrent instability rate of 4.2% and significant improvement in functional scores [38]. Older age and previous procedures increased the likelihood of patellofemoral chondral damage with the potential of inferior outcomes. It is worth noting that the threshold for medialisation was a TT-TG distance of 16 mm or more as measured on axial MRI slices. In the other study, 30 knees underwent a combined procedure with 4 patients having a distalisation as well as a medialisation [39]. Although two-thirds of patients had high-grade trochlear dysplasia, the recurrence rate was only 6.7%. Medialisation of the tibial tubercle by more than 10 mm was associated with poorer functional outcomes.

Previous studies have also reported satisfactory outcomes of combining medialisation or anteromedialisation of the tibial tubercle with MPFL reconstruction but add little further information to the current discussion other than the importance of appropriate patient selection [40–44].

## 20.3 Pain and Osteoarthritis

### 20.3.1 Principles

In general, TTO in the treatment of patellofemoral pain is reserved for pain in the setting of patellofemoral chondral damage, rather than for pain that is present with normal articular surfaces. TTO may be used as the primary procedure or in conjunction with a procedure to modify the articular surface of the patella, the trochlea or both. In either situation the aim is to unload the affected area of the patellofemoral compartment.

The TTO can be in a medial, distal or anterior direction or a combination of these. If the chondral damage is in the lateral half of the compartment, the TTO would be in a medial direction, possibly combined with anteriorisation. If the chondral damage is on the inferior pole of the patella in the setting of patella alta, distalising the tibial tubercle would both shift the contact area proximally on the patella onto intact articular cartilage and also increase the contact area, thereby reducing the force per unit area. For more global disease, direct anteriorisation might be considered. Of these options, anteromedialisation is the most frequently used.

### 20.3.2 Biomechanics

Biomechanical studies of the effect of tibial tubercle osteotomy on patellofemoral contact pressures have essentially been done to address one of the two scenarios: The first is to identify any unwanted increase in medial contact pressures after medialisation, whether it be performed in isolation or as part of anteromedialisation. The second is to determine whether unloading of areas can be achieved with the aim of treating articular cartilage damage.

In an early laboratory study, Kuroda et al. found that medialisation of the tibial tubercle significantly increased the patellofemoral contact pressure and also increased the average contact pressure of the medial tibiofemoral compartment, thereby changing the balance of tibiofemoral joint loading [8].

Investigating anteromedialisation as a treatment for patellofemoral articular cartilage defects, Beck et al. measured patellofemoral contact pressures in a cadaveric model [45]. Anteromedialisation was found to decrease the mean total contact pressure whilst shifting loading of the articular surfaces towards the medial aspect of the trochlea. The authors suggested that anteromedialisation is appropriate for unloading the lateral trochlea, but probably has minimal benefit on central chondral defects, and may actually increase the load on with medial chondral lesions. In an earlier study, Fulkerson et al. had created a model of increased loading of the lateral half of the patellofemoral joint and demonstrated that anteromedialisation was associated with a decrease in this loading in early knee flexion [46]. In addition, load was increased in the medial half of the compartment.

In a similar cadaveric model, Saranathan et al. demonstrated that both medialisation and anteromedialisation of the tibial tubercle resulted in decreased contact pressure in the lateral half of the patellofemoral compartment, both with the articular cartilage intact and also with a 12-mm full-thickness cartilage defect on the patella [47]. The anteriorisation component of anteromedialisation had less influence than the medialisation component. Unlike the previous study, both medialisation and anteromedialisation did not increase the pressure in the medial half of the compartment or around a medial full-thickness patellar cartilage defect as much as expected.

When performing an anteromedialisation of the tibial tubercle, it has been reported that intraoperatively, surgeons may overestimate the amount of anteriorisation as well as the angle of the slope of the osteotomy [48]. Although the slope of the osteotomy has been described as being up to 60° in reports of the surgical technique, it is in fact difficult to make it greater than 45° without violating the posterior cortex of the tibia [48]. Thus, the maximum anteriorisation achievable with this technique is inherently limited, and other strategies are needed if greater anteriorisation is required. It is worth noting that Fulkerson had already recognised this in his original description of the technique, in which he stated that anteromedialisation was “not appropriate for patients who need anteriorization alone” [49].

Rue et al. did in fact study contact pressures in the patellofemoral compartment following a straight anteriorisation osteotomy which was a modification of the Fulkerson anteromedialisation osteotomy [50]. In a cadaveric model, they demonstrated significantly decreased trochlear contact forces, without the medial shift of the centre of force that had previously been observed with anteromedialisation. They suggested that this straight anteriorisation osteotomy may be useful to unload medial articular defects of the patellar or trochlea.

### 20.3.3 Indications

Direct anteriorisation has fallen out of favour, in part due to previously reported high rates of complications. As a treatment for patellofemoral pain due to chondral damage, it has largely been replaced by anteromedialisation. The indications for anteromedialisation have, however, also been refined with the best results seen when the articular cartilage damage on the patella is lateral or distal [51, 52].

But the real issue is whether and when to undertake surgery in the treatment of patellofemoral pain associated with chondral lesions. This is even more complicated with the introduction of cartilage reparative techniques. The conundrum is beyond the scope of this chapter, but readers are referred to the review by Arendt et al. [53]. However, it is probably safe to say that the role of TTO has reduced significantly over the past decade.

#### 20.3.3.1 Author's Approach

As a general approach, the author tries to avoid surgery in the management of patellofemoral pain. However, in the presence of patellofemoral articular cartilage damage and after failure of non-operative management, there can be a role for surgical intervention. In the author's practice, this rarely involves TTO.

Arthroscopic debridement can provide some relief in the setting of localised chondral breakdown with significant pain and swelling. Lateral retinacular lengthening or release have a role when there are lateral patellofemoral changes in association with tightness of the lateral retinaculum and reduced medial patellar glide. With significant lateral patellar overhang and osteophytosis, lateral patellar facetectomy provides the next level of intervention, again for lateral articular cartilage changes. In patients who are deemed to be in an old-enough age group, generally over 50 years, patellofemoral arthroplasty also provides an option, particularly for osteoarthritis that is global or involves the medial half of the compartment. In the latter setting, a medialising TTO may occasionally have a role to achieve satisfactory patellar tracking, although this can generally be achieved with careful attention to component alignment and an occasional lateral release.

### 20.3.4 Results

Despite the contemporary difficulties in deciding when a TTO is warranted in the management of patellofemoral pain and osteoarthritis, there is some literature reporting what are essentially historical outcomes. Although TTO can be performed in conjunction with cartilage reparative techniques, the results discussed below relate to procedures without such additional surgery.

#### 20.3.4.1 Tibial Tubercle Anteriorisation

In 1976, Maquet reported the results of direct anteriorisation for patellofemoral osteoarthritis [54]. Thirty-nine of forty-one patients were followed up at a mean of 4.7 years (range from 1 to 10 years). Thirty-seven had good or excellent results. Radin et al. subsequently also reported high rates of satisfactory outcomes in patients with patellofemoral osteoarthritis following osteochondral injuries (94%) and following recurrent patellar subluxation (88%) [55]. Twenty years after Maquet's publication, Jenny et al. reported the results for 100 patients who had undergone the same procedure [56]. All were reviewed at a mean of 4 years, and 65 were reviewed again at 11 years. Overall they reported 62% satisfactory results but noted that patients with more advanced chondral changes did better at the early review, with a 69% success rate.

#### 20.3.4.2 Tibial Tubercle Anteromedialisation

Following his original description of the technique of anteromedialisation [49], Fulkerson subsequently reported the results in 30 patients followed for a mean of 35 months [46]. Subjectively, 93% reported good or excellent results with objective results being good or excellent in 89%. Interestingly, in patients with advanced patellofemoral osteoarthritis, no excellent results were reported, but 75% reported good outcomes. In a later publication, the same group also demonstrated that distal and lateral patellar chondral lesions are associated with better outcomes than medial or proximal lesions [52]. More recently Lin et al. described a series of patients with advanced lateral patellofemoral osteoarthritis treated with anteromedialisation and lateral release and reported not only good functional outcomes but also restoration of the lateral patellofemoral joint space on skyline radiographs [51].

Good outcomes have also been reported in other studies. Bellemans et al. reported high rates of success following anteromedialisation for persistent anterior knee pain in the setting of patellar subluxation on a skyline radiograph at 30° knee flexion [57]. Buuck and Fulkerson reported the results of anteromedialisation in 36 knees with mild to moderate patellar chondral damage at a minimum of 4.4 years [58]. Subjective results were good or excellent in 86%, whilst 19 of 22 knees that were examined were rated as good or excellent.

## 20.4 Complications

The complications of TTO include general complications of surgery such as infection, both superficial and deep, venous thrombosis and local sensory disturbance related to the incision and damage to cutaneous nerves. There are also significant specific complications relating to osteotomy, such as fractures, issues with bone healing, compartment syndrome and skin necrosis.

Although uncommon, fracture of the proximal tibia represents a major complication. It seems to be mainly a problem associated with anteromedialisation [57, 59–63] but has also been reported with medialisation alone [64]. It appears to be mainly due to returning to impact activities too early in the recovery phase, but surgical technique may also play a role. Using an oscillating saw rather than an osteotome may reduce the risk of fracture. For reasons that are not clear, fracture seems to be more frequent when the tibia tubercle is completely detached [65]. Fractures of the tibial tubercle have also been reported, possibly related to the osteotomised fragment being too thin [62, 63].

As with all osteotomies, delayed or non-union is a potential problem. Once again, the risk seems to be greater if the fragment is completely detached [65]. The risk appears to be greater for distalisation rather than medialisation, possibly related to greater stress on the osteotomy site and having to disrupt more of the soft tissue attachments to shift the tubercle distally. Sound internal fixation with good compression across the osteotomy and a cautious return to full weight bearing may reduce the risk of problems with union [66, 67].

Skin necrosis and acute compartment syndrome are serious complications that have been reported following direct anteriorisation of the tibial tubercle [55]. However, use of an anterolateral incision and careful surgical technique can reduce and potentially eliminate skin problems [68]. For all tibial tubercle osteotomies, it is important to be conscious of the blood vessels in the posterior compartment when drilling, and it is safest to aim for the medial third of the posterior cortex of the tibia [69].

Hardware may be prominent anteriorly and cause local irritation and discomfort, particularly when kneeling, and the need for removal is relatively common [65]. Countersinking screw heads and using small fragment screws may help reduce the need for removal, although if using small fragment screws, additional screws may be required to achieve adequate fixation. The author’s preference is to electively remove screws at about 12 months following surgery.

Long-term patellofemoral osteoarthritis may simply reflect the natural progression of chondral damage present at the time of surgery. However, excessive medialisation of the tibial tubercle may increase loads in the medial half of the patellofemoral compartment with the risk of the development or more rapid deterioration of articular cartilage loss [70].

Post-operative patella baja has been associated with poor results due to pain [71]. It may be a direct result of the biomechanics of the osteotomy itself, particularly with distalisation but also potentially with anteriorisation. It may also reflect delayed activation of the quadriceps muscle in the post-operative period [67]. Similarly, excessive distalisation has the potential to cause patella baja. It is unclear how far the tibial tubercle should be distalised, but it seems prudent to keep indices such as the Caton–Deschamps ratio in the upper part of the normal range.

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# 21

# Tibial Tubercle Anteromedialization Osteotomy

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## 21.1 Introduction

Tibial tubercle osteotomies (TTOs) are procedures designed to address patellofemoral (PF) joint disorders including malalignment, instability, and articular cartilage lesions or arthritis through distal realignment of the extensor mechanism. These osteotomies are generally performed to correct excessive lateralization (external rotation) of the tibial tubercle and/or unload portions of the PF joint. Multiple osteotomy techniques have been described, including the Elmslie–Trillat [1] procedure for direct medialization, Maquet procedure for direct anteriorization [2], and the Fulkerson procedure for anteromedialization (AMZ) [3]. The tibial tubercle can also be moved proximally or distally to correct patella infera or patella alta, respectively.

Due to its ability to both realign the extensor mechanism and unload portions of the PF joint, the AMZ osteotomy is frequently utilized in the treatment of PF joint pathology. The osteotomy has indications in the treatment of articular cartilage defects, PF osteoarthritis, and instability of the PF joint and is the focus of this chapter.

## 21.2 Biomechanics

The biomechanics of the PF joint are important to understand when considering any TTO. In the absence of significant patella alta, the inferior portion of the patella first engages within the trochlea at approximately 10°–20° of knee flexion. As knee flexion increases, the patellar contact area increases and moves proximally on the patellar articular surface. At knee flexion angles greater than 90°, the medial and lateral patellar facets are the primary areas of articulation with the femoral condyles with the quadriceps tendon sharing some of the load [4].

In full extension, there is essentially zero PF joint reaction force. As knee flexion angle increases, posteriorly directed PF joint reaction forces increase as well due to tension in the quadriceps and patellar tendon [4]. Lateralization of the tibial tubercle and an increased Q-angle have been shown to significantly increase lateral patellar facet pressures by a mean of over 40% and decrease lateral facet contact area by approximately 20% [5].

Anteriorization of the tibial tubercle will decrease PF joint reaction forces as it increases

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the angle between the quadriceps and patellar tendon [2, 4]. A minimum of 12 mm of anteriorization will decrease joint reactive forces [6, 7], and 20 mm of anteriorization decreases contact pressures within the PF joint by 50% [2]. Anteriorization of the tubercle also anteriorly rotates the inferior pole of the patella and transfers the contact area proximally on the patella [6]. Medialization of the tibial tubercle similarly has been shown to decrease PF contact forces by a mean of 7 ± 4% and lateral facet contact pressure by a mean of 13 ± 5% [5].

Not surprisingly, the AMZ osteotomy is quite effective in offloading the lateral patellar facet through both medialization and anteriorization. With anteromedial translation between 8 and 15 mm, Fulkerson et al. demonstrated considerable decrease in lateral facet contact pressure at full extension and in early flexion and slight proximal translation of the patellar contact area [8]. In another biomechanical study, Beck et al. showed that the AMZ osteotomy decreased both mean contact pressure and mean lateral trochlear contact pressure and transferred the contact pressures to the medial PF joint [9]. Similarly, Ramappa et al. showed that AMZ of the TT was able to significantly decrease mean and maximum patella pressures and lateral facet pressures [5].

## 21.3 Evaluation

### 21.3.1 History

It is important to obtain a thorough history from the patient including symptoms, instability events, prior treatment, and surgical history. Attention should focus on the onset (traumatic versus insidious), chronicity (acute versus chronic), and location (lateral versus medial versus diffuse) of the patient's symptoms. Additionally, the presence of swelling or mechanical symptoms may indicate osteochondral lesions. It is critical to differentiate complaints of PF pain from PF instability. When considering instability, the mechanism of injury, number of episodes, dislocations versus subluxations, and need for reduction (self versus medical professional) are key aspects to delineate. Any prior treatment including medications, injections, physical therapy, bracing, or surgical intervention should be discussed, and operative reports and images should be evaluated.

### 21.3.2 Physical Examination

A complete evaluation of the patient's lower extremity should be performed including gait and limb alignment and rotation, considering genu valgum, femoral anteversion, and tibial torsion. A standard general orthopedic examination of the knee should assess presence of effusion, range of motion, tenderness, ligamentous stability, and muscle strength. This exam is followed by a thorough examination of the PF joint including assessment of the *Q*-angle, presence of tenderness along the medial or lateral patella, crepitus with range of motion, patellar tracking, and patellar tilt. Patellar mobility, both medially and laterally, should be documented and the endpoint assessed. Lateral patellar tilt that is unable to be corrected indicates lateral retinacular tightness. Special tests including J-sign and patellar apprehension are critical as well. The J-sign assesses dynamic patellar tracking and is considered positive if the patella deviates laterally as the patient actively extends the knee from a flexed position and may indicate abnormal bony morphology or soft tissue structures. Patellar apprehension should initially be performed in full extension, and the examiner should manually translate the patella laterally. It is considered positive if the patient has apprehension (a sense of impending dislocation) or guarding (involuntary quadriceps contraction). The exam should be repeated with increasing degrees of knee flexion and should diminish as the patella engages the trochlea. Persistent apprehension in knee flexion beyond approximately 45° may indicate patella alta or trochlear dysplasia.

## 21.3.3 Imaging

### 21.3.3.1 Radiographs

Plain radiographs of the knee are important to obtain to evaluate the bony anatomy and presence of any pathology including osteoarthritis, abnormal patellar height or tilt, and trochlear dysplasia. Standard views include bilateral-weight bearing, anteroposterior, flexed posteroanterior, lateral, and flexed axial views of the affected knee. It is especially important to have appropriately aligned lateral views in order to evaluate the trochlea as well as assess patellar height. Evaluating patellar height is an important consideration when planning AMZ in order to determine whether any distalization is needed as well. There are multiple methods to assess patellar height including the Insall–Salvati method, Blackburn–Peele method, and Caton–Deschamps (C-D) methods. We prefer to use the C-D method, as this measurement is independent of the patellar tendon length and can still be utilized after prior TTO. The C-D ratio is calculated by dividing the distance from the inferior aspect of the patellar articular cartilage to the anterosuperior margin of the tibial plateau by the length of the patellar articular margin. A value greater than 1.3 is considered abnormal (Fig. 21.1).

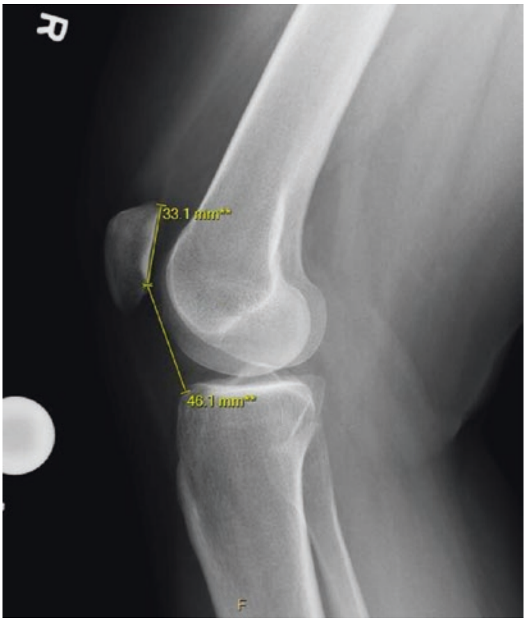

**Fig. 21.1** Lateral radiograph of the right knee demonstrating elevated Caton–Deschamps ratio

### 21.3.3.2 Computed Tomography and Magnetic Resonance Imaging

Cross-sectional imaging including both computed tomography (CT) and magnetic resonance imaging (MRI) are important secondary imaging modalities used to evaluate the PF joint and for preoperative planning. Both modalities are comparable in showing the PF joint morphology and ability to perform additional measurements. MRI has the additional benefit of accurate localization and assessment of chondral lesions. Rotational abnormalities of the lower extremity are best evaluated using CT.

Axial CT and MRI images are useful in evaluating patellar tilt and trochlear dysplasia. Lateral patellar tilt greater than 20° are considered abnormal and may be indicative of a tight lateral retinaculum or trochlear dysplasia. Trochlear dysplasia is evaluated by measuring the sulcus angle and trochlear inclination. A sulcus angle of 145° or greater and trochlear inclination angle less than 11° are abnormal and consistent with trochlear dysplasia.

Axial imaging also allows assessment of the lateralization of the tibial tubercle relative to the trochlear groove or PCL. Originally described by Goutallier et al. [10], the tibial tubercle to trochlear groove (TT-TG) distance is measured as the distance between the center of the tibial tubercle and the deepest portion of the trochlear groove on a line parallel to the posterior condylar axis (Fig. 21.2). 10–15 mm is considered normal, and greater than 20 mm is deemed abnormal. The classic modality to measure the TT-TG distance is CT, but MRI is also accurate and reliable in measuring the TT-TG distance. One must consider that MRI typically underestimates the TT-TG distance relative to measures made on CT due to the required flexion of the knee to position it in a coil. The average difference in values

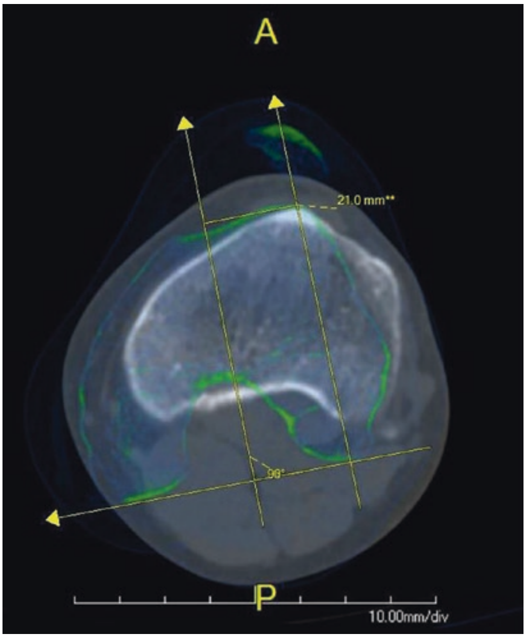

**Fig. 21.2** Superimposed axial CT scan images demonstrating proper measurement technique and elevated tibial tubercle to trochlear groove distance

obtained from CT and MRI is about 2 mm but may be larger in knees with a high TT-TG distance [11]. Assessing TT-TG on an MRI can also be more challenging as most imaging software is unable to superimpose images. Camp et al. demonstrated accuracy and reliability of a simple alternative utilizing an external alignment method that any practitioner may employ [12].

## 21.4 Indications

There are two distinct and yet frequently overlapping indications of AMZ osteotomy. The first indication is to unload specific portions of the PF joint—particularly the lateral and distal aspects of the patella. Numerous pathologic processes may result in cartilage damage in these areas that require unloading as part of their treatment, including PF osteoarthritis and focal articular cartilage defects.

The second indication for AMZ osteotomy is the correction of an increased TT-TG distance and lateral patellar tracking in the setting of patellar instability. While addressing damage to the medial PF complex through reconstruction of the medial patellofemoral ligament (MPFL) has become the mainstay of treatment of recurrent lateral patellar instability, distal realignment still plays an important role as an adjunct procedure in patients with abnormal patellar tracking and tibial tubercle position. A recent biomechanical study by Stephen et al. demonstrated poor correction of patellar tracking with isolated MPFL reconstruction in patients with a TT-TG distance greater than 15 mm [13]. The addition of an AMZ osteotomy to MPFL reconstruction may improve patellar tracking and decrease recurrence risk in this population. Patients with both patellar instability and cartilage damage in the lateral and/or distal aspects of the PF joint are an ideal population for AMZ osteotomy.

While AMZ osteotomies are sometimes performed in isolation, it is commonly performed in conjunction with other procedures depending on the underlying pathology. Patients with lateral overload in the absence of instability may benefit from a lateral procedure such as lateral release or lengthening. Patients with focal cartilage defects of the lateral or distal PF joint may benefit from concomitant cartilage treatment. Finally, as discussed above, patients with instability will likely benefit from MPFL reconstruction in most cases, with osteotomy as an adjunct.

## 21.5 Contraindications

Contraindications to AMZ osteotomy include patients with significant medial PF chondral damage as AMZ will increase medial patellar fact forces and could lead to further damage in this area. Work by Pidoriano et al. also demonstrated relatively poor outcomes of AMZ osteotomy for the treatment of diffuse PF osteoarthritis [14]. A further contraindication to AMZ osteotomy is the treatment of patients with patellar instability who lack a pathologically increased TT-TG distance. Further tibial tubercle medialization in these patients could lead to iatrogenic medial patellar instability—particularly when a lateral release is also performed. Additionally, relative contraindications to any lower extremity osteotomy apply to TTO as well, including tobacco use, poor bone quality that would prevent adequate fixation, and the inability to follow postoperative protocols.

## 21.6 Surgical Technique

### 21.6.1 Preoperative Planning

Key to the versatility of the AMZ osteotomy is the ability to vary the relative degree of anteriorization and medialization achieved based on the angle at which the primary cut is made (Fig. 21.3). An increased obliquity of the cut allows for more anteriorization than medialization. Conversely, a flatter cut allows for more medialization than anteriorization. The TT-TG distance as described above provides useful insight into the degree of medialization that is needed. As above, cases with more PF chondral damage may benefit from more anteriorization. Examples of common osteotomy angles and the resulting displacement after a 10 mm anteromedialization are provided in Table 21.1.

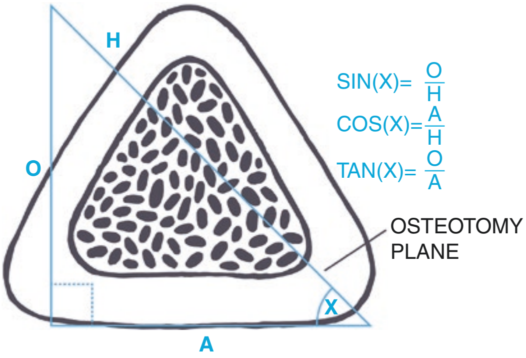

**Fig. 21.3** Illustration of axial tibia demonstrating right angle trigonometry to calculate translation amount. Reprinted from Arthroscopy Techniques, Ridley TJ, Baer M, Macalena JA, Revisiting Fulkerson's Original Technique for Tibial Tubercle Transfer: Easing Technical Demand and Improving Versatility, e1211–e1224, 2017, with permission from Elsevier

**Table 21.1** Degree of obliquity of the osteotomy and approximate resulting amount of anteriorization and medialization of a 10 mm tibial tubercle anteromedialization

| Osteotomy slope (°) | Anteriorization (mm) | Medialization (mm) |
|---|---|---|
| 30 | 5 | 8.6 |
| 45 | 7.1 | 7.1 |
| 60 | 8.6 | 5 |

### 21.6.2 Positioning

The patient is placed supine on the operating room table with all extremities and bony prominences well padded. A small padded bump is placed under the ipsilateral hip to position the lower extremity in neutral rotation. A lateral thigh post is used in order to facilitate arthroscopic evaluation and provide lateral positioning support during the remainder of the procedure. A tourniquet is placed high on the thigh, and standard preoperative antibiotics are administered. Examination under anesthesia is performed including evaluation of range of motion, ligamentous stability, patellar tracking, patellar tilt, and patellar translation and ability to dislocate in through the full range of motion. The lower extremity is then prepped and draped in standard sterile fashion, and a preoperative timeout is performed. Planned skin incisions are marked, taking into account all potential concomitant procedures and ensuring appropriate skin bridges (Fig. 21.4).

### 21.6.3 Arthroscopy

Diagnostic arthroscopy is performed through standard inferolateral and inferomedial portals. The entire joint is inspected, taking particular care to inspect the PF joint. The articular surfaces are inspected, and areas of chondral wear and damage are documented. The creation of a superolateral portal may also be useful to provide a proximal view of patellar tracking as the knee is brought through range of motion. The arthroscopic evaluation may identify severe PF cartilage damage or chondrosis or other contraindications that precludes proceeding with the

**Fig. 21.4** Intraoperative photograph of planned skin incision for tibial tubercle osteotomy and potential concomitant procedures

AMZ osteotomy. If concomitant procedures are planned, arthroscopic preparation for these is performed, and any additional intra-articular pathology (meniscal tears, loose bodies, plicae, etc.) is addressed at this time as well.

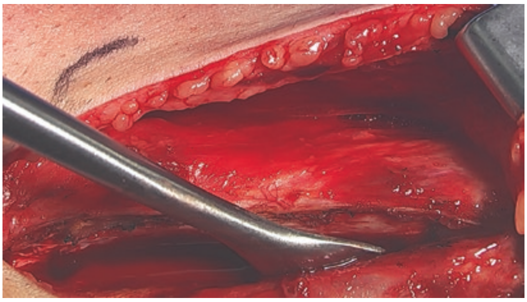

**Fig. 21.5** Intraoperative photograph of subperiosteal elevation of anterior compartment

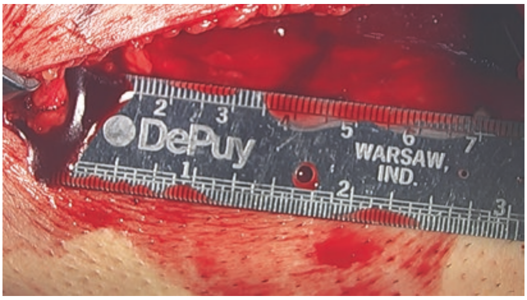

**Fig. 21.6** Intraoperative photograph demonstrating measurement of osteotomy length

## 21.6.4 Open Procedure

### 21.6.4.1 Exposure

An approximately 10 cm incision is made from Gerdy's tubercle and carried distally and medially along the lateral aspect of the tibial tubercle and tibial crest. Dissection is carried through the skin and subcutaneous tissue until the anterior compartment fascia is identified. The fascia is incised longitudinally just lateral to the tibial crest, maintaining a small cuff of tissue for closure, and the anterior compartment musculature is elevated off the tibia in a subperiosteal fashion (Fig. 21.5). Both edges of the patellar tendon are identified and cleared of tissue. A blunt retractor is placed behind the patellar tendon for protection and to identify the insertion point on the tibia.

### 21.6.4.2 Osteotomy

The osteotomy is then marked out. The distal aspect of the osteotomy is measured 7 cm distally from the patellar tendon insertion, and the anterior tibia is marked at this point (Fig. 21.6). Two parallel K-wires are inserted in the tibia as a guide for the oblique osteotomy at the pre-determined angle as described above. One K-wire is placed at the distal aspect that was previously marked and the second at the patellar tendon insertion on the tibia. The K-wires are inserted from medial to lateral starting 1–2 mm medial to the tibial crest, aimed at the angle of the planned osteotomy and passed just through the lateral cortex (Fig. 21.7). Using a handheld oscillating saw, the medial tibial cortex is scored (Fig. 21.8). The tibia is then cut in plane with the K-wires starting centrally between the K-wires (Fig. 21.9). The cut is carried through the far (lateral) cortex and extended proximally and distally, taking care to protect the lateral structures with retractors. The K-wires are removed once the plane of the cut has been established to prevent interference with the oscillating saw. It is important to taper the distal aspect of the osteotomy anteriorly so that the bone is about 1–2 mm thick at the most distal aspect to minimize fracture risk. The distal 1–2 mm of the anterior tibial cor-

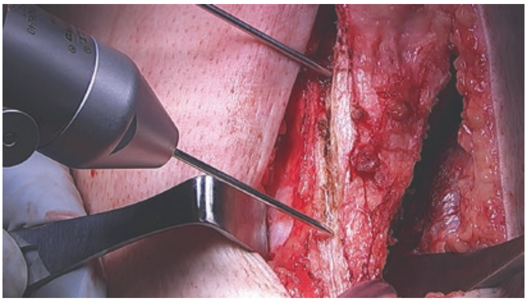

**Fig. 21.7** Intraoperative photograph of insertion of parallel K-wires at planned osteotomy slope

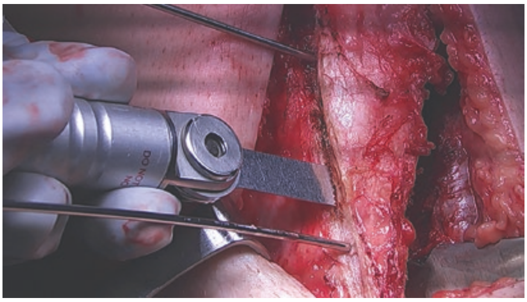

**Fig. 21.8** Intraoperative photograph of oscillating saw scoring the medial cortex of the tibia

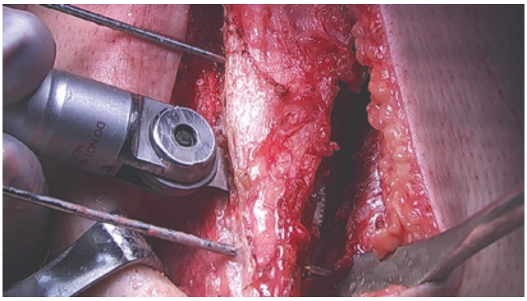

**Fig. 21.9** Intraoperative photograph of osteotomy cut in plane with the previously placed K-wires and carried through the lateral cortex

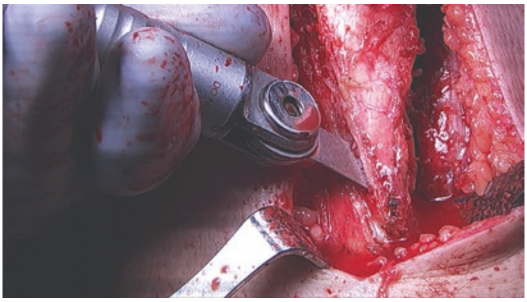

**Fig. 21.10** Intraoperative photograph of distal aspect of osteotomy, leaving 1–2 mm of cortex intact to act as a hinge for the osteotomy

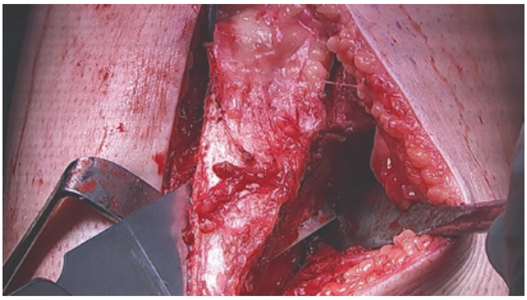

**Fig. 21.11** Intraoperative photograph demonstrating the use of an osteotome for completing the proximal aspect of the osteotomy through the lateral cortex

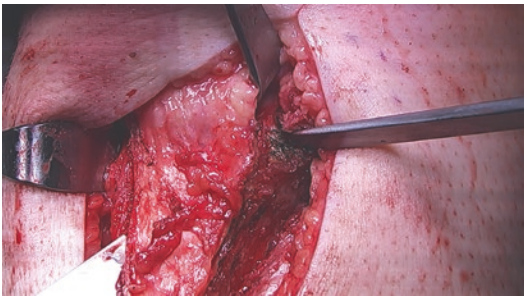

**Fig. 21.12** Intraoperative photograph demonstrating the transverse osteotomy posterior to the patellar tendon. Note the retractor behind the patellar tendon

tex of the osteotomy is left intact to act as a hinge (Fig. 21.10). Proximally, osteotomes are used to complete the osteotomy through the lateral cortex in order to prevent damage to the lateral neurovascular structures (Fig. 21.11). The transverse portion of the proximal osteotomy is made with an osteotome (Fig. 21.12), and a small back cut may be made with the oscillating saw (Fig. 21.13) or an osteotome. This results in a triangular shape to the osteotomy. Alternatively, commercially available jigs and cutting guides may be used for this portion.

At this point in the case, any required cartilage procedures can be performed by extending the incision proximally and utilizing the osteotomy to provide excellent exposure and visualization prior to osteotomy fixation.

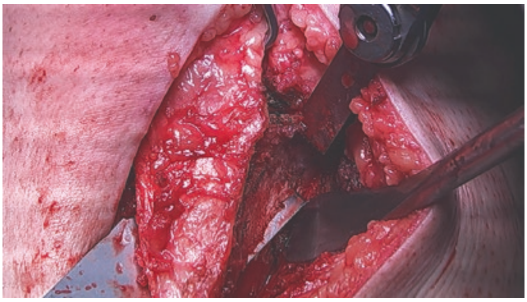

**Fig. 21.13** Intraoperative photograph of use of an oscillating saw to make a back cut to connect the transverse and lateral aspects of the tibial tubercle osteotomy

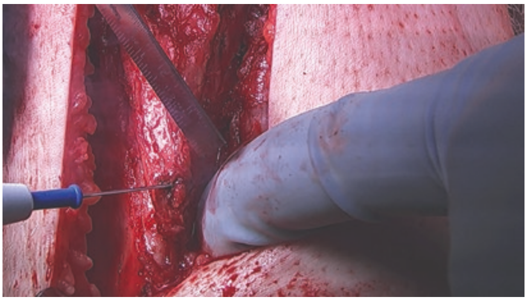

**Fig. 21.14** Intraoperative photograph demonstrating measurement of translation of tibial tubercle

#### 21.6.4.3 Fixation

Using the preoperatively calculated distances, the amount of anteromedialization is measured, and the tubercle is moved along the cut and held in the appropriate position (Fig. 21.14). The tubercle may also be moved distally or proximally to account for pre-existing alta or infera respectively if necessary, but this does require completion of the cut distally. The tubercle is then drilled perpendicular to the osteotomy (anterolateral to posteromedial) using a lag technique and fixed in place using two 4.5 mm cortical screws in a bicortical fashion (Fig. 21.15). It is important to countersink the anterior cortex to minimize postoperative irritation and the need for hardware removal. Depending on the amount of anteriorization and medialization, there may be prominence of the medial aspect of the tubercle, which may be removed to prevent skin and soft tissue irritation. Final fluoroscopic images are obtained ensuring appropriate position and fixation. The incision is then closed in standard layered fashion.

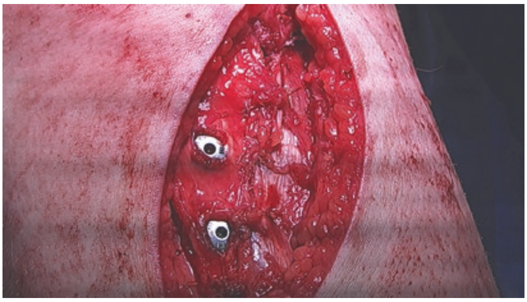

**Fig. 21.15** Intraoperative photograph demonstrating final screw fixation of tibial tubercle

#### 21.6.4.4 Additional Procedures for Instability

If a lateral lengthening or release or MPFL reconstruction is to be performed in addition to the AMZ osteotomy, it is important to complete osteotomy first. The osteotomy may change patellar tracking, particularly if distalization is involved. This change may obviate the need for or possibly necessitate a lateral procedure. Further it may change the isometry of the graft if the MPFL reconstruction is done first, resulting an anisometry and associated complications.

## 21.7 Postoperative Management

Postoperatively, patients are placed in a hinged knee brace. They are kept non-weight bearing for the first 2 weeks to allow for healing of the osteotomy site. If the distal hinge was maintained intra-op, patients begin a progressive weight-bearing program after 2 weeks, beginning with increasing 25% body weight weekly until they are full weight bearing at 6 weeks. Patients without an intact distal cortical hinge (distalization or loss of the hinge intra-op) are kept non-weight bearing for the entire 6 weeks. Patients are allowed full range of motion immediately postoperatively. Patients are taught home exercises before discharge and start physical therapy within the first week postoperatively to work on range of motion and quadriceps strengthening. All patients are placed on venous thromboembolism (VTE) prophylaxis (our preference is apixaban 2.5 mg twice daily) until they are full weight bearing and are then transitioned to aspirin 325 mg daily for an additional 4 weeks.

Radiographs are obtained at 2, 6, and 12 weeks postoperatively and then at 3-month intervals until osteotomy healing is complete. No impact activities are allowed until complete osteotomy healing is noted radiographically. Patients are allowed to return to sport once they have met the following additional goals: (1) single-leg and three crossover hop test for distance within 15% of uninvolved limb; (2) ≤10% deficit in isokinetic peak torque with knee extension and knee flexion (60°/sec and 300°/sec) compared to uninvolved limb; and (3) able to complete sport-specific drills without compensatory movements, exacerbation of symptoms, or reactive effusion. Patients typically meet these goals between 6 and 9 months postoperatively.

## 21.8 Complications and Prevention

Complications of AMZ osteotomy include common complications associated with any surgical intervention and those lower extremity osteotomies including infection, excess bleeding, compartment syndrome, VTE, incision breakdown or delayed wound healing, persistent pain, complex regional pain syndrome, loss of fixation, malunion, delayed union, nonunion, or tibia fracture [15, 16]. Additional AMZ procedure-specific complications include pain associated with the hardware requiring future removal, arthrofibrosis or stiffness, progressive PF joint articular cartilage degeneration, nonunion of the osteotomy site, fracture of the tibia or osteotomy shingle, and intraoperative neurovascular injury to the popliteal or anterior tibial arteries and deep peroneal nerve. In a systematic review of complications associated with TTO, Payne et al. found an overall complication rate of 3.7% associated with AMZ with hardware removal being the most common complication with a rate of 49% [17]. Complications related to nonunion and fracture were decreased in cases where an intact distal cortical hinge was maintained.

Risk of complication can be mitigated with careful planning. Utilizing anticoagulation postoperatively and early motion can help reduce the risk of VTE. Early non-weight bearing with gradual progression can help prevent tibial fracture or loss of fixation [15]. Arthrofibrosis can be avoided with early range of motion exercises and consideration of a continuous passive motion (CPM) device [8].

## 21.9 Pearls and Pitfalls

### 21.9.1 Pearls

- A thorough diagnostic arthroscopy is imperative to ensure no chondral damage could compromise outcomes.
- A uniform osteotomy plane is important to ensure good bony contact after transfer.
- Do not over-medialize the tibial tubercle. Restoring the TT-TG distance to between 10 and 15 mm is the goal, never less than 10 mm.
- Hardware-related pain is not uncommon and may require a second surgery for removal.
- Many patients require concomitant procedures such as lateral release/lengthening, MPFL reconstruction, or cartilage restoration procedures. These should be performed simultaneously with the osteotomy.

### 21.9.2 Pitfalls

- A deep cut or cortical notch distally increases the risk of tibia fracture.
- Loss of the distal cortical hinge should be avoided unless distalization is planned.
- Appropriate screw length is critical as over-protrusion of the screws may result in neurovascular injury while an undersized screw may result in loss of fixation.

## 21.10 Outcomes

AMZ of the TT has proven to be a successful operation for PF chondral disease as well as instability. In a series of patients treated for patellar articular degeneration, Fulkerson et al.

reported 93% good to excellent subjective outcomes and 89% good to excellent objective outcomes at a mean of 35 months postoperatively [8]. In an analysis of 42 knees undergoing AMZ for patellar malalignment or cartilage breakdown, Buuck and Fulkerson reported 86% good to excellent subjective outcomes and 86% good to excellent results on physical examination with 95% of patients willing to undergo the procedure again [18]. Rosso et al. demonstrated longevity of the procedure with 77% survivorship at 108 months [19]. Outcomes are dependent on the location of cartilage damage. Pidoriano demonstrated 87% good to excellent outcomes for distal or lateral patellar chondral lesions but only 55% good to excellent results for medial facet lesions and 20% good to excellent results for proximal or diffuse lesions [14].

AMZ osteotomy can be very effective when performed with additional procedures to address concomitant cartilage pathology. Gillogly and Arnold reported significant improvement in IKDC, Lysholm, Cincinnati Knee Score, and SF-12 scores for patients undergoing concomitant PF ACI and AMZ, with 83% good or excellent outcomes [20]. Farr evaluated patients undergoing ACI for grade III and IV PF chondral lesions with concomitant ACI with 75% good to excellent outcomes on the modified Lysholm scale [21]. When he compared his outcomes to those reported by Pidoriano [14], he noted improved outcomes with ACI with AMZ compared to AMZ alone. Similarly, in a systematic review, Trinh et al. found that in studies comparing ACI to ACI with TTO for treatment of PF chondral pathology, those undergoing TTO had significantly greater improvement [22].

While most cases with patellar instability today are treated with MPFL reconstruction with the possible additional of a tibial tubercle osteotomy depending on anatomy and patellar tracking, AMZ osteotomy in isolation has also been reported with relatively good outcomes. In an evaluation of 107 knees treated with AMZ for patellar maltracking or dislocation, Palmer et al. reported 79% had good to excellent outcomes at a mean of 5.6 years follow-up [23]. Tjoumakaris et al. reported good outcomes of 44 patients treated with isolated AMZ osteotomy and lateral release for patellar instability and lateral maltracking [24]. In patients undergoing combined MPFL reconstruction with AMZ, Allen et al. found good subjective outcomes, a low rate of recurrent instability (6.7%), and that 87% of patients were able to return to sport. Several other authors have confirmed the ability to return to sports at the same or higher level than pre-op following AMZ osteotomy performed for PF pain or arthritis [25] as well as instability [24].

## 21.11 Conclusions

AMZ osteotomy is a reliable and useful procedure that allows for patellofemoral realignment as well as unloading of portions of the patellofemoral joint. Careful evaluation and consideration of the patient's pathology with diligent preoperatively planning allow the surgeon to perform this procedure with relatively low complication risk.

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## 22

# Tibial Tubercle Osteotomies: Techniques and Distalization

C. Batailler, S. Lustig, and E. Servien

## 22.1 Introduction

Symptomatic patellar instability is a very disabling pathology. It is most likely a result of a number of anatomic and physiologic factors causing a failure of the extensor mechanism to deliver the patella into the femoral sulcus. Several morphological anomalies have been identified which facilitate or allow patellar dislocation [1]. We perform "à la carte" surgery, according to the present anomalies on preoperative radiography and CT scan [2]. In more than 96% of cases, the radiographic examination will detect at least one of the following features in episodic patellar dislocation (EPD) group: trochlear dysplasia, patella alta, tibial tubercle–trochlear groove distance (TT–TG) >20 mm, or patellar tilt >20°. The objective of the tibial tubercle osteotomy is to correct one or two main factors of patellar instability [3]. In order to lower or medialize the distal extensor mechanism, different surgical techniques have been described.

The aim of this chapter is to clarify the indications of tibial tubercle osteotomy and to describe the surgical technique.

## 22.2 Indications

The distalization of the tibial tubercle is indicated to correct patella alta [4, 5]. Patella alta, measured by Caton-Deschamps ratio on the strict lateral radiograph (Fig. 22.1), is defined by a Caton-Deschamps index greater than 1.2 [6]. This abnormality is corrected to between 0.8 and 1.0 by distal transfer of the tibial tubercle. The aim is to bring the anterior tibial tubercle (ATT) to a more distal position in order to obtain a Caton-Deschamps index of 1. For example, in a patient with a Caton-Deschamps index of 1.3, with AT distance of 39 mm and an AP distance of 30 mm, the distalization necessary is 9 mm to reach an index of 1.

If the ATT is too lateral, a medialization of the ATT can be performed in the same time. This morphological abnormality is assessed on CT scan. A TT–TG superior to 20 mm is considered abnormal and requires a medialization of the tibial tubercle in the same time than the distalization. All distalization of ATT cause systematically a small medialization in the same time of almost 4 mm.

## 22.3 Surgical Technique

### 22.3.1 Installation

The patient is placed on the operating table in supine position with the knee in a 90° flexed position. A tourniquet is applied high on the proximal thigh.

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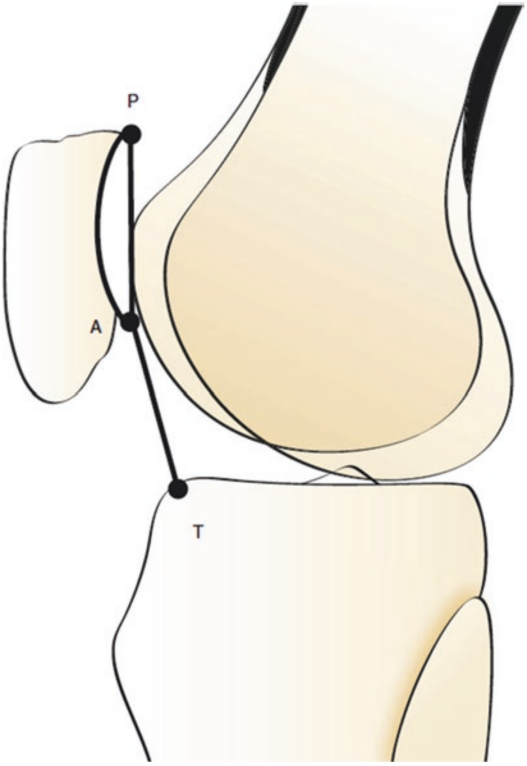

**Fig. 22.1** The Caton-Deschamps index is the ratio of the distance from the lower edge of the articular surface of the patella to the anterosuperior angle of the tibia outline (AT) to the length of the articular surface of the patella (AP)

### 22.3.2 Arthroscopy

According to the patient, an arthroscopy should be done at the beginning of the procedure to assess associated lesions, chondral injuries, and patellar tracking, which can be done using an accessory superolateral portal.

### 22.3.3 ATT Transfer

The approach is anteromedial and extended from the lower third of the patella to 6 cm above the patellar tendon's insertion. ATT was exposed on both medial and lateral sides. The patellar tendon and the inferior pole of the patella are identified. A 6-cm-long bone block will be harvested.

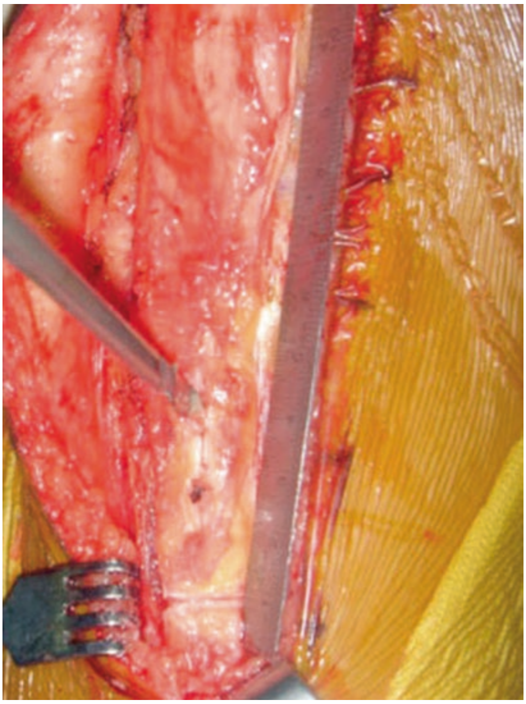

**Fig. 22.2** The tibial tubercle osteotomy measures 6 cm of length. Two 4.5 mm holes are drilled in the midline of the ATT, before the osteotomy

Prior to carrying out osteotomy, the first step is to prepare the fixation. Usually, the anterior cortex is drilled with a 4.5 mm drill (Fig. 22.2). A countersink is used in the two holes in order to avoid prominence of the screw heads underneath the skin.

Osteotomy is done with an oscillating saw and completed with an osteotome. The lateral cut is done first, in a horizontal direction, followed by the medial cut, in an almost vertical direction, followed by the distal cut (Figs. 22.3 and 22.4). The bone block should be 6–8 cm in length and sufficiently thick, i.e., in cancellous bone. In the distal part of ATT, an additional bone block is removed of which the length corresponds to the amount of distalization. It is primordial to finish the ATT osteotomy with a gentle slope, to reduce the risk of fracture of the tibial shaft.

The ATT transfer is performed according to the preoperative plan: the aim of the postoperative

**Fig. 22.3** The osteotomy is done with an oscillating saw. The lateral cut is done first, in a horizontal direction, followed by the medial cut, in an almost vertical direction, and finally the transverse distal cut

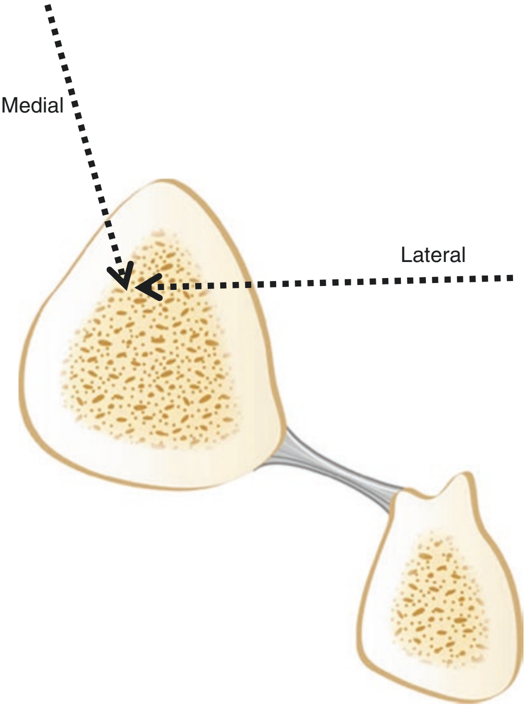

**Fig. 22.4** Lateral cut is in a horizontal direction, and medial cut is in a vertical direction

Caton-Deschamps index is equal to 1; the target was a postoperative TT–TG distance around 12 mm. Two extra millimeters can be added due to possible proximal movement of tibial tubercle during screw fixation.

Two 3.5 mm orifices are done through the posterior cortex perpendicular to the tibial shaft, and fixation of the osteotomy bone block is assured by two 4.5 mm cortical screws, 2 mm longer than the measured orifice. It is important that the screws are fixed in a strict perpendicular position in relation to the tibial shaft. Care must be taken to keep the TT parallel to its original bed; otherwise, a lateral patellar tilt might occur.

In case of large lowering, the medial and the lateral retinaculum must be released.

### 22.3.4 Patellar Tenodesis

In some cases, an ATT distalization is not sufficient to normalize the patellar tracking.

In case of excessively long patellar tendon, ATT transfer does not correct the length of the patellar tendon and does not avoid a windshield wiper effect. Thus, it might be considered when the patellar tendon length is superior to 52 mm [7]. The contraindications of the patellar tendon tenodesis associated with a tibial tubercle distalization are a normal patellar height, a femoro-patellar osteoarthritis on preoperative X-ray, and open physes in skeletally immature patients.

The tibial tubercle distalization is performed as usual. Before fixation of the bone block, two suture anchors are placed on both sides of the patellar tendon, near the top of the original location of the tibial tubercle, approximately 3 cm below the joint line, the normal insertion level of the tendon. The bone block is then fixed in the new, distalized position with two 4.5 mm bicortical screws. After fixation of the osteotomy, the tendon is vertically incised at 1/3 and 2/3 of its width with a 23 scalpel blade. The sutures from each anchor are tied across the lateral and medial 1/3, tenodesing the patellar tendon into the proximal tibia (Fig. 22.5).

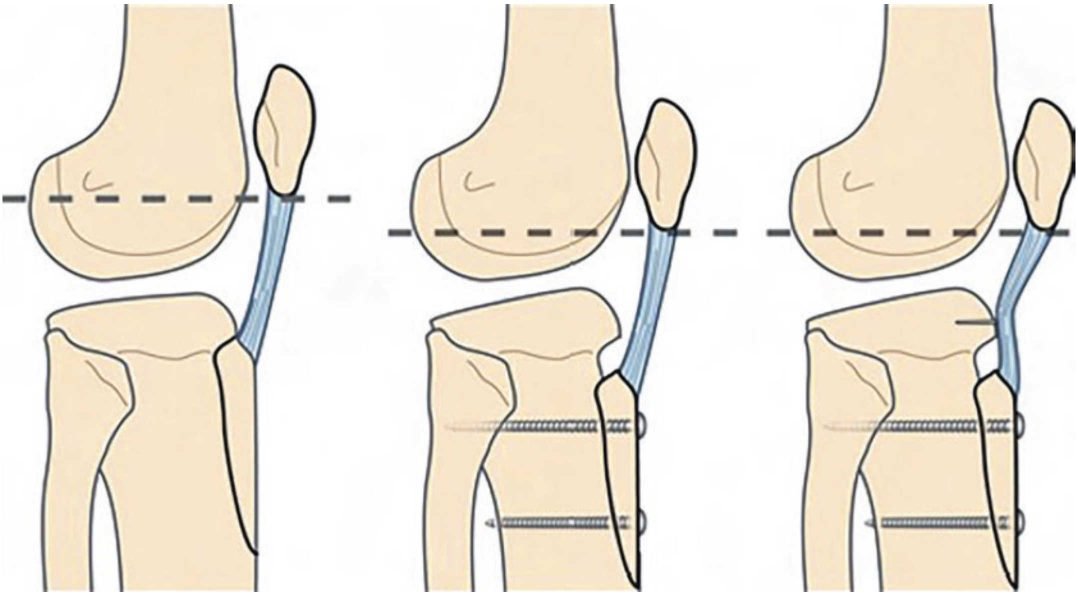

**Fig. 22.5** The tenodesis of the patellar tendon associated with a tibial tubercle distalization consists to perform a tenodesis on the tibia at the point where the patellar tendon was previously inserted, after the distalization of the tibial tubercle. This will be approximately 29 mm below the joint line

## 22.4 Postoperative Care

On postoperative X-ray, we must use preferentially the Caton-Deschamps index, because the Insall-Salvati ratio is not corrected by the tibial tubercle osteotomy or by the patellar tenodesis. The Caton-Deschamps index shows clearly the distalization of the tibial tubercle with a decrease of the patella height. But it remains the same with or without a tenodesis of the patellar tendon. By contrast MRI shows the functional length of the patellar tendon after a patellar tenodesis.

Full weight bearing is possible immediately with a brace and crutches. A locked brace in extension is necessary during 45 days. Rehabilitation begins in postoperative period and consists of active isometric quadriceps contractions with good patellar ascension and medial-lateral patellar mobilization. Passive flexion is limited at 95° during 45 days. Thromboprophylaxis is continued for 15 days.

A control radiograph is performed at 45 days to check the bone consolidation. When bone consolidation is obtained, the brace is removed and the flexion is progressively increased.

After 60 days, normal activities of daily life and driving are started. Forced kneeling is avoided for 6 months. Open kinetic chain exercises are indicated. Patient can commence sports activities after 4 months. Jumping is not allowed until 6 months.

## 22.5 Complications

The most frequent complication is hematoma. Infection stays uncommon. Complex regional pain syndromes can occur and cause a patella baja.

The mechanical complications include failure of the ATT fixation, undercorrection, overcorrection, tibial or patellar fracture, and disruption of the extensor mechanism.

**Fig. 22.6** The failure of ATT fixation can result in non-union of the ATT osteotomy and in its migration

Insufficient of ATT osteotomy fixation can cause ATT migration, delayed union, or non-union (Fig. 22.6). For these cases, a surgical revision is necessary, with a new fixation of the ATT osteotomy associated often with a bone graft. It is of major importance to always use a screw 2 mm longer than the measured drill trajectory in order to provide adequate fixation. The risk of non-union can be minimized with a TT fragment larger than 6 cm.

The fractures of the tibial shaft are rare and most likely iatrogenic. They can occur at the end of the osteotomy, if the cuts are too aggressive and abruptly stopped (Fig. 22.7). The shape and the thickness of the ATT osteotomy are thus primordial.

**Fig. 22.7** The fracture of the tibial shaft can occur on the distal part of the ATT osteotomy, when the distal cut is too aggressive

The mistakes of correction can result in persistent instability and patellar dislocation (undercorrection) or, at the opposite, patella baja with patellar pain and medial patellar impingement (overcorrection) (Fig. 22.8). These complications frequently cause more disability than the instability itself.

## 22.6 Conclusion

Patella alta is a frequent factor predisposing to patellar instability. In the literature, distal tibial tubercle realignment is described as an efficient procedure to correct abnormal patellar kinematics, correcting the patellar height and restoring the patellofemoral stability. Its surgical management is primordial to avoid recurrence of patellar instability. Some tips and tricks are useful to perform distalization of ATT osteotomy without complication.

**Fig. 22.8** An overcorrection or a complex regional pain syndrome can induce a patella baja, with the risk of persistent pain and a low flexion

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# Tibial Tubercle Osteotomies: Techniques and Medialization

## 23

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## 23.1 Introduction

Recurrent patellar instability is a disabling condition which occurs mainly in young patients and is responsible for functional limitation during both daily life and sports activities.

Originally the term patellofemoral malalignment (PFM) introduced by Insall in 1979 [1] including a wide range of pathological conditions is an expression of abnormal patellar tracking on the trochlea with unbalanced transmitted loads on the cartilage.

In the 1990s, Dejour et al. classified [2, 3] patellofemoral disorders into three major categories:

- *Objective patellar instability* (*OPI*): at least one documented patellar dislocation and one of the four instability factors presets on radiographic imaging.
- *Potential patellar instability* (*PPI*): at least one of the instability factors but non-documented patellar dislocation.
- *Patellofemoral pain syndrome* (*PFPS*): pain with no patellar dislocation and no anatomical (radiographic) abnormalities. This represents the largest group since anterior knee pain has been reported in up to 30% of adolescents, with roughly 75% of these patients describing limitation in sport activity.

Patellofemoral instability is generally defined as an abnormal movement of the patella with respect to the trochlear groove of the femur [4], and it occurs most often when the knee is between 0° and 30° of flexion and the patella is not fully engaged into the patellar groove [5].

Instability of patellofemoral joint is generally multifactorial, and several factors have been recognized as responsible for these condition. Among these, primary factors are represented by trochlear dysplasia, patella alta, and excessive tibial tuberosity-trochlear groove (TT-TG) distance, whereas secondary factors are genu valgum, genu recurvatum, femoral and tibial torsion (lower limb malalignment), insufficiency of the vastus medialis obliquus (VMO) or of the medial retinaculum, and a generalized ligamentous laxity.

Several surgical techniques have been described to correct each of the primary factors since the Lyonnaise school introduced the term "menu a la carte" in the treatment of patellofemoral instability.

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Concerning the treatment of excessive TT-TG, Roux first introduced medial tibial tuberosity transfer in 1888. The Elmslie–Trillat (ET) procedure, then, was published by Trillat et al. in France as a modification of Roux's tibial tuberosity transfer. It involves a combination of soft tissue and bony procedures, namely, lateral release and medial capsular reefing, as well as a tibial tubercle osteotomy and medial displacement over a distal periosteal pedicle.

## 23.2 Patellofemoral Biomechanics of Medialization

Biomechanical studies are essential to assess the efficacy of a surgical procedure.

As a general biomechanics assumption, chronic symptoms of recurrent instability or pain, once nonoperative treatment fails, may be treated with TT transfer surgery in patients with an increased *Q* angle and TT-trochlear groove (TG) distance. Medialization of the TT reduces forces applied on the lateral side of the patella through a change in the direction of the patellar tendon. However, medialization may interrupt well-balanced joint and conversely increase overall contact pressures on the medial side of the patellofemoral joint, leading to iatrogenic medial overload. Actually, we're missing a general consensus to define the threshold of TT malalignment at which surgical treatment is considered appropriate.

Many biomechanical and computational simulation studies have been published but may not be easy to interpret since they showed similar results but not often comparable.

Summarizing these kinds of studies, Elias et al. [6] stated that several conclusions can also be drawn from the literature on tibial tuberosity medialization.

A lateralized TT tends to increase lateral patellar shift and tilt, whereas medial transposition of the TT increases forces on the medial side and decreases lateral patellar contact pressures. However, while medial contact pressures tended to reach a plateau during progressive medialization, unlike lateral contact pressures during lateralization, which continued to rise, Stephen et al. [7] conducted a study comparing the effects of TT lateral and medial transposition and hypothesized that the smaller effect of TT medialization compared with lateralization occurred as a consequence of the tension in the iliotibial band and lateral retinaculum and the lower stiffness of the medial retinaculum and medial patellofemoral ligament (MPFL).

Moreover, anteromedialization of the TT also gives a force reduction on the lateral side, but the change was not consistently greater compared to what has been showed with medialization.

Medialization of the TT caused also an increase of tibial external rotation, which may reduce the effect of the surgical correction, limiting moreover the risk of overcorrection. The effect of an increased tibial external rotation on tibiofemoral cartilage is currently unknown [6, 8].

## 23.3 Indications

The surgical treatment of patellar instability should be customized to the anatomy and pathology of the patients, taking into account also the timing of the trauma.

An acute patellar instability (first-time dislocation) is traditionally treated conservatively by bracing and physical therapy, unless there is the presence of an unstable osteochondral lesion.

Surgery is typically indicated for recurrent dislocations.

Cox [9] has outlined the indications for the ET procedure which include (1) recurrent subluxation or dislocation of the patella with an abnormal quadriceps angle or patella alta, (2) patellofemoral symptoms with abnormal extensor mechanism as measured by an increased *Q* angle, and (3) acute patellar dislocation or subluxation with intra-articular pathology, such as osteochondral fractures and torn medial retinaculum.

Brown [10] added an abnormal *Q* angle measured preoperatively and after surgical correction. In his study the correction of the *Q* angle to 10° was correlated with good or excellent results. However Naranja et al. [11] measured an abnormal *Q* angle in all patients in their series, but it was not correlated to the results. Shelbourne et al.

[12] has found the congruence angle a good and reliable measurement for assessing the need for surgical intervention.

In the 1990s some authors have restricted the indications to patellar instability with recurrent patellar dislocation or subluxation [13] sometimes with personal modification of the technique [14, 15]. Karataglis et al. [16] still have in their series patients with anterior knee pain with malalignment who had worse results compared to the instability group alone. Barber [17] has selected a group of patients with recurrent lateral dislocation (minimum three) or increasingly frequent subluxations with no patellofemoral pain or arthritis which could be seen radiographically.

The CT is performed according to a dedicated protocol developed in Lyon [18] by superimposing CT coronal images of the summit of the trochlear groove and the tibial tubercle in full extension of the knee. The distance between the deepest point of the trochlear groove and the middle point of the tibial tubercle is defined as the TT-TG distance. This measurement if superior to 20 mm is considered abnormal. A proper assessing of patellar tilt or subluxation preoperatively using CT images allows an accurate selection of surgical technique.

The goal of the TT transposition is reducing the TT-TG distance in a range going from 12 to 16 mm.

In our practice we have restricted the use of this technique to young patients with recurrent patellar instability, no sign of arthritis with related pain and with a TT-TG distance higher than 20 mm measured on CT scan. Some authors [16, 19] consider the TT-TG distance over 15 mm as pathologic because associated with a greater probability of patellar instability. We combine to the tibial tuberosity medialization with MPFL reconstruction in cases with grade C trochlear dysplasia or in revision surgery.

## 23.4 Surgical Technique

### 23.4.1 Historical Perspective

The original technique described by Trillat has been modified and personalized by different authors, but the classical technique combines lateral release, medial capsular reefing, and medial displacement of the bony insertion of the patellar tendon with distal displacement according preoperative planning.

The ET procedure combines lateral retinacular release, medial capsular reefing, and medial displacement of the anterior TT hinged on a distal periosteal flap according to preoperative planning [7].

The operation consists of an isolated medialization of the TT. The primary indication is for patients with patellar instability or lateral maltracking.

#### 23.4.1.1 Skin Incision

In the original description, it goes from the superolateral margin of the patella to the midportion of the patellar tendon and then curves medially to the TT, 4–5 cm below its inferior margin. Cox and Brown [9, 10] have used a full lateral incision which has become shorter [12], oblique [20], or centered on the tibial tubercle [16, 17, 21].

#### 23.4.1.2 Medial Reefing

Always performed in the 1980s [9, 10, 22], it has been gradually abandoned [12, 14] or performed in difficult cases sometimes with VMO muscle advancement [11]. Marcacci [14] has dissected the VMO to assess the medial facet of the patella and make a clearer evaluation of its tracking in the trochlear groove. Barber [17] has used an intra-articular thermal shrinking of the medial retinaculum with a monopolar probe.

#### 23.4.1.3 Lateral Release

Every author has described an extensive lateral release from the tibial tubercle distally to the vastus lateralis tendon proximally, preserving the muscle fibers. At the beginning the release was made with a z-plasty of superficial and deep fibers of the retinaculum [7, 13]. Later only the synovium has been preserved with open techniques. With arthroscopic technique [17], the release starts from inside the joint under direct visualization.

#### 23.4.1.4 Tibial Tubercle Osteotomy

This part of the technique has been subjected to different evolutions. The osteotome is widely accepted as the main bone cutter; some authors begin with a microsagittal oscillating saw [23, 24]. The osteoperiosteal flap is from 4 to 7 cm long, from 0.7 to 1 cm thick, and from 1.5 to 2 cm wide. The medialization on the periosteal hinge is 10 mm on average (from 0.7 to 15 mm maximum); this choice is always driven by accommodation of patellar tracking. Fixation of the medialized tubercle is achieved with one or two cancellous [9, 12, 20] or bicortical [11, 16] screws. Some authors have developed a personal modification of the technique: Marcacci [14] isolated the medial third of the patellar tendon with a corresponding bone plug that is attached near the medial collateral ligament under tension; a similar technique was used by Rillman [20] who has not described any proximal realignments.

## 23.4.2 Surgical Procedure

### 23.4.2.1 Patient Positioning and Sterile Field

The patient is placed in a supine position and clinically re-evaluated under anesthesia.

The evaluation under anesthesia is performed to assess the patellar tracking and dislocation of the patella. A laterally directed force is applied to the patella to establish whether or not the patella can be dislocated. If the patella is dislocated, maintaining the force of dislocation, the angle of flexion at which the patella relocates is evaluated.

If the patella could not be fully dislocated, the displacement is evaluated using the quadrant method.

A pneumatic tourniquet is placed on the proximal third of the thigh; the operative limb is placed on an arthroscopic leg holder or a roll and sustainer are applied. After setting up a sterile field, an arthroscopy is performed using standard anteromedial and anterolateral portals.

This last portal may be placed at a more distal level and may be used as an instrument portal during the lateral release.

An arthroscopic assessment of patellar tracking is performed. The examination includes the lateral deviation of the patella (overhang sign) at varying degrees of knee flexion and incongruity of tracking in the intertrochlear sulcus.

A proper assessment of patellar tracking should be conducted with the tourniquet deflated and the inflow turned off.

Osteochondral damages may result from recurrent dislocation episodes or from chronic trauma secondary to a patellar instability with osteochondral fragments on the medial patellar border or lateral femoral condyle.

Meniscal and chondral lesions are treated first. The chondral fragments are removed as loose bodies or detached from the soft tissue.

### 23.4.2.2 Lateral Release

The patellar tilt and the amount of limited medial translation after direct pressure on the lateral side, performed before the arthroscopy, are the two main indicators for a lateral release. This procedure is patient specific and sometimes not necessary.

Since the ET technique has been described, the lateral release has developed from an open technique to an all arthroscopic procedure. We now use only two standard arthroscopic approaches using a short skin incision just for the medialization of the tubercle. The arthroscope is placed into the anteromedial portal, and the lateral retinaculum must be well visualized. The incision of the retinaculum starts at the middle third of the patella, 1–2 cm below its lateral border toward the distal end of the retinaculum.

We usually prefer cutting bipolar arthroscopy radio frequency systems. The first layer is the synovial covering and then the retinaculum to the level of the sub-cutaneous tissue. Proceeding upward, the release must carefully avoid the distal fibers of the vastus lateralis: it may cause bleeding and a painful scar tissue. After the release, it is possible to control the bleeding using the same bipolar tool as an electrocauter. If the vascular stump is difficult to be visualized, deflating the tourniquet can help to identify and cauterize the vessels.

The release may not be complete at this stage because of some fibers left intact at the distal part of the ligament. During the TT transposition, it will be completed with scissors.

After the lateral release, the patella should be displayed better balanced in the trochlea and the tilt reduced or neutralized. An adequate release allows everting the articular surface 90° laterally.

#### 23.4.2.3 Tibial Tuberosity Medial Displacement

A longitudinal lateral incision of about 5–6 cm is made just lateral to the TT to avoid the infrapatellar branch of the saphenous nerve. The soft tissue is carefully removed, and the TT is identified. The periosteum on the medial side is incised longitudinally for 5 cm with electrocautery along the planned osteotomy plane which should be no less than 0.5 cm height and tapered distally to allow a greenstick fracture (Fig. 23.1a, b). On the lateral edge of the TT, periosteum and anterior tibialis muscle are detached with a blunt subperiosteal elevator for a depth of approximately 10 mm to allow complete visualization of the lateral aspect of the tubercle and posterolateral tibia. A retractor can be placed just posterior to the lateral tibial cortex to provide protection to the tibial artery and deep peroneal nerve (Fig. 23.2).

In our technique, two single Kirschner wires (K-wires) from the medial to lateral direction are placed as a guide for the freehand cut (Fig. 23.3). In case of a desired anteriorization, the K-wires could be tilted in the anteroposterior plane from 30° to 60°. The cut is started proximally over the two K-wires, with an oscillating sagittal saw blade, through the desired inclination of about 1 cm deep and 5 cm distally, toward the distal extent of the tuberosity (Fig. 23.4). Next, a small osteotome is used to complete the osteotomy with a transverse cut just proximal and lateral to the patellar tendon tibial attachment. The shingle should then be free to toggle, with its only remaining attachment site being a distal periosteal hinge (Fig. 23.5).

Once the tuberosity is raised, the capsule is incised on the lateral side (to complete eventually the lateral release) and on the medial side to release the patellar tendon. These releases are left open.

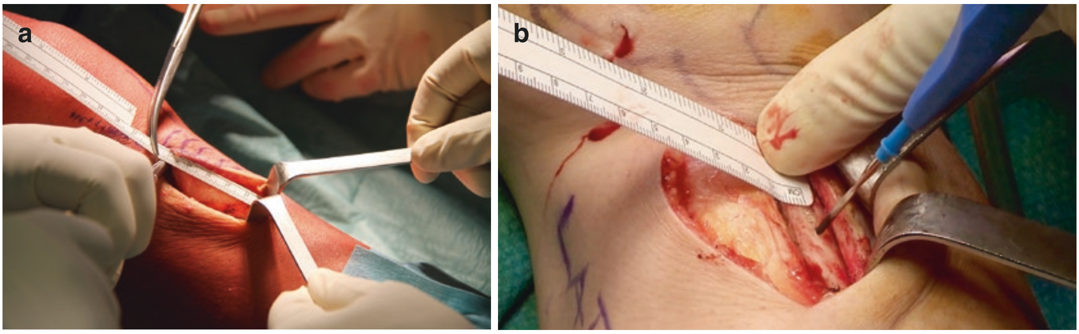

**Fig. 23.1** (**a**, **b**) The bone plug length should be from 4 to 7 cm and from 0.7 to 1 cm thick

**Fig. 23.2** Two retractors are placed just posterior to the lateral tibial cortex to protect the tibial artery and deep peroneal nerve

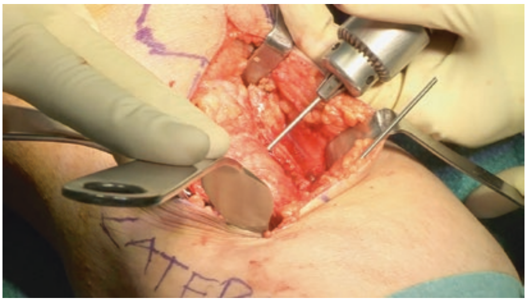

**Fig. 23.3** Two K-wires from the medial to lateral direction are placed as a guide for the freehand cut

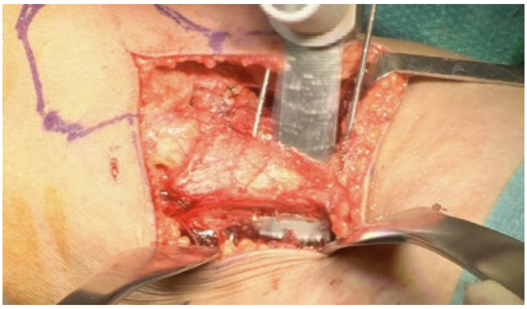

**Fig. 23.4** Inclination of the pins goes from 0° in straight medialization up to 60° depending on the amount of anteriorization desired

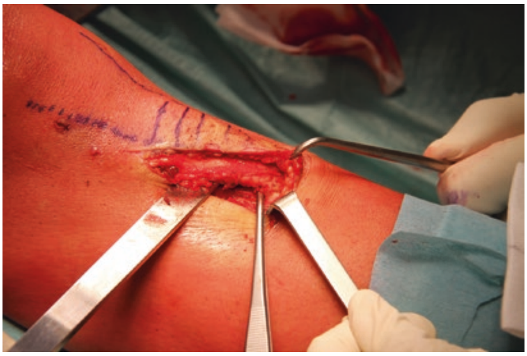

**Fig. 23.5** An osteotome is used to release the pedicle with a light pressure on its proximal end, leaving a distal periosteal hinge

A small osteotome or a curette is used to remove the excess bone on the medial side and create a flat bed of cancellous bone. The pedicle is displaced medially about 1 cm (as measured on CT scan) and pierced temporarily with a drill bit in order to evaluate the patellar tracking in the selected position (Fig. 23.6). This inspection can be better carried out introducing the arthroscope into the joint without inflow and tourniquet and from a superolateral portal. Finally the tibial tubercle is fixed with one or sometimes two bicortical screws (Fig. 23.7).

#### 23.4.2.4 Medial Reefing

In the literature this procedure is no longer associated with TT transposition. MPFL reconstruction is performed as second step in case of grade C trochlea dysplasia (Fig. 23.8).

**Fig. 23.6** The plug rotation is temporarily locked with a drill bit in order to evaluate the patellar tracking in the selected position

**Fig. 23.7** Tibial tubercle in the new position is fixed with one or sometimes two bicortical screws

**Fig. 23.8** MPFL reconstruction could be performed as second step in selected cases

## 23.5 Postoperative Treatment

After surgery, the knee is placed in a hinge brace. Early weight-bearing should follow a gradual progression from full protection with a rigid brace locked at full extension to an unlocked brace with crutches. Gradual increase to full weight-bearing should be permitted as quadriceps strength is restored [25].

The brace is discarded 6 weeks postoperatively, and full motion should be reached within 6 weeks.

The patients should move through rehabilitation phases depending on functional goals which must be reached to allow the recovery of normal walking, running, and finally sport activities. Boldrini et al. [26] suggested five steps: (1) resolution of swelling and inflammation; (2) recovery of range of motion and muscle flexibility; (3) recovery of muscle strength and resistance; (4) recovery of neuromuscular control and coordination; and (5) recovery of specific gestures.

Rehabilitation starts in the first days post-op. An early mobilization is performed in the first 2–3 weeks after surgery, using CPM for 6–8 h per day with a gradual increase in the ROM (as tolerated). Progress to full active flexion and extension is allowed as soon as possible.

Running can be started after 12 weeks, and return to sport is allowed between 4 and 6 months postoperatively.

## 23.6 Discussion

The patellofemoral instability is becoming increasingly popular, and, since Insall coined the term “patellofemoral malalignment” [27], more and more studies are focused on this topic.

A better understanding of the biomechanics of the patellofemoral joint has given the surgeon the possibilities of differentiating the source of the anterior knee pain from that of patellar instability, leaving only a restricted area in common.

A wide series of patellofemoral problems doesn’t need a surgical treatment and can be successfully treated with conservative therapy so that the surgeon deals with more selected cases than in the past.

Despite what has been said, a high number of conservative treatment fails, so the surgical treatment is appropriate.

Proximal realignment has been widely used in the past with good results through the open technique. After 5 years, Abraham et al. [28] had a 78% of improvement in the unstable group, while only 53% of improvement in patients suffered patellofemoral pain. This surgical procedure is able to restore a normal congruence angle [29, 30], but it cannot modify the TT-TG off-set or the patellar height.

Isolated lateral releases are not effective in the long term because a decline of good results is showed at medium terms [31] and nowadays is no more used as isolated procedure.

Distal tibial tubercle realignment is considered an effective procedure for correcting the patellar tracking and for unloading the patellofemoral joint in a population with increased lateral distance of the TT-TG.

There are two main surgical techniques used by most surgeons for distal realignment: the Fulkerson osteotomy [23] and the Elmslie–Trillat procedure. The first combines medialization and anteriorization producing an added “Maquet effect.”

The ET technique for medial realignment of tibial tuberosity has undergone readjustment and improvement though the principles of the technique are still efficient and supported by good mid- and long-term results if referred to patellar instability.

The medialization of the TT allows to correct abnormal patellar kinematics and to set a patellar lowering of about 5 mm [32]. Marcacci [14] has found a supplementary effect on patella height with a normalized Insall–Salvati index (1.19 from 1.49 preoperative value); Brown and Shelbourne [10, 12] report excellent results in patients with patella alta.

Cox [9] published a preliminary report on a group of 52 knees operated on for patellar instability. He found 88% good results, but he has also recorded many associated problems like fractures of the patella or lateral femoral condyle, meniscus, or MCL (medial collateral ligament) lesions.

A few years later, the same author [33] reviewed 116 patients: 104 for patellar dislocation and 12 for patellofemoral pain and malalignment, including the same group of patients in the first study. He found 7% recurrent dislocation and a worsening of results in the group controlled in the first study with 66% of satisfactory results at 1–7 years follow-up. However, the realignment reduced the anterior knee pain even in those who did not receive any cartilage treatment.

Carney et al. [32] from the same group of the Naval Medical Service, San Diego, CA, USA, identified 18 patients from the group of 104 operated on for patellofemoral subluxation or dislocation between 1975 and 1979. The patients included in the study did not have any associated intra-articular or extra-articular pathology at the time of surgery nor any additional surgery or major trauma at the involved knee. Fourteen patients (15 knees) answered a questionnaire about recurrent episodes of patellar instability. One patient (7%) had recurrent instability, like the first study; 54% were rated as satisfactory results compared to 73% of the larger study group at 3 years FU. Carney's study is unique because it reports results of the ET procedure at 26 years follow-up. There is of course a declined functional status of this subset group difficult to assess if compared with the original large study population, but it is interesting to underline how this surgical procedure, applied in patients suffering just from patellar instability, may be effective even after 26 years.

Brown et al. [10] reviewed 27 knees at a mean follow-up of 45.9 months that were classified as dislocators (16 knees) or subluxator (11 knees). Though the authors do not give detailed information about anterior knee pain, they found 81% of patients rated as good or excellent. Excellent and good results are obtained after surgery for 11° of *Q* angle measurement values, while fair and poor results are described for 15° or greater. They stated that 1 cm of medial displacement results in 1 mm of patellar lowering and a decrease of the Q angle from 20° to 10°. They also described an oblique osteotomy of the tibial tuberosity so that its medial transfer elevates the tubercle reducing the patellofemoral joint reaction force.

The measurement of the congruence angle as an objective assessment of patellar malalignment has been emphasized by Shelbourne et al. [12] who found a significant correlation between the congruence angle and the incidence of patellar instability and demonstrated that its correction to less than +15° resulted in a decreased incidence of postoperative patellar instability. The authors studied 40 athletically active patients who underwent 45 distal realignment procedures with a modified ET technique with a mean preoperative congruence angle of 21.5°. The authors identified a large congruence angle as the only reason for instability; in fact, their mean postoperative angle was 45° (range 26°–62°) and accomplished that the ET distal realignment provides an average correction of 25° of congruence angle and more correction may be needed for patients with preoperative values higher than 40°.

Naraja et al. [11] reported the first long-term evaluation of ET associated with Maquet procedure (a 1-cm thick bone block placed underneath the tibial tubercle) for PF disorders. They had an 84% subjective improvement of their status over a 74-month average follow-up period. Age >31.5 years, less than two dislocations, and degenerative changes from 2° at the medial and lateral tibiofemoral compartment were considered risk factors that worsened results. The redislocation rate at final follow-up was 11%. A decrease of results occurred between the third and fourth years post-op. Nakagawa et al. [22] analyzed the deterioration of clinical results after ET procedure in 45 knees operated on for patellar instability. Subjectively the instability did not change with time, while PF pain worsened in half the knees. The patients were divided into two groups: good and fair results. The *Q* angle difference was wide but not significant between the groups, and increasing the grade of trochlear dysplasia affected the results in a negative way. Radiological changes and intervals between the first episode of dislocation and surgery longer than 1 year were associated with poorer results. The main cause of deterioration of clinical results was PF pain, not instability.

Rillman et al. [20] described a modified ET technique; the medial third of the patellar tendon was detached together with a bone chip 2 cm long and 0.7 cm wide and fixed with a cancellous screw in a new groove placed 1 cm medially. This technique was used in a consecutive series of 41 patients with persistent patellar instability. The author reported good results with no redislocation, and 11% had instability symptoms during vigorous sport. The X-rays showed no signs of osteoarthritis, one case of patella infera, and significant correction of the patellar congruence angle. Marcacci et al. [14] in their series of 18 knees with severe instability have associated an extensive lateral release, dissection of vastus medialis obliquus, and, if the patella was still unstable, a medialization of the medial third of the patellar tendon with correspondent bone block. Four patients with severe trochlear dysplasia received a deepening trochleoplasty procedure. At 5 years follow-up, 88% showed satisfactory clinical results with no episodes of patellar dislocation. Significant improvement in the Tegner activity score, correction of the congruence angle, and patellar height were recorded. This procedure had a supplementary effect on patellar height with an automatic lowering to normal values according to the Insall–Salvati index. Barber and McGarry [17] confirmed the hypothesis of restricted indication of the ET technique to a young population suffering only from patellar instability without chondral lesions although they were not able to link the results with trochlear dysplasia or any other radiographic measurement.

Farr et al. [34] reported a clear association between distal bone realignment procedures (like Elmslie–Trillat) and long-term patellar degeneration due to OA, especially in patients with delayed treatment.

However, in this retrospective case control study, the authors had no preoperative radiographs neither surgical descriptions of cartilage status available but only a review of radiography documents which revealed no cases of apparent preoperative joint degeneration. Since the mean age at the only follow-up available was 51.0 years (range 30.9–74.5 years) and the mean follow-up period was 20.9 years (range 12.3–28.7 years), these data in our opinion are not sufficient to draw definitive conclusions about correlation between this procedure and patellar degenerative changes.

Naveed et al. [15] enrolled 31 patients (34 knees) with chronic patellar subluxation or dislocation which underwent an Elmslie–Trillat osteotomy. Arthroscopy was performed before the osteotomy to document tracking and chondral damage with Outerbridge grading from 0 to 4. At the final review (mean 12 years, range 10–15 years), only 25 patients (28 knees) were available: each of them underwent clinical examination, knee radiographs, and Cox and Insall functional knee scores preoperatively and at the last follow-up. Four knees had undergone knee replacement, and, in the remaining 24 knees, with complete follow-up, 79.2% of them were reported to have a good or excellent outcome at 4 years and 62.5% at long-term follow-up. Furthermore the functional and radiological results showed that the development of patellofemoral osteoarthritis is directly related to the extent of preoperatively chondral damage.

Longo et al. [35] in their systematic review collected 38 articles, a total of 1182 knees belonging to 1023 patients, all of them were treated with distal realignment procedures (Elmslie–Trillat, Maquet, Fulkerson, Roux Goldthwait, and other distal realignment procedures); ET procedure was performed for 232 knees. The most important findings of this review are that distal realignment procedures performed alone or in combination with additional procedures provide good clinical results both in the short-medium-term and in the long-term follow-up. Postoperative complication and recurrence (2.1% with a mean follow-up of 56 months) considered as dislocation or subluxation are very low.

Another recent similar systematic review by Grimm et al. [24] confirmed the trend of good or excellent outcomes at long-term follow-up in patients treated with medial realignment: poorer outcomes were associated more to patellofemoral pain rather than patellar instability. Additionally, poorer initial outcomes were reported for patients with degenerative changes as noted on radiographs.

Filho et al. [36] reported their modified ET procedure, where the first cut is made horizontally in a downward curvilinear fashion and the second cut is made using a saw blade from the lateral to the medial side in an obliquely elevating manner; the osseous fragment, with the intact distal attachment, is rolled medially in the gutter created by the horizontal curvilinear cut. The horizontal gutter provides an inherent stability to the bone fragment; moreover the thicker dimension of the osseous fragment significantly increases the osteotomy union. They conclude that this technique allows early mobilization, avoiding complications due to prolonged immobilization, and provides adequate pain relief and stability with very low postoperative morbidity.

## 23.7 Conclusions

The ET procedure is a valid treatment for chronic patellar instability in a patient with closed growth plates, a TT-TG distance higher than 20 mm in absence of chondral lesions over grade 2. This surgical technique is a relative not aggressive, reproducible procedure. It can be associated with soft tissue proximal realignment, with a prerogative of fast postoperative recovery and quick rehabilitation program.

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# 24

# Complications of Tibial Tubercle Osteotomies

Marc Tompkins and Jeffrey Macalena

## 24.1 Introduction

Tibial tubercle osteotomy is a powerful surgical tool that can be used in multiple patellofemoral pathologic conditions [1]. It can be used to change the position/load between the patella and the trochlear sulcus by moving the tubercle in different directions including distal, medial, anterior, or a combination of these. It is important to understand, however, that there are many complications that can arise if the surgeon is not careful preoperatively, intraoperatively, or postoperatively. This chapter discusses the various complications that can occur and provides suggestions to minimize the risk of complications following tibial tubercle osteotomy.

## 24.2 Distalization of the Tibial Tubercle

Distalization of the tibial tubercle can improve the engagement between the patella and trochlea when patella alta is present. Patella alta is present in the setting of an elongated patellar tendon and/or a shortened trochlea. Functional patella alta is present in the setting of hyperlaxity and knee hyperextension. Distalization of the tibial tubercle is used in cases of patellar instability to improve engagement of the patella and the trochlear groove earlier in range of motion. It can also aid unloading of distal patellar chondral lesions by increased load sharing due to greater patellar contact.

Overcorrection of alta will lead to patellar baja, which can cause pain as well as decreased range of motion. Undercorrection of patella alta risks continued instability and a persistently elevated patella. There can be delayed healing of the distal aspect of the osteotomy [2].

### 24.2.1 Minimize the Risk of Complication in Distalization

- Avoid undercorrection or overcorrection (Fig. 24.1a) with adequate preoperative planning. On preoperative imaging, measure the estimated distance for distalization and then recalculate patella alta measurements and estimate the engagement of the patella and trochlea (Fig. 24.1b).
- Accurate measurement intraoperatively is also essential; be sure to carefully measure how much distal tibial tubercle bone is removed

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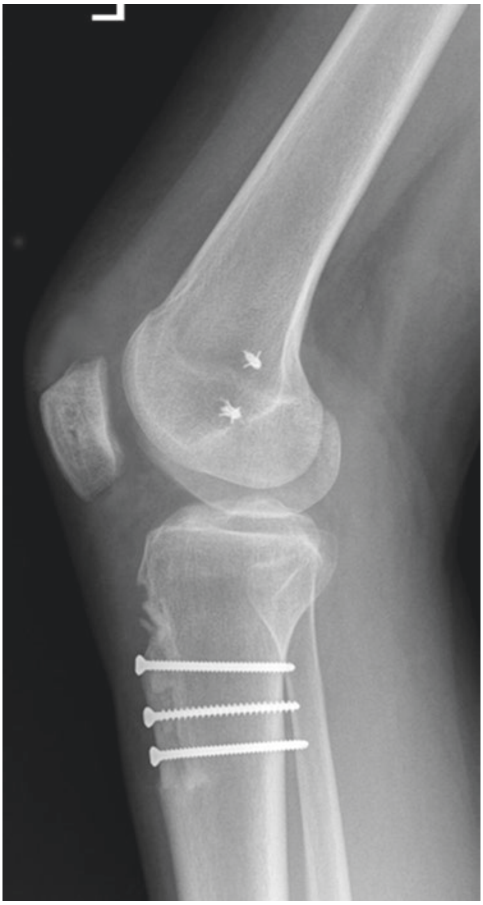

**Fig. 24.1** Lateral radiograph showing patella baja after distalizationc

(which equals the distance of distalization). This is rarely more than 1 cm; most commonly it is between 4 and 8 mm.

- The amount of patella trochlear overlap (engagement) should be directly visualized intraoperatively before final tubercle fixation (Fig. 24.1c,d).
- Reduce the tibial tubercle as close as possible at the distal osteotomy cut and fix the tubercle with the knee in extension.
- Early restoration of quad function during rehabilitation can also help to reduce the risk of patella baja as lack of quadriceps activation can lead to patella tendon shortening over time.

## 24.3 Anteromedialization of the Tibial Tubercle

Anteromedialization (AMZ) [3] of the tubercle can improve the vector of the extensor mechanism and can change the loading between the patella and the trochlea [4]. This procedure was described [5] to improve the articulation between the patella and trochlea in order to relieve pressure on the inferior and lateral patellofemoral cartilage surfaces in cases of anterior knee pain or patellofemoral chondromalacia [6]. It has also been used for patients with patellar instability in order to reduce the lateral pull of the extensor mechanism on the patella.

It is possible to overmedialize the tubercle. This can lead to increased contact forces between the medial patella and trochlea that are undesired. Depending on the congruence of the patellofemoral joint, this can lead to symptoms,

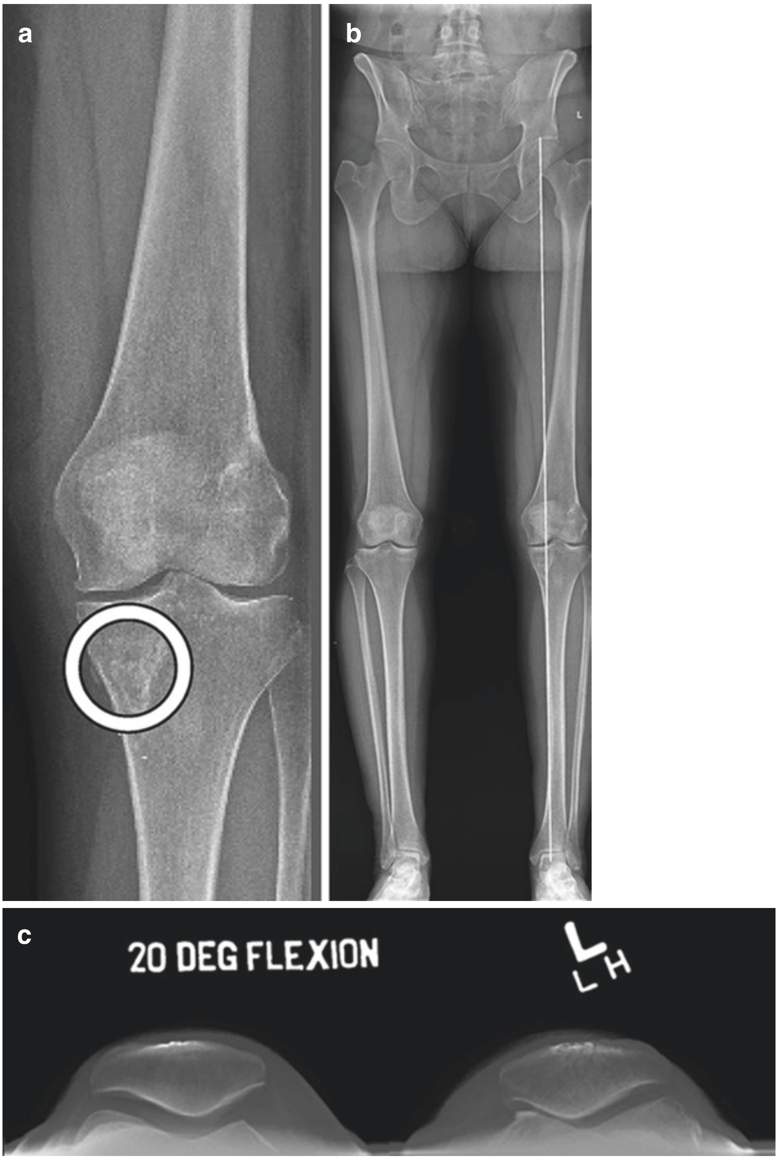

**Fig. 24.2** Medial patellofemoral overload following overmedialization of the tibial tubercle in AMZ osteotomy in the left knee. (**a**) AP of left knee with circle indicating the placement of the tibial tubercle following medialization. (**b**) Long leg AP films showing a varus alignment of the left limb. (**c**) Axial view of both patellae showing medial patellofemoral arthritis in the left knee 15 years after AMZ in that limb

such as swelling and pain, as well as degenerative changes in the medial patellar chondral surfaces (Fig. 24.2a). Overmedialization can also change forces in the tibiofemoral compartments and lead to undesired increased force in the medial compartment [7] (Fig. 24.2b). It is possible to produce too much anterior translation of the tubercle. In addition to some of chondral loading problems mentioned above, the primary problem with too much anteriorization is issues with wound healing. If there is too much stress on the skin, there can be skin breakdown. Also, greater anteriorization leads to less bone-to-bone contact which can delay healing of the osteotomy site.

### 24.3.1 Minimize the Risk of Complication in AMZ

- If the goal of the anteromedialization osteotomy is to reduce pressure on the cartilage, lateral and distal chondral lesions on the patella and lateral lesions on the trochlea have the best clinical outcomes when performing this procedure [8]. This procedure should be carefully considered if the chondral lesions are present elsewhere.
- Preoperative planning to evaluate how far medial to move the tubercle can avoid overmedialization. In addition, overmedialization can be avoided with intraoperative assessment of the tubercle sulcus angle because the relationship of the patella and trochlea at deeper degrees of knee flexion can be different than at lower degrees of flexion [9]. Tubercle sulcus angle of zero should be the intraoperative goal (Fig. 24.3).
- Moving the tubercle too anterior can be minimized by ensuring that attention is paid to the position of the leg and knee when the osteotomy cut is made such that the saw blade is not directed too posteriorly.
- Make sure the lateral retinaculum is not overly tight because a tight lateral retinaculum can prevent some of the desired medial movement of the patella [4].

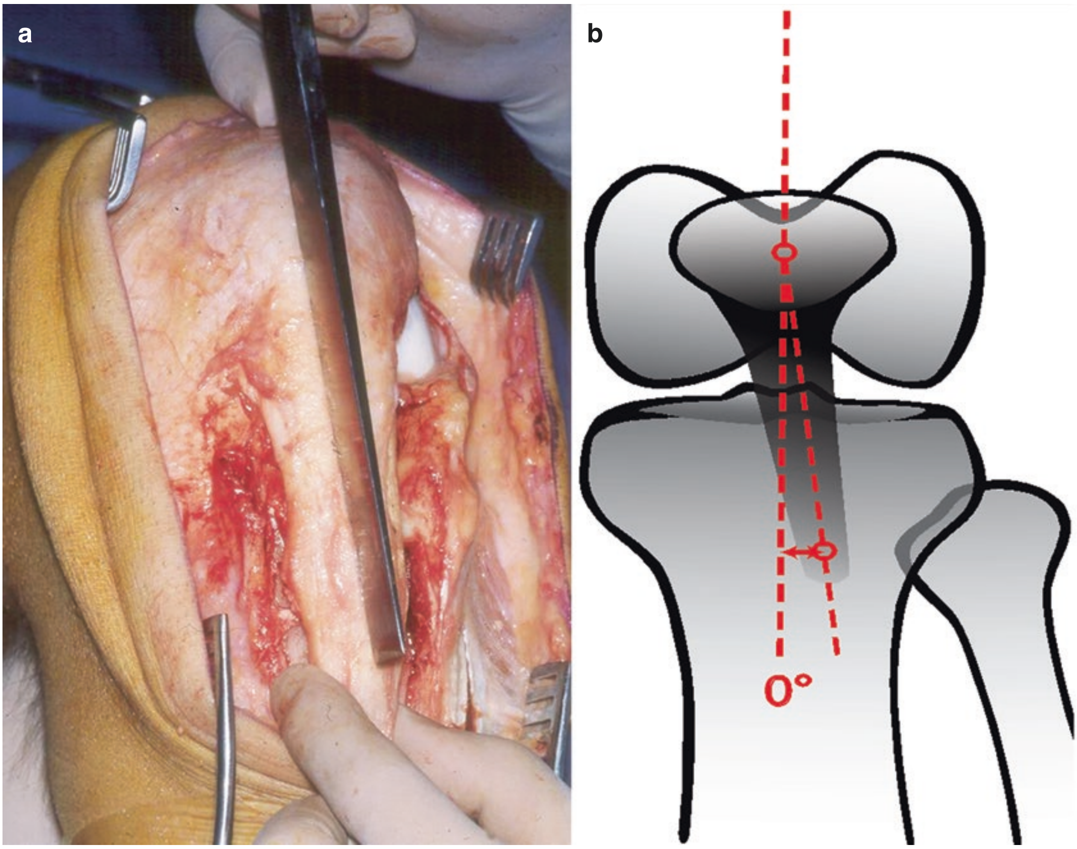

**Fig. 24.3** (**a**) Intraoperative measurement of tubercle sulcus angle. (**b**) Schematic demonstrating measurement of tubercle sulcus angle

## 24.4 Considerations for Distalizing or AMZ Osteotomies

Gerdy's tubercle can be damaged by the penetrating oscillating saw or osteotomes. With screws placed anteriorly, patients can experience symptomatic hardware.

### 24.4.1 Minimize the Risk of Complication in Both Osteotomies

- Protect Gerdy's tubercle by placing a longitudinal cut between the tibial tubercle and Gerdy's tubercle. Be sure not to penetrate too laterally with the saw blade or osteotome.
- Consider countersinking screws to minimize the prominence of the screws; be careful not to countersink too deeply. Low-profile screw heads may also reduce this risk.

## 24.5 Nonunion

The tibial tubercle generally has a broad surface area for healing; however, there is a risk of nonunion [2] (Fig. 24.4). This can be one of the more difficult complications to treat and may occur for many reasons including poor healing capacity of the patient, inadequate fixation, bone necrosis, and poor blood supply via adjacent soft tissue damage.

**Fig. 24.4** Nonunion of tibial tubercle fragment. Notice the lucency between the tubercle fragment and the tibia, the bent distal screw, and the lucency surrounding the screws, suggestive of loosening

### 24.5.1 Minimize the Risk of Nonunion

- Maximize patient healing capacity by asking about whether they are getting adequate nutrition in their daily diet. In particular, vitamin D and calcium are important nutrients for enabling bone healing.
- Ensure that patients are optimized for surgery by completing smoking cessation.
- Achieve bicortical fixation. Consider washers when tibial tubercle is too thin or osteoporotic. However, this can increase the risk of prominent hardware, so must be planned carefully.
- Consider three points of fixation, with good spanning of screws across tubercle fragment.
- Consider a tubercle fragment of at least 5–6 cm, depending on size of the patient [4].
- When placing screws, consider temporary fixation such as a K wire, which can prevent

the loss of reduction during screw placement.
- Minimize heat necrosis by rasping all osteotomy surfaces prior to final fixation.
- Protect the soft tissues, especially fascia and periosteum, at all times. In AMZ osteotomies, maintain the distal periosteum and lateral fascia.

## 24.6 Tibial Tubercle Fracture

Without careful surgical technique, it is possible to cause a fracture of the tibial tubercle fragment intraoperatively or to have a fracture of the tubercle postoperatively (Fig. 24.5). This has to do with how well the osteotomy is performed, the fixation of the tubercle, and postoperative rehabilitation.

**Fig. 24.5** Fragmentation of the tibial tubercle and pull-through of the proximal screws

### 24.6.1 Minimize the Risk of Tibial Tubercle Fracture

- Regardless of the size and shape of the tubercle shingle, the same forces from the extensor mechanism will be placed through the fixated tibial tubercle. So, plan ahead such that the tubercle will be thick enough and wide enough to hold fixation.
- The osteotomy should be at least 1 cm in thickness and through cancellous bone of the tubercle (not through only a shell of cortical bone).
- Ensure bicortical fixation and a tubercle fragment of adequate length [4].
- In cases of soft bone, avoid overly aggressive fixation; this is a good situation to consider washers.

## 24.7 Proximal Tibia Fracture

Proximal tibial fractures (Fig. 24.6), following tibial tubercle osteotomies, can occur from perpetuation of the osteotomy cut through the proximal tibia since the anterior cortex of the proximal tibia is disrupted with any osteotomy. Depth and direction of the osteotomy cut can impact the risk for this fracture. Speed of postoperative bone healing to re-establish the anterior cortex is important. Postoperative forces placed on the proximal tibia also impact the risk for fracture.

### 24.7.1 Minimize the Risk of Proximal Tibia Fracture

- Attempt to place osteotomy cut only through bone that will be involved in the osteotomy. In particular in distalizing osteotomies, avoid placing a cut too deeply in a posterior direction.
- Use an oscillating saw to minimize the risk of perpetuation of tibial fracture, which can occur using osteotomes.
- Adequate nutrition, rigid internal fixation, and optimization of smoking status can improve the healing so that the anterior cortex can absorb stresses more quickly.

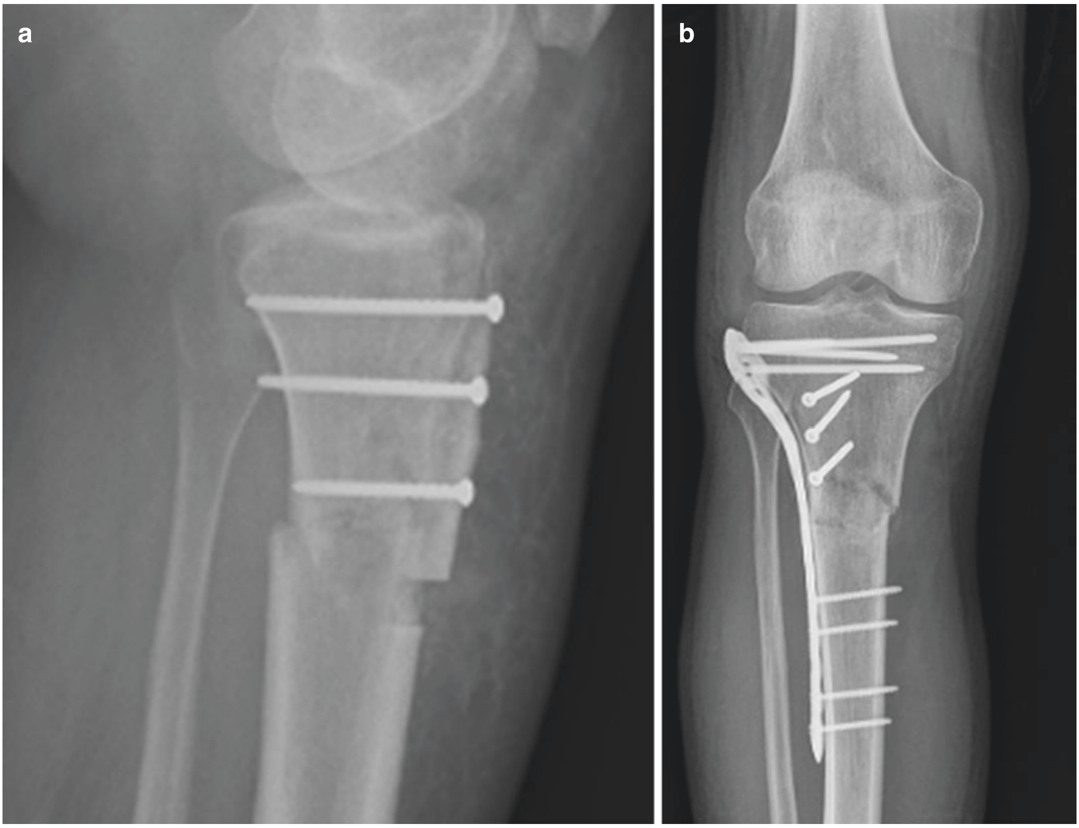

**Fig. 24.6** (**a**) Fracture though the distal aspect of the tibial tubercle osteotomy. (**b**) This fracture was displaced and required open reduction and internal fixation

## 24.8 Postoperative Rehabilitation

Appropriate postoperative rehabilitation is critical to avoid placing too much stress on the tubercle while at the same time maintaining good knee range of motion and quadriceps function.

### 24.8.1 Minimize the Risk of Complications During Postoperative Rehabilitation

- Counsel patients about the importance of adherence to postoperative recommendations, so they understand the risks associated with lack of adherence.
- When appropriate, especially if there is concern for the depth of osteotomy cut or inadequate tibial tubercle fixation, weight-bearing restrictions should be considered.
- Avoid open chain knee extension in the early postoperative period.
- Do not return the patient to higher-level activities until they are pain free and have regained normal ambulation and radiographs show evidence of union.

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# 25 Trochleoplasty: Indications and Results

J. Michael Smith, Jeremy K. Rush,
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## 25.1 Indications

Correct patient selection is critical to the success of the deepening trochleoplasty procedure. Furthermore, the treating surgeon must have a complete understanding of the type and severity of the dysplasia as well as associated anatomic risk factors (ARFs) such as patella alta or a lateralized tibial tuberosity. It must be emphasized that the mere presence of type A dysplasia, a shallow groove, is not an indication for a deepening trochleoplasty (Fig. 25.1).

The most commonly utilized indications for trochleoplasty include persistent patellar instability refractory to conservative treatment in patients with a Dejour type B or D trochlea and a spur height >5–7 mm and a "J sign" on physical exam [1–5]. The key feature of Dejour type B and D dysplasia is the presence of the large supratrochlear spur (Figs. 25.2 and 25.3). This spur can act in a manner analogous to a "ski ramp." As the knee moves into flexion, the patella will encounter the spur producing lateral subluxation or dislocation. Additionally, biomechanical testing has demonstrated that Dejour B, C, and D types have increased chondral contact pressures, decreased contact areas, and altered kinematics with resultant patellar instability [6]. High-grade dysplasia (greater than type B) is also associated with increasing patellofemoral arthrosis severity [7, 8].

The presence of a "J sign," an indicator of pathological patellar tracking, is a critical finding on physical examination as it demonstrates the influence of the spur on the patella [9, 10]. The "J sign" occurs when the knee is actively brought from flexion to extension and the patella demonstrates a sudden lateral translation as it exits the trochlear groove when approaching full extension (Video 25.1). This physical examination finding reflects either trochlea dysplasia, patella alta, or a combination of both. In patients with a spur (Dejour B or D dysplasia), the J sign is seen when the patella "jumps" or "falls" off the supratrochlear spur. A large or tall supratrochlear spur often leads to a more dramatic J sign.

The importance of the supratrochlear spur as a requirement for deepening trochleoplasty cannot be overstated. A primary objective of trochleoplasty is removing the spur and bringing the height of the trochlea to a level flush with the anterior femoral cortex. In our experience, the presence of patella alta (patellotrochlear index (PTI) <0.20 or Caton–Deschamps (CD) index

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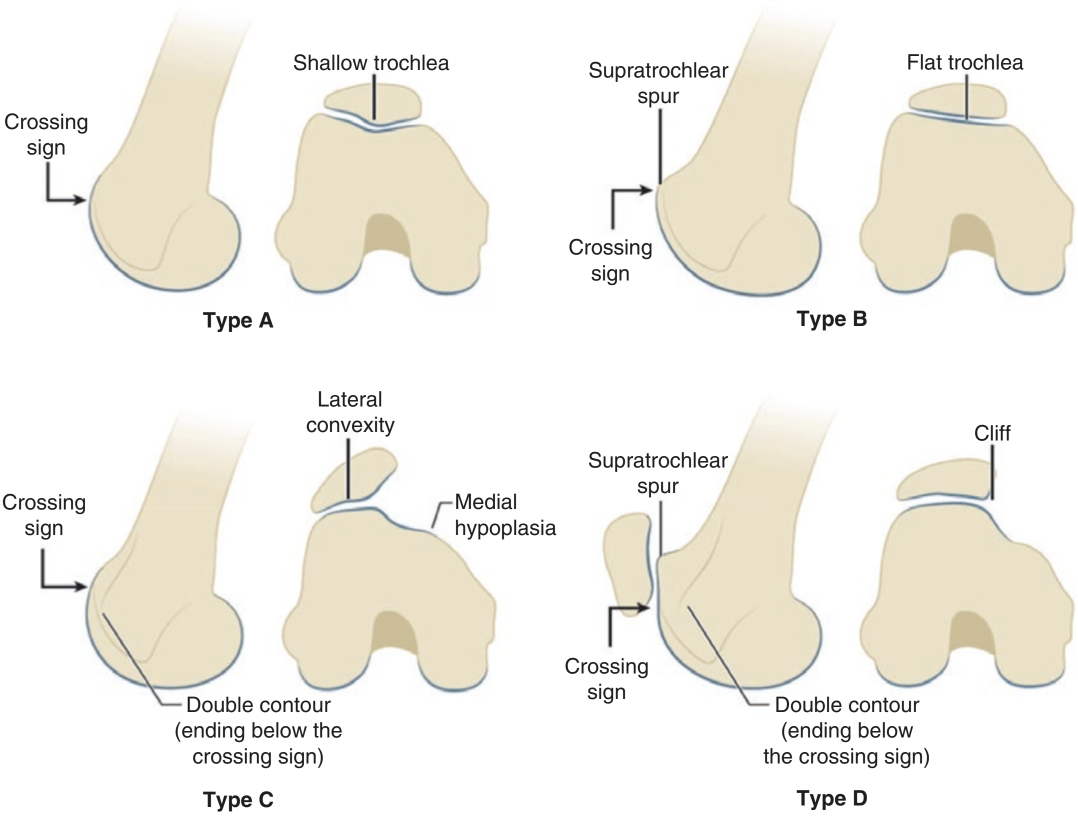

**Fig. 25.1** Graphical representation of the Dejour classification of trochlear dysplasia

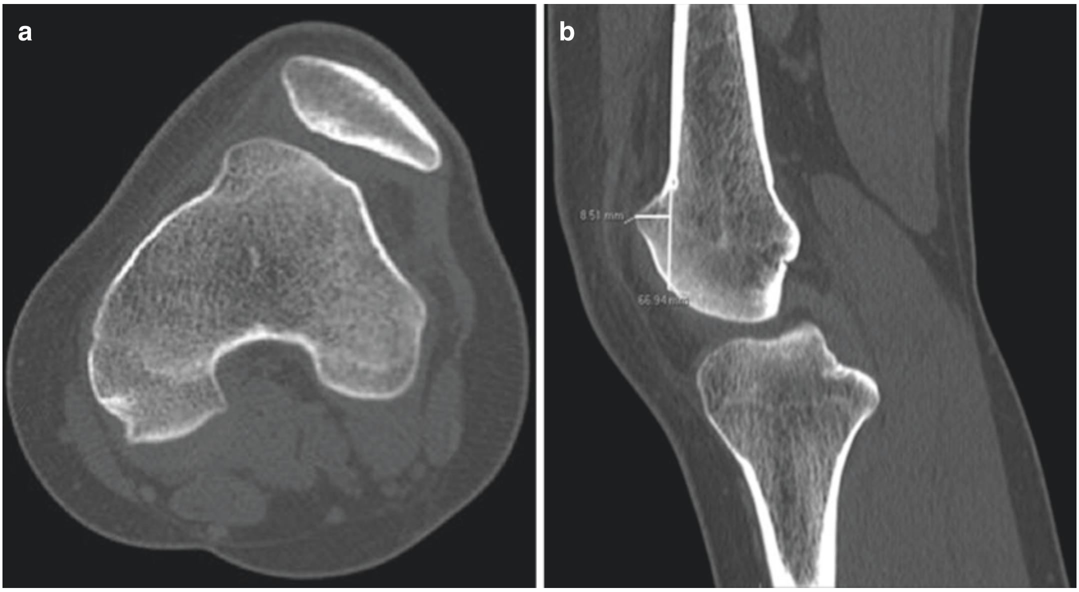

**Fig. 25.2** Sagital and axial CT scan views of a large supratrochlear spur measuring 8.51 mm relative to the anterior border of the femur

>1.4) lowers the surgical threshold to perform a deepening trochleoplasty (Fig. 25.4). The presence of patella alta magnifies the effect of the supratrochlear spur as the patella must navigate past this spur each time the knee flexes. These knees typically have the most pronounced J signs on exam.

Trochleoplasty should also be strongly considered in revision procedures in patients with Dejour B and D dysplasia who have previously undergone an isolated soft tissue procedure. Multiple studies have demonstrated an association between the severity of a patient's trochlear dysplasia and their clinical outcome and risk of persistent instability following an isolated soft tissue procedure such as a medial patellofemoral ligament (MPFL) reconstruction [11–14]. Hopper et al. noted in their series of 68 patients treated with MPFL reconstruction that all 7 of the patients with Dejour C or D dysplasia had recurrent or persistent instability [15]. More recently, Balcarek et al. performed a systematic review of published studies of patients with high-grade trochlear dysplasia treated with (1) medial patellofemoral ligament reconstruction or (2) combined trochleoplasty and extensor apparatus balancing [16]. The MPFL group was comprised of four studies with a total of 210 patients (221 knees), and the trochleoplasty group was comprised of six studies with a total of 164 patients (186 knees). The rate of persistent instability was 7% in the isolated MPFL group compared to 2.1% in the trochleoplasty group.

Contraindications to trochleoplasty include advanced patellofemoral arthrosis [1, 17]. Attempts to perform a deepening trochleoplasty in the presence of brittle, eburnated, and sclerotic trochlear bone can lead to fracture propagation when attempting to cut the osteochondral shell with a scalpel or osteotome. This could potentially result in unstable fragments that might

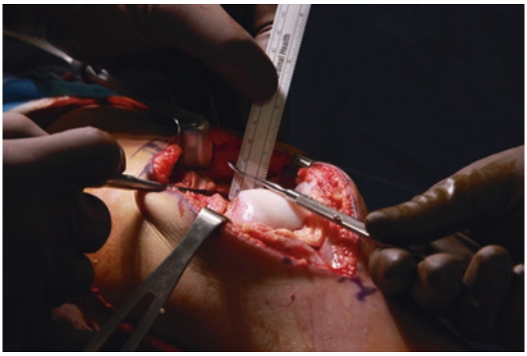

**Fig. 25.3** Intra-operative photograph demonstrating the presence of a large supratrochlear spur

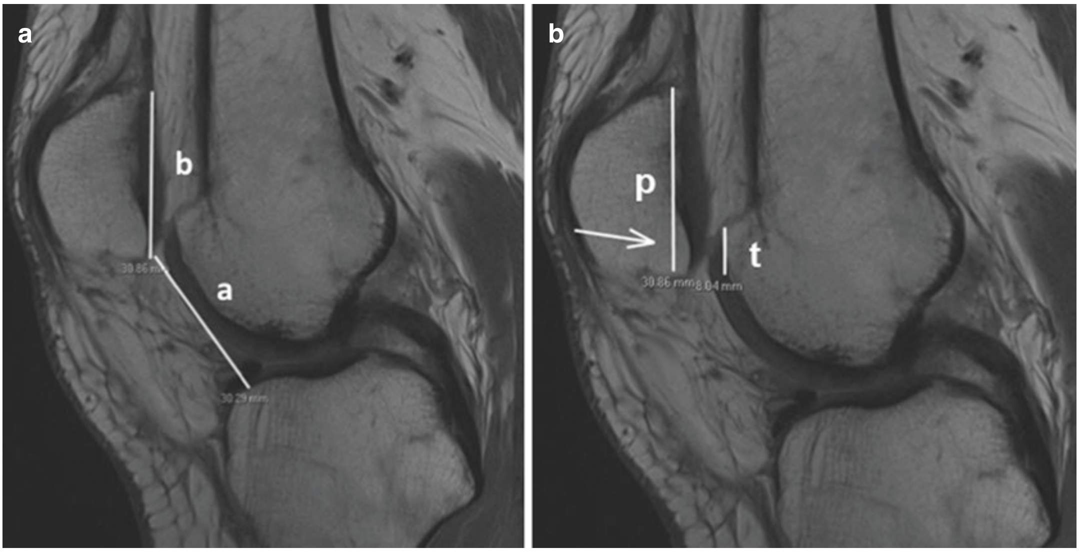

**Fig. 25.4** Sagital MRI with lines drawn to demonstrate (**a**) CD ratio which is represented as a/b, and (**b**) PTI which is represented as t/p

require additional fixation or alterations to postoperative rehabilitation. Likewise, if using the "thin-flap" technique, the flap may be too brittle and stiff to reshape properly.

Open physes or skeletal immaturity is also frequently cited as contraindication to trochleoplasty due to the risk of growth arrest or angular abnormality [17]. Interestingly, Nelitz et al. performed thin-flap trochleoplasty in 18 adolescents with less than 2 years of growth remaining [18]. There were no cases of growth arrest or disturbance and no episodes of recurrent instability. Additional research, however, is necessary before trochleoplasty can be advocated in skeletally immature patients, and caution should be exercised.

### 25.1.1 Associated Procedures

Trochleoplasty is frequently combined with other procedures in order to fully address the multifactorial contributors to patellar instability. In patients with chronic patellar instability, the medial soft tissue restraints, including the MPFL, are disrupted or attenuated. For this reason, a MPFL reconstruction should be included with any trochleoplasty procedure [1, 17].

Patella alta is a critical ARF for patellar instability and frequently coexists with trochlear dysplasia [19, 20]. Patella alta promotes instability, as the patella does not engage the trochlear groove until deeper degrees of flexion. A distalizing tibial tubercle osteotomy may be considered in patients with a CD >1.3, a PTI <0.32, or a sagittal patellofemoral engagement (SPE) ratio <0.45 [21, 22]. Given the additional morbidity of a distalizing osteotomy, most surgeons (including the authors) generally accept a CD ratio >1.4 or a PTI <20% as an indication. It is important to note that distalizing the patella will help minimize the influence of the supratrochlear spur in producing lateral patellar dislocation as the patella is brought further into the groove, thereby avoiding the effects of the spur proximally. This is especially important in "borderline cases" with significant patella alta (CD ratio of >1.4) and a smaller spur (≤5 mm). Distalizing the tubercle in these cases will effectively diminish the effect of the spur and potentially obviate the need for trochleoplasty.

In patients who also have genu valgum or a laterally positioned tibial tuberosity, the effect of trochlear dysplasia is magnified. The combination of all three anatomic risk factors (trochlear dysplasia, patella alta, and elevated tibial tubercle-trochlear groove (TT-TG) distance) is especially problematic for surgical success unless all three are addressed. An elevated TT-TG >20 mm is often utilized as criteria for a bony procedure such as a tibial tubercle osteotomy (TTO) [23, 24]. Measurement of TT-TG is most accurate using CT, as MRI can underestimate this measurement by up to 4 mm [25]. A trochleoplasty may obviate the need for TTO in patients with type B or D dysplasia and borderline elevated TT-TG. In our experience, the new trochlear groove achieved during trochleoplasty can be created up to 3–5 mm laterally, thus effectively decreasing the TT-TG distance. Schöttle et al. noted an even more dramatic improvement in TT-TG (20 mm preoperatively to 9.9 mm postoperatively) in 19 patients treated with a thin-shell technique [26]. Thus, in the setting of a trochleoplasty, a more elevated TT-TG of >23 mm may be considered a threshold for TTO given that a minimally elevated TT-TG (18–22 mm) can be normalized by lateralization of the newly created trochlear sulcus (Video 25.2).

## 25.2 Results

Results following trochleoplasty are generally positive but demonstrate some variability which may be attributed to the heterogeneity of the patient population afflicted with patellar instability and the resulting complex surgical decision-making. Since trochleoplasty is relatively rarely performed, no current level I trials investigating trochleoplasty exist. Therefore, the available studies are smaller case series with short- and midterm follow-up which can be challenging to use as a basis for clinical decision-making due to the varying combinations of procedures utilized. A recent consensus statement was issued by a work group jointly funded by the American Orthopedic Society for Sports Medicine (AOSSM) and the Patellofemoral Foundation (PFF) that based its recommendations largely on expert opinion and basic anatomic principles in the absence of high-level evidence in the literature [27]. Nevertheless, a review of published outcomes reveals several trends to guide practice and helps lay a foundation for future investigations.

### 25.2.1 Biomechanical Studies

Biomechanical and anatomic studies have examined the effect of trochlear dysplasia on patellofemoral biomechanics and demonstrated the effectiveness of trochleoplasty through normalizing patellofemoral kinematics and reducing instability in cadaveric specimens. Van Haver et al. designed a study with four cadaveric knees and implanted in them a series of 3D-printed trochleas with typical dysplasia patterns (based on Dejour's classification scheme) to objectively demonstrate increased contact pressures, increased lateral translation, and decreased stability in trochlear dysplasia compared to normal [6]. Amis et al. used fresh frozen cadaver knees to simulate patellar instability by surgically raising the central anterior trochlear which significantly increased the degree of instability in their model [28]. The researchers then subsequently performed a trochleoplasty procedure and recorded a decrease in instability. An anatomic study was performed by Fucentese et al., who utilized CT scans before and after sulcus-deepening trochleoplasty in 14 patients (17 knees) to demonstrate the improvement in key anatomic features [29]. The trochlear groove was lateralized by a mean of 6.1 mm proximally and 2.5 mm distally, while the patella medialized 5 mm. The depth of the groove also improved, increasing by 5.9 mm proximally and 2.8 mm distally. Others have assessed the sulcus angle pre- and postoperative with a reported correction from 12° to 39° following deepening trochleoplasty [30–32].

### 25.2.2 Clinical Results

There has been a growing body of literature investigating the clinical outcomes of trochleoplasty with some early results being unfavorable. Surgical techniques have evolved over time, and some techniques have fallen out of favor with contemporary authors. Albee was the first to propose a trochleoplasty technique in 1915 that involved elevating the lateral aspect of the trochlea with a bone wedge graft in an attempt to restore normal patellar tracking [33]. This technique was later found to significantly increase patellofemoral contact pressures and subsequently observed to result in poor outcomes [34, 35]. Masse then introduced the concept of the deepening trochleoplasty in 1978 which involved removing subchondral bone and molding the articular cartilage with direct impaction using a mallet [36]. A study by Rouanet presented 15-year results for this technique in 34 patients which showed a 20% failure rate, including seven patients that subsequently underwent arthroplasty procedure during the study period due to advanced patellofemoral arthritis [37]. Despite this high failure rate, the authors reported no recurrent instability episodes in their 34 patients.

Techniques have been further refined to include the three most commonly performed techniques today: (1) the Lyon procedure, i.e., Dejour or "thick shell," (2) the Bereiter procedure or "thin flap" and its arthroscopic modification, and (3) the Goutallier recession wedge [1, 38–40]. The outcomes of these modern techniques have been more promising, and the following reviewed articles focus on these contemporary techniques. The inclusion (or exclusion) of other patellofemoral-stabilizing procedures continues to be confounding as the indications for these procedures are not universally agreed upon, and consequently the outcomes must be interpreted in light of these differences.

### 25.2.3 Lyon Technique

The Lyon technique involves creating a thick, 3–5 mm osteochondral shell by undermining the trochlea with a high-speed burr to remove the subchondral bone. An osteotomy is then created using an osteotome or scalpel forming two “shingles” which are fixed in place using small anchors and absorbable sutures draped over each side to form a new trochlea [1]. A large level IV study utilizing the Lyon technique was published by McNamara et al., including 90 patients (107 knees) with severe dysplasia who underwent deepening trochleoplasty in addition to other indicated stabilizing procedures [41]. In this cohort, 83% of patients reported satisfaction with their outcome. At 6-year follow-up, there where were significant improvements in Kujala scores from a mean of 63 to 84 postoperatively ($p < 0.05$). Of note, only 14 (13.1%) of patients had MPFL reconstruction at the index procedure, and the authors reported 21 knees (19.6%) required a second operation for recurrent instability including 10 MPFL reconstructions, 2 of which were revisions. These results suggest that additional patellar stabilization procedures should be considered at the index procedure, which has been suggested by other authors [1, 17]. In their series, sports participation increased from 40% to 67% at final follow-up.

In another level IV study, Ntagiopoulous et al. presented midterm results on 31 knees treated with trochleoplasty for high-grade dysplasia and demonstrated substantial improvements from preoperative Kujala and IKDC scores [32]. Radiographically, their mean sulcus angles improved, and there were no reported postoperative patellar dislocations reported although a patellar apprehension sign was found on exam in six knees.

Other smaller series include Dejour et al. which examined 22 patients (24 knees). The authors showed no instability events and improvements in Kujala score from 44 to 81 over a mean follow-up period of 66 months. Pain decreased in 72% of patients, and the apprehension sign was negative in 75%. No patients exhibited evidence of osteoarthritis during the study period [30].

### 25.2.4 Bereiter Technique

The Bereiter technique involves making a thin osteochondral flap or “flake” 2–3 mm thick, which is elevated from the anterior femur using a burr or a combination of osteotomes. A bony sulcus is fashioned beneath the flap to create depth, and the flap is molded into the new sulcus and fixed with absorbable sutures and anchors draped over the top [38]. The largest published study on trochleoplasty to date comes from Metcalf et al., who reported on prospectively collected outcomes in 199 Bereiter trochleoplasties performed on 173 patients over a study period of 12 years [42]. Their mean follow-up time was 4.4 years (range 1–12). Eighty-eight percent of patients were satisfied with their outcomes, 90% of patients said their symptoms had resolved, and 73.6% had returned to sport. Kujala scores increased from 51.5 to 82.5 and IKDC scores increased from 44.3 to 71.3. Sixteen patients experienced a recurrent patellar dislocation, for an 8.3% recurrence rate. Twenty-seven patients (14%) underwent reoperations, nine of which were MPFL reconstructions. During the course of the investigation, it appears that the authors began to augment trochleoplasty with soft tissue balancing procedure which resulted in a changing incidence of subsequent MPFL reconstructions. Four of the first 40 patients underwent later MPFL compared to 5 of the next 174. In their cohort, patients were less likely to be satisfied if they had undergone a previous procedure. Of knees with X-rays more than 5 years after surgery, 7.7% demonstrated evidence of OA. In a subgroup analysis of 29 patients who had had been seen more than 8 years following surgery, the results appeared durable with Kujala scores of 83 and IKDC scores of 79.

Utting reported on prospectively collected outcomes for 59 knees undergoing deepening trochleoplasty with 2-year follow-up and showed improvement in all scores: Kujala, IKDC, Lysholm, Oxford, and WOMAC [43]. Nelitz et al. reported minimum 2-year follow-up on 23 patients (26 knees) who underwent combined trochleoplasty and MPFL reconstruction and showed no recurrent dislocations, Kujala score improvement from 79 to 96, IKDC improvement from 74 to 90, and VAS improvement from 3 to 1, with 95.7% of patients being satisfied with their outcome [44].

Isolated trochleoplasty was investigated by Camathias et al. in 44 adolescent patients (50 knees) with recurrent instability and trochlear dysplasia [45]. The authors reported improvements in both outcome measures and exam findings; Kujala scores increased from 71 to 92, and Lysholm scores increased from 71 to 95, while the J sign disappeared in 39 of 45, and apprehension disappeared in 33 of 41. A single redislocation was observed at 38 months. This patient group was reported to have no torsional or axial malalignment.

### 25.2.5 Goutallier Technique

The Goutallier technique involves an osteotomy to remove a section of bone from beneath the trochlea with a distal osteochondral hinge that is closed and secured with two or three 3.5 mm cancellous screws. The primary goal is to decrease the height of the supratrochlear spur rather than reposition or deepen the trochlear groove [40, 46]. Results from Thaunat et al. demonstrated that functional results trended toward, but did not reach, statistical significance in their study of 17 patients (19 knees) with a mean of 34 months of follow-up [40]. The supratrochlear spur height was decreased from a mean of 4.8 to −0.8 mm, and two patients experienced recurrent instability.

### 25.2.6 Systematic Reviews

Systematic reviews have also been conducted to compare available literature including a 2017 review of 15 articles regarding trochleoplasty for patellofemoral instability which showed improvements in Kujala scores (from 61.4 to 80.8), Lysholm scores (from 55.5 to 78.5), and a low redislocation rate of 2% [47]. Longo et al. published a systematic review that encompassed 392 knees in 371 patients across 14 articles [48]. Interestingly, this review also stratified which technique was performed including Bereiter, Dejour, or Goutallier recession trochleoplasty. All resulted in significant improvements in instability and outcome scores in the majority of patients. The Bereiter technique was associated with the lowest rate of recurrence and least range of motion deficiency. The Dejour technique was associated with the highest mean Kujala scores postoperatively. The authors concluded that there was no superiority for one technique over the others.

### 25.2.7 Our Results

At our institution, we have had high satisfaction rates following deepening trochleoplasty. A total of 64 patients (71 knees) with severe trochlear dysplasia were prospectively enrolled from 2011 to 2017. All patients underwent sulcus-deepening trochleoplasty using the Dejour, thick shell osteotomy method. All patients in our study underwent concomitant procedures during their trochleoplasty which included MPFL reconstruction (100%), lateral release or lengthening (50.7%), tibial tubercle osteotomy (32.8%), and some type of cartilage procedure (41.8%) to include shaving chondroplasty (38.8%), chondral allograft (10.4%), microfracture (7.5%), and/or removal of loose body (22.4%).

The majority of patients were female (81.6%) with a mean age of 19.6 ± 6.8 years. Follow-up ranged from 12 months to 78.4 months (mean 27.7 ± 15.4). All knees were either Dejour B (81.3%) or D (18.8%) with a mean Caton–Deschamps index (CDI) of 1.20 (±0.2). Mean spur height preoperatively was 7.41 mm (±1.84 mm) with a mean trochlear depth of only −0.18 mm (±2.71). Mean patellotrochlear index (PTI) was 0.41 (±0.41).

Most importantly, there were zero episodes of recurrent instability. One patient had patellar apprehension and a recurrent J sign at terminal extension postoperatively requiring a distal femoral osteotomy for genu valgum. All patients reported clinically significant improvements compared with baseline preoperative outcome scores. The mean preoperative IKDC score improved from 49.99 to 79.86 ($p < 0.001$), and the mean preoperative Kujala score improved from 55.88 to 85.80 ($p < 0.001$). Patients reported high satisfaction rates (mean 9.5 ± 1.6 out of 10). All but one patient (96.9%) returned to work, while 88.2% of patients were able to return to sport. Ten knees (20.4%) developed arthrofibrosis and required manipulation under anesthesia, while eight of which underwent simultaneous arthroscopic lysis of adhesions. No patients had fixation failure or progression of arthritis noted on yearly X-rays.

### 25.2.8 Complications

Trochleoplasty is a technically challenging procedure that requires a three-dimensional understanding of the problem and steps to correction. Even with the most thoughtful approach, complications can and do occur. Injury to the articular cartilage, over- or under-correction, and recurrent instability have all been reported. An overall complication rate of 13.4% has been reported by Song et al. following trochleoplasty [3]. This includes a 6.8% of redislocation and 65.9% with increased patellofemoral pain. Nearly 8% went on to develop progression of patellofemoral joint arthritis at mean follow-up of 69.9 months [3].

The primary complication reported after trochleoplasty is stiffness, which has been reported as high as 46% of knees [3, 37, 41, 49]. More recent investigations have estimated a 0–20% incidence of stiffness which is more in line with our unpublished findings above [32, 50, 51]. In many cases, patients suffering from stiffness return to the operating room for manipulation under anesthesia (MUA) and/or arthroscopic lysis of adhesions (LOA). Several sources have identified satisfactory return to function after LOA/MUA [49, 50, 52]. During arthroscopic LOA, these knees have been described as having massive periarticular scar formation, and it has been proposed that early passive range of motion exercises may reduce the incidence of this complication [53]. Our experience echoes this with more stiffness noted early in our learning curve when our postoperative rehab protocol was more conservative. Emphasizing early motion has reduced the need for LOA/MUA for us dramatically.

A concerning potential complication of trochleoplasty is subchondral collapse. There are risk of direct damage to the articular cartilage while osteotomizing the osteochondral shell and also risk of indirect damage to the articular cartilage while burring beneath the surface due to thermal injury or over-resection of subchondral bone. Use of a measured offset guide with the burr or drill bit adds a measure of safety as well as reproducibility in our experience and seems to reduce this risk.

In many cases, patients undergoing trochleoplasty have already sustained multiple patella dislocations leading to a high burden of existing chondral damage and the possibility of postoperative patellofemoral pain despite surgical correction [31]. This complication has been observed in 10–14% of patients [48]. Despite radiographic improvement of the patellofemoral joint, it is possible that trochleoplasty may not be protective against progression of osteoarthritis. While osteoarthritis rates have been reported as low as 0–7%, the lack of long-term results of the contemporary techniques leaves this question unresolved [30, 42, 48].

## 25.3 Conclusion

Current literature and expert opinion favors trochleoplasty as an effective option to surgically treat patellofemoral instability in carefully selected patients. There is no consensus as to which technique should be employed; however, it is our opinion that whichever technique is chosen should be used in conjunction with MPFL reconstruction in all cases and paired with additional bony reconstructive procedures if indicated. With the lack of any large-scale randomized series, more efforts are needed to better understand this challenging clinical problem and the appropriate application of these surgical techniques.

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# Patellofemoral Pain, Instability, and Arthritis Trochleoplasty Techniques: Arthroscopy

## 26

Lars Blønd

## 26.1 Introduction

Arthroscopic trochleoplasty (AT) is one out of several established trochleoplasty procedures [1–4]. The trochleoplasty procedures intend to restore anatomy, reduce malalignment, reduce patella tilt, and unload the patella but most importantly to provide osseous stability to the patella by providing a lateral buttress. Trochlear dysplasia (TD) significantly affects the kinematics of the patellofemoral joint, and the stabilizing forces for the patella are reduced [5, 6]. TD predisposes to both patellar instability, anterior knee pain, as well as patellofemoral osteoarthritis [7–12]. AT is a variant based upon the Bereiter technique, also called the thin flap technique [16]. The AT divide from the open procedure by being less invasive. The AT might have the same known advantages from other techniques based on minimal invasive surgery by reducing the surgical trauma. Theoretically this should reduce the risk of infection, arthrofibrosis, and scar formation. The first two case series after AT in combination with MFPL reconstruction (MFPL-R) have demonstrated results comparable with the results obtained for open trochleoplasty procedures [13, 14]. Before starting to perform arthroscopic trochleoplasty, it is recommended first to become a skilled arthroscopic knee surgeon and to be familiar with pathomorphology related to TD. It is recommended to initially practice on cadaver knees. This said, it must be noted that since cadaver knees mostly have a normal V-shaped trochlea and since the cartilage quality is fragile, the AT procedure is very demanding in this setting. In living human knees when TD is present and the trochlea is more flat, both angulation and quality of the tissue are more easy to handle. The AT technique is typically combined with MPFL reconstruction and arthroscopic lateral release. This chapter will concentrate only on the AT technique.

## 26.2 Indication

The precise indication for AT procedures has not yet been defined. The author typically combines AT with MPFL reconstruction and arthroscopic lateral release in patients with severe trochlear dysplasia evaluated by MRI axial scans and symptomatic patellar instability. In rare cases the procedure has been used in patients having chronic anterior knee pain and severe trochlear dysplasia. The author's preferred parameter for the evaluation of the degree of trochlear dysplasia is the lateral trochlea inclination (LTI) angle that expresses the amount of lateral buttress to support

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the patella [15, 16]. The angle changes substantially going from proximal to distal, and the level is not clearly defined yet. First of all I measure the LTI angle on the cartilage, since the articulation is between the cartilage and not the bone. This is important especially when there is cartilage/bone mismatch. A line is drawn tangential to the posterior femur condyles, at the most proximal level where the condyles are well defined. At the same level, the next line is then drawn tangential to the lateral trochlea cartilage, and this line must be placed so it represents the lateral trochlea angulation (Figs. 26.1 and 26.2).

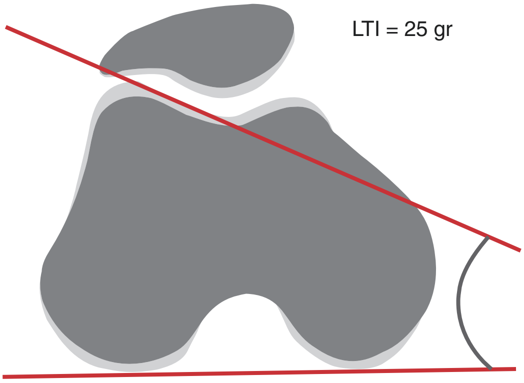

**Fig. 26.1** Lateral trochlea inclination angle

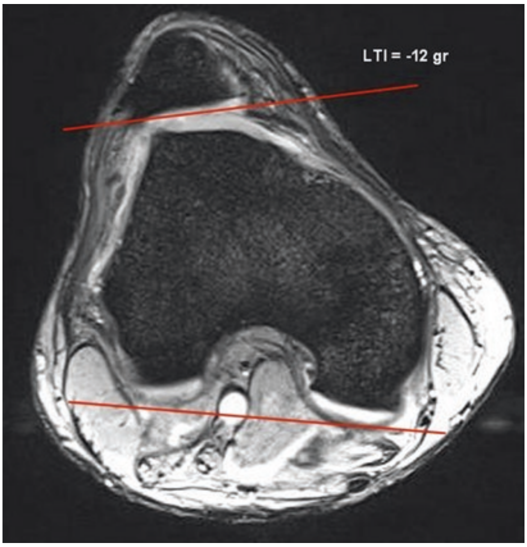

**Fig. 26.2** LTI MRI

The angle can be difficult to measure when the trochlea is dome shaped, and the line has to be parallel to the cartilage (Fig. 26.3). In these situations, I recommend to do measurement on the axial slice just distal, where it is likely to be more easy to measure.

Figure 26.4 demonstrates an example of a dysplastic trochlea and cartilage/bone mismatch.

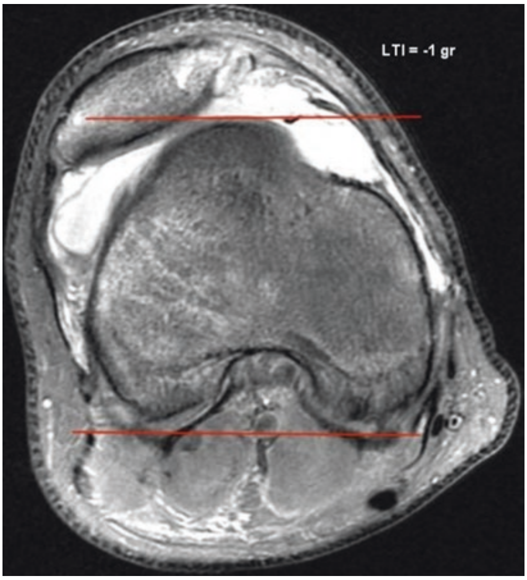

**Fig. 26.3** LTI low

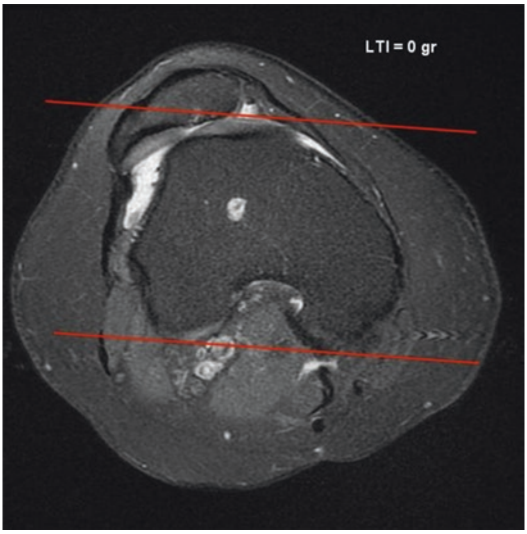

**Fig. 26.4** LTI cartilage mismatch

Through clinical examination patients with patellar instability must have a positive reverse dynamic apprehension test at least 30° [17].

Initially, grade 3 to grade 4 cartilage lesions in the trochlea were regarded as absolute contraindications; however in the past years, these have been interpreted to be more liberal, supported by a study from Neumann et al. [18]. Also observations from a few resections of arthroplasties have loosened the indications [19]. Nevertheless these lesions must be small; otherwise it is not technically possible to complete the formation of the cartilage flap without breakage. Open growth plates are a relative contraindication. If the growing potential is nearing its end, meaning that the patients are close to the height of the parents, and if the girls have had menstruation for more than a year, the procedure can be done safely [20].

## 26.3 Technique

It is recommended not to use a tourniquet in order to prevent free radicals. Theoretically this can affect healing and increase the risk of arthrofibrosis. Intraoperative bleeding can be controlled by keeping the water pressure sufficiently high. This can be managed by keeping the portals to a minimum, to reduce the outflow, and by delicately balancing the amount of shaver suction. To minimize soft tissue swelling, an arthroscopic pump is needed, and the water pressure should be adjusted to a minimum. One dose of intravenous antibiotics is given pre- and postoperatively. Antithrombotic prophylactic treatment is considered in patients above the age of 40 or in cases with a history of thrombotic complications.

### 26.3.1 Preparation and Portal Placement

Initially knee arthroscopy is done through two small standard anterior portals, and the knee is inspected for other intra-articular pathologies. Besides that the portals be kept small, they also need to be relatively distal, since one of those are later used for the implant of the first suture anchor distal to the cartilage flap. The dysplastic trochlear configuration is confirmed, and the cartilage status is evaluated. A superior portal must be created as proximal as possible to reach an optimal view of the trochlea, and this is placed just medial to the quadriceps tendon. If a suprapatellar plica interferes with the arthroscope, it must be removed. By insertion of a hypodermic needle, the correct placement is identified, and a switching stick is introduced in the same direction into the most proximal part of the suprapatellar pouch followed by the introduction of the arthroscope. The author's preferable scope is 45°, but a 30° or 70° scope can be used as well. With the scope introduced in the suprapatellar portal, the patella and trochlea can be clearly inspected. The correct position for the lateral suprapatellar portal is localized by the needle technique, and the placement of this portal is vital. The needle needs to run parallel to the proximal extent of the flat part of the trochlear groove in both the frontal and transversal planes, in order to give the right working angle for the instruments. A too distal or too posterior placement can be detrimental, since it will not be possible to create a correct lateral wall angulation. A too proximal portal can make it difficult to reach the most distal part of the trochlea. A 8-mm PassPort Button Cannula (Arthrex Inc., Naples, FL) is useful as a working portal (Fig. 26.5).

This demonstrates the superior suprapatellar portal with the arthroscope introduced and the lateral suprapatellar portal with a PassPort cannula mounted.

### 26.3.2 Creation of the Cartilage Flap

A 90° radio-frequency device is introduced through the lateral suprapatellar portal, and by this the synovium/periosteum is released from the area proximal to the trochlear cartilage. The release is continued proximally in order to achieve a clear area for the placement of the proximal anchors in the end of the procedure. Once the bone is cleared, a 3- or 4-mm round shaver burr (the 4-mm with a shorter shield) is used to take away the bone proximal and poste-

**Fig. 26.5** Portal

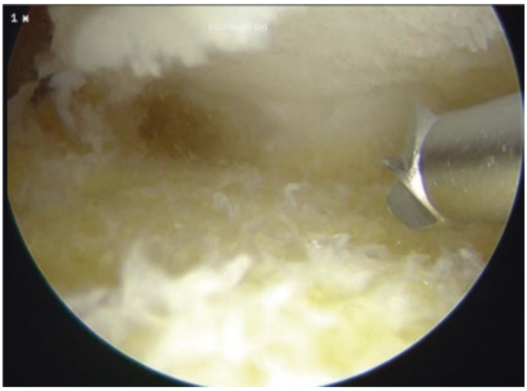

**Fig. 26.6** Cartilage flap

rior to the trochlea cartilage. The release of the cartilage flap is initiated by moving the shaver burr from medial to lateral and vice versa. Slowly, the cartilage is undermined, and the progression of the shaver continues more and more distally beneath the cartilage (Fig. 26.6).

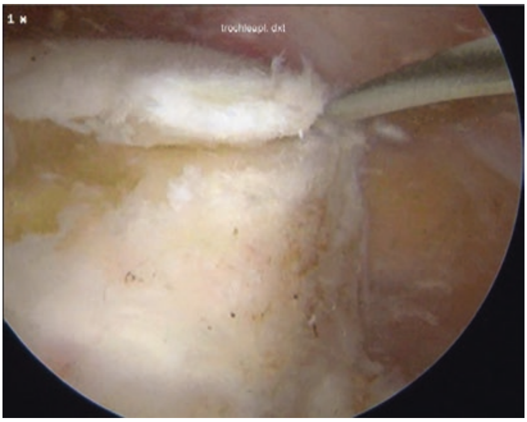

**Fig. 26.7** Lambotte

This demonstrates the release of the cartilage flap using a shaver burr.

As a supplement to the shaver, a straight and curved Lambotte osteotome (6 mm × 27 cm) is helpful. Laterally the osteotome is of importance in order to minimize the amount of bone resection at the most lateral part of the trochlea, helping to achieve a normal lateral trochlear wall and thereby achieving a more anatomic lateral trochlea inclination angle (Fig. 26.7).

This demonstrates the use of the osteotome to avoid taking away too much bone most laterally.

The cartilage flap separation from the bone is continued distally until the shaver meets the curvature of the femoral condyles. Before this point is reached distally, it is recommended to change the 4-mm shaver burr to a smaller 3-mm burr, thereby minimizing the bone resection in the area close to the hinge of the cartilage flap. The release should be continued in the medial and lateral directions; otherwise the hinge of the flap will not become sufficiently elastic.

### 26.3.3 Formation and Shaping of a Deeper Trochlear Groove

The aim is to approximate the trochlear depth to 4.5 mm, and also the trochlear should be lateralized to approximate a more normal figure of 50% trochlear symmetry [19]. By lateralizing the groove, the TT-TG is also reduced by several millimeters [20]. First of all the groove needs to be deepened and centralized using shaver burrs. A PowerRasp (Arthrex Inc., Naples, FL) is useful for smoothening the bony surface of the lateral wall of the trochlea. Part of the trochlear dysplasia is the medialized groove, so the amount of lateralization of the new groove should reflect the increased TT-TG or better decreased the TG-PCL distance measured preoperatively. A trochlea depth of 4.5 mm is sought, taking into account the size of the involved knee. The amount of bone resection for the deepening of the trochlea and for taking away the trochlear bump can be estimated during surgery by looking both the diameter of the shaver burr and the most anterior part of the femur, since resection proximally should allow for a smooth transition between the groove and the anterior cortex of the femur. The new groove is therefore trimmed with the shaver burr or PowerRasp according to the preoperative plan, and a good lateral wall is aimed (Fig. 26.8).

This demonstrates how the PowerRasp can help in creating a smooth lateral wall of the new trochlea.

The cartilage flap needs to have sufficient elasticity to integrate into the new groove, to get in contact with the underlying bone, and to achieve the correct trochlea shape. Flap elasticity is tested, by pressing the flap into the new deepened trochlea using a blunt instrument (Fig. 26.9).

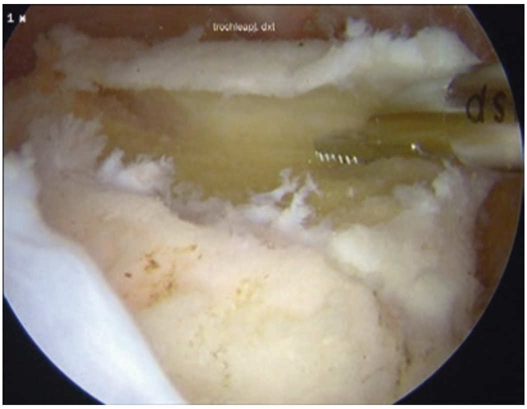

**Fig. 26.8** Powerrasper

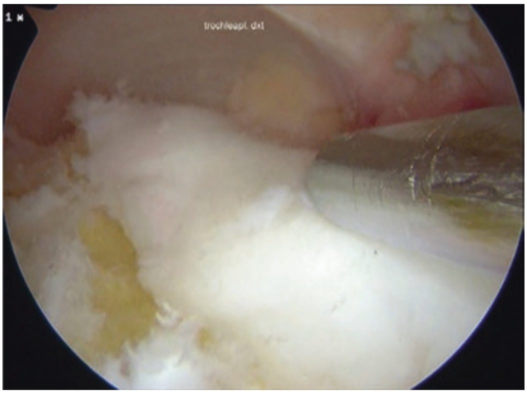

**Fig. 26.9** Testing elasticity

This demonstrates how the elasticity of cartilage flap can be tested using a stump instrument.

In cases where the cartilage flap is too stiff, excessive bone on the rear side of the flap should be gently and gradually removed until the needed elasticity is reached.

### 26.3.4 Fixation of the Cartilage Flap

Still with the arthroscope in the superior medial portal, a suture anchor is placed distal to the cartilage hinge through either the medial or lateral joint line portal, depending on which one gives the most optimal angle perpendicular to the distal trochlea. In order to achieve a 90° insertion angle of the anchor, the knee has to be flexed 45°–60°. The portal is first cleared with a radiofrequency device for smooth introduction of instruments. A bone socket for the anchor is initially drilled central in the most distal part of the trochlea, just proximal to the notch and still distally from the cartilage flap. A biocomposite 3.5-mm PushLock anchor (Arthrex Inc., Naples, FL) with an eyelet is loaded with a resorbable tape and a suture, so the end of the tape and the sutures are equal in length. The anchor is placed into the bone socket (one tape—Vicryl 3mm BP-1, V152G, Ethicon, and one 1-0 suture Vicryl CT-2 plus, V335 H). Alternatively the tapes can be replaced successfully by multiple sutures. A suture grasper is introduced through the superior lateral portal, grasping one of the tape endings and bringing it out through the cannula, and loaded into another similar anchor. On the lateral side, the socket is drilled in a spot superior to the cartilage flap and lateral to the center of the groove. The tape is gradually tensioned, thereby pressing the cartilage flap into the new groove, and the first proximal anchor is positioned, and the anchor is introduced, and the tape is then locked, and the excess is cut. Next the arthroscope is shifted to the superior lateral cannula, and the next anchor is inserted through the superior medial portal. This should also be placed superior to the cartilage flap and medial to the center of the groove. Optimally it is placed superior to the bone resection. In most cases the cartilage flap is now sufficiently stabilized into the new trochlea groove. In about 30% of the cases, there remains a gap between the cartilage flap and the new trochlea, and this requires an additional anchor now loaded with extra suture (Fig. 26.10).

This demonstrates how the cartilage flap is pressed into the new trochlear groove by the tape and suture fixation.

Eventually comorbidities are supplementarily treated. These could be medial patellofemoral ligament insufficiency with MPFL reconstruction and arthroscopic lateral release, tibial tubercle distalization, tibial tubercle medialization, and varus or rotational osteotomies of the femur or tibial. Special considerations have to be noticed when the MPFL reconstruction is done in conjunction to AT. MPFL-R is performed after AT. Due to bone resection caused by AT, the axis of rotation around the femoral epicondylar axis, as described by Coughlin et al. [21, 22], is affected. The distance (radius) from the center of rotation (the footprint in the epicondyle) to the resection area in the new groove is shortened. Consequently both the native MPFL and the MPFL graft are relatively slack in extension. If this is not taken into account, this can have a detrimental impact on the outcome. This is especially meant for those who only use radiographic for femoral tunnel placement. The MPFL insertion point needs to be placed in a more distal anisometrical position and should be fixed with the knee in the specific degree of flexion (approx. 70°), where the patella is placed in the unaffected trochlea area; otherwise the graft will become too tight in flexion and consequently leads to flexion problems resulting in over tensioning of the graft and compression of the PF articular cartilage. Therefore it is important to check for graft tension during the range of movement.

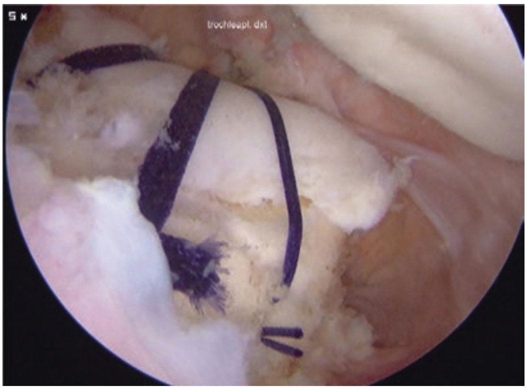

**Fig. 26.10** Reinserted cartilage flap

#### 26.3.4.1 Postoperative Regime

Immediately after the surgery, the patients are allowed to do a full range of movements and a full weight-bearing.

Postoperative rehabilitation is detailed in Table 26.1.

**Table 26.1** The postoperative protocol after arthroscopic trochleoplasty

| | |
|---|---|
| Weeks 1–2 | Knee mobilizing, heel glide, one leg balance, neuromuscular electric stimulation (NMES disuse 35 Hz) for m. Quadriceps and m. gluteus medius. Stretching iliotibial band and hamstrings and venous pumping exercises |
| Weeks 3–5 | Adding walking training, unloaded high-saddle bicycling, hip abduction and adduction, pelvic lift, and NMES 35 Hz at hamstring muscles |
| Weeks 6–8 | Adding walking on treadmill, walking backward with 10% inclination, cross trainer (having full extension), bicycling with resistance (having flexion above 110°), water running, and NMES resistance 45 Hz |
| Weeks 9–12 | Adding Wobble board and Airfix balance, step and lunges |
| Weeks 13–16 | Adding NMES with one leg on Bosu balance trainer, perturbation, and jogging on trampoline and crawl |

Full weight-bearing is allowed from day 1 postoperatively.

## 26.4 Results

The author has conducted the AT procedure in 115 knees 99 patients (72 females and 27 males) with a median age of 20 (range from 12 to 57). In 103 cases the surgeries have been combined with MPFL reconstructions. For those twelve cases without MPFL reconstruction, the isolated AT has been done for instability and previous MPFL reconstruction in one case and for severe chronic anterior knee pain in eleven cases. The surgery is a 1-day surgery. The results from the first 29 cases of AT in combination with MPFL reconstruction have been published [23], in which significant improvements in Kujala and KOOS scores were observed with 93% satisfied with the outcome and 55% returning to sports. In all cases the preoperative range of movements or more have been achieved. A later smaller case series with similar results have been published as an abstract [24].

This figure demonstrates the pre- and postoperative axial view. Above are the preoperative pictures that represent the two most proximal slices containing trochlear cartilage, and below are the similar slices postoperatively (Fig. 26.11).

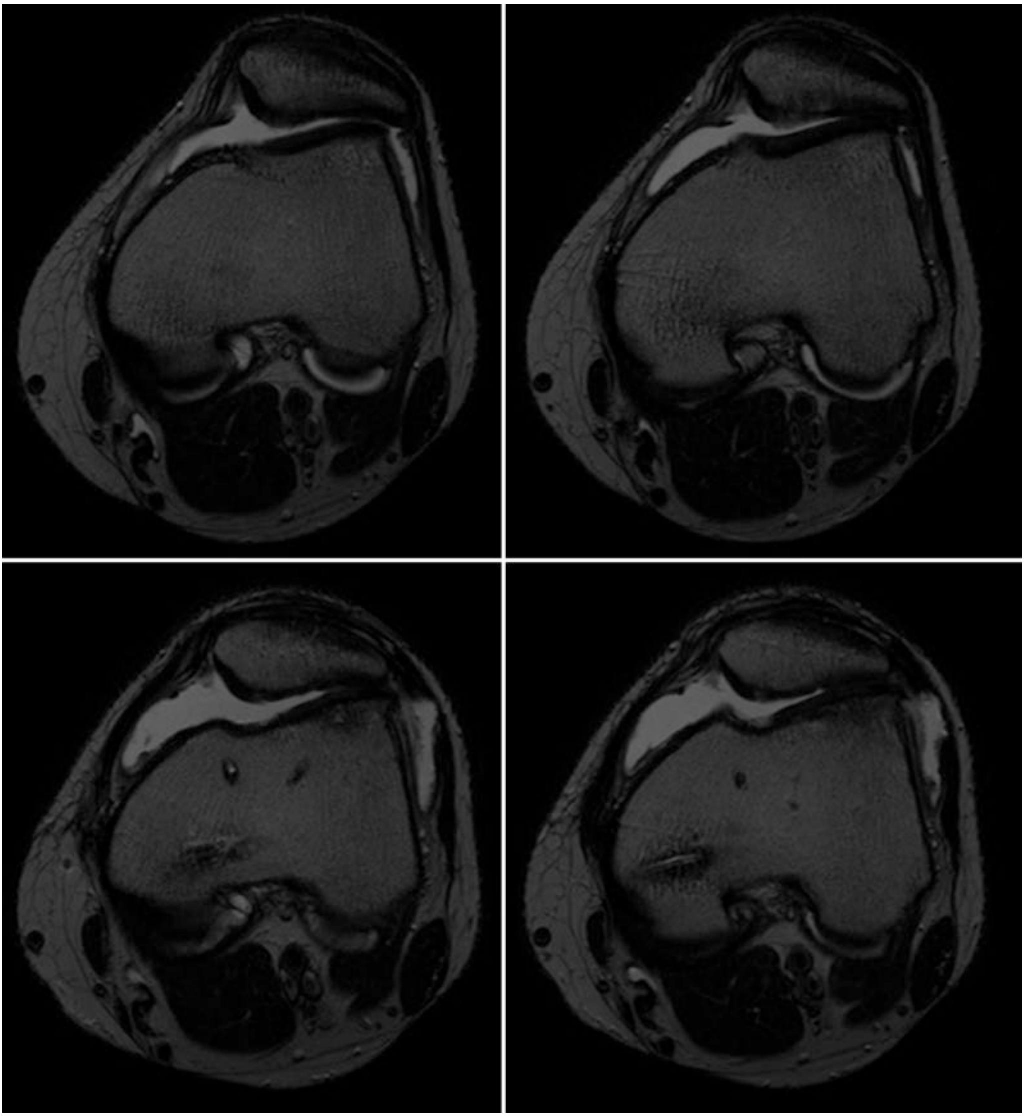

**Fig. 26.11** Pre and postoperative MRI axial views

## 26.5 Complications

Three moderate complications have occurred, all were deep vene thrombosis. Three patients who had high TT-TG distances above 20 mm developed symptomatic subluxations postoperatively and were subsequently successfully corrected by medialization of the tibial tubercle. Those cases were all operated at the start of the series and at that phase, and due to lack of knowledge, the new trochlear groove was not lateralized during the trochleoplasty procedure. Three patients also from the start of the series experienced pronounced postoperative anterior knee pain in flexion. On examination, tightness of the lateral retinaculum was found, indicating lateral hyper-pressure syndrome, and they all responded positively to a subsequent lateral release. This has resulted in a more liberal use of a subsequent arthroscopic lateral release. Since there have been no further cases developing symptoms of hyper-pressure. One patient who already has had five operations developed severe anterior knee pain due to degeneration of the cartilage in the lateral part of the trochlear. At further examination increased femoral anteversion was recognized. The patients had undergone external rotational distal femoral osteotomy and tibial internal osteotomy elsewhere. This procedure worsened the situation. Case number 7 had not concomitantly revision MPFL-R and redislocated (by report) and undergone a revision trochleoplasty and revision MPFL-R elsewhere.

Figure 26.12 is meant as a momento. This is pre- and postoperative MRI scans for an arthroscopic trochleoplasty from elsewhere. Notice that surgery has impaired the lateral trochlear inclination due to inferior surgical technique.

## 26.6 Discussion

The author has for the past 12-year period performed AT in 115 knees, with no cases of arthrofibrosis or infections; however complications as mentioned above have occurred. The AT procedure are today carried out in eleven countries. The procedure has undergone minor changes since it was introduced in 2008 [25]. The superior lateral cannula has been omitted, based on the fact that it wasn’t necessary, and the PowerRasp 4.0 mm × 13 cm AR-8400PR (Arthrex Inc., Naples, FL) has lately been introduced for smoothening of the new trochlear groove, but this in not mandatory. In the primary study, a median VAS

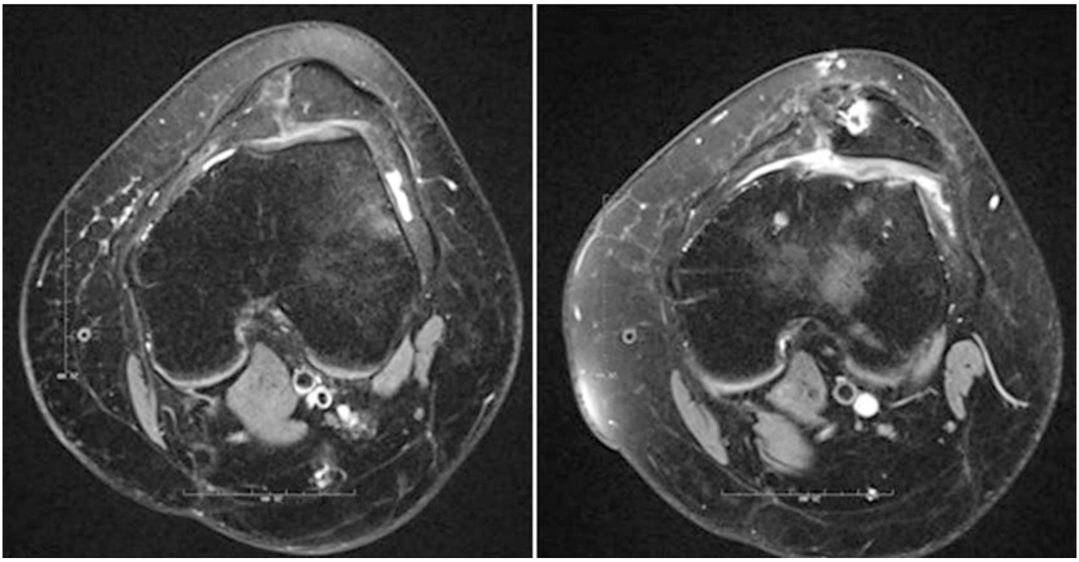

**Fig. 26.12** Momento how not to do

pain score of 3 was observed 24 h postoperatively, and this equalized the level of pain scores from MPFL reconstructions alone. Based on these findings and later observations, we have experienced that the combined AT and MPFL procedure is carried out as a 1-day surgery. In a follow-up study of a consecutive series of 29 knees in patients troubled by patella instability and treated by combined AT and MPFL reconstruction, significantly improved median knee scores for all measured parameters with no re-dislocations were found [23]. These results have later been confirmed in a second follow-up study including 18 more knees [24]. Based on the theory that trochleoplasty doesn't provide sufficient stability to the patella in the initial 20°–30° of flexion, concomitant MPFL reconstructions are frequently a concomitant procedure with trochleoplasty [23, 26–29].

A significant relationship between trochlea cartilage lesions and trochlea dysplasia has been documented [12, 30, 31]. Neumann et al. [18] observed, in a 50-month follow-up of 46 patients after trochleoplasty, that in a subgroup of 26 patients with radiographic degenerative changes or intraoperative findings of chondromalacia, there were comparable subjective postoperative improvements in this group compared to the patients without chondral changes. Based on these results, the author has found it reasonable to include patients with more degenerative cartilage changes in the trochlea as an indication for AT, and the findings are similar to Neumann et al.

## 26.7 Conclusion

This is a description of AT, a technique that has been slightly optimized since the original paper. The technique has been found to be a reproducible and safe technique with limited serious complications. Clinically AT has been found to give significant improvements in postoperative Kujala and KOOS scores and also to provide stable patellae with no reported cases of arthrofibrosis.

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# 27

# Trochleoplasty Techniques: Sulcus Deepening acc. Bereiter

Florian Dirisamer and Christian Patsch

Trochleadysplasia is the main static risk factor for patella dislocation due to the alteration of patellofemoral congruency. In a normal patellofemoral joint the trochlear sulcus is more or less concave from proximal to distal and works as a guide rail for the kneecap, keeping it on track. Characterizing for a dysplastic trochlea is the flat or even convex shape of the "sulcus" and the superelevation of the proximal entry—the trochlear bump. Usually this is caused by dysplastic central and dys- or hypoplastic medial portions of the trochlea, whereas the lateral portion is commonly normal. These anatomic factors produce an alteration of patellofemoral kinematics with the consequences of lateral patella dislocation. The presence of a dysplastic trochlea groove in 85% of patella dislocation documents the importance of this pathology [1–4].

The idea of normalizing the sulcus anatomy is not new. Fred Albee was the first who described a lateral elevation trochlea osteotomy to address dysplasia in 1905. The first sulcus deepening technique was published by Masse in 1978 [5], the concept was later modified and standardized by Henri Dejour in 1987 [6, 7]. Heinz Bereiter developed his technique trying to optimize possible disadvantages of the so far used methods and published it in 1991 [8].

## 27.1 Indication

Trochleoplasty is indicated in high grade trochleadysplasia, as the main risk factor for patella dislocation. The lateral trochlea inclination (LTI) is always measured on axial MRI or CT scan [9]. If the LTI is $\leq 10°$ or negative trochleoplasty should be considered. Originally trochleoplasty was recommended for recurrent patella dislocation or as a revision procedure for previous failed surgical procedures. Meanwhile this has changed a bit. Depending on the risk assessment for recurrent dislocations (e.g. Patella Instability Severity Index [10]) one should consider trochleoplasty as a primary treatment in certain severe pathologies.

Higher grade cartilage defects (ICRS III/IV) and patient's age over 30 are relative contraindications. The individual cartilage and bone quality has to be considered. The use of Bereiter's technique in patients with open physes cannot be recommended in general, on the other hand there are no reports of growth disturbance published. For details on indications see also Chaps. 4 and 25.

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## 27.2 Surgical Technique

The patient is placed in supine position, tourniquet is recommended. The knee is positioned in midflexion (45°). The approach to the knee depends on the need for concomitant procedures. Therefor thorough planning is mandatory. Starting with a median skin incision from the patella pole to proximal of about 8 cm length one has to decide where to open the joint. If any intervention with the lateral soft tissue structures is needed (lateral retinacular lengthening, LRL) a lateral arthrotomy according to Keblish should be performed [11]. The superficial layer of the lateral retinaculum is incised and separated from the deep layer by blunt dissection. The deep layer is then cut more posterior so one has the option to achieve a lengthening effect when closing the arthrotomy at the end of the procedure. When this LRL is not needed a medial parapatellar approach can be performed. The patella is inspected and retracted medially or laterally depending on the approach. The whole trochlea is exposed and assessed in terms of cartilage situation and characteristics of the dysplasia to plan the needed extent of osteochondral flap preparation (Fig. 27.1).

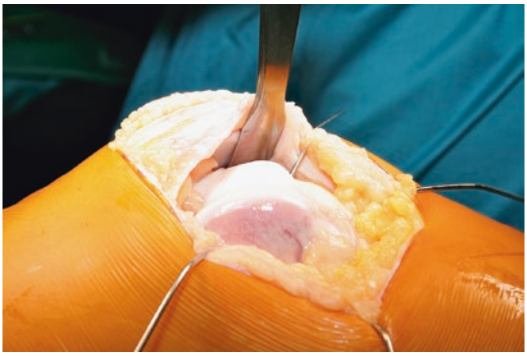

**Fig. 27.1** A lateral arthrotomy is done in cases with the need for LRL. A Hohman retractor is placed in the medial gutter to protect the patella, K-wires can be used for comfortable spreading the wound

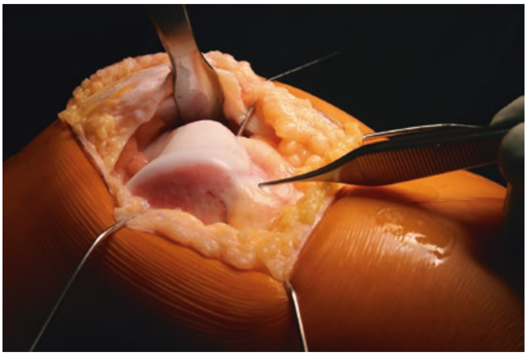

**Fig. 27.2** The soft tissue ramp proximal to the bone-cartilage-border should be left attached to the later osteochondral flap (see also Fig. 27.4)

Usually one can find a soft tissue ramp in the lateroproximal aspect of the trochlea-entry (Fig. 27.2). This structure represents the runway of the patella before entering the trochlea. When dissecting the periosteum at the bone-cartilage-border it is recommended to save this soft tissue structure attached to the cartilage flap, as it can be very useful for later refixation of the flap. Then the osteochondral flap is carefully elevated in small steps using various osteotomes. Especially in the initial phase when removing the flap from the often konvex bump region a curved Lambotte osteotome is needed (Figs. 27.3, 27.4, and 27.5). One should aim for a flap thickness of about 3–5 mm (cartilage + 1–3 mm of bone). Usually a high-speed burr is used for thinning certain regions of the flap to achieve a stable but flexible osteochondral flap (Figs. 27.6 and 27.7). The use of an offset-guide may be helpful for this step.

The next step is shaping the new trochlea groove. Starting from a slightly lateralized entry-point the sulcus is created from proximal to distal by removing cancellous bone using a gouge or chisels. If a bump is present the complete resection is essential. The central depth of the sulcus should be below the ventral cortex of the distal femur. Once a rough shaping is done, preparation is completed with the burr to create the final

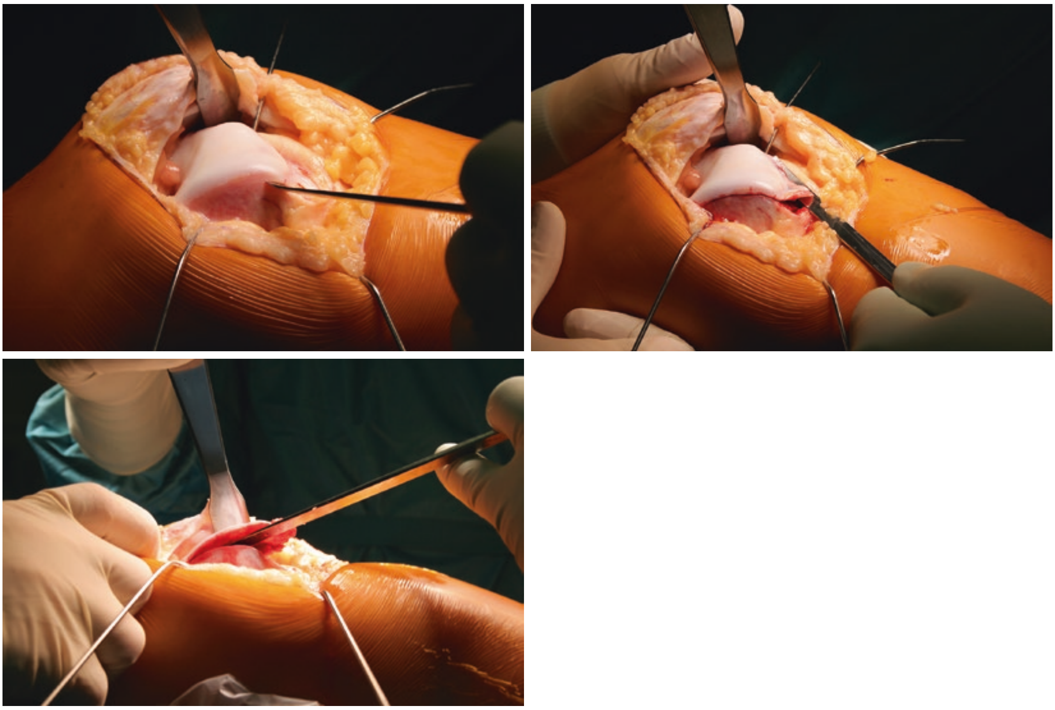

**Fig. 27.3–27.5** Starting at the bone-cartilage-border the osteochondral flap is elevated using different osteotomes. The process is done carefully from proximal to distal. A flap thickness of max. 5 mm should be achieved

shape. The goal is to achieve a situation with good containment of the patella and the new groove, usually the groove doesn't have to be too deep—removing the bump and creating a slight sulcus is the main objective (Fig. 27.8). The flap is then reduced into the bony bed using a blunt rasp or a finger. Sometimes it is necessary to "massage" the Flap carefully back (Fig. 27.9).

Once an optimal shaping is achieved the osteochondral flap can be fixed. In his original technique Bereiter used a resorbable tape that was placed in transosseous tunnels and tied on the medial/lateral condylar cheek. In our modified technique we avoid these bone tunnels using knotless anchors. The first device (loaded with 5 mm Vicryl tape, Ethicon) is introduced centrally in the very distal end of the new groove. Depending on the extent of the Trochleoplasty the number of anchors needed is determined. Usually a second anchor is used in the middle of the groove and a third one proximal to the entry. The Vicryl tape is loaded to the eyelets prior to insertion, so U-shaped fixation is achieved between two anchors. Usually this fixation is very stable and needs nothing more. If the medial or lateral edges are not perfectly stable transosseous sutures can be added. The resected bone can be used for grafting underneath the flap if needed. The osteotomy is finally sealed with fibrin glue to avoid postoperative bleeding (Figs. 27.10, 27.11, 27.12, 27.13, 27.14, and 27.15).

The further steps are depending on possible additional procedures. Normally at least an MPFL reconstruction is performed. Before adding this procedure, a lateral arthrotomy should be closed in 70° of flexion (LRL) to avoid over-medialization.

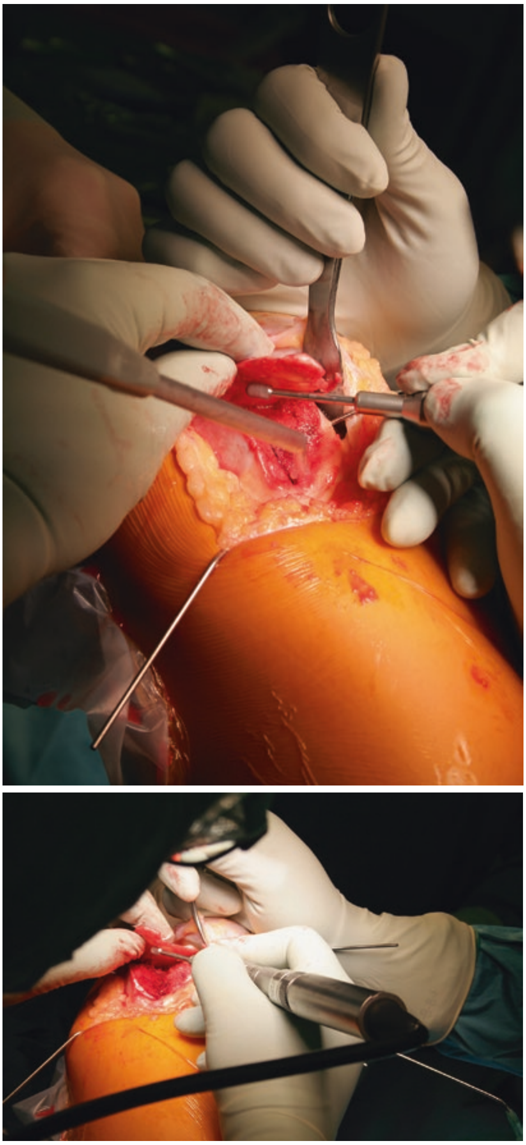

**Fig. 27.6 and 27.7** A high-speed burr is used for thinning the osteochondral flap to result with a stable but flexible osteochondral flap

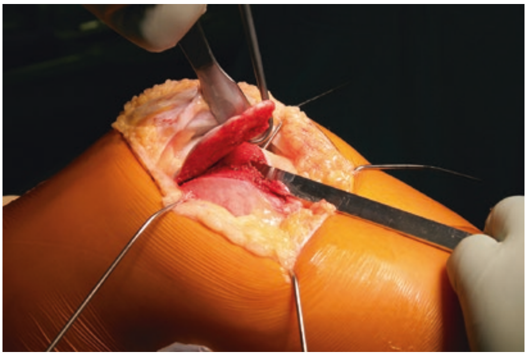

**Fig. 27.8** Shaping the new trochlea groove is initially started with a chisel from proximal to distal. The direction of the groove is from slightly lateroproximal to the entry of the notch, where there is nearly always at least a shallow natural groove that should be respected

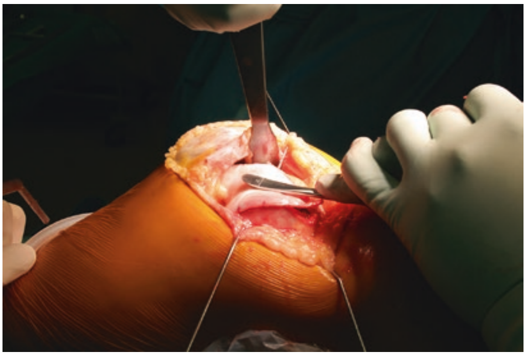

**Fig. 27.9** A blunt Rasp is used to carefully reduce the osteochondral flap into the new bony groove

## 27.3 Postoperative Protocol

Partial weightbearing is recommended for 2 weeks, afterwards individual weightbearing as tolerated is allowed. Patients are braced (0–0–60°) for 6 weeks but the ROM limit is individually increased to 0–0–90° as soon as 60° are easily exceeded. In supine position we recommend to rest the knee in 20° of flexion to achieve continuous pressure of the patella against the osteochondral flap. A lack of extension has to be avoided by fully extending the knee several times per day. CPM is done twice a day for 30 min with flexion up to 90° as tolerated starting from day one. At week 7 ROM is not restricted and active physiotherapy (strength, sensorimotor function) is intensified.

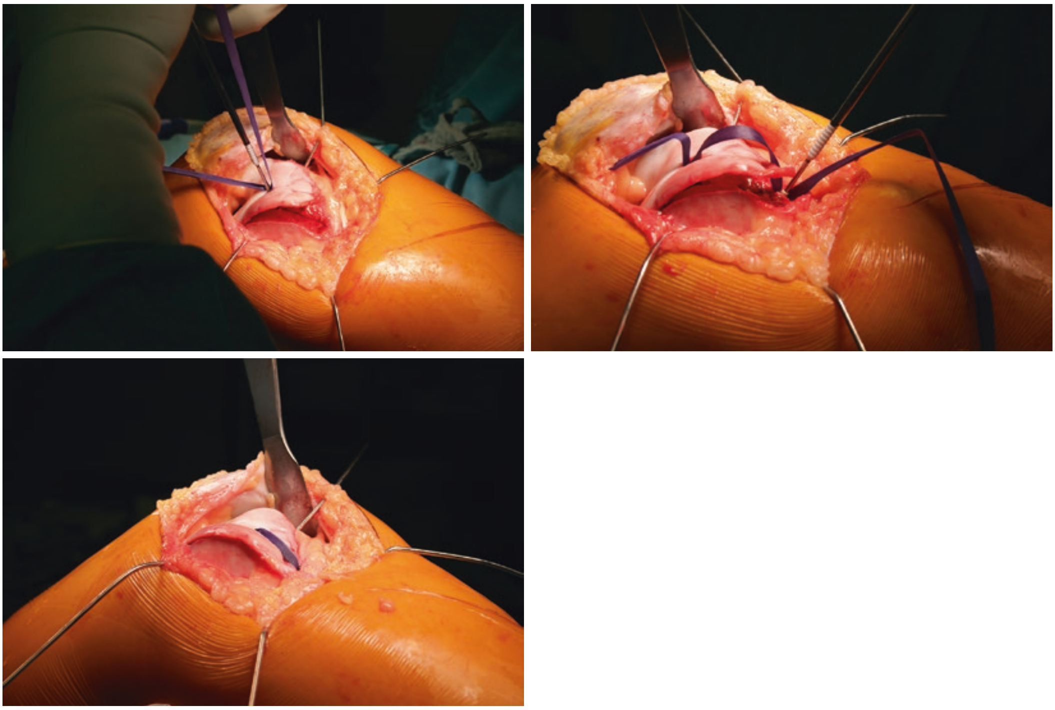

**Fig. 27.10–27.12** Refixation of the flap is done with resorbable tape and knotless anchors. The tape is placed in the center of the groove. The number of anchors depends on the extent and stability of the flap, normally 2–3 are enough. The tension of the tape can be varied by the insertion depth of the anchors

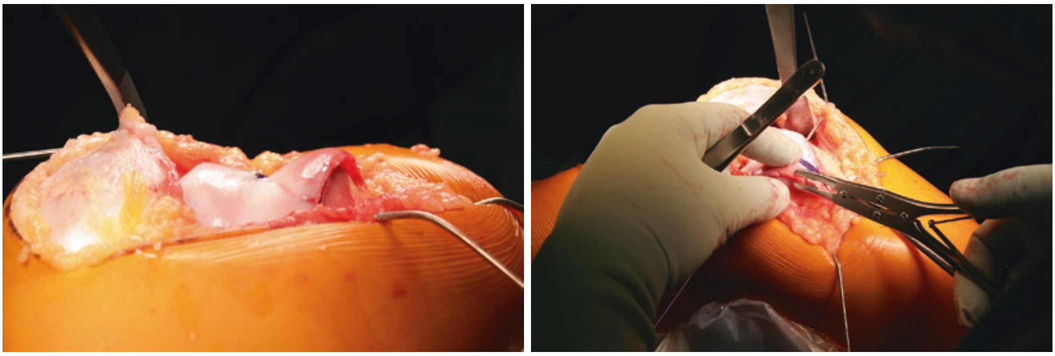

**Fig. 27.13 and 27.14** The final shape of the new trochlea after fixation. Usually reshaping the groove leads to excess bone on the lateral trochlea edge. This bone can be removed with a sharp knife for a chondrotomy and a Luer

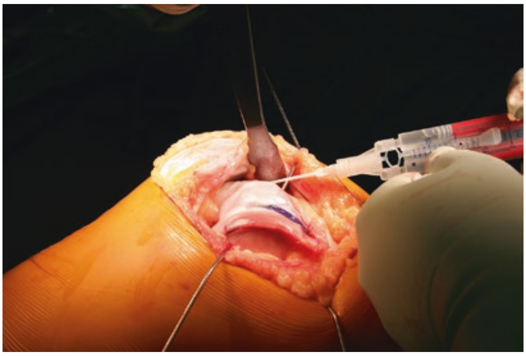

**Fig. 27.15** Finally the osteotomy gap is sealed with Fibrin glue

The overall recovery time for activities for daily living can be expected to be 8–12 weeks.

**Box**

*Instruments needed*

- Standard knee instruments
- Curved Lambotte osteotomes 6, 8, 10 mm
- Gouge 8 or 10 mm
- High-speed burr with appropriate burr attachment
- Offset guide (optional)

*Used implants*

- Resorbable suture tape 5 mm width (e.g. Vicryl®)
- Knotless suture anchors (eg. Arthrex PushLock® 3.5 mm)
- Fibrin glue

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# 28

# Trochleoplasty Techniques: Deepening Lyon

Sebastiano Vasta, Pedro Castelhanito,
and David Dejour

## 28.1 Introduction

Several predisposing factors, mostly congenital, may lead to chronic patellar dislocation; those factors have a high genetic incidence. The patellar and trochlear groove bone and chondral geometry are essential in guiding the patella in the distal femur as the knee flexes, and it has been clearly demonstrated that a flat trochlea is more likely to induce lateral patellar translation than an injured medial retinaculum or a released vastus medialis [1]. Henri Dejour described four major instability factors: trochlear dysplasia, patella alta, excessive distance between tibial tubercle and trochlear groove (TT–TG > 20 mm), and excessive patellar tilt (>20°) [2]. Trochlear dysplasia is the main determinant; it is present in 96% of the objective patellar dislocation (OPD) population (at least one patellar dislocation). Trochlear dysplasia was classified firstly by Henri Dejour [2] and, successively, by David Dejour and Le Coultre [3]. Trochlear dysplasia has been pointed as the predominant factor in inducing patellar instability; in fact, it is responsible for significantly altered congruence between the groove and the patella, reducing its fit into the trochlea during range of motion. The patellar tilt is directly related to the shape of the trochlea; from type A to type D, the tilt in extension increases; this is the reason why the "patellar tilt" which was considered as an "instability factor" is now considered as a consequence and no more as a risk factor. This incongruence is particularly important during the early degree of flexion, since the proximal groove is shallower, flat, or even convex compared to the distal [4]. In case of high-grade trochlear dysplasia and chronic patellar instability, it is necessary to surgically address the deformity to achieve stability and congruency to bring back the patella femoral joint to a normal biomechanical behavior. Different surgical techniques have been described, the lateral facet-elevating trochleoplasty (Albee's procedure) [5], the Bereiter trochleoplasty (thin flap technique) [6], the arthroscopic deepening trochleoplasty [7] and the sulcus-deepening trochleoplasty (thick flap technique) [8, 9]. The deepening trochleoplasty will be described in this chapter.

## 28.2 Indications

Indications for trochleoplasty are very narrow, and it arises from a combination of clinical and radiological analysis. Candidates for such surgery

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are patients complaining from permanent, habitual, or frequent dislocation during their daily activities and patients with an abnormal patellar tracking during flexion and extension with passive and or active motion. Looking to the radiographic analysis, trochleoplasty is indicated in patients with high-grade dysplasia. According to Dejour's classification [3], the best indication is in types B and D, in which the trochlea is prominent and convex, leading to patellar impingement in sagittal plane and axial plane during knee flexion.

Before performing trochleoplasty, all the major instability factors must be evaluated and rated. Often multiple factors are present; consequently trochleoplasty is seldom performed as an isolated procedure. Patella height, excessive TT-TG, and rotational abnormalities should be addressed. When a deepening trochleoplasty is performed, a new groove is created in a more anatomic (lateral) position, thereby performing a type of proximal realignment which should be taken in account in the global realignment done, if a TT osteotomy is combined. This will effectively decrease the TT-TG distance by the lateralization of the groove. However, in case of severely increased TT-TG, it could not be enough, making a distal realignment necessary. In case of patella alta, (Caton-Deschamps >1.2) or in case of poor sagittal engagement (sagittal patellofemoral engagement (SPE) index <0.45) [10], consider associating tibial tubercle distalization. Although less common, severe deformities of the femur (or tibia) on the axial plane can result in patella-femoral malalignment and instability. Since femoral torsion plays a significant role in patella-femoral kinematics, some authors proposed performing femoral derotational osteotomy in patients with recurrent patellar dislocations and severe torsional abnormalities. Once the anatomical abnormalities are treated, the "torn" anatomy with the MPFL rupture has to be repaired; this is why a systematic MPFL reconstruction is added to the trochleoplasty.

## 28.3 Contraindications

Trochleoplasty is contraindicated in:

- High-grade trochlear dysplasia with instability associated with patellofemoral pre-arthritis or arthritis
- Anterior knee pain without instability
- Absence of the trochlear bump (supratrochlear spur)

## 28.4 Surgical Technique

The procedure can be performed either under general or regional anesthesia and patient sedation. The patient is positioned supine, with a lateral post and a foot support to hold the knee at 90° of flexion. Tourniquet is applied at the thigh. The whole lower extremity is prepped and draped.

A straight midline incision is performed, and a full thickness skin flap including the three medial layers is developed. Although in the original technique the arthrotomy was performed by a midvastus approach, in the most recent years, we switched toward a limited medial parapatellar approach, extending 4 cm above the superior pole of the patella to just above the tibial plateau, paying special attention to avoid injury to the anterior horn of the medial meniscus (if a concomitant tibial tubercle will be performed, the incision will be extended 5–7 cm below the plateau). The transquadricipital approach allowed a mild mid-vastus plasty when closing the knee. The patella is not everted but carefully inspected; the chondral lesions are rated upon ICRS classification as well as the trochlear cartilage damages. The peritrochlear synovium and the periosteum are incised midline on the femoral shaft and along the osteochondral junction in an inverted "Y" shape, developing a medial and a lateral flaps by a periosteal elevator, in order to achieve a clear vision of the anterior femoral cortex and to be able to define the amount of bone to be removed. Once the trochlea is fully exposed, the new one is planned and drawn with a sterile pen. The new trochlear groove is drawn using a starting point on the top of the intercondylar notch (Fig. 28.1). From there, a straight line representing the new sulcus is directed proximally and laterally, aiming to the femoral anatomical axis. This is useful to improve the TT–TG distance (e.g., "proximal realignment" in order to get a postoperative value of 10–15 mm). The amount of lateralization is measured and quantified. The superior limit is the osteochondral edge. Two divergent lines are also drawn, starting at the notch and going proximally, representing lateral and medial facet's limits. The superior limits are the medial and lateral condylotrochlear sulcus.

The next step is to remove the bump of the proximal trochlea and gain access to its undersurface (Figs. 28.2 and 28.3). The aim is to have the new trochlea flush with the anterior femoral cortex. For this purpose, a thin strip of cortical bone is removed from the osteochondral edge, going from there to the anterior cortex of the femur. A small oscillating saw (alternatively a sharp osteotome) is used to cut the strip of cortical bone, and a rongeur is used next, to remove it. Subsequently, the cancellous bone must be removed from the undersurface of the trochlea, by using a high-speed burr. A special guide is used to preserve a 5-mm-thick osteochondral layer (Fig. 28.4a and 28.4b). That is helpful to maintain an adequate amount of subchondral bone and avoid thermal injury to the cartilage. It is important to go distal enough, toward the intercondylar notch, to achieve good mobility of the osteochondral flap allowing for modeling without being

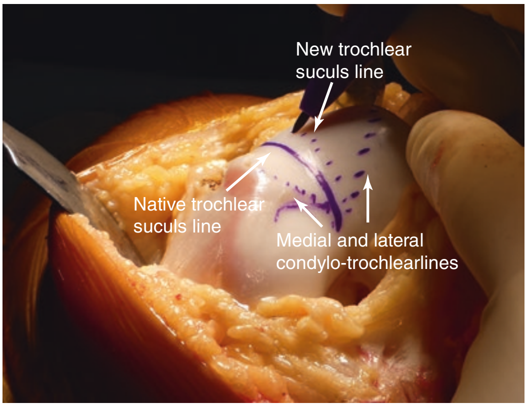

**Fig. 28.1** Planning the new trochlea

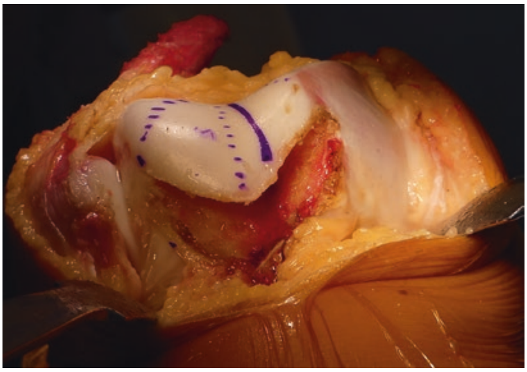

**Fig. 28.3** The bump has been removed, and there is good access to the proximal trochlea undersurface

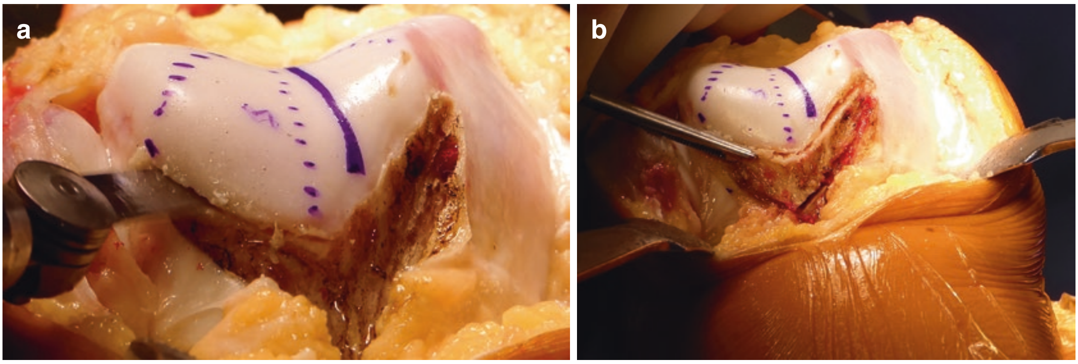

**Fig. 28.2** (**a**) The bump of the proximal trochlea is sawed off. (**b**) After completing the cut with the saw, Remove the bump of the proximal trochlea and gain access to its undersurface

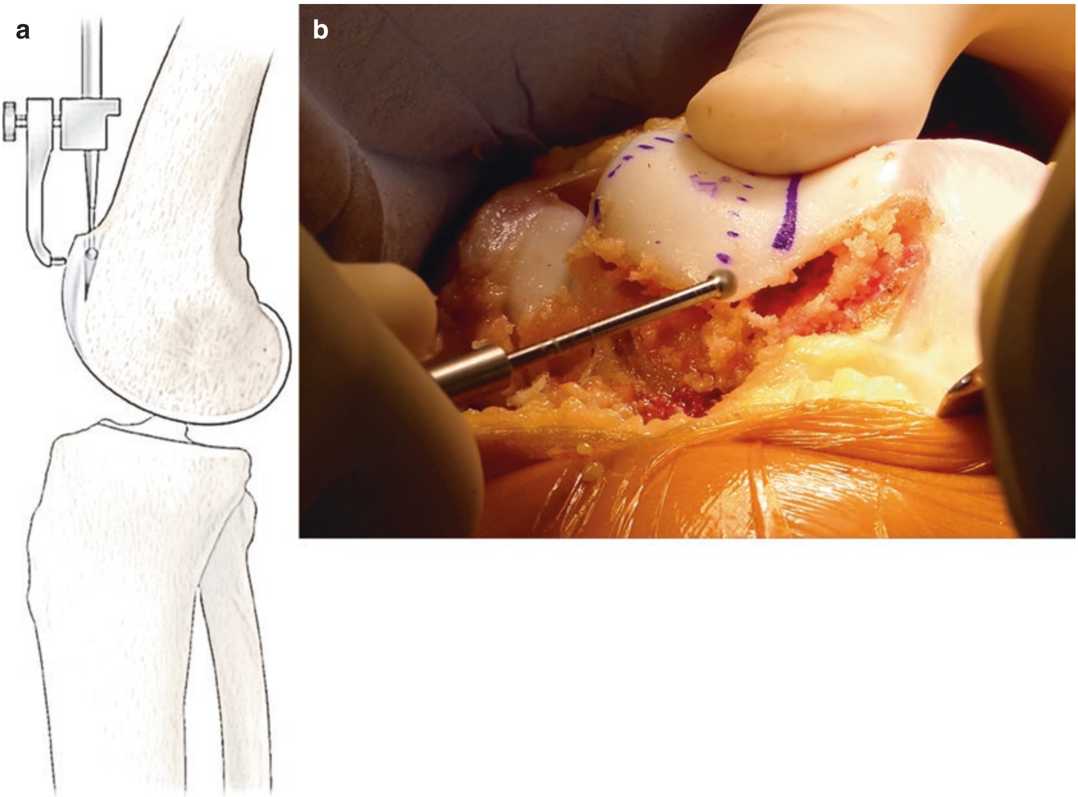

**Fig. 28.4** (**a**) The special guide is used to preserve a 5-mm thick osteochondral layer. (**b**) Removing the cancellous bone from the undersurface of the trochlea and verifying the osteochondral flap mobility

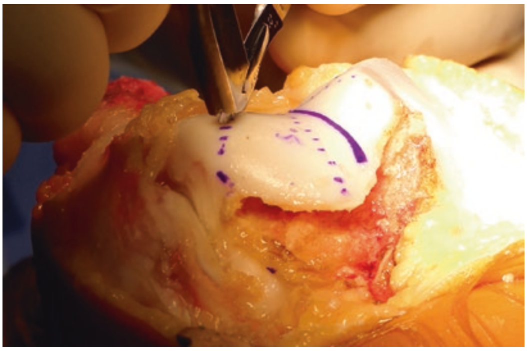

**Fig. 28.5** The new sulcus and the external margin of the lateral and medial facets are osteotomized by gently tapping over a scalpel

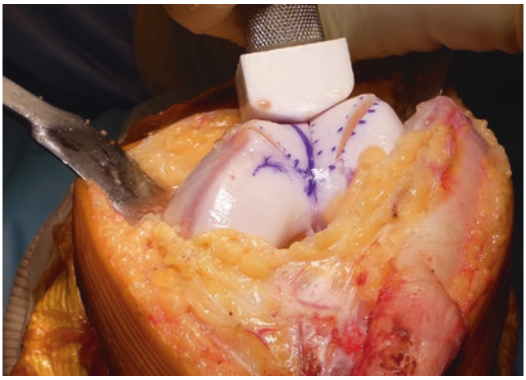

**Fig. 28.6** Use a "V" bone impactor, with a 140° angle, to gently tapping over the new trochlea

fractured. More cancellous bone is removed from the central portion where the new sulcus will rest. The new sulcus and the external margin of the lateral and medial facets should be osteotomized by gently tapping over a scalpel (Fig. 28.5) first for the cartilaginous part and then by using a sharp osteotome with an inclination of 45° to avoid any trochlear fracture. To allow for proper contact between the osteochondral flap and the underlying cancellous bone bed in the distal femur (Fig. 28.6), it is possible to use a "V" bone impactor, with a 140° angle, to gently tap over the new trochlea

(Fig. 28.7). The facets are then mobile, and the final stage will be to adapt the amount of deepening necessary with the high-speed burr; the goal is to have a sulcus angle close to 140° with no over deepening which could lead to lack of congruence with the dysplastic patella. Usually the medial trochlear facet doesn't need any correction but just being flush with the anterior cortex; for the lateral facet, a rotation combined to a slight elevation might be necessary to increase the quality of the trochlear reshaping; a bone graft could be added under the fact to maintain the perfect correction.

If the correction obtained is satisfactory, the new trochlea is fixated with two absorbable no. 2 sutures coming from a double-loaded anchor applied near the notch (vertex) (Fig. 28.7); one doubled suture spans each facet from the anchor in the notch to another anchor applied in the supratrochlear fossa, proximal to the end of the cartilage. The sutures are tensioned and fixated as the proximal knotless anchors are inserted. Pressure is applied on the medial and lateral facets, while the sutures are being tensioned, ensuring that the prominence is removed and that the facets are flush with the anterior femoral cortex (Fig. 28.8). The final result is shown in (Fig. 28.9). Patellar tracking is tested. Often the lateral structures are very tight, and a release of the lateral retinaculum is needed to correct the lateral tilt of the patella. The lateral release has to come from the tibial plateau toward the vastus lateralis, and if the quality of the tissue is good, a lateral lengthening is better than a simple section. Periosteum and synovial tissue are carefully sutured to the osteochondral edge.

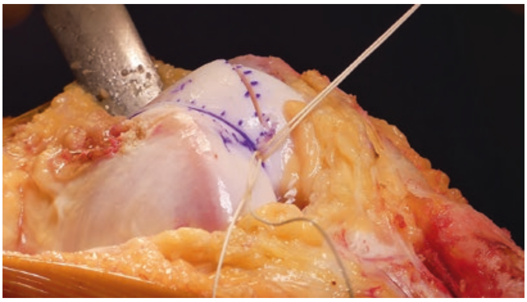

**Fig. 28.7** The new trochlea is fixated with two absorbable no. 2 sutures coming from a double-loaded anchor applied near the notch (vertex)

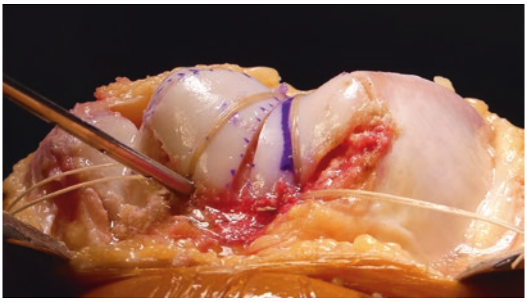

**Fig. 28.8** The sutures are tensioned and fixated proximally at the end of the cartilage by knotless anchors

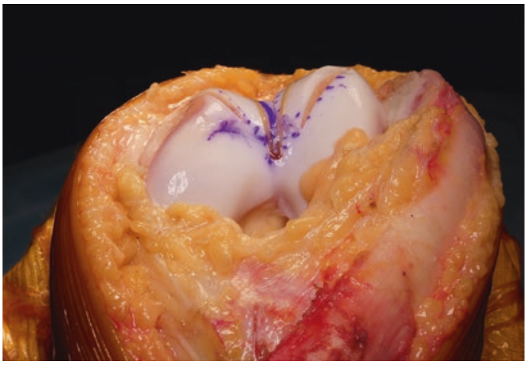

**Fig. 28.9** Final result

After trochleoplasty is completed, the next step is medial patellofemoral ligament reconstruction. The classical technique uses a gracilis tendon autograft with two patellar tunnels (transosseous fixation) and one blind tunnel at the isometric point in the femoral insertion's area identified by the fluoroscopy, close to the medial epicondyle (anatomic point). A medializing tibial tubercle (TT) osteotomy is also often performed to further correct the TT–TG distance according to the preoperative planning, and distalization of the TT is associated in case of patella alta.

## 28.5 Postoperative Care

Trochleoplasty does not need weight protection or range of motion limitation, when performed as an isolated procedure. Movement may in fact improve cartilage healing and further molding of the trochlea; continuous passive movement

(CPM) is usually used during the first days. The postoperative rehabilitation is mainly guided by the associated procedures in particular the TT osteotomy.

In case of TT osteotomy, full weight bearing is allowed with an extension brace for the first 30 days and aided by crutches. The brace must be removed during the exercises and during the rest time. If there is no TT osteotomy, no brace is necessary.

During the first 45 days, patients are encouraged to perform exercises for range of motion, as tolerated, including isometric quadriceps and hamstring strengthening. Passive patellar mobilizations are also indicated. Range of motion is gradually recovered, avoiding forced or painful postures. Quadriceps strengthening with weights on the feet or tibial tubercle is discouraged.

After 6 weeks, closed chain and weight-bearing proprioception exercises can be performed. Cycling is usually possible, with light resistance initially. Active ascension of the patella can be performed seated, with the leg stretched and the knee unlocked, by static and isometric quadriceps contractions. Quadriceps strengthening with weights on the feet or tibial tubercle is still discouraged. The anterior and posterior muscular chains are stretched. Weight-bearing proprioception exercises are started when full extension is complete, first in bipodal stance and later in monopodal stance when there is no pain. Running can be initiated on a straight line after 3 months. Closed kinetic chain muscular strengthening between 0° and 60° with minor loads but long series are allowed. Stretching of the anterior and posterior muscular chains is continued. The patient is encouraged to proceed with the rehabilitation on his or her own. After 6 months, sports on a recreational or competitive level can be resumed.

Radiological follow-ups are scheduled at 6 weeks postoperatively, including anteroposterior view, lateral view, and axial view in 30° of flexion. After 6 months a CT scan is obtained to document the achieved correction.

## 28.6 Conclusion

Sulcus-deepening trochleoplasty is a technically demanding procedure with precise indications. It has the advantage of addressing one of the major causes of patellar instability—trochlear dysplasia—but often it is performed in combination with other procedures to address associated abnormalities. As any surgical procedure, it is at risk for complications. It shouldn't be done in case of pain or in the presence of osteoarthritis.

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# 29 Lengthening Osteotomy with or Without Elevation of the Lateral Trochlear Facet

Roland M. Biedert

## 29.1 Introduction

The femoral trochlea is important for controlling the patellofemoral gliding mechanism [1, 2]. Normal articular shape of trochlea and patella allows for undisturbed patellar engagement and tracking. The normal cartilaginous surface of the trochlea consists of the lateral and medial facets of the femoral sulcus and is defined by different criteria in the proximal-distal, medio-lateral, and anteroposterior direction [3–7]. The normal trochlea deepens from proximal to distal [3, 5, 7]. In the proximal-distal direction, it is longest laterally and shortest on the medial side (Fig. 29.1). The deepened trochlear groove separates the lateral facet from the medial part. In the antero-posterior measurements, the most anterior aspect of the lateral condyle is normally higher than the medial condyle, and the deepest point is represented by the centre of the trochlear groove [4, 6].

Trochlear dysplasia is an abnormality of shape and depth of the trochlear groove, mainly in its proximal extent [8, 9]. It represents an important pathologic articular morphology that is a strong risk factor for permanent patellar instability [1, 5, 8, 10–20]. Femoral trochlear dysplasia is present in 85% of patients with recurrent patellar dislocation and in 96% with objective patellar dislocation [13]. Dejour et al. [14] described several types of trochlear dysplasia with increasing severity. The trochlear depth may be decreased, the trochlea may be flat, or a trochlear bump (anterior translation of the trochlear floor) is present. According to this, different classifications are described in the literature [11, 21].

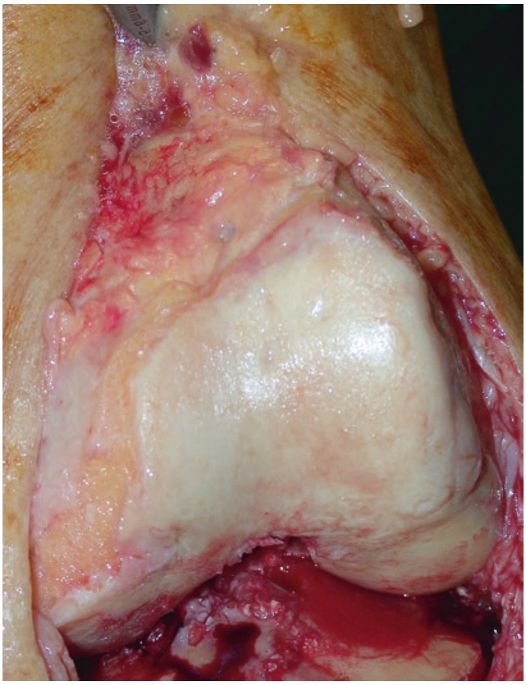

**Fig. 29.1** Normal shape and length of the lateral articular trochlea (anterior view, left knee, patient with degenerative joint disease)

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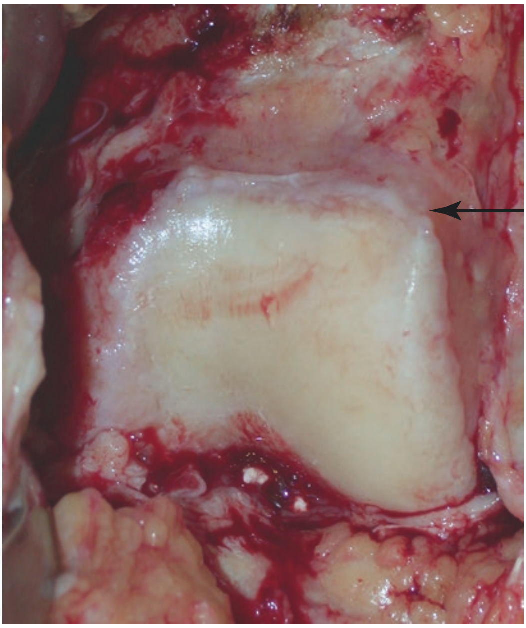

**Fig. 29.2** Too short lateral articular trochlea (end marked by arrow) compared to the medial facet. Trochlear groove and shape are normal (anterior view, left knee, patient with degenerative joint disease)

These forms of dysplastic trochlea are located proximally and cause decreased bony stability in the trochlear grove. The patella is insufficiently engaged at the entrance into the trochlea at the beginning of knee flexion, and lateral instability may occur. There exists a widespread variability of combinations of trochlear dysplasia [5]. Additionally, a different and less known type of trochlear dysplasia, the too short lateral articular trochlea, was described (Fig. 29.2) [22–24]. The short lateral trochlea is another relevant factor for lateral patellar instability. Accordingly, surgical treatment should aim to correct this specific type of dysplastic trochlea.

## 29.2 Physical Examination

The patients with a too short lateral trochlear facet suffer from dynamic supero-lateral patellar instability. The patella is well-centered in the trochlea under relaxed conditions with the leg in extension (Fig. 29.3a). Contraction of the quadriceps muscle causes proximalization and lateralization of the patella resulting in dynamic supero-lateral subluxation (Fig. 29.3b). The lateral subluxation of the patella is caused due to the missing osteochondral opposing force of the proximal lateral trochlear facet.

This type of patella instability may be depicted by manual examination in complete extension of the knee. Only minimal manual pressure to lateral causes subluxation of the patella and discomfort to the patient. In most cases the patient feels pain and tries to resist this manoeuvre. This test in full extension must be differentiated from the patellar apprehension test which is performed in 20°–30° of knee flexion [1, 25]. With increasing knee flexion, the patella enters into the more distal and normally shaped part of the trochlear groove and becomes therefore more stable. The patellar apprehension test is therefore negative. The difference between a well-centered patella without muscle contraction and the dynamic supero-lateral subluxation caused by quadriceps contraction confirms the proximal lateral patellar instability.

## 29.3 Imaging

### 29.3.1 Radiographs

The radiologic examination of patients with a too short lateral facet of the trochlea is normal in most cases. Typical findings of trochlear dysplasia in the true lateral view (crossing sign, supratrochlear spur, double contour, lateral trochlear sign) are missing or only present in combined trochlear pathologies [8, 11, 13, 14, 26]. Different radiographic indices used for patellar height measurements are also normal.

### 29.3.2 MR Measurements

MR imaging allows complete and precise visualization of the patellofemoral joint and is therefore the best modality to assess the proximal part of the trochlea in patients with suspected (history and physical examination) too short lateral facet [11, 27].

**Fig. 29.3** (**a**) Well-centered patella without muscle contraction. (**b**) Dynamic supero-lateral patellar subluxation (direction of arrow) caused by quadriceps contraction

MR measurements are performed with the knees placed in a standard knee coil in extension (0° of flexion), the foot in 15° external rotation, and the quadriceps muscle consciously relaxed. Measurements on sagittal images include different parameters (Fig. 29.4) [22–24]. The parameters are measured on the most lateral section of the lateral condyle with visible articular cartilage in the trochlea (Fig. 29.5). The length of the anterior articular cartilage of the lateral trochlea (*a*) is calculated using as a reference the length of the posterior articular cartilage of the lateral condyle (*p*) [24]. For each individual subject, *p* is always considered to be 100%. The variable length of *a* is calculated in percentages with regard to *p*. The *lateral condyle index* compares the length *a* with the length *p* and is expressed in percentages.

The values of the lateral condyle index found in a normal control population without any patellofemoral disorder are on average 93% [24]. Therefore an anterior length of the lateral articular facet of the trochlea with index values of 93% or more of the length of the posterior articular cartilage is considered as normal (Fig. 29.5). Lateral condyle index values of 86% (on average) were found in patients with chronic lateral patellar subluxation and instability documenting a too short lateral articular facet of the trochlea (Fig. 29.6). Index values of less than 93% must therefore be considered as pathologic, and values of 86% or less confirm the presence of a too short lateral facet. Index values between 86% and 93% need additional assessment such as the patellotrochlear index or radiologic patellar height measurements (Caton-Deschamps index) to document or exclude additional patella alta [28]. In cases with pathologic lateral condyle index and normal patellar height measurements, lengthening of the anterior lateral articular facet of the trochlea is recommended. In cases with patella alta, other surgical interventions, such as distalization of the tibial tubercle, may be needed. Combined surgical procedures (lengthening and distalization) may also be indicated in specific cases.

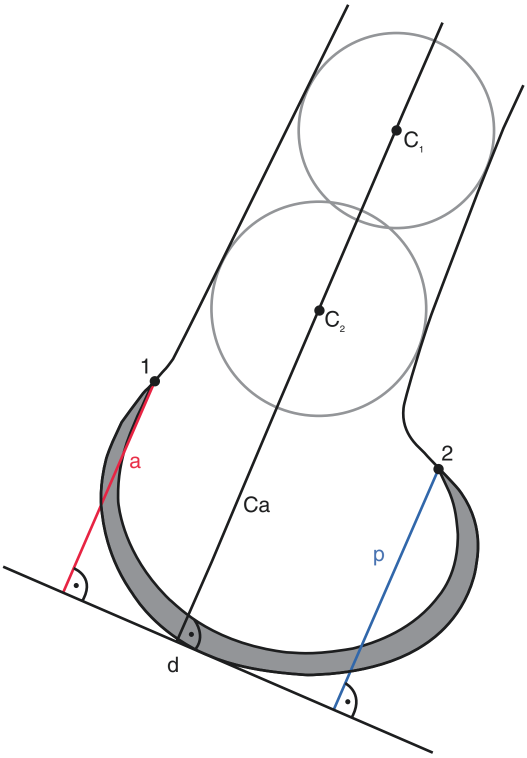

**Fig. 29.4** MR measurements [24]

$C_1$ Proximal circle in the femoral shaft
$C_2$ Distal circle in the femoral shaft
Ca Central axis
d Baseline distal condyle (perpendicular to Ca)
1 Superior most aspect of anterior cartilage of the lateral condyle
2 Superior most aspect of posterior cartilage of the lateral condyle
*a* Length of the anterior articular cartilage of the lateral condyle (red line)
*p* Length of the posterior articular cartilage of the lateral condyle (blue line)

## 29.4 Surgery

Surgery aims to correct the present pathomorphology. Lengthening of the lateral facet is indicated when a too short lateral trochlea is documented (clinically and with MRI) and when the patients remain symptomatic after conservative treatment. A clear indication for lengthening is given when the LCI is 86% or less (Fig. 29.6). Lengthening trochleoplasty is designed to create an extension of the proximal part of the lateral trochlear facet to improve the engagement of the patella into the trochlea and to increase the contact within the patellofemoral joint, both relaxed and under muscle contraction. A longer lateral trochlear facet is the

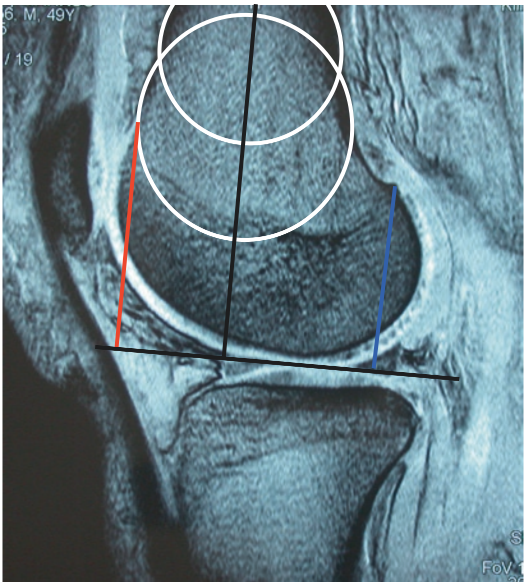

**Fig. 29.5** MR measurement with normal length of the anterior articular cartilage of the lateral facet of the trochlea (LCI 121%)

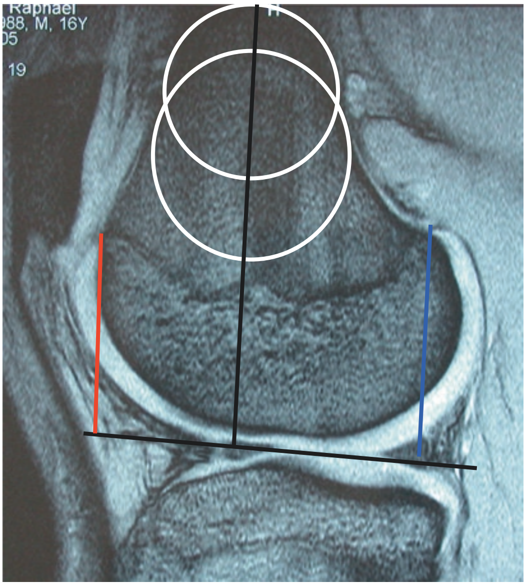

**Fig. 29.6** MR measurement with too short anterior articular cartilage of the lateral facet of the trochlea (same patient as Figs. 29.9, 29.10, and 29.11; LCI 84%)

feature that must “capture” the patella in extension before the knee starts to flex, to ensure that it is guided into the more distal trochlear groove. Normally, the overlapping between the articular surface of the trochlea and the articular cartilage of the patella is about one third of the length of the patellar cartilage (measured using the patellotrochlear index on MRI) [28]. This value is helpful for planning and during surgery to determine how much lengthening to proximal should be performed.

### 29.4.1 Lengthening

Using a short lateral parapatellar incision, the superficial retinaculum is localized. About 1 cm from the border of the patella, it is longitudinally incised and carefully separated from the oblique part of the retinaculum in the posterior direction to allow at the end of surgery lengthening of the lateral retinaculum at the same time if needed [1, 29]. Then the oblique part is cut posteriorly, together with the synovial membrane. The patellofemoral joint is opened and the intraarticular inspection possible. Other pathologies can be depicted and treated if necessary. The proximal shape of the lateral facet of the trochlea and the length of the articular cartilage are assessed with regard to the length of the sulcus and the medial facet of the trochlea (Fig. 29.7). The presence of a too short lateral articular facet is reconfirmed. The present overlap allows now to determine the amount of lengthening of the lateral facet and should be about one-third at the end, measured in extension (0° of flexion) [1, 28]. The incomplete lateral osteotomy is made at least 5 mm away from the cartilage of the trochlea to prevent osteochondral necrosis or breaking of the lateral facet. The osteotomy starts at the proximal end of the cartilage (arrow). Then it is continued approximately 1–1.5 cm to distal into the femoral condyle and to proximal into the femoral shaft, always according to the aimed patellofemoral overlapping. The osteotomy is opened carefully with the use of a chisel. Fracture of the distal cartilage may occur and has no consequences; however sharp edges must be smoothed. Cancellous bone (obtained through a small cortical opening of the lateral condyle more posterior) is inserted and impacted (Fig. 29.8). Additional fixation is possible using resorbable sutures. To finish, the lateral retinaculum is reconstructed in about 60° of knee flexion to avoid overtensioning.

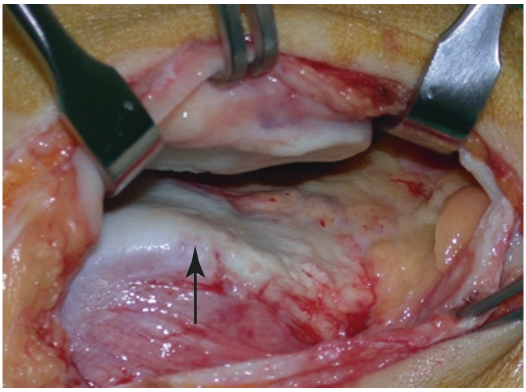

**Fig. 29.7** Intraarticular inspection shows the too short articular cartilage of the lateral facet (arrow) with destruction and osteophytes caused by chronic patellar subluxation (left knee, lateral view)

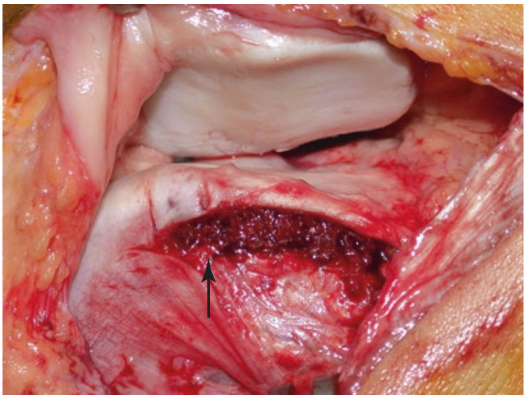

**Fig. 29.8** Completed lengthening osteotomy with inserted cancellous bone (arrow indicates former end of articular cartilage). The patellotrochlear overlap is increased now

### 29.4.2 Elevation

Combined pathologies with a too short but also a flat lateral facet of the trochlea can occur (Fig. 29.9). The surgical steps consist then of a

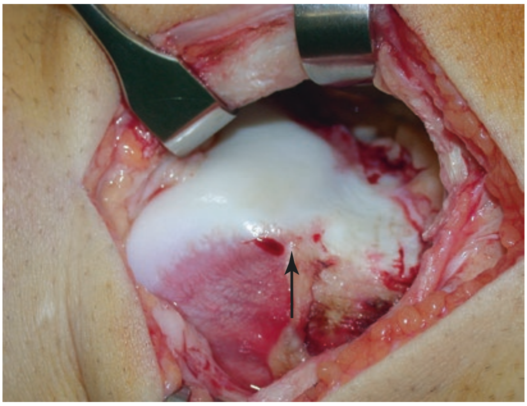

**Fig. 29.9** Too short and flat lateral articular trochlea (arrow) (lateral view; same patient as Fig. 29.6)

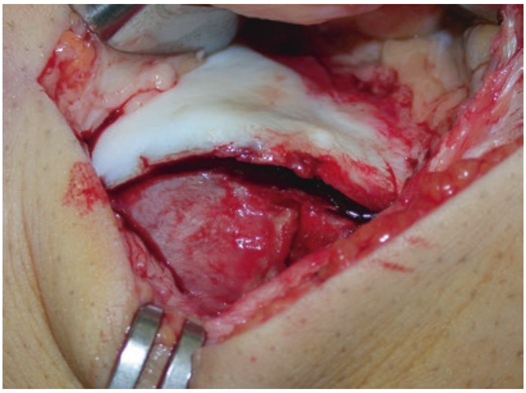

**Fig. 29.10** Shape and amount of the lateral osteotomy

lengthening osteotomy with additional elevation of the proximal flat lateral facet. The approach is the same. The osteotomy is opened carefully and the lateral facet lifted up to the desired height (Fig. 29.10). The amount of elevation depends on the present pathomorphology. The lateral facet of the sulcus should be higher than the medial facet (Fig. 29.11). The anterior cortex of the distal femoral shaft serves as an orientation of the necessary elevation. In most cases 5 mm elevation is sufficient. Overcorrection performing too much elevation causing hypercompression must strictly be avoided. It must be taken into account that in five out of six cases, the lateral condyle is not too flat but the floor of the trochlea too high [4, 6]. This is visible on axial MR images and must absolutely be assessed preoperatively.

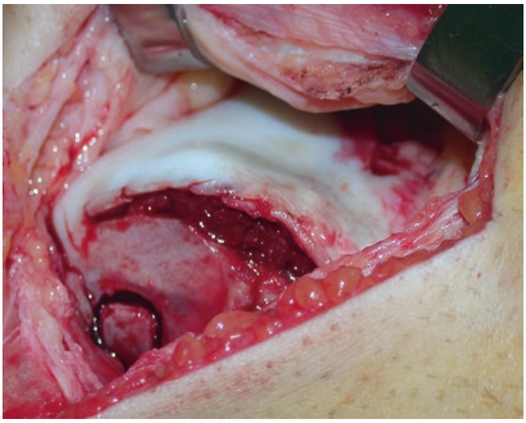

**Fig. 29.11** Intraoperative view after combined osteotomy with lengthening and elevation. The reconstructed proximal trochlea represents normal shape and length. The osteotomy gap is filled with cancellous bone (access to the lateral condyle to the take cancellous bone is closed)

## 29.5 Postoperative Care

Partial weight bearing (20 kg) is recommended for 3–4 weeks to avoid high compression of the osteotomy. Range of motion is limited (0°–0°–90°) for some days to decrease swelling and pain. Continuous passive motion starts immediately to optimize the patellofemoral gliding mechanism. Also physical therapy starts the first day after surgery and is continued until normal knee function is regained. Bicycling and swimming are allowed after 2–3 weeks and complete healing of the incision. Unrestricted sports activities are permitted after 3 months.

## 29.6 Conclusions

Lateral-facet lengthening represents another and less known type of trochleoplasty in patients with dynamic supero-lateral patellar instability due to a too short lateral articular facet. Physical examination and sagittal MR imaging are helpful to document this type of trochlear dysplasia. The LCI is the most reliable measurement for the diagnosis. Index values of less than 86% confirm the presence of a too short lateral facet. In cases with additional flat lateral facet, moderate elevation of the proximal lateral trochlea may be necessary.

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# 30 Trochleoplasty Techniques: Recession Osteotomy

Nicolas Pujol and Philippe Beaufils

## 30.1 Introduction

Major trochlear dysplasia is characterized by the combination of a flat and/or prominent trochlea which results in inadequate patellar tracking and almost complete knee extension and leads to patellar subluxation or dislocation [1].

Many surgical techniques have been proposed for the treatment of patellar instability [2–6]. Trochleoplasty has been described as a corrective treatment for bony abnormalities for many years, with the goal of restoring normal anatomy and congruence. Correcting the trochlear depth abnormality plays a major role in stabilizing the patella, as it facilitates proper entrance of the patella into the groove of the trochlea when the knee starts a flexion movement [7–9]. Recession trochleoplasty was first described by Goutallier et al. [5].

Trochleoplasty is considered a demanding technique and frequently may be underused due to a lack of familiarity. However, it can be a useful addition to the surgical panel when treating patellofemoral problems [6, 10–14].

Complication rates are comparable to other patellar-stabilizing procedures [15, 16].

In our experience, the restoration of the trochlea groove by such a trochleoplasty prevents future recurrent patellar dislocations and is also effective in reducing anterior knee pain [6, 17]. We will describe the surgical technique of recession wedge trochleoplasty in this chapter.

## 30.2 Indications

A trochleoplasty is a surgical correction of the femoral trochlea aiming to restore normal or nearly normal entry of the patella into the trochlear groove during extension and flexion. Our indications for a patellar stabilization surgery (including a trochleoplasty) are patients having had two or more episodes of patellar dislocations, with a persistent apprehension sign from 0° to 30° of flexion and trochlear dysplasia grade B, C, or D as defined by Dejour et al. [1].

Trochleoplasty can be proposed as a primary procedure for recurrent patellar instability or objective patellar instability (i.e., two or more patellar dislocations with a persistent apprehension sign from 0° to 30° of flexion and trochlear dysplasia grade B, C, or D) or as a secondary procedure in case of failure after a previous patellar alignment surgery, mainly the isolated anterior tibial tubercle transfer (ATTT).

It is also important to note that trochleoplasty procedures are often performed with other associated surgical procedures such as the ATTT (medialization or distalization) or the medial patellofemoral ligament reconstruction (MPFL).

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**Fig. 30.1** Trochlear dysplasia

The height of the trochlear spur should be superior to 5 mm (Fig. 30.1) for considering a trochleoplasty.

Figure 30.2 shows the current indications for performing such a procedure, depending on the associated lesions and femoral dysplasia.

## 30.3 Surgical Technique

The skin incision is made just lateral to the patella, extending from the superior pole to the level of patella, beyond the tibial tubercle onto the anterior ridge of the tibia. This permits a tibial tubercle transfer or a MPFL reconstruction to be performed during the same procedure if it is required (Fig. 30.3). A layered lateral retinacular lengthening is first performed through a lateral parapatellar incision. The superficial lateral retinaculum is exposed and is incised longitudinally, 1 cm from the border of the patella. This portion is then separated from the oblique portion of the retinaculum.

The oblique portion and synovial layer are then incised to gain access to the patellofemoral joint. The lateral retinaculum is closed with the synovial layer while doing a Z-plasty at the end of the procedure.

Preoperative imaging and intraoperative measurements are used to determine the size of the wedge to be excised and the angle to be corrected (Fig. 30.4).

Using a reciprocal saw, the anteroposterior cut is performed first above the trochlea, beginning approximately 5 mm from the cartilage edge (Fig. 30.5). The posterior cut is then made from the lateral side, parallel to the frontal plane of the femur and directed medially. It is more precise to start the cut with a small saw and to then complete it with the osteotome. The distal extent of the osteotomy should be approximately 5 mm from the sulcus terminalis in order to provide an optimal distal osteochondral hinge and to allow for ease in closing the wedge. Next, the anterior oblique osteotomy completes the bone cuts, linking the first two cuts (Fig. 30.6). The proximal-based bone wedge is then removed, and correction is achieved by progressively applying sustained gentle digital pressure on the trochlea. The amount of bone removed is just enough to allow the trochlea to settle into a deeper position without modifying the trochlear groove. The correction is then secured using 4.5 mm cortical screws, positioned just medially and laterally to the cartilage surface (Fig. 30.7). There is potential for distal fracture of the cartilage, which should be avoided by carefully closing the wedge. Moreover, it is important not to under correct the flat trochlea.

Postoperatively, the knee is placed in an extension brace for 3 weeks. The patients are maintained on a protective partial weight-bearing for 6 weeks. Knee flexion is restricted from 0°–60°

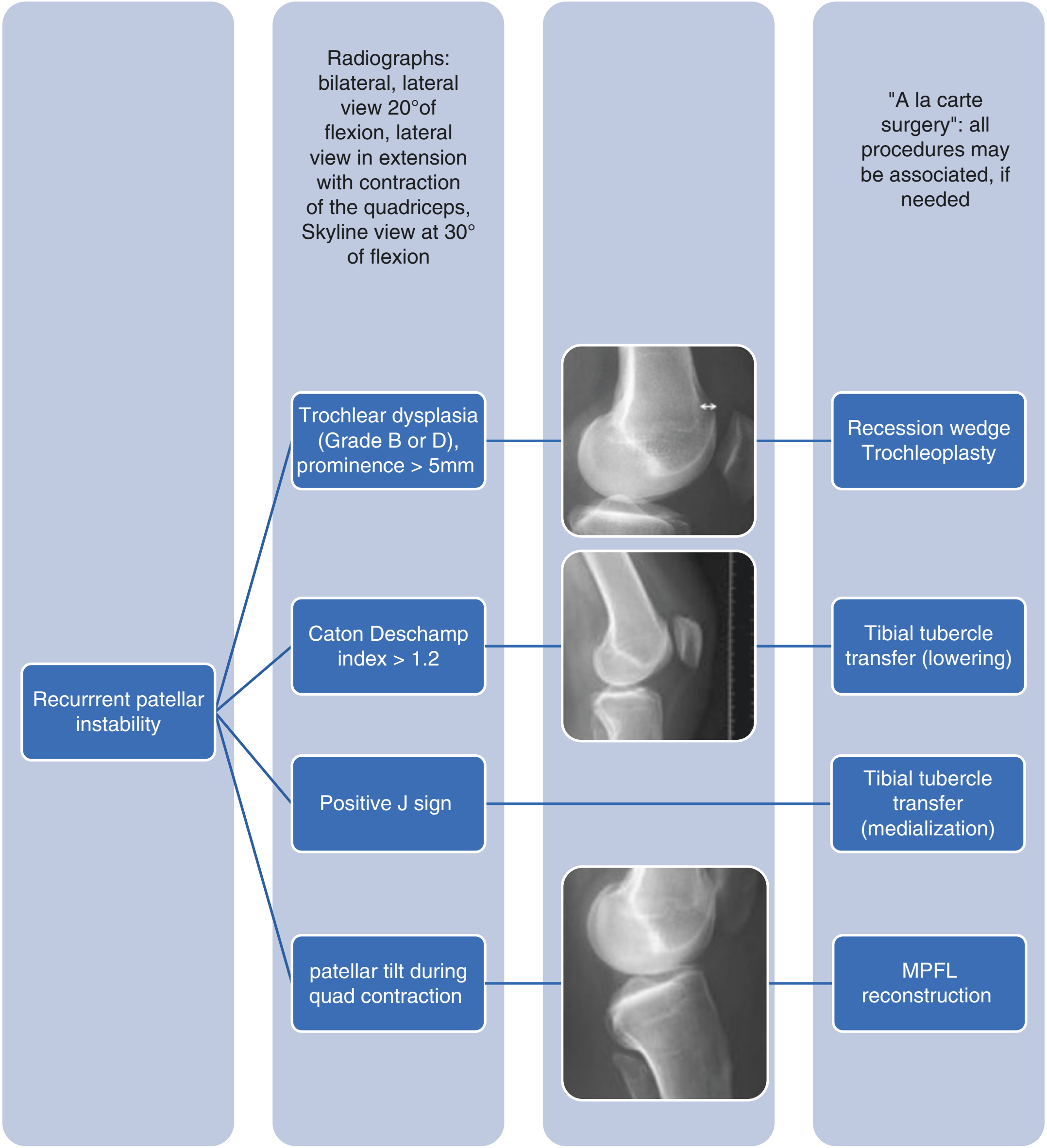

**Fig. 30.2** Flowchart describing the surgical options for patellar instability

for the first 3 postoperative weeks and then slowly increased to reach 90° on the sixth week. Return to sports is allowed at 6 months. This trochleoplasty postoperative protocol is identical whether or not ATTT or MPFL reconstructions are added to the procedure (Fig. 30.8).

## 30.4 Conclusions

Recession osteotomy trochleoplasty is indicated as a primary procedure for major trochlear dysplasia with a trochlear spur >5 mm. It can be also proposed in the case of revisions when a previous

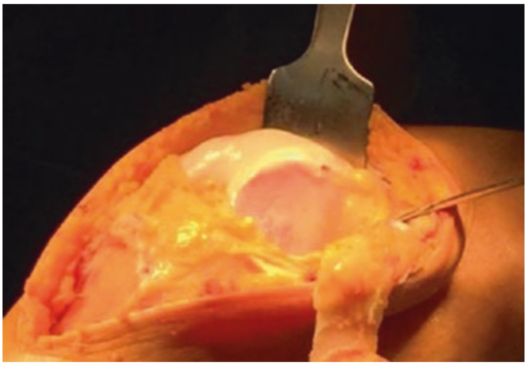

**Fig. 30.3** Surgical approach through a tibial tubercle osteotomy

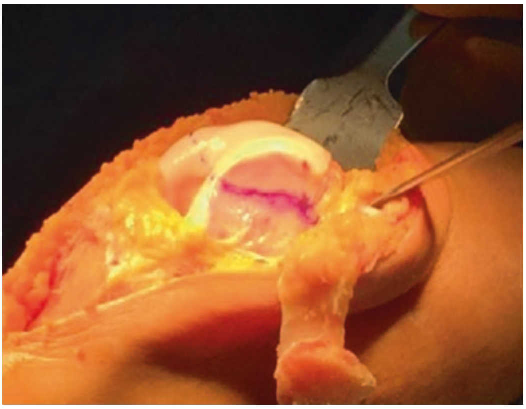

**Fig. 30.4** Landmarks of the osteotomy

**Fig. 30.5** Horizontal cut

**Fig. 30.6** Closing wedge osteotomy

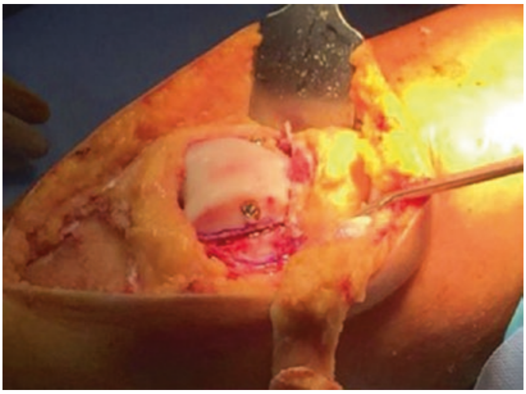

**Fig. 30.7** Internal fixation with 4.5 screws

surgery has failed. The reported results are encouraging in terms prevention of re-dislocation and the satisfaction index, and the rate of complications is low. It is however technically demanding due to the absence of ancillary guides to perform the femoral cuts. Long-term outcomes have not been reported yet, and there is no consistent data regarding the capacity of this technique in terms of prevention of secondary arthritis. However, the unreported preliminary data are promising.

**Fig. 30.8** Postoperative radiographs

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# 31 Trochleoplasty Techniques: Complications

Sandro F. Fucentese

Trochlear dysplasia has been identified as the most consistent anatomic factor in patient with recurrent patellofemoral instability [1]. Trochleoplasty strives to address this anomaly with two main goals: first to reach a stable patellofemoral joint with free range of motion of the knee joint and second to stop or at least decelerate patellofemoral degeneration [1–4].

There are different techniques described to address the anomalies. The very first technique as reported by Albee is the elevation of the lateral trochlear facet osteotomy [5]. The second and most used technique nowadays is the sulcus-deepening techniques according to Dejour [1, 6] or Bereiter [2, 7]. And the third group is the recession wedge trochleoplasty described by Goutallier [8]. Of course, there is some variability with modifications in the correction technique until the difference between open and arthroscopic procedures [9].

Reports on complication rate are rare [10, 11]. Furthermore, trochleoplasty is rarely performed as a single procedure [3, 7, 9, 12–15]. In most cases, it is combined by an additional procedure as reconstruction of the medial patellofemoral ligament (MPFL), tibial tubercle transfer, lateral release or lengthening, cartilage surgery, and/or derotational osteotomies of the femur or tibia. Therefore, it is also difficult to define only the complications of trochleoplasty.

However, the overall complication rate is reported up to 44% with an average around 15% [10, 11].

Formally complications can occur pre-, intra-, or postoperatively and in the follow-up.

## 31.1 Preoperative Complications

Correct indication is probably the most important factor to avoid unnecessary surgeries, resulting in complications. Indication for trochleoplasty is in the most cases patellofemoral instability with an underlying trochlear dysplasia. It could be shown that severe trochlear dysplasia has a better benefit after trochleoplasty than such patients with a mild dysplasia [3]. The last mentioned can be treated very successfully with a soft tissue procedure, for example, an MPFL reconstruction [16]. Further, as shown in a systematic review between trochleoplasty and nontrochleoplasty for severe trochlear dysplasia, it seems to be advantageous to perform trochleoplasty [4]. While some authors see patellofemoral osteoarthritis as a contraindication, some authors see this as an indication typically for recession-type trochleoplasty [17]. Another nowadays previously discussed

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clear contraindication is to perform this surgery in growing patients. At the beginning of trochleoplasty, the growth had to be completed. Newer studies are published that trochleoplasty can be performed also in children [18]. However, this chapter must be followed [19, 20].

## 31.2 Intra-/Peri-/Postoperative Complications

Intra- or perioperative complications are reported [10, 14, 21]. General complications are rare. Pulmonary embolism was reported by McNamara in one patient. Minor complications as superficial wound infection in two patients are reported by Utting and in four patients by McNamara. Deep infection is not reported. Further, listed general complications are deep venous thrombosis, complications related to anesthesia in two patients, complex regional pain syndrome in two patients, and postoperative bleeding in one patient.

However, the minor self-eliminating complications are probably more frequent than reported. Interestingly, intraoperative complications are almost not reported. Reasons therefore may be that trochleoplasty as a very delicate surgery is mostly performed or at least assisted by an experienced surgeon. Further, and probably also true, it is simply not reported. However, depending on the chosen technique, perforation caused by a high-speed drill or even partial fractures of the osteochondral flap can occur. While perforations probably are not so problematic, fractures can result in a destruction of the patellofemoral joint. However, in case of a fracture, the fragment can be fixed directly intraoperatively with screws or with sutures.

One main problem consists in “how much” must be corrected. It seems to be clear that the bump which is responsible for the maltracking and the J-sign must be eliminated [12]. Deepening and how deep the new groove must be done are still on debate. A too deep sulcus can provoke high-pressure points at the edge of the trochlea with the patella. Also a too elevated lateral trochlear facet creates higher pressure. It seems that the congruency of the patellofemoral joint must be considered, and in such cases, closing wedge patellar osteotomy must be considered [22]. While some authors propagate for a deep sulcus, others advocate more to reduce the severity of dysplasia and perform additional surgery, mostly a MPFL reconstruction. This is still a field of research. It is crucial to improve knowledge in this issue for better results.

Depending on the approach, hematoma can occur especially during the step of lateral release or nowadays more frequently performed lateral lengthening. Because of the peripatellar vessels, meticulous hemostasis is mandatory. In case of use of tourniquet, it makes sense to open the tourniquet to control bleeding to avoid hematoma.

## 31.3 Complications in the Follow-Up

One of the biggest concerns at the beginning of trochleoplasty was the risk of chondrolysis of the osteochondral flap. This worry could have been eliminated. The study of Schoettle showed in a few cases with biopsy harvested after second-look arthroscopy vital cartilage with retention of distinctive hyaline architecture and composition and only a few minor changes in the calcified layer [23]. Also in a postoperative MRI analysis, none of the cases revealed any necrosis or separation of the cartilage [3]. It seems to be important to create a flap with an enough bony layer to achieve healing. Authors of the recession-type trochleoplasty see the advantage in their technique for older patient with less pliable cartilage because of the better healing of the fragment [17]. Only one case is reported to fracture with detachment of the flap after a trauma postoperatively [24].

In the follow-up, different points must be clarified between expected additional surgery as removal of fixation devices, real complications as infection or arthrofibrosis, failure with dislocation or instability, and the problem with progression of osteoarthritis and pain.

There are different techniques to fix the trochlear osteochondral flap. Techniques with absorbable tapes or sutures reported no problems related to fixation. None has been reported, but dislocation of an anchor fixation device seems to be possible. Removal of K-wire or screws occurs more frequently and must be mentioned before index surgery.

A relevant reported complication is the postoperative stiffness or arthrofibrosis. The limitation is mostly found for flexion. The extent varies from 10% less range of motion than contralateral until real arthrofibrosis [11]. Not all needed an intervention consisting in a mobilization under anesthesia or in a surgical arthrolysis. In the comparative study, trochleoplasty versus nontrochleoplasty, the loss of range of motion was the main negative point in the trochleoplasty group [4]. Therefore, stiffness or arthrofibrosis must be mentioned in the informed consent discussion.

A main goal of trochleoplasty is to achieve patellofemoral stability [11]. The results of the different studies are variable. Overall stability can be achieved. Going into the detailed view, some authors define failure in cases of new dislocation. In other studies a positive apprehension test or a maltracking was defined as a not achieved goal. A real dislocation occurred in up to 27%, while an instability/subluxation is reported in up to 37%. A positive apprehension sign was not reported in a lot of studies. In those they mentioned the positive apprehension sign, it was found in around a quarter of patients. In one study even 74.5% of patients had a positive apprehension sign. The J-sign was not always noted in the studies, but it was found in up to 50% of the cases. Also here most studies report definitively less. It seems that in these cases, correction was not performed sufficiently. Overall, although the large differences of the results, in the most cases stability, can be improved, the main question remains if additional procedures must be performed, or better, in which cases not.

Crepitus was often not mentioned in the studies, but in those reported, more than half had crepitus. Although crepitus is not the main finding point, pain is a very important issue. Unfortunately, persistent or even increased pain is reported after trochleoplasty. The interaction between surgery and pain is not yet understood. It was the goal of a study to find a correlation between pain and cartilage status, but that fact could not be proven [3]. Because of this unclear situation, pain must be also discussed preoperatively. Interestingly, pain and onset or progression of patellofemoral osteoarthritis do not always come together. However, evolution of patellofemoral osteoarthritis often is declared as a complication. This is probably not correct. Due to the fact that some trochleoplasties are performed in patients with already relevant degeneration of the patellofemoral joint [8, 25], such a statement must be done very carefully. We know that osteoarthritis occurs faster in patellofemoral dysplastic joint. In the review of Song et al. in the trochleoplasty group, 7.9% have in the final follow-up degenerative PFJ arthritis, while in the nontrochleoplasty group, 35.7% had degenerative PFJ arthritis [4]. Of course, all that must be analyzed very carefully.

How far trochleoplasty can influence the progression is not yet clear, but it seems to be rational to improve the kinematics of that joint with the help of trochleoplasty. The follow-up of the actual literature is too short to give the answer. Even with longer follow-up, the real answer probably is not given. However, the solution might be in a very individualized surgery with or without soft tissue alignment and stabilization and bony correction with the transfer of tibial tuberosity or even with derotational osteotomies of the femur and/or tibia.

In conclusion, trochleoplasty is a very delicate surgical procedure which includes all aspect of the treatment of patellofemoral instability. A serious and open informed consent discussion with the patient must be done before surgery to explain the risks, complications, and expectable results. It is important to realize that in case of failure or symptomatic patellofemoral osteoarthritis, a patellofemoral joint replacement is still feasible. However, when possible a joint-preserving surgery should be preferred.

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# 32

# Lateral Release of the Lateral Patellar Retinaculum: Literature Review for Select Patellofemoral Disorders

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## 32.1 Introduction

Patellar lateral retinaculum presents two layers [1, 2]: the superficial layer (that includes fibers that from the ileo-tibial band extend to the vastus lateralis), and the deep layer (that includes two ligaments, proximally the patellofemoral epicondyle ligament and distally the patellotibial ligament). A capsule-synovial layer is under the deep transverse retinaculum, supporting the lateral side of the patella. Behind the lateral retinaculum is located the fascia lata. Other anatomical studies describe the lateral retinaculum as a complex structure difficult to delineate, because of different converging structures, and subdivide that into three layers: superficial (deep fascia), intermediate (quadriceps aponeurosis and iliotibial band), and deep (joint capsule).

Patellar lateral retinaculum release (LRR) is a relatively frequent treatment performed in knee surgery, with satisfying results ranging from 14% to 99% [3–6]. LLR can be an isolated procedure or associated with other surgeries. Indications to patellar LLR could include different disorders of the extensor mechanism, acute or chronic instability, anterior knee pain, patellofemoral (PF) cartilaginous injury, or osteoarthritis. Anyway, concerns exist about an indiscriminate use of LRR [3]. Some biomechanical studies have reported a potential risk of medial patellar dislocation following LRR, with increasing load on the medial facet of patella between 60° and 120° of flexion [7]. Instead, an extended LRR may contribute to increase iatrogenic medial dislocation of the patella, with medial patellar instability [8]. The aim of this study was to analyze the literature to report indications and clinical efficacy of LRR for the treatment of the main PF disorders.

## 32.2 Physical Examination

Physical examination includes the study of PF joint in different positions. Standing position allows to evaluate the leg alignment and eventual rotational anomalies. Seated position allows to evaluate the patellar position (alta, baja, or lateralized) and the sulcus angle with knee flexion of 90°. With supine position and relaxed quadriceps, it is possible to appreciate patellar crepitation, tenderness of the patellar facets, and perform the passive patellar tilt test which can demonstrate

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an excessive restraint of lateral retinaculum. Additionally, in supine position it is possible to perform the patellar glide test to diagnose medial or lateral retinaculum integrity or tightness: patellar displacement of more than three quadrants could indicate a hypermobile patella, while medial displacement of less than one quadrant indicates tightness of the lateral structures.

## 32.3 Patellofemoral Instability

PF joint stability is multifactorial and depends on several factors, including the anatomy of the femoral trochlear groove, the integrity of the medial and lateral ligaments, and the dynamic stabilizers of the knee [9–11]. Therefore, it is important an accurate diagnosis, distinguishing a primary traumatic patellar dislocation from chronic patellar instability with recurrent dislocations, or a painful patellar syndrome [12] for appropriate LRR indication. Although lateral retinaculum contributes to only 10% of the lateral stability of the patella [13], LRR performed for PF instability could lead an abnormal contact of the patella against the trochlea (especially of the medial facet), increasing patellar tilt and therefore maltracking. Depending of the several potential causes of PF instability, a large number of surgeries could be performed, isolated on in association, with or without LRR: trochleoplasty, medial retinaculum retention, proximal or distal realignments, and MPFL reconstruction. In these cases, LRR is generally indicated when a severe patellar tilt still persists during surgery [14–23].

On the other hand, many concerns still exist about isolated LRR. Satisfaction following an isolated LRR has been reported ranging from 30% to 100% [14, 24, 25]. Aglietti et al. [24] demonstrated that isolated LRR may lead a recurrence rate of 35% of PF instability. Dainer et al. [26] concluded that this treatment could be highly ineffective in recurrent patellar dislocation. Analyzing long-term results of a case series of 100 patients who underwent LRR with an average follow-up of 12 years, Panni et al. [27] noted satisfying results decreased from 72% to 50% at the latest follow-up in patients with PF instability (Figs. 32.1 and 32.2), while patients with only anterior knee pain maintained on time the satisfying results (70%). They concluded that other factors contributed to patellar instability, whose correction would not possible with only a lateral release. Lattermann et al. [5] analyzed the results of 14 studies on the role of LRR in patients with PF instability, reporting how the initial mean satisfaction rate of 80% decreased to 63.5% in the long time, concluding that the isolated procedure had little or no utility and could be helpful in cases of patellar hyper-pressure syndrome without objective instability. Ricchetti et al. [16] in a systematic review found that isolated LRR was not sufficient alone but should be used in association with a medial realignment procedure (reefing, plication or

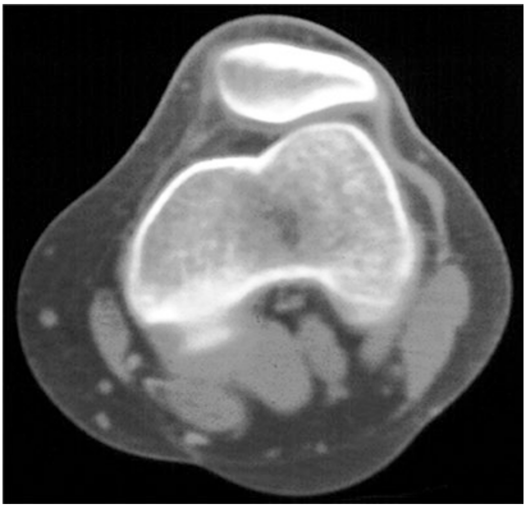

**Fig. 32.1** Patellar instability: pre-op CT-scan

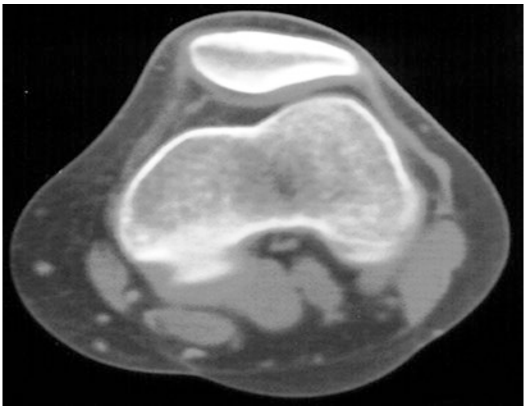

**Fig. 32.2** Patellar instability: post-op CT-scan

VMO advance) in case of recurrent PF instability. The authors concluded that the use of isolated LRR led to worse results when compared with associated procedures.

Finally, some authors have stressed how an inappropriate and/or inaccurate isolated LRR could cause iatrogenic medial subluxation of the patella, a complication that usually occurs when the release is extended beyond the VLO muscle fibers or exceedingly distal until Gerdy tubercle [5, 8, 10, 15, 28]. Woods et al. [15] described another possible cause of postoperative unsatisfaction, that is strictly correlated to the loss of quadriceps torque force, with consequent impairment of the knee.

## 32.4 Patellofemoral Pain

In patients with anterior knee pain or painful patellar syndrome, LRR was commonly used during the 1970s. Studies showed varying postoperative satisfaction rates, whereas no uniformity about the methodologies used, patient selection, follow-up, and evaluation criteria were reported [29–32]. Furthermore, many studies did not distinguish between patients who had only anterior knee pain or only instability from those who presented both conditions [14, 20, 21, 32]. In case of anterior knee pain, without patellar instability and with only a contracture of the lateral retinaculum with consequent excessive lateral patellar tilt, arthroscopic or opened LRR have been reported relieving anterior knee pain [17, 18]. Significant improvement of the pain was observed in the short-term follow-up, but less satisfaction was found in patients with high-grade PF cartilage degeneration or with PF instability [10, 12, 31, 33–35]. Panni et al. [27] reported a retrospective clinical trial comparing long-term results in a group of patients only with anterior knee pain (Fig. 32.3) with those of patients with patellar instability. The most important finding was that the rate of satisfaction in patients with only pain remained at 70% at the latest follow-up, while the results of patients with instability decreased on time. Finally, Lattermann et al. [6] in a systematic review on the use of LRR for anterior knee pain observed that the isolated procedure yielded 76% of good results, with no difference between arthroscopic and open procedures, and with low rate of complications.

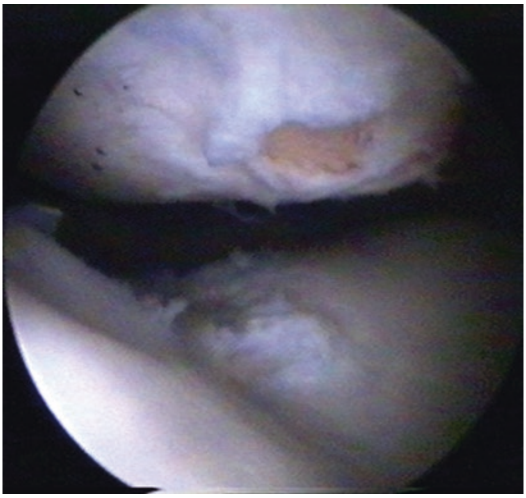

**Fig. 32.3** Chondromalacia of the patella and of the trochlear groove

## 32.5 Isolated Patellofemoral Osteoarthritis

Isolated PF osteoarthritis incidence varies from 13.6% in females older than 60 years to 15.4% in males older than 60 years with anterior knee pain in a radiological study of Davies and colleagues. Another study by McAlindon and associates found that as many as 24% of females and 11% of males older than 55 years with symptomatic knee arthritis had isolated degeneration of the patellofemoral articulation. PF osteoarthritis is generally associated with other deformities, especially trochlear dysplasia or malalignment of the lower limb, so that isolated LRR could lead unsatisfactory results. Aderinto and Cobb [3] conducted a retrospective study on a group of patients affected of isolated PF OA treated with LRR. The results were not promising, with 42% of patients remained unsatisfied after a mean follow-up of 31 months. Authors concluded that this procedure is only indicated in a restricted selection of patients to promoting temporary pain relief before major surgery such as PF or total knee replacement. Christensen [36] published a study comparing two groups of patients treated with isolated PF osteoarthritis. Patients in group I had presented recurrent subluxation of the patella, while patients in group II had no symptoms of instability. At a 4.5 years of follow-up evaluation, results of LRR were significantly better in patients without patellar instability, but only 24% of the patients reports good clinical outcomes. The author concluded that LRR is a good temporary treatment in patients with PF degeneration not responding to conservative treatment. Osborne [37] compared clinical outcomes of LRR performed in two groups of patients: group A included patients with grade I and II of PF chondromalacia, while group B included patients with grade III and IV of PF chondromalacia. The results demonstrated an improvement of the symptoms only in group A, although after 3 years follow-up those patients showed a recurrence of symptomatology.

## 32.6 Complications

As above already mentioned, LRR could present some complications. Hemarthrosis is one of the most common complications, and its incidence depends on the technique used: arthroscopic procedure (Figs. 32.4, 32.5, and 32.6) is associated with a greater risk of hemarthrosis because of the eventual difficult identification and hemostasis of the superolateral genicular artery [15, 19]. Similarly, medial patellar dislocation and/or hyper-pressure is another possible complication, as already described: in order to avoid that, release should not extend beyond the fibers of VLO; anyway, intraoperative flexion and extension of the knee after LRR is always necessary to check that [9, 28]. Less frequent complications could be injury of extensor mechanism and complex regional pain [38]. Finally, an insufficiency of LRR could maintain the previous clinical symptoms.

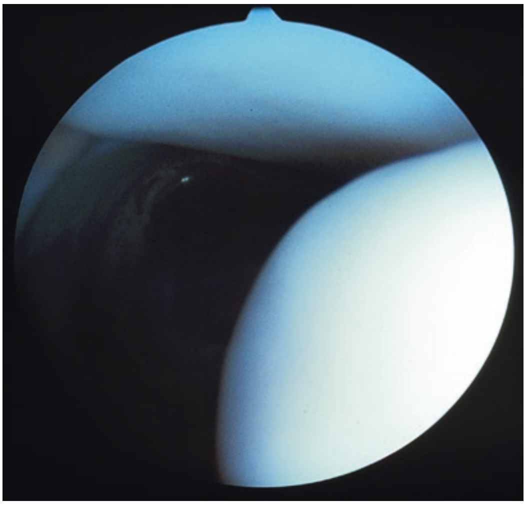

**Fig. 32.4** Arthroscopic view of patellar instability

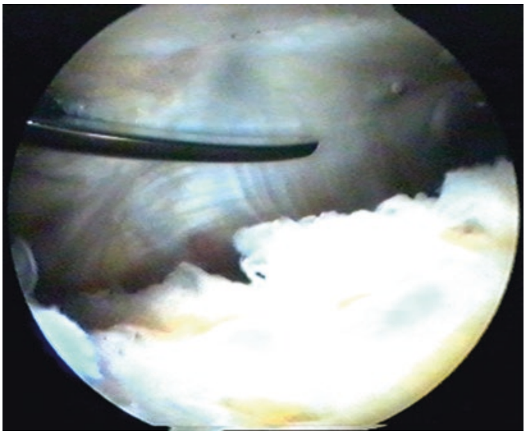

**Fig. 32.5** Arthroscopic lateral release

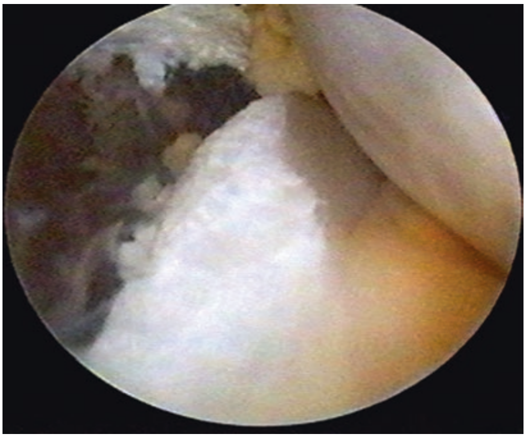

**Fig. 32.6** Arthroscopic lateral release

## 32.7 Conclusion

The use of LRR, isolated or in association with other procedures, is still highly debated. In patients with anterior knee pain and an excessive lateral patellar tilt without other important symptoms and signs of PF instability, a correctly performed LRR could decompress the lateral surface of the patella, reducing pain and risk of medial iatrogenic dislocation. On the other hand, in case of recurrent patellar instability, other procedures are always necessary, whereas isolated LRR has been demonstrated insufficient. In case of PF osteoarthritis, LRR (eventually combined with procedure on the cartilage) is associated with encouraging results only in a short follow-up and only in patients with low-grade chondromalacia.

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# Surgical Rehabilitation for Select Patellar Stabilizing Procedures

# 33

Elizabeth Niemuth and Jill Monson

## 33.1 Introduction

Lateral patellar dislocation is one of the primary diagnoses identified in children and adolescents presenting with an acute knee injury with hemarthrosis [1, 2]. Soft tissue and ligamentous injury at the medial aspect of the patella is common sequelae to patellar dislocation, with one of the primary stabilizing ligaments, the medial patellofemoral ligament (MPFL), ruptured in up to 90–99% of injuries [2, 3]. More recently, the medial ligamentous restraints (termed medial patellar complex) against lateral patellar dislocation have been more thoroughly explored in anatomic and biomechanical studies. The term “proximal medial patellar complex” has been used to describe the MPFL and a medial quadriceps tendon femoral ligament (MQTFL) at the superomedial aspect of the patella [4, 5]. This bundle is the primary restraint to lateral patellar translation in early knee flexion. More inferiorly along the patella, the medial patellotibial ligament (MPTL) and medial patellomeniscal ligament (MPML) have been identified and function to prevent excessive lateral translation deeper into knee flexion [5].

In addition to soft tissue and ligamentous restraints at the medial knee, patellar stability is also influenced by the morphology and relative alignment of the bony elements of the patellofemoral compartment [6]. Four distinct anatomic patellar instability risk factors (APIFs) have been identified as contributors to elevated risk of recurrent patellar instability [6, 7]. These include trochlear dysplasia, patella alta, excessive lateral patellar tilt, and increased quadriceps vector primarily defined by the tibial tubercle-trochlear groove distance on slice imaging [6, 8, 9]. These anatomic factors warrant consideration not only for optimal surgical planning but, when surgically addressed, for postoperative rehabilitation expectations and timelines.

## 33.2 Course of Care

This text will focus on rehabilitation following surgical management of patellar instability. However, it should be noted that restoring critical elements of knee function preoperatively through “pre-habilitation” has value for maximizing postoperative outcomes. In the anterior cruciate reconstruction (ACL-R) population, preoperative quadriceps muscle strength has been shown to be associated with postoperative quadriceps strength and impaired self-reported knee function up to 2 years following the procedure [10].

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## 33.3 Phase 0: Preoperative Rehabilitation ("Pre-Habilitation")

Preoperative rehabilitation should aim to reduce joint irritability, restore full joint range of motion (ROM), restore quadriceps muscle strength, and maximize proprioception and postural stability. Reduced knee ROM and asymmetrical quadriceps muscle strength are two common issues following surgery to address patellar instability; thus, preoperative rehabilitation to address these elements is well advised [11]. Kadawoski et al. investigated somatosensory and neurologic elements associated with recurrent patellar instability using functional MRI. Their findings suggested MPFL rupture and deficiency may lead to diminished somatic sensation against lateral patellar shift. They also identified increased activity in brain regions associated with anxiety and fear related to patellar instability [12]. Addressing proprioception about the knee and general postural control preoperatively in addition to performing therapeutic activities to reset neurocognitive expectations or fears related to the sensation of patellar apprehension postoperatively are both advisable. Increased apprehension to lateral patellar translation has been associated with poorer return to sport rate in an athletic population [13] and reduced quality of life [14], even in the absence of frank recurrent instability [13]. These findings give merit to integrating elements of a biopsychosocial model into rehabilitation strategies.

In this text, rehabilitation progressions will be described for the following procedures: MPFL-reconstruction (MPFL-R), tibial tubercle osteotomy (TTO), and trochleoplasty. The rehabilitation phases will be described globally, with precautions for specific procedures discussed separately.

## 33.4 Phase I: Rehabilitation—Acute Postoperative Management

Early postoperative rehabilitation aims to restore normal joint function and homeostasis while honoring precautions that protect the joint to support healing at the structures involved in the specific procedure. Few studies exist that expressly quantify structure-specific precautions following patellar stabilizing surgery. Early rehabilitation precautions followed at our center and the associated rationale are detailed in Table 33.1. Time-based progressions of precautions are detailed in Table 33.2.

Goals for phase I postoperative care include pain and effusion control, achieving a strong volitional quadriceps contraction and early functional quadriceps control, improving ROM, and restoring normal body movement patterns. These goals will remain a theme throughout the entire course of rehabilitation following patellar stabilization procedures.

### 33.4.1 Effusion Management

Management of joint effusion is a top priority in the early and late phases of rehabilitation. An effusion of the joint causes inhibition of the quadriceps muscle [15], as well as reduction of knee ROM. Utilization of a compression mechanism, such as an ace wrap or tubigrip, can be helpful to manage swelling postoperatively as well as elevation of the limb [16]. Cryotherapy can aide in early joint effusion management, in addition to aiding in pain control by decreasing nerve conduction velocity [17]. Proper management of joint effusion in early management can help improve muscle strengthening efforts throughout the course of rehabilitation. Monitoring joint effusion during each phase of rehabilitation is critical, as effusion can signal the general disposition of the joint in response to load and volume progressions with therapy activities [18, 19]. Of note, there is a positive correlation between time from injury to surgery in regards to the effusion present following knee ligament surgery [20].

### 33.4.2 Weight-Bearing Status and Gait Progressions

During normal ambulation, there is minimal functional engagement of the patellar articular

**Table 33.1** Postoperative precautions and rationale

| Procedure | Structure protected | Specific precautions |
|---|---|---|
| MPFL-R | Fixation of MPFL graft | Avoid excessive lateral patellar translation<br>(a) No OKC quad through arc of motion 40° → 0°<br>Manage medial-sided knee pain at graft site<br>(a) Gradual progress into end-range knee flexion to avoid medial-sided pain at graft site<br>(b) Soft tissue work at quadriceps, adductors, medial hamstrings<br>(c) Caution with adductor and hamstring strengthening |
| TTO | Bony healing at osteotomy site | Avoid excessive stress/traction at tibial tuberosity (osteotomy site) via stretch and/or quadriceps muscle contraction<br>(a) Gradual progression with knee flexion ROM<br>(b) No OKC quad through arc of motion × 6+ weeks (pending healing status)<br>(c) Gradual progression with WB/gait/stairs<br>(d) Gradual progression into deeper knee flexion with CKC strength, 2 → 1 leg per healing status and strength gains |
| Trochleoplasty | Osteochondral healing at the trochleoplasty site | Avoid excessive shear load at trochlea<br>(a) Gradual progression of ROM (passive → active)<br>(b) No OKC quad strength through arc of motion for first 6–8 weeks<br>(c) Gradual progression with WB<br>(d) Gradual progression into deeper knee flexion with CKC strength |
| Global precautions | • Increased pain and/or swelling = regress protocol<br>• Functional quadriceps control guides crutch and brace weaning with gait (in addition to bony healing in TTO) | |

**Table 33.2** Early postoperative precautions—timeline

| Procedure | 0–6 weeks | 6–12 weeks |
|---|---|---|
| MPFL-R | PWB → WBAT; no forceful flexion | Avoid pivoting on planted foot |
| TTO | TTWB → PWB; flexion ROM 0°–90° | Radiographic healing of osteotomy to progress weight-bearing and quad strength activities |
| Trochleoplasty | PWB → WBAT pending quadriceps control; careful management of ROM due to high rates of arthrofibrosis | Improve flexion range of motion; continued quadriceps strengthening |

cartilage with the articular cartilage of the trochlea. Compressive and shear forces are generally low with level ground walking, with the inferior pole having more contact in walking, which is magnified patients with patella alta [21, 22]. Restricted weight-bearing and use of a hinged knee brace (initially locked) is advised for both early postoperative joint comfort and stabilization of the knee against potential buckling due to quadriceps inhibition. We recommend locking the brace at 10° of flexion, as this allows for easier limb progression during swing phase, reducing the likelihood of excessive and repetitive limb circumduction with gait. It is unlikely for a knee flexion contracture to develop with this small degree of knee flexion, but if concern arises, adjusting the brace to 0° extension is recommended. The use of axillary crutches can at times be of great frustration to patients, but if properly educated, the patient will experience the benefit of unloading the limb in early recovery and allow for restoration of normal gait mechanics.

Proper fitting and understanding of use of the hinged knee brace is ensured during the first physical therapy visit and monitored over time. During the early phase of rehabilitation, it is advised to remove the hinged knee brace for mat-based exercise to allow for optimal quadriceps contraction as well as ease of ROM. Patients are educated on removing their brace for their home exercise program once pain control and proper brace application knowledge is sufficient. The hinged knee brace is recommended for sleep for at least 2–3 weeks following MPFL-R and trochleoplasty, while utilization of the brace following TTO may be recommended for 4–6 weeks pending bony healing.

Weight-bearing (WB) status following patellar stabilization surgery is procedure dependent. Overall, PF compressive forces, shear, and quadriceps muscle demand have been shown to be minimal with gait, justifying a more permissive WB protocol following surgery [22].

Following *MPFL-R*, weight-bearing as tolerated (WBAT) is permitted in a locked hinged knee brace. No deleterious effects have been observed with this degree of WB following MPFL-R [23].

Following TTO, partial weight-bearing (PWB) is employed. PWB is favored to toe-touch weight-bearing (TTWB) or non-weight-bearing (NWB) following TTO, as the isolated quadriceps muscle demand caused by lifting up the surgical limb to remain NWB creates greater concern for stress at the osteotomy site than allowing controlled WB with the limb down in a more natural position. TTWB status is difficult for patients to consistently replicate and maintain, with more weight typically being put through the surgical limb than what is instructed [24]. Therefore, for PWB (≤50% body weight) is recommended following TTO. This extent of offloading should be adequate to modulate closed kinetic chain (CKC) quadriceps muscle forces at the tibial tubercle (via the patellar tendon) while still permitting healthy cyclical loading forces to facilitate bone healing at the osteotomy site.

In our center we employ PWB status until first post-op X-ray, which is typically at 4 weeks.

Advancement off crutches is then dictated by pain, limb strength, and radiographic imaging, with TTO distalizing the patella typically taking 2 weeks longer to get off crutches than medialization alone. Though some surgeons favor full WB in a straight leg brace after TTO [25], this has been found to increase fracture risk [26, 27] and can delay recovery of knee motion and strength.

For trochleoplasty, PWB is recommended with crutches and a hinged knee brace (initially locked) until functional quadriceps control is achieved. Weight-bearing is to be gradually advanced as the quadriceps strength increases and joint inflammation decreases over the course of typically 2–4 weeks. Progression of weight-bearing following surgery should be advanced as tolerated through monitoring of pain, effusion, ROM, and quadriceps strength.

Altered quadriceps function has been observed with gait and stairs in the patellofemoral pain population [28–30]. Restoration of proper quadriceps function during the loading response of gait is imperative, as patients with recurrent patellar dislocation have been shown to have a lower knee extension moment compared to healthy controls. This difference was eliminated in subjects 1 year after MPFL-R and knee extension moment of the dislocation group increased to be similar to that of the control group [31]. The patella is most mobile in early knee flexion when not fully engaged in the trochlear groove, potentially making the healing MPFL graft susceptible to over-elongation. This concern, however, is offset by known graft strength values, which have been found to match or exceed that of the native ligament [5, 32–34]. As quadriceps strength improves, the hinged knee brace may then be progressively opened (e.g. 0°–50°) or unlocked to encourage more quadriceps activation during gait.

Use of a hinged knee brace is recommended at our center for up to 6 weeks postoperatively, removing it indoors based on individual patient factors including maturity level, safety of surroundings, as well as knee-related factors including strength, motion, and pain.

### 33.4.3 Joint Range of Motion

Early knee range of motion compared to some degree of joint immobilization following knee surgery remains somewhat controversial. Early mobilization promotes increased collagen proliferation, organization, and tissue strength, while prolonged immobilization can contribute to the leaching of ground substance from the bony attachment zone of the ligament and a decrease in the biomechanical properties of the ligament [35, 36]. Early ROM has not been shown to have adverse effects following MPFL-R [23]. Similar studies following outcomes of early mobilization are not available following TTO and trochleoplasty.

A flexion ROM limit of 90° of knee flexion is recommended following TTO for the first 4 weeks, in order to decrease excessive pull at the osteotomy site. A high rate of arthrofibrosis, defined by requiring secondary surgery, has been reported in the trochleoplasty population (0–46%) [37–39], as well as in the TTO population (9%) [40]. For this reason, a gradual progression of maximal knee flexion, progressing every 1–2 weeks, is recommended rather than a prolonged period of immobilization for all PF procedures, unless there are surgical concerns regarding fixation strength of primary or secondary procedures. Adjunctive therapy interventions to improve joint mobility are beneficial in the immediate postoperative phase. These include patellar joint mobilizations and soft tissue mobilization techniques at the quadriceps and patellar tendon, infrapatellar fat pad/anterior interval, peripatellar regions, and musculature proximal and distal to the knee. An adequate volitional quadriceps muscle contraction, when performed frequently with good quality, can also reduce early joint stiffness. A strong quadriceps contraction draws the patella superiorly, mobilizing the PF compartment, creating stretch at the patellar tendon, and mobilizing the infrapatellar space. Observing superior patella translation with quadriceps activation, and when needed manually assisting with this patellar motion, is crucial in the early phase of rehabilitation.

Utilization of continuous passive motion (CPM) may be helpful following TTO and trochleoplasty for the first 4–6 weeks. CPM has been found to increase synovial fluid movement and joint articulation [41]. CPM may be an additional tool to improve ROM and joint health in addition to the prescribed ROM exercises but should not be considered a replacement. CPM is not typically employed following MPFL-R, as ROM typically progresses without difficulty and rates of arthrofibrosis are low.

### 33.4.4 Strengthening

Selection of exercise is critical during the early recovery phases and throughout the entire rehabilitation process following patellar stabilizing procedures, particularly with targeted strengthening of the quadriceps muscle. Quadriceps weakness has been observed with patellofemoral pathology [42, 43]. Variables that change patellofemoral stress include closed kinetic chain (CKC) or open kinetic chain (OKC) conditions, angle of knee flexion, variable or constant loading conditions, and underlying kinematics/body position during functional movement. Neuromuscular electrical stimulation (NMES) is beneficial for obtaining a more robust quadriceps muscle contraction immediately postoperatively and helps establish a solid foundation for ongoing rehabilitative strengthening [44, 45]. NMES in standing has been recommended by some authors to produce a stronger contraction, versus long sitting [16]. A strong volitional quadriceps contraction is imperative prior to advancing to more difficult strengthening.

OKC strengthening following patellar stabilization can be a source of great debate. Please refer to phase II for specific biomechanical considerations of the PF compartment. The straight leg raise (SLR) exercise can be a great tool to strengthen the quadriceps; however, there may be concern regarding potential overload at the osteotomy site for TTO, especially distalizing TTO. We suggest a graduated progression from modified to traditional SLR, progressed per symptoms and increasing quadriceps strength, observed through maintenance of full knee extension with no lag into flexion. Once a proper volitional quadriceps contraction is demonstrated, SLR flexion can be initiated in a standing position, where the individual is able to achieve and maintain full knee extension while lifting into flexion by starting with limb in a gravity eliminated position. The patient progresses into positions of greater challenge (tall sitting/reclined→supine) based on maintenance of full knee extension (no lag) with the lift and well-controlled symptoms at PF structures (pain and/or perceived tissue stress ≤3/10 numerical pain scale). As the SLR flexion is not particularly "functional" exercise, it may be discontinued from the home exercise program when the individual is able to successfully perform 20–30 repetitions × 2 consecutive sets with no extensor lag and minimal fatigue. At this point therapy exercises can progress to more CKC exercise while preserving some quadriceps-focused OKC drills. See Fig. 33.1 for details.

**Fig. 33.1** Progressive demand SLR: standing, reclined standing, supine

Another OKC quadriceps exercise that may be employed is the short-arc quadriceps (SAQ). This exercise is appropriate following MPFL-R at deeper angles of knee flexion (e.g., 90°–60°) as the patella is safely engaged in the trochlea, once comfortable knee ROM into these degrees is established. The SAQ is not advised in early rehabilitation phases for the TTO population, as the OKC demand could produce negative effects on healing of the osteotomy site by the isolated quadriceps pull. This exercise may not be appropriate for the trochleoplasty population due to compression of the PF joint and likely previous history of significant lateralization of the patella with OKC knee extension. Use of the progressive SLR and multi-angle quadriceps isometrics at lower intensities can allow for good quadriceps isolation with more controlled forces through the trochlea and tibial tubercle during the early postoperative phases.

CKC exercise can also be initiated in the first phase of rehabilitation, with specific attention paid to any weight-bearing restrictions. Squatting is permitted through shallow angles of knee flexion (0°–45°) once a proper quadriceps contraction is demonstrated, for less compression of the PF compartment. Functional knee extension in standing with an elastic resistance band can be utilized, not only as a quadriceps strengthening exercise but also as a gait drill to restore proper quadriceps contraction during the loading response of ambulation (see Fig. 33.2). Initiation of proximal hip strengthening and core stability, in PF safe positions, is also important in the early phase of rehabilitation.

## 33.5 Clinical Pearls for Common PostOperative Complications in Phase I

Rehabilitation techniques and progressions can be tailored to address unique consequences of technical elements of each specific surgical procedure. MPFL-R performed using an adductor sling technique may create soft tissue irritability at the adductor magnus tendon insertion region and reactive hypertonicity up the adductor muscle bundle, lending to pain with progression into knee flexion or activation of the adductor muscles with strength progressions. With interference screw and tunnel fixation at medial condyle, pain can complicate progression. Soft tissue mobilization techniques may be employed to normalize tissue mobility and muscle tone to help restore full knee motion and progress strengthening activities more comfortably.

**Fig. 33.2** Functional loading response drill to facilitate quadriceps activation during stance phase of gait

TTO with distalization lengthens the entire extensor mechanism, creating a tension which theoretically could impair recovery of knee flexion ROM. Soft tissue mobilization along the quadriceps, in particular the rectus femoris, early in rehabilitation and gentle progressions with stretching once the osteotomy site is more fully healed can minimize this consequence of the surgical technique (Table 33.3).

## 33.6 Phase II: Recovery of Function and Fitness

Once basic joint recovery is attained and adequate healing of the involved structures is observed, the focus of therapy shifts from

**Table 33.3** Criteria based rehabilitation phase progression

| Phase | Rehabilitation focus | Criteria for progression |
|---|---|---|
| 0<br>Preoperative rehabilitation | • Resolve joint effusion and pain<br>• Restore full ROM<br>• Neuromotor/proprioceptive training<br>• Quadriceps muscle activation and progressive training (NMES) | • 1+ effusion or less<br>• Full knee ROM<br>• Quadriceps strength maximized (ideally ≥90% LSI)<br>• Adequate single limb proprioceptive control |
| I<br>Acute recovery | • Protect healing structures<br>• Resolve swelling and pain<br>• Mobilize the patella and peripatellar region<br>• Gradually restore joint ROM<br>• Strong volitional quad activation (NMES)<br>• Normalize gait pattern within WB limit<br>• Maintain regional muscle strength | • 1+ effusion or less<br>• Full knee extension<br>• Knee flexion ROM ≥120°<br>• Strong volitional quad contraction<br>• SLR with no extensor lag<br>• Functional quad control observed with gait (with or without AD)<br>• Observation of bony healing (TTO) |
| II<br>Return to function and fitness | • Ongoing swelling and pain control<br>• Fully recovery of joint ROM<br>• Recovery of normal gait pattern<br>• Muscular training: endurance → strength (OKC and CKC training, external loads)[a]<br>• Proprioceptive training progressions<br>• Initiate low impact cardiovascular fitness<br>• Core and hip strength progressions<br>• Progress regional muscle strength | • No increase in joint effusion or soreness >24 h after exercise<br>• Full knee ROM<br>• ≥80% LSI with isolated muscle strength testing<br>• Normal squatting mechanics with tolerance for single limb training<br>• Symmetrical single limb balance<br>• Tolerate 30 min brisk low impact cardio workout (no joint reaction) |
| III<br>Return to activity and run | • Ongoing maintenance of swelling, pain, and full joint ROM<br>• Muscular training: strength → power (external loads, acceleration)[a]<br>• Proprioceptive training progressions<br>• Return to run progression[a]<br>• Core and hip strength progressions<br>• Progress regional muscle strength<br>• Directional movement training<br>• Introduction of plyometric and agility training<br>• Progressive overall training workload | • No increase in joint effusion or soreness >24 h after exercise<br>• ≥90% LSI with isolated muscle strength testing<br>• ≤4 cm side to side difference with single leg squat<br>• ≥90% with physical performance testing (hop series, SEBT, squat endurance test, core stability)<br>• Tolerate 30 min running workout with no joint reaction<br>• Normal squat and jump mechanics observed |
| IV<br>Return to sport training and sport reentry | • Maintenance and progression of phase III training activities<br>• Progression of plyometric, agility, directional movement, and speed training (planned, reactive, variable)<br>• On-field/court sport/position-specific simulations<br>• Progressive return to live play scenarios (non-contact initially, progressive duration and intensity per symptoms)<br>• Progressive sport-/position-tailored fashion training workloads | • Ongoing symptom control<br>• Psychological readiness for sport reentry<br>• Successful progression through higher demand on-field/court progressions<br>• Well-tolerated progression of internal and external training loads at sport-/position-specific intensities and durations |

[a] Prior level of function, postoperative performance goals, baseline knee joint health, and observation of adequate bony healing at osteotomy site dictate progressions into higher level therapy activities

protection and recovery to rebuilding. Ongoing maintenance of baseline joint functions (ROM, muscle activation) and reduced joint irritability (soreness, swelling) are critical for a successful progression through phase II training activities. The patellofemoral compartment is central to the function of the quadriceps muscle and the extensor mechanism as a whole. Patients with PF pathology, especially instability, may experience a decline in quadriceps muscle strength or exhibit chronic quadriceps muscle dysfunction resulting from the disruption of the pulley mechanism when the patella is unstable within the trochlea either traumatically or chronically. Changes in quadriceps muscle strength and activation patterns with function have historically been better quantified in the PF pain population than the instability population [28, 29, 43]; however, recent studies demonstrate quadriceps strength deficits are present and persistent following patellar stabilization surgery [7, 13, 46]. Additionally, within the patellofemoral pain population, reduced gluteal muscle strength and endurance have been observed [47, 48]. Strength training for both quadriceps and gluteal musculature is supported for optimal recovery of function in patients with PF pain [49, 50].

### 33.6.1 PF Biomechanical Considerations for Safe PostOperative Strength Progressions

Muscular training goals transition from basic muscle activation and endurance training in phases I–II to a hypertrophy and strength building focus in phases II–III. These transitions are based on healing, joint irritability, and task mastery with progressive exercise intensity. A combination of open kinetic chain (OKC) and closed kinetic chain (CKC) exercises is supported for most effectively addressing quadriceps strength [51]. Known PF biomechanics should be considered when selecting exercises following surgery, specifically as it relates to lateral patellar translation and PF compartment stress. Increased lateral patellar translation is observed with quadriceps muscle activation as the knee moves from 40° flexion into full extension. Lateral translation is most pronounced in the OKC condition, with an isolated pull of the quadriceps muscle [52–54]. In the CKC condition, the pull of the quadriceps is less isolated, with greater co-activation of other large muscle groups across the joint to cope with axial loading forces in weight-bearing. As a result, lateral translation of the patella is reduced in shallow knee flexion angles in CKC compared to OKC [52–54]. In deeper angles of knee flexion, the patella becomes stable within the trochlea (the degree varies between individual patients per the morphology of the trochlea). Consequently, the concern over excessive lateral translation is diminished in deeper flexion.

As with patellar translation, PF compartment stress also varies per knee flexion angle and exercise condition (OKC or CKC). Stress is the product of compressive forces at the joint (generated by quadriceps muscle pulling) divided by the area of contact between the patella and the trochlea. Under constant load (fixed external weight) with OKC knee extension, PF stress remains steady until the knee approaches full extension, where it increases [55]. Conversely, with a variable load (i.e., elastic resistance band), PF compartment stress is found to increase as the knee moves closer to full extension. CKC squatting creates relatively low PF compartment stress when performed through shallow angles of knee flexion (0°–45°); however, stress increases with progressively greater squat depth [56]. Altered lower body kinematics has been shown to increase PF compartment stress, with excessive anterior knee excursion and an upright trunk posture (Fig. 33.3) compared to a more balanced squatting technique in the sagittal plane (Fig. 33.4), with flexion more evenly distributed between the lower body joints [56]. PF compartment stress has been found to increase when the dynamic *Q*-angle of the lower limb is exaggerated. Biomechanically, this is produced by a combination of increased tibial external rotation and increased femoral adduction and/or internal rotation [57–59]. This movement pattern is commonly referred to as “valgus collapse” or “functional valgus” (Fig. 33.5). Patients should be cued by the therapist to avoid this movement flaw while performing CKC exercises (squatting, stepping, and lunging) as therapy exercises progress.

Delayed union or fracture at the osteotomy site is a great concern following TTO. For this

**Fig. 33.3** Double-leg squat with excessive anterior knee excursion, reduced posterior hip excursion

**Fig. 33.4** Normal double-leg squat mechanics

**Fig. 33.5** Functional valgus in double-leg squat

reason, exercise selection for safe quadriceps strengthening should be thoughtful and measured due to the direct relationship between the osteotomy site and the quadriceps muscle pulling forces via the patellar tendon. Sparse literature exists exploring the strength of TTO fixation or quantification of tibial tubercle stress caused by common strengthening exercises. Two biomechanical laboratory studies identified TTO fixation strength values ranging from 1429 ± 348 N to 1925 ± 982 N with bicortical screw fixation [60, 61]. Estimated quadriceps muscle pulling force at the tibial tubercle has been explored through vector diagram analysis, estimating 400 N of force with a straight leg raise (SLR) exercise and 250 N with active knee extension against gravity [60]. Powers et al. investigated patellar tendon to quadriceps muscle force ratios in a laboratory setting. Average patellar tendon loading forces were found to be the lowest at 125 N at 60° of knee flexion and the highest at 205 N at 0° knee flexion with a simulated multiplane loading condition [62]. These muscle activation force values fall well below the load to failure values identified for the osteotomy fixation techniques. Similar loading data were not explored for WB tasks with any of these studies. Caution should be taken in translating the findings of these studies to direct clinical practice, as they may not be accurate in real-life conditions, particularly for patients with a higher magnetic resonance imaging, under different angles of loading or under conditions of greater or more repetitive bony loading encountered with activities of daily living WB and various therapy activities.

## 33.7 Phase III: Return to Activity and Return to Run

Leading up to return to run, activity, and sport, ongoing progress must continue with all elements of rehabilitation. By this time, ROM should be full and pain-free, and a robust program of strengthening, both OKC and CKC, should be in place to address quadriceps muscle strength in addition to all other large muscle groups. Resistance training should be part of the program at this time to continue to stimulate ongoing recovery of strength, including squatting, stepping, and lunging activities. Examples of strength training program structure can be found in Table 33.4. Persistent deficits in quadriceps strength following PF surgery may reflect inadequate load progressions and workout structure modifications with higher level therapy.

Early in the rehabilitation process, load-modulated strengthening is necessary to protect healing structures and avoid provoking or prolonging joint swelling and pain. However, as the joint quiets and healing structures mature, strength training principles should be employed to drive ongoing and meaningful changes in muscle force production, rate of force development, and hypertrophy. ACSM guidelines state strength training at 60–70% of a 1 repetition maximum (1RM) for 8–12 weeks or longer is required to drive measurable strength gains (ACSM). Traditional use of 1RM testing to determine appropriate training intensity with strength activities is not always feasible in a postsurgical rehabilitation setting; however, a patient reported rate of perceived exertion (RPE) and a measured progression of workload (resistance, reps, sets) with individual exercises is often adequate in early recovery phases. Application of progressive external load, training structure variation, and contractile speed manipulation are all necessary to increase the maximal volitional contraction capabilities of target muscle groups. The structure of the training workout needs to evolve over time in order to achieve higher level muscle recovery goals (strength, hypertrophy, power), especially with patients intending to return to sport.

Low-impact cardio training is advanced through increased workout duration and/or higher intensity intervals. Balance and core stability exercises are progressed to add more dynamic challenge with external perturbation and directional elements. Recurrence of knee swelling or

**Table 33.4** Example of varying resistance training workout structures

| Training goal | Workload (% of 1RM) | Reps (speed of movement) | Sets | Rest | Days/week |
|---|---|---|---|---|---|
| Muscle endurance | 30–60% | 15+<br>(variable) | 2–3 | <90 s | 2–4 |
| Muscle hypertrophy | ≥60% | 8–12<br>(slow → moderate) | 3 | 1–2 min | 2–4 |
| Muscle strength | ≥70–80% | 6–12<br>(slow → moderate) | 4–6 | 1–3 min | 2–4 |
| Muscle power | 30–60% | 3–6 (fast) | 1–3 | 2–4 min | 2–3 |

soreness lasting beyond 24 h after a workout or pain at the osteotomy site would merit a regression of the protocol to restore joint homeostasis.

Mid- to high-level physical performance testing should be applied at this time to gate progressions into more intensive physical activity. The anterior reach of the Star Excursion Balance Test (SEBT) is useful tool for measuring squat performance and is clinically efficient for observing side to side functional strength deficits [63, 64] (Fig. 33.6). The complete SEBT is also useful for assessing proprioceptive control and has been shown to be one of the only tests capable of predicting elevated risk of lower extremity injury [63, 65]. Hop testing continues to show value for appraising side to side strength, power, and physical performance following knee surgery [19, 66–68]. A commonly accepted target for proceeding into a sport reentry training phase is 90% limb symmetry index (LSI) [69]. Isokinetic strength testing is the gold standard for targeted muscle strength measurements, with a goal of 90% LSI for initiating return to sport training [69].

**Fig. 33.6** Star Excursion Balance Test—anterior reach

### 33.7.1 Return to Run

Biological healing of the MPFL graft, tibial tubercle osteotomy site, and trochlear groove is of utmost importance when initiating significant load such as running. Timelines recommended in the literature to initiate a return to run progression after MPFL-R range from 6 to 12 weeks postoperatively and return to sport ranges from 3 to 6 months [70]. In the ACL-R population, return to run timeframes range from 8 to 16 weeks postoperatively, with a median time of 12 weeks, as reported in a systematic review [71]. This range of time to initiate return to run may highlight intent of early return to sport by initiating running at 8 weeks and conversely the intent of protecting of the healing ACL graft (16 weeks). There is limited understanding of ACL graft healing timelines in humans [72], but substantial change may take place from weeks 8 to 16. These graft incorporation timelines cannot be directly extrapolated out from ACL literature to apply to the MPFL, but it does establish a biological rationale for the value of both time-based and function-based guidelines for progressing the postoperative rehabilitation protocol.

At our center, healing of the osteotomy site following TTO must be radiographically confirmed in order to initiate return to run, typically around 4–6 months postoperatively for medialization and 6–8 months for distalization. Distalization of the tibial tubercle can be associated with prolonged time to heal the osteotomy site distally between the bone and osteotomy site, and as such can be a stress riser in diaphyseal bone. Krych et al. reported slower return to sport timeframes following MPFL-R with concomitant TTO in comparison to isolated MPFL-R (9.8 ± 5.5 months and 7.0 ± 1.9 months, respectively). Recommendation for returning to sport following trochleoplasty range in the literature between 3 and 6 months [73, 74]. There were no corresponding reports of muscle strength or physical performance testing outcomes aligning with this recommended timeframe.

Limited criteria are published to justify and guide the initiation of a return to run program following patellar stabilizing procedures; therefore criteria are often extrapolated from the ACL-R population. In a literature review, Rambaud et al. found that fewer than one in five studies reported clinical, strength, or performance-based criteria for RTR even though high-level evidence recommends performance-based criteria in addition to time-based criteria to begin running activities following ACL reconstruction [71]. Clinical criteria to initiate return to run included pain <2/10 on visual analog scale, 95% knee flexion ROM, full extension ROM (0° knee extension), and no effusion/trace effusion. These criteria were considered "nonnegotiable" criteria. Strength and performance-based criteria were isometric assessment of strength of the lower limb >70% and quadriceps strength >80% and isokinetic assessment >70% limb symmetry. Functional tests utilized included single leg squats at 45° knee flexion and hop tests. More importantly, the quality of movement pattern must be addressed, in order to monitor for dynamic valgus. Return to run initiation is best determined by a battery of criteria including time, strength, and function [75].

A formal return to run program is best initiated by a rehabilitation professional with transition to independent program for patient. Monitoring of increase in pain, swelling, or decrease of range of motion will alter the progression of the running program. A sample return to run program is outlined in Table 33.5, emphasizing a gradual increase in loading over the course of 4 weeks. A day of rest in between running days is to be implemented. Tailoring the return to run program to the individual is recommended for proper return (e.g., decreasing or increasing running/walking times).

**Table 33.5** Sample return to run program

| Week | Session 1 | Session 2 | Session 3 |
|---|---|---|---|
| 1 | Run 1 min;<br>walk 4 min<br>25 min total | Run 1 min;<br>walk 4 min<br>25 min total | Run 1 min;<br>walk 4 min<br>30 min total |
| 2 | Run 2 min;<br>walk 3 min<br>25 min total | Run 2 min;<br>walk 3 min<br>25 min total | Run 2 min;<br>walk 3 min<br>30 min total |
| 3 | Run 3 min;<br>walk 2 min<br>25 min total | Run 3 min;<br>walk 2 min<br>25 min total | Run 3 min;<br>walk 2 min<br>30 min total |
| 4 | Run 4 min;<br>walk 1 min<br>25 min total | Run 4 min;<br>walk 1 min<br>25 min total | Run 20 min<br>continuously |

## 33.8 Phase IV: Return to Sport Training and Sport Reentry

Return to sport following patellar stabilization surgery is both time and criteria based. Level of function prior to surgery must be taken into consideration as an individual who was not an athlete prior to surgery may demonstrate poor potential to begin these activities following surgery. In addition, many patients requiring trochleoplasty typically have not routinely engaged in jumping and pounding sports due to level of disability from patellar instability and may not have return to run and sport as a goal.

Return to sport following MPFL-R and TTO have demonstrated good to excellent results ranging from 85% to 91% [13, 76]. The achievement of returning to previous level of play has inconsistencies following MPFL-R, ranging from 53% to 77% [76, 77]. Various reasons have been identified, including knee function (ROM and strength), fear of reinjury, desire to avoid cutting and pivoting sports following surgery, as well as lack of interest or time [76]. Increased age is correlated with poorer outcomes for returning to previous level of play as well as lower general satisfaction with the knee following surgery [76]. Return to sport data has not been widely reported in the trochleoplasty population.

As with running, return to sport guidelines described in current literature following MPFL-R primarily utilize time-based criteria. Physical performance testing criteria are not well defined [70]. Several authors have recommended a checklist of criteria in order to return to sport, as outlined in Table 33.6. What is most difficult to measure is the quality of the movement pattern for the intended functional test measure. For example, in the patellar instability population, a quadriceps avoidant movement pattern is commonly observed in double-leg and single-leg squatting activities for inherent fear of redisloca-

**Table 33.6** Return to sport criteria

| Author | Recommended criteria and assessments for return to sport |
|---|---|
| Menetrey et al. *KSSTA* 2014 | No pain<br>No effusion<br>No PF instability<br>Full ROM<br>Near symmetrical strength: 85%–90% LSI<br>Excellent dynamic stability |
| Fisher et al. *Arthroscopy* 2010 | Single leg squat<br>Star Excursion Balance Test<br>Drop jump<br>Side hop |
| Arendt *KSSTA* 2011 | Prone and side plank<br>Single leg stance<br>Stand and reach balance<br>Star Excursion Balance Test<br>Single leg squat<br>Retro step up |
| Arendt and Kelberine ISAKOS meeting 2012 | No effusion<br>No knee pain<br>Full ROM<br>Stable core strength<br>Complete neuromuscular training<br>Ability to perform dynamic activities<br>Hop testing limb symmetry index ≥85%<br>Psychological readiness for sport |
| Monson and Arendt *Sports Med Arthrosc Rev* 2012 | Prone and side planks<br>Single-leg bridge<br>Stand and reach balance test<br>SEBT<br>Hop testing |

tion [78]. In this pattern, patients exhibit excessive posterior hip excursion and avoid anterior knee excursion (Fig. 33.7). Functional valgus may also be observed and is thought to be correlated with poor gluteal and core strength and control [54, 57–59] (Fig. 33.8) Careful attention must be paid to body movement patterns at both limbs during the course of rehabilitation, with emphasis on equal hinging moments of the hip and knee in the sagittal plane and pelvic stability and proper alignment in the frontal plane during squatting activities (Fig. 33.9). At this point in the rehabilitation process, the full battery of hop testing should be employed to assess quadriceps muscle strength, power, and overall athletic per-

**Fig. 33.7** Double-leg squat with excessive posterior hip excursion or quadriceps avoidant movement pattern

**Fig. 33.8** Functional valgus in single-leg squat

**Fig. 33.9** Normal single-leg squat mechanics

formance. Frequent functional testing at intervals throughout the rehabilitation process is useful to assure ongoing patient engagement and measurable improvement in critical outcomes [79]. Further investigation is needed to more adequately define return to run and sport criteria for the patellar instability population.

Utilization of a formal and progressive return to sport program, as described within the ACL-R population, may be an excellent adjunct or transition after a traditional clinic-based physical therapy program nears completion and sport reentry training begins. In the athletic population, a progressive training protocol that gradually restores the athlete to an appropriate training load (volume, intensity, frequency of training activities) for their sport and position is a critical overarching goal of sport reentry training. Inadequate recovery of training load or training progressions that are sporadic or too fast can lead to increased risk of injury upon return to competition [80]. Training progressions should not only attempt to duplicate the demands of sport movement (cutting, braking, jumping, external contact, etc.); it should also replicate the overall intensity and duration of sport. Additionally, cognitive and psychological readiness for sport reentry should be assessed as the athlete approaches a return to formal team-based training and competition [81].

Athlete or not, patient reported outcome measures are valuable tools for assessing response to intervention and progress with rehabilitation. In recent years, outcome scales more specific to patellar instability, rather than pain, have been developed and are being advocated for use following surgery to address instability. These include the Banff Patella Instability Instrument and the Norwich Patellar Instability (NPI) score [82, 83].

## 33.9 Complications

The recommended postoperative guidelines described in this chapter are utilized at our center for rehabilitation as well as distributed to rehabilitation professionals providing care outside of our center. Postoperative complications have been reported by the lead PF surgeon at our center, with patients following our postoperative rehabilitation protocols. Following MPFL-R, redislocation was 4% and arthrofibrosis was 8% [84].

Following TTO with distalization, tibial fracture occurred in 4% and loss of fixation was 1.7%. Arthrofibrosis following distalization TTO was 13%; the mean distalization of tibial tubercle in the arthrofibrosis group was 11.8 mm. This difference was significantly different from those not requiring a manipulation (Tables 33.7 and 33.8) [85].

Following trochleoplasty plus MPFL-R, the dislocation rate after 2 years was 0%, arthrofibrosis rate 11% [86].

## 33.10 Conclusion

Patellar instability, especially when recurrent, contributes to disability and altered activity-centered lifestyle choices, especially in young patients. Patellar instability is a multifactorial problem that

**Table 33.7** Authors' recommendations for functional testing items and intervals

| | MPFL-R | | TTO | | Trochleoplasty | |
|---|---|---|---|---|---|---|
| | 6 months | 9 months | 6 months | 9 months | 6 months | 9 months |
| SEBT × 3 directions | • | • | • | • | • | • |
| Two-minute single leg squat endurance | • | • | • | • | • | • |
| Retro step up | • | • | • | • | • | • |
| Prone and side plank | • | • | • | • | • | • |
| Single leg bridge | • | • | • | • | • | • |
| Hop testing: single leg, triple crossover, 6 M timed hop | • | • | *Single-leg hop only if radiographic healing present, and progressing well with rehab* | • | *Single-leg hop only if radiographic healing present, and progressing well with rehab* | |
| Dynamometry: quadriceps strength | • | • | | • | | *Not appropriate if previous excessive lateralization of patella or J-sign* |
| Video analysis of hopping and sport activities (repeated tuck jump, drop countermovement jump, sport movements) | • | • | | • | | • |

**Table 33.8** Clearance to return to sport following MPFL-R, TTO, and trochleoplasty

| Criteria |
|---|
| • No effusion<br>• Full knee extension, flexion ROM ≥95% of contralateral limb<br>• LSI ≥90% for functional test items<br>• LSI ≥90% for hop testing triad<br>• Reported psychological confidence in the knee<br>• Excellent body movement patterns double and single legged |

merits careful evaluation of the entire PF compartment when selecting a treatment pathway. The presence of more anatomic patellar instability risk factors may justify more extensive surgery; however, more extensive surgery often carries greater risk of postsurgical complications and lengthier postoperative disability.

When surgery is warranted, preoperative rehabilitation should aim to minimize joint irritability, restore ROM, and maximize quadriceps strength and overall function. The same goals carry over to postoperative management. Special attention is given to soft tissue and bony healing in the early postoperative time frame, especially for the more invasive procedures of TTO and trochleoplasty. These procedures also warrant more restrictive precautions in the early postoperative time period and (potential) delay or diminished expectations for progressions through typical postoperative milestones such as return to run and return to sport. For many patients in this population, return to higher level activity or sport may not be warranted nor expected due to the patient's baseline levels of function and disability leading up to the surgery.

Within the athletic population, effort should be made to comprehensively address faulty movement patterns with special attention to hip stability, restore joint proprioception, and more completely resolve quadriceps muscle strength deficits through effective early muscle activation and progressive strength training in the later stages of the rehabilitation protocol. Frequent communication between surgeon and physical therapist facilitates a safe and effective recovery following surgery and often lends to a superior experience for the patient.

**Key Messages**

- Itemization of patient's preoperative level of function and goals for postoperative activity.
- Itemization of underlying anatomical patellar instability risk factors, which were addressed surgically.
- Prioritize reducing joint irritability and restoring full ROM gradually and restoring strong volitional quadriceps contraction in the acute phases.
- Control of joint effusion and pain as prerequisite for advancement through phases of rehabilitation.
- Progressively restore knee strength, specifically quadriceps.
- Address joint and postural proprioception deficits.
- Initiate baseline cardiovascular fitness.
- Apply optimal loading principles to fully regain strength in athletic population.
- Introduce higher-level power, speed, and development training with structured sport-specific progressions in athletic population.

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# 34

# Designing a Rehabilitation Programme for the Patient with Patellofemoral Pain

Joanna Stephen, Caroline Ephgrave, Simon Ball, and Sam Church

## 34.1 Introduction

Patellofemoral pain (PFP) is a highly prevalent condition, affecting up to 23% of the general and 28% of the adolescent population [1]. Recent evidence suggests that patellofemoral joint (PFJ) osteoarthritis is a sequelae of PFP [2, 3] challenging the traditional notion that adolescent anterior knee pain is a benign pathology. Furthermore, high levels of depression and anxiety are reported amongst patients suffering PFP [4]. It is therefore concerning that despite the implementation of evidence-based interventions including exercise therapy, the prognosis of this condition remains poor, with 40–56% of patients reporting ongoing symptoms 1–2 years following conservative treatment [5, 6]. It is estimated that over 50% of people with the condition will report symptoms continuing beyond 5 years following diagnosis [7]. In addition, those patients who complain of high base levels of pain and longer duration of symptoms are typically found to have the most unfavourable recovery [5]. These poor long-term outcomes highlight that despite PFP populations being widely investigated, at present the answers on how best to manage these patients are lacking. With this in mind, how then does the treating clinician go about designing a successful rehabilitation programme for these patients? This chapter reviews current evidence in this field and discusses biomechanical principles to help guide how this might be achieved. We note that growing evidence highlights the importance of also considering psychological factors affecting this population [4], and these are discussed in a separate chapter.

## 34.2 Where Does the Pain Come From?

Despite their high prevalence and decades of dedicated research, conditions of the anterior aspect of the knee remain a source of continued controversy. Disagreement exists regarding the explanation of the aetiology, as well as the methods of

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treatment that are likely to result in symptom resolution [8]. Consensus and definitive data are currently lacking to elucidate the precise cause of pain in these patients, making successful treatment very challenging. Theoretical models have suggested that altered patellar tracking causing elevated patellofemoral joint contact pressure [9], neovascular changes in the lateral retinaculum [10], increased subchondral bone water content [9], elevated articular cartilage stress [11] or a loss of tissue homeostasis in the surrounding innervated tissues such as the infrapatellar fat pad [12] may be responsible for the pain. The absence of association between changes in cartilage composition and PFP symptoms recently reported continues to challenge the assumption that PFP can be explained by local structural changes in isolation [13]. Patellofemoral pain is a musculoskeletal condition with possibly the worst-known etiopathogenesis. Consequently these patients will often undergo treatments with little scientific basis. A plethora of treatment options have been described with different levels of agreement. Likely the great number of variables thought to be associated with PFP, most of which lack valid measurement tools, explain this confusion.

High loads, often many multitudes of body weight [14], are accepted and redirected by the patellofemoral joint (PFJ) [15]. Its asymmetrical geometry highlights its complex function and reflects the demand for it to withstand high compressive and tensile loads through a large range of motion relative to its size [16]. Given the magnitude of forces and torques applied to the PFJ, it is perhaps unsurprising that dysfunction in the PFJ is so prevalent. Since PFP patients typically report symptoms and pain around or behind the patella that are aggravated by activities placing increased load on the PFJ such as squatting, stair ascent or descent, prolonged sitting and running, the condition is hypothesised to be a load-related injury [12, 17]. This appears to be a logical explanation given patients with PFP will typically encounter their first symptoms as a result of a change in loading—either increased such as when training for a marathon or as consequence of reduced activity levels and training often following a change in life circumstances. Current evidence and clinical practice advocate exercise therapy as the cornerstone of management for PFP [18]. This is logical given muscles both apply and dissipate (dampen) forces directly to the skeletal system and therefore have the capacity to play a significant role in loading. In support of this, research findings suggest that both altered kinematics and muscle weakness are present in these patients [19, 20]. Consequently, prior research in PFP populations has heavily focussed on exercise therapy interventions commonly directed at biomechanical variables such as kinematic and muscular function. However, as discussed below, the findings from these studies are not always consistent. This primarily reflects the lack of adequate tools to take robust measurements of these complex patients, meaning decision-making about how optimally to rehabilitate these patients continues to present a significant challenge to clinicians.

## 34.3 Local, Proximal and Distal Mechanics: What Does the Current Biomechanical Evidence Tell Us?

Changes in kinematics and muscle function locally at the level of the knee joint have been widely investigated. Reduced peak knee flexion during stair ascent is reported in PFP cohorts compared to those unaffected [15, 21]. This may reflect a conscious or unconscious strategy to reduce PFJ and quadriceps load and demand [22] or possibly underlying kinesiophobia [21]. Reduced knee flexion has also been identified prospectively in populations who subsequently develop PFP, in whom there was also quadriceps weakness, meaning that underlying strength deficits may also be a contributing factor [19]. Historically lateral patellar tracking has been hypothesised, in some cases, to result from ‘delayed’ or inadequate activation of the vastus medialis oblique (VMO) in comparison with the vastus lateralis (VL) [23, 24]. However this is not a consistent finding, with other authors finding no delay between these muscle groups in PFP cohorts [25, 26]. Cross-sectional area (CSA) measures found that muscle wasting in PF cohorts occurred through all quadriceps portions and was not selective to the VMO alone [27]. Further, generalised quadriceps strengthening, without specific VMO focus, has been found to benefit PF patients, at least, in the short term [28].

Over the past decade, there has been considerable interest directed towards hip function in PF patients and its relationship with knee joint mechanics. Increased peak hip internal rotation during a 'drop landing' was identified in military recruits who developed PFP [19], with increased peak hip adduction found in individuals whilst running who were subsequently diagnosed with PFP compared with those who did not [29]. The presence of both excessive hip internal rotation and adduction has also been reported in retrospective studies amongst patients with PF dysfunction during functional tasks [30, 31]. Other retrospective studies have identified excessive hip external rotation to be present in PF populations [20, 32], with hip muscle weakness also found in these populations [31, 33, 34]. Consequently gluteal muscle strengthening has been implemented as a common treatment intervention and found to give positive clinical outcomes in these cohorts [35]. This is hypothesised to reduce adduction and internal rotation of the femur, thus preventing lateralisation of the patella as the femur rotates internally underneath it. However, prospective strength study reports are somewhat conflicting to this, with those patients who subsequently developed PFP found to have *greater* hip strength initially than those who did not [19, 36, 37]. Muscle 'onset' measures from electromyography (EMG) recordings are also variable. Some studies identified earlier onset of gluteal muscles during functional tasks [38], whilst others reported delayed timing [39] of the gluteal muscles to be implicated in PFP pathology.

Distally, the foot and ankle complex is less evaluated. However a more pronated foot posture has been linked to the subsequent onset of PF symptoms when assessed statically [40], with greater rear-foot eversion during stair ascent identified in patients with PF symptoms [21]. Limited evidence examines interventions for the distal complex beyond prescription of foot orthoses, which have been found to offer some short-term benefits, but no greater than physical therapy [41].

Overall, evidence supports rehabilitation interventions directed towards lower limb muscle strengthening and correction of kinematics, particularly hip adduction and internal rotation in PFP patients. However some evidence is conflicting, and in the context of high levels of ongoing symptoms 1 year following treatment [5, 6, 42], it is clear how challenging this condition is to adequately manage. The lack of consensus and treatment success suggests that deficits in these patients are not presently adequately understood or addressed.

## 34.4 Limitations of Current Measurements

One reason for the lack of consistent evidence in this field is that the dynamic measures taken from PF cohorts are typically focused on biomechanical assessments many of which, as discussed, have significant limitations. The major limitation in motion capture methods applied to collect kinematic data is the significant error associated with such measurements. This is largely a result of skin and skin-marker movement (in the region of 16 mm displacement and 13° rotation) [43], as well as error in consistent landmark identification for marker placement [44]. Consequently when kinematic differences between populations are small, as is commonly the case in the majority of PFP studies, the findings should be interpreted with caution. Furthermore, skin-marker measurement cannot account for underlying bone geometry abnormality. Thus, for example, these methods cannot differentiate actual increased limb rotation from that which is occurring as a consequence of bone torsion. This is particularly problematic when applying these methods to PFP populations given the known association between symptoms and femoral [45] and tibial torsion [46]. Musculoskeletal modelling is an evolving field and provides promising methodology which, in the future, should be developed to understand human motion with greater accuracy and will likely further understanding of the kinematics presented by this complex clinical population.

Electromyography techniques commonly assessed to provide a measure of muscle activation also have limitations. Firstly, normalisation of data is significantly affected by the plane of motion the muscle is assessed in [47] as well as the presence of pain [48]. Concerns regarding muscle crosstalk, where a signal is recorded over a non-active muscle due to detection of a muscle signal from a different muscle nearby, are also particularly challenging to overcome especially around regions such as the hip with complex muscle architecture [49, 50]. Consequently, as highlighted above, there is often disparity in EMG findings amongst studies performed on the same populations [38, 39]. Furthermore, there is no consensus as to whether muscle activation differences, often occurring at millisecond level, can be altered with clinical interventions.

## 34.5 The Importance of Considering Dynamic and Skeletal Alignment During Assessment and Treatment

Muscular dynamics incorporate a range of variables, beyond routinely assessed measures of strength (force generation) and muscle 'activation'. The efficiency of a muscle is primarily dependent on the orientation of the force generated by the muscle to the 'reference frame' of the joint being moved [51]. Essentially, since muscles attach one bone to another—the relative position of these bones when a contraction occurs is clearly going to be critical in determining the resulting force and motion generated by the muscle contraction. Related to this is the moment arm, which reflects the mechanical advantage a muscle has at a particular joint; the greater the mechanical advantage, the lesser the effort required by the muscle to perform the movement [52]. As well as roles in shock absorbency ('damping') and posture maintenance and optimisation, muscles are designed to act as well-functioning motors to move the human skeleton, possessing specific architectural properties uniquely suited for specific functions in relation to their position in the kinematic chain [53]. Thus, dependence on muscles whose fibres are not aligned to the direction of intended motion is not optimal and is likely to place the limb under increased load, particularly if this movement strategy is performed repetitively during limb motion [54]. Our research group believe this is a significant problem in many PFP patients, which can often go untreated. It is critical that dynamic alignment of the normal skeleton is addressed to enable optimal load transfer through the lower limb. A good example to consider is proximal hip function where, as discussed, the presence of excessive hip adduction and weak hip abductors has been identified in PFP cohorts [31, 33, 34]. Gluteus medius is the largest hip abductor muscle with 60% of the total cross-sectional area of the abductor group [55]. In addition its attachment from the greater trochanter to the flared ilium provides it with the greatest moment arm of all the abductor muscles [56]. This makes it optimally positioned to abduct the hip, which combined with its size means this can be performed with minimal effort. However its fibre orientation in relation to the femoral head changes significantly with both increasing hip flexion and pelvic tilt (since this alters the orientation of its muscle fibres) [57]. Thus as a result, with anterior pelvic tilt or hip flexion, it becomes a potent internal rotator of the hip [54] (Fig. 34.1). This may explain the previously discussed finding of increased hip abduction strength (measured at 0° hip flexion), in patients who subsequently develop PF pain [36, 37]. If these patients adopt an anterior pelvic tilted posture during functional tasks, gluteus medius would act as an internal rotator aiding increased femoral internal rotation [54], a movement pattern linked with PFP [19]. It can therefore be seen that muscle function must be considered in the context that the instantaneous axis of rotation of joints is constantly changing during motion. The limitations of muscle strength measures taken at one joint angle position are therefore apparent; they may in fact give little information in regard to that muscle performance overall, since joint position will vary. The development of more advanced methods to assess muscular function is therefore

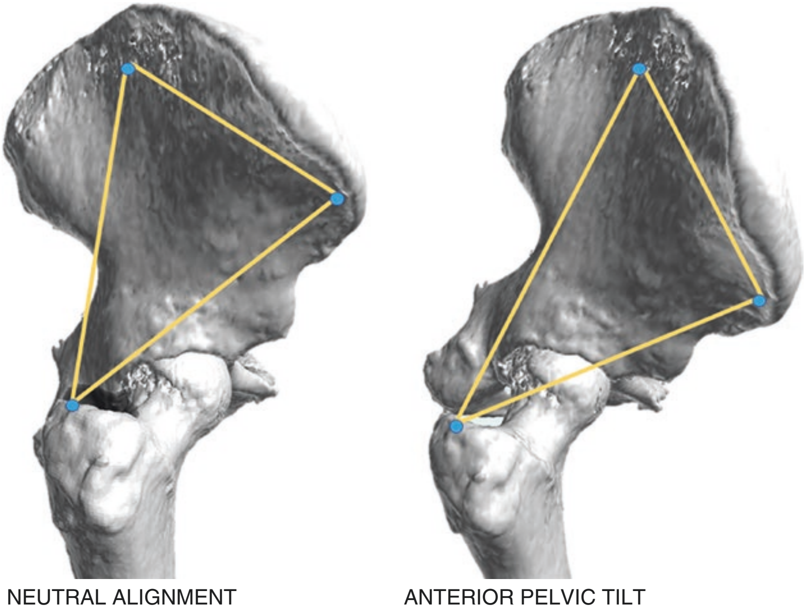

**Fig. 34.1** Yellow lines depicting the muscular lever arm of the gluteus medius muscle in a right-sided, neutrally positioned pelvis (left image) and a right-sided anteriorly tilted pelvis (right image). It is evident that with anterior tilt of the pelvis, contraction of the gluteus medius (where the ends of the yellow lines would approximate) would lead to internal rotation of the femur, whereas in a neutral position it would function primarily as a hip abductor

necessary. Meanwhile, the clinician treating these patients must recognise the importance of patient alignment during exercise and how this will affect muscle activation.

Similar effects of altered muscle orientation and leverage depending on alignment are evident throughout the skeletal chain. Considering the knee locally, if the femur is internally rotated then the knee extensor, vastus lateralis (VL), will have a clear mechanical advantage over vastus medialis (VM). This results from the lever arm of the VL moving more centrally over the PFJ, whilst the VM is moved medially. This may explain the suggestion regarding preferential onset of VL versus VMO as a cause of PF dysfunction, which could in fact simply reflect the mechanical advantage the VL has to recruit over the medially positioned quadriceps in patients with femoral internal rotation. This would also be the case with a femur internally rotated as a result of femoral anteversion. Tibial external rotation meanwhile will alter the mechanical leverage and orientation of the tibialis posterior muscle, potentially resulting in pronation and reduced medial longitudinal arch of the foot. This together with the abnormal tibial rotation would encourage compensatory femoral adduction and internal rotation higher up the kinematic.

Finally, it is important to also consider that although these alignments can result from dynamic muscle function, skeletal architecture can also impact patient dynamics as a consequence of their effect on muscle lever arms and orientation. For example, at the hip femoral anteversion reduces the efficiency of gluteus medius due to the resultant more posterior and medial position of the greater trochanter (Fig. 34.2). At the same time, it enhances the lever arm of rectus femoris and the VL further compounding the impact on the PFJ [58]. This will alter patients' capacity to move the limb efficiently and absorb load and thus will directly affect the magnitude, location and orientation of forces in the leg. It is beyond the scope of this chapter to go into this in depth. However treating clinicians should be aware that if bony skeletal alignment goes unaddressed, it will likely result in suboptimal movement strategies and excessive joint forces and potentially therefore ongoing pain. For example, if the hip cannot externally rotate due to excessive femoral anteversion, then no amount of strengthening hip external rotation or training will prevent the inward pointing of the knee. This distinct patient population may therefore be less likely to respond to physiotherapy interventions and movement re-education alone and instead

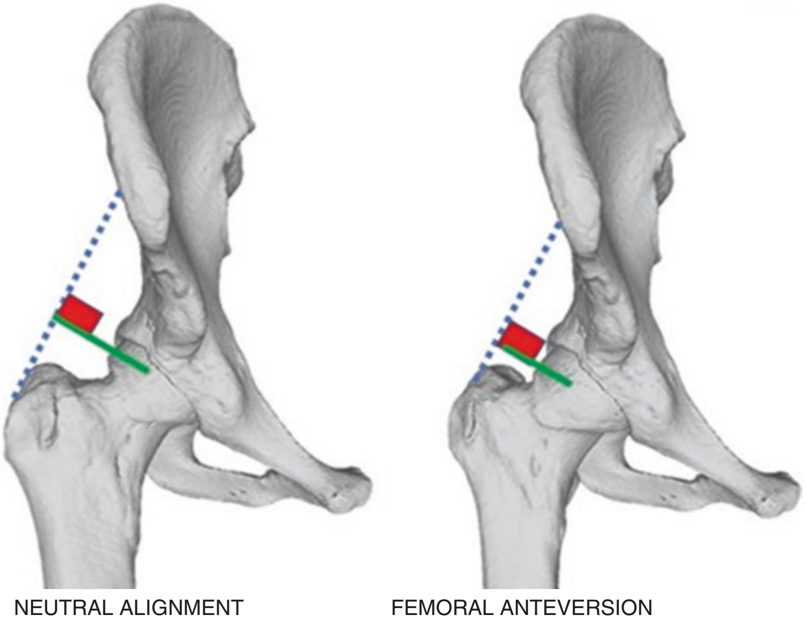

**Fig. 34.2** Two images of the right-sided pelvis and hip, taken with the knee pointing forwards to demonstrate the length of the femoral neck changing relative to the anterior knee. The lever arm (green line) of the gluteus medius alters as femoral torsion changes. With the knee pointing forward, anteversion (right image) creates a relatively shorter femoral neck reducing the gluteus medius lever arm (green line), effectively shortening the muscle and making it less efficient (blue line). Thus differing femoral neck anteversion patterns have potent effects on muscle power and consequently knee and PFJ loading

may require corrective realignment surgery, such as de-rotational osteotomy [46], to help optimise their muscular levers and joint loading.

## 34.6 How to Design a Rehabilitation Programme?

Given the conflicting evidence and lack of success outlined in implementing current 'best practice' rehabilitation programmes the question remains: How can a clinician go about designing a successful rehabilitation programme for the presenting patient with PFP? Based on the outlined biomechanical knowledge, our research group designed a study to investigate the effect of not only treating these patients with rehabilitation programmes, as advocated by the current literature, but also by ensuring optimal alignment (defined as ensuring muscular efficiency) was attained by these patients during their rehabilitation exercises. We designed a study to answer the question 'can a progressive rehabilitation programme targeted at improving the mechanical efficiency of lower limb muscles improve PFP symptoms in patients who have failed prior courses of physiotherapy?'.

## 34.7 Study Methodology

Forty-eight patients with PFP (aged 19–46 years), with at least 3 months of symptoms and who had undergone at least one course of prior physiotherapy that included hip muscle strengthening, were recruited to the study. In total the patients had undergone a mean of three prior physiotherapy courses. Patients with activity-related pain in the anterior knee were invited to participate in the study. They were required to meet the following inclusion criteria to be considered for the study: (1) pain localised to the anterior knee, (2) activity-related symptoms (i.e. symptoms occurring with activities such as running, jumping and/or ascending/descending stairs) and (3) confirmation of an injury to the fat pad based on an MRI scan taken directly after provocative activity. Exclusion from the study occurred if patients had any of the following criteria: (1) patellar instability (subluxation or dislocation), (2) patellar tendinopathy or (3) advanced patellofemoral osteoarthritis. Patients with evidence suggesting rotational malalignment were sent for CT imaging, and these were reported by a consultant radiologist.

## 34.8 Static Alignment Evaluation

Patients were assessed by two experienced physiotherapists. The alignment of the entire skeleton from anterior and lateral views was included in the assessment. This is important since postural alignment provides the basis for movement patterns [59] and, as discussed determines the resulting action of muscle contraction forces. With optimal posture, the posture line passes through the axes of all joints (shoulder, hip, knee and ankle), with the body segments aligned vertically [60], this results in less gravitational stress being placed on the skeletal soft tissues. During examination particular attention was therefore paid to the alignment adopted by the patients during static double- and single-legged stance as well as during a series of dynamic tasks. Following prior classification of double-legged stance, in our study all patients adopted one of the two previously reported static posture types—a sway-back posture ($n = 29$) or an excessive lumbar lordosis ($n = 19$) [61] (Fig. 34.3). In the sway-back posture, the pelvis is the most anterior body segment as it is 'swayed' forwards relative to the posture line. The hip joint also moves forwards of the posture line causing the lumbar lordosis to reduce and resulting in lumbar extension occurring almost like a 'hinge' segment in the lower lumbar spine. The knees are locked back into a hyperextended position, and the ankles are either neutral or often slightly dorsiflexed as a result of the shift of body weight anteriorly. Prior reports have suggested that this posture is associated with a posterior pelvic tilt [60, 61]. We however identified a mild anterior tilt to consistently be present in this group when the anterior superior iliac spine and posterior superior iliac spine levels were compared. This postural type was most prevalent in, but not isolated to, slender female patients. With the increased lumbar lordosis posture, the pelvis is anteriorly tilted, and the lumbar lordosis increased, and knees are hyperextended but with the ankles typically slightly plantar flexed in response to the relative posterior shift of body weight.

When patients were asked to stand single legged, further variations were evident (Fig. 34.4). During single-leg stance in the sway posture patient group, the pelvis tilts down at the side of the non-weight-bearing leg, whilst the standing leg internally rotates at the femur and appears lengthened. The shoulders are rolled forwards and the thoracic spine flexed to counter the anterior pelvic shift and maintain equilibrium around the central posture line. In contrast in single-leg stance with a lordotic posture, the shoulders are typically held in a posterior position as a result of strong back extensors, increased lumbar lordosis and anterior pelvic tilt. This therefore ensures the patients maintain equilibrium. Again the stance leg is seen to internally rotate and hyperextend. This corresponds with prior findings of a strong positive correlation between anterior pelvic tilt and femoral internal rotation [62], meaning as anterior pelvic tilt increases, so too does femoral internal rotation.

## 34.9 Assessment of Muscle Length

These defined postural types result in specific muscular imbalances which, as discussed, affect the action of muscles in the skeletal chain since the positions of the bones the muscles attach to are therefore altered [60]. Firstly, we identified the sway-back posture resulted in lengthened lower abdominals since these are not effectively recruited during standing to maintain posture. Instead these patients relaxed at the pelvis so it moves anteriorly and locked back through

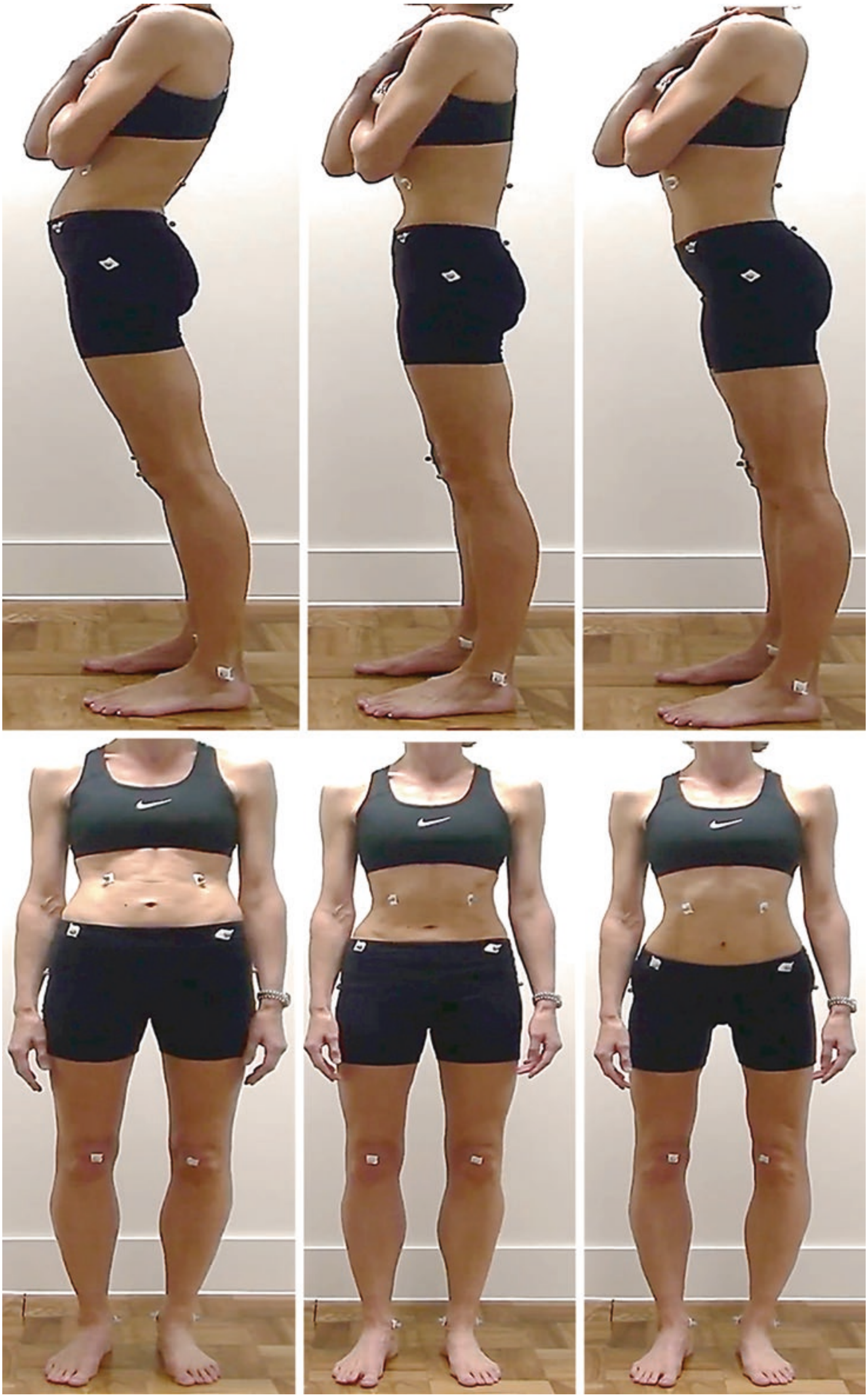

**Fig. 34.3** Lateral (top images) and anterior (lower images) views of double-legged examples of sway-back (left), neutral (centre) and lumbar lordosis (right) postures

**Fig. 34.4** Anterior views of example sway-back (left), neutral (centre) and lumbar lordosis (right) postures

hyperextended knees into a relatively passive stance. In this position the femur and hip joint rest in a relatively flexed position given the mild anterior tilt of the pelvis. Proximally, equilibrium is maintained by thoracic flexion, lengthening the thoracic extensors, with the shoulders rolling anteriorly. Patients typically hold themselves through the shortened upper abdominals. Tensor fascia lata (TFL) was consistently tight and overactive in this posture, particularly during single-leg activities. We hypothesise that this occurs since, as discussed, the gluteus medius is given such poor mechanical advantage in this posture. Since TFL terminates in the iliotibial band (ITB), this will have a direct effect on the PFJ. In essence these patient's use relative counterbalancing of body weight (forwards hips and backwards shoulders) instead of muscle actions to passively remain upright. Typically as a result these patients are usually quite weak.

Despite a very contrasting presentation and patient type, the hyperlordotic posture has a relatively similar imbalance, except these patients typically compensate by becoming strong and overactive in certain muscle groups rather than just passively relaxing into the posture as in the sway-back example. Although appearing to have well-defined gluteal musculature, in fact these muscles are typically lengthened and weak, with the appearance of gluteal bulk instead resulting from the increased lumbar lordosis and anterior pelvic tilt with lengthened lower abdominals. These patients will have a tendency to extend the back rather than the hip, using the back extensors as opposed to the gluteals to maintain an upright position. Consequently they all had tight lower back muscles and markedly tight hip flexor muscles. In particular tightness in rectus femoris is common and likely to affect PFJ loading given its anatomical attachments. As a result of the anterior pelvic tilt, hyperextended knees and the resulting fall of body weight relative to the line of gravity, these patients are in slight plantar flexion during standing, and so it was also common to identify tight calf musculature on examination of gastrocnemius and soleus.

A primary concern in the two commonly identified postures in our study is that the pelvis is moved into an anterior tilt resulting in what has been previously defined as the crossing sign at the pelvis [63]. This is characterised by facilitation (shortening) of the thoracolumbar extensors, rectus femoris, iliopsoas and TFL and inhibition (lengthening) of the abdominals (particularly lower fibres of rectus abdominis) and the gluteal muscles. We therefore recommend that these muscle groups are carefully assessed, as has been advocated in the literature previously [64]. However when testing these imbalances, it must be ensured that the alignment of the patient is monitored carefully. In particular attention should be paid to the position of the pelvis. For example, considering flexibility and muscle shortening: at least one of the hip flexors, (TFL and rectus femoris muscles), was found to be shortened and tight in all our patients on assessment. However this will not be apparent if the patient is allowed to anteriorly tilt their pelvis during assessment. In our experience this is a common compensatory strategy in this group of patients, in tests such as Thomas test [65]. If this occurs during the assessment of hip flexor length, underlying muscle tightness may not be identified. Further where it is present, it is typical that these patients will also employ this strategy when performing flexibility exercises prescribed by the clinician to address the identified tightness, i.e. they will increasingly overextend their lower back to maintain an anterior pelvis, rather than extend at the hip. It is therefore critical to ensure patients are educated on the correct/optimal movement technique to perform the stretch and understand the importance of this. In our patients, muscle lengths of the quadriceps, TFL, hip flexors, hamstring, gastrocnemius and soleus muscles were assessed and any concerns addressed with a flexibility programme [64].

## 34.10 Dynamic Alignment Evaluation

Evidence of deficits in hip abduction, extension and external rotation strength in PFP populations have been discussed [33]. Assessment of these movements is therefore recommended. Often it is suggested that the strength of these movements should be examined by manual muscle testing or using dynamometry for quantification [66]. Undoubtedly strength is an important variable and a common deficit in these populations. However, our experience is that the primary aim of dynamic assessment should firstly be to establish how the patients perform these movements prior to attempting to quantify strength. For example, in the group of lumbar lordosis patients tested, we identified that in standing and supine when asked to extend their hip these patients would typically arch and extend their lumbar spine. This gives the appearance of hip extension, but in reality during this motion minimal actual movement is occurring as a result of the hip joint moving into extension, but rather the lumbar spine extending. Resisting this movement to assess strength would therefore provide a greater reflection of lumbar extension strength as opposed to the hip extension strength intended. A further common example we identified was observed during hip abduction. In the sway-back posture when this is assessed in side lying patients were commonly observed to hip hitch—so to approximate the pelvic crest to the lower rib cage. Again an apparent hip abduction motion results from this, but in reality this is not the primary movement occurring, rather it is side flexion of the trunk. This group also demonstrate a preference to move into slight hip flexion during hip abduction, which provides a mechanical advantage to TFL, allowing it to compensate for gluteus medius weakness. Given the fibres of the TFL terminate into the ITB, this movement may result in increased load being applied to the lateral patella. Optimal movement has been defined as utilising the muscle group designed to perform a movement. It is intuitive therefore that this will result in least demand and load being applied to the skeleton. In the above examples, it is clear this is not occurring, and therefore, even if strength deficits are identified, prescribing strengthening programmes to these patients without improving their underlying movement patterning is unlikely to resolve symptoms. In our study we assessed functional movements of the pelvis, hip, knee and ankle joints in progressively loaded positions and complex tasks (i.e. non-weight bearing and then weight bearing) as long as they were pain-free. Once movement patterning is improved with less complex tasks, functional tasks that load the PFJ and cause pain can be evaluated. For example, hip extension was first evaluated in supine and then standing before evaluation during complex tasks also demanding hip extension, such as rising from a chair and stair climbing. Once a good movement pattern is evident and pain levels are controlled then muscle strength can be evaluated to determine deficits.

Examination of the foot has been historically deemed important since it has been hypothesised that pronated feet have an important role in the genesis of PFP [67]. Whilst this is a factor in some patients, we commonly found that foot pronation was resolved by correcting proximal mechanics, to reduce anterior pelvic tilt and the resultant limb internal rotation [62], so leading to an increased arch in the foot. Any apparent foot issues were therefore only addressed after proximal mechanics at the hip were optimised.

Alongside hip weakness it has been reported that core strength deficits are common in these patients [68]. However the precise definition of 'core' and what this encompasses is not well defined. In our study we were focussed on optimising skeletal alignment. Therefore we considered assessment of core to be the position of the pelvis. Since the patients in our study all presented an anterior pelvic tilt, we were particularly interested in the function of the lower abdominal muscles, since these are lengthened in this posture. To evaluate these we asked patients to perform a pelvic tilt in the supine position with the knees bent. We wanted them to demonstrate the ability to dissociate, so isolate, movement of the pelvis from the rib cage and hip, by tilting the pelvis posteriorly and then anteriorly through range. Interestingly we found patients demonstrated a number of consistent compensation strategies when performing this. Video 34.1 demonstrates a pelvic tilt performed optimally, with the rib cage stationary and the pelvis rotated on the hips. Moving the pelvis from an anterior to posterior tilt requires a combination of the lower rectus femoris and the gluteals to activate. However, Video 34.2 shows a common strategy identified, particularly in the sway-back group, where patients are observed instead drawing the rib cage down towards the pelvis. This movement recruits the typically shortened and strong upper abdominals to flex the trunk down, rather than demonstrating a true posterior tilt of the pelvis. Video 34.1 demonstrates another common strategy, particularly evident in the lordotic group, and that is bracing and pushing outward through the abdominals rather than isolating and moving the pelvis. Consistently therefore we identified these patients had weakened lower abdominals. This was often observed in even very slender patients where defined upper abdominal musculature was evident, but in combination with a protruding lower stomach area, where the lower rectus abdominis was lengthened and more relaxed. Although not formally assessed, we hypothesise that this could be a result of preferential activation of the upper versus lower rectus abdominis. Selective activation of the upper rectus abdominis muscle is possible since this muscle has different portions than the lower fibres, and each has a different innervation [69]. Support for the ability to differentially recruit lower and upper regions of the rectus abdominis has been reported in professional tennis players, who perform repetitive one-hand dominant movements [70]. Both postural alignments described in our study would result in the upper rectus abdominis fibres becoming shortened with the lower fibres lengthened, so we believe this merits particular attention during assessment.

The need for examination of muscle function in the context of limb alignment is therefore clear. It is our experience that in patients with PFP, it is useful to consider separately the anatomical structures responsible for the production of forces that cross the PFJ, from the PF complex itself which is being acted upon by those forces. In this patient group, understanding, identifying and addressing the forces that are applied to the PF joint are likely to be more beneficial than addressing directly the PFJ, which is the recipient of these forces.

## 34.11 Exercise Prescription

Findings from the physical examination were applied to design a rehabilitation programme for these patients. Movement optimisation and specifically lumbo-pelvic dissociation, to reduce anterior pelvic tilt and improve conscious separation of hip, pelvic and lumbar spine motion, has been proposed as an intervention for a range of pathologies including PFP cohorts [71–74]. However, it has been argued that despite the widespread uptake of such interventions, there is very limited scientific evidence for their benefit [75]. It is our experience that these interventions are successful clinically. However, sadly, given the previously discussed limitations of current biomechanical measurements, these subtle changes are an example of those which are of importance but are not amenable to detection and quantification with current biomechanical assessment methods. However, their effect is clear and can be explained by applying biomechanical principles of muscle function previously discussed.

Forty-five muscles attach to the pelvis [76], meaning alterations in its position, even small, will have significant effects on the mechanical function and leverage of the muscles and forces acting on the lower limb. This will therefore significantly affect the magnitude, direction and location of forces acting on the lower limb. Put simply, some pelvic/lower limb/spinal postures are optimal for efficient muscle action, whilst others will not be. Suboptimal movement patterns, that is, utilising muscles to perform movements that they are not primarily designed to perform, will result in increased energy expenditure, adverse load application to the skeleton and potential injury. A skilled examiner is therefore required to identify these movement strategies and address them. Given the loads applied to and accepted by the PFJ during basic daily activities, it is particularly susceptible to adverse load application.

It is our experience that attention to pelvic position is paramount to restoring optimal movement patterns, which are key to successfully rehabilitating PFP patients. Therefore all patients were taught to correctly perform a pelvic tilt, firstly in supine as the body has maximal support; so typically this is the easiest position to educate the movement. Some patients grasped this easily within a single session, but it was more common that it took several sessions for the majority of patients to learn this. Pelvic tilting, recruiting the lower abdominals, was then also taught in standing and sitting positions. Interestingly on performing this in standing, it was observed that many patients are observed to instantly improve their lower limb alignment—with the knees coming out of a hyperextended position, with the femurs externally rotating so that the knee caps pointed forwards and not inwards. This is likely a consequence of the previously reported coupling of motion between the pelvis and femur [62]. Further, in this position some patients reported a reduction in their pain and discomfort on adopting this stance. We hypothesise that this could be a result of this posture reducing the pressure on the infrapatellar fat pad which is known to be compressed in full knee extension [77]. When using the lower abdominals to lift the anterior pelvis, it alters the fall of body weight around the fulcrum of the hip joint, making it harder to push the knees back into hyperextension. It is important to note that our population of PFP patients all had fat pad inflammation identified on imaging.

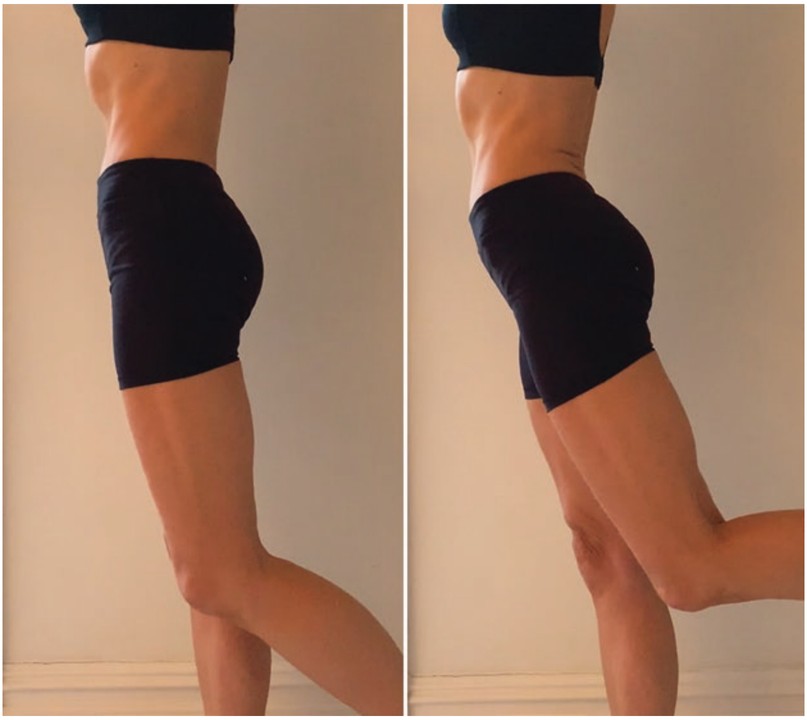

**Fig. 34.5** Optimal method to perform hip extension—the pelvis is maintained in a neutral position and the femur extended under a stable pelvis. In the right example, suboptimal movement patterning is evident. The hip is extended by arching the lower back, rather than recruiting through the gluteals to extend the femur under the pelvis

In the initial stages of rehabilitation, a flexibility programme was also given to patients to address any areas of muscle tightness that were identified. The most commonly addressed tight muscles in the sway-back group were the TFL and lateral quadriceps and in the hyperlordotic group were the hip flexors, lumbar extensors and gastrocnemius. Subsequent rehabilitation targeted the hip, knee and foot and ankle complex in turn. Movements were taught from proximal to distal since alterations in proximal alignment alter distal alignment, as described in the example above. Initially exercises were simply to perform basic single plane, isolated movements optimally, such as hip extension (Fig. 34.5 example), abduction and external rotation. From experience we have found patients typically perform these exercises well when supervised in the clinic; however, when they practice them at home and return, they have often reverted to their old, suboptimal movement patterning. To address this therefore in clinic we asked patients to draw on a digital body map the area they felt their muscles working when they performed the movement—both using their preferred movement method and then following instruction on optimal movement. Interestingly this proved to correlate well with the area and muscles we would anticipate to be loaded based on assessment of the patients' movements (Fig. 34.6). Patients were encouraged when at home to think about where they were feeling the sensation of work as they practiced the prescribed exercises. They were advised only to continue with the exercises if they could feel the correct area of muscles working—if they could not, we reviewed them again to correct this. We find this free and effective method to be very useful with patients in clinic and would recommend others to use it when working with these patients by simply asking 'where do you feel the muscles working?'. It can be argued that even with complex time, expensive and consuming tests like EMG, given the previously discussed limitations, there is no way to ensure this data is accurate, particularly given the complexity of muscles around the hip. Further, most clinicians do not have access to

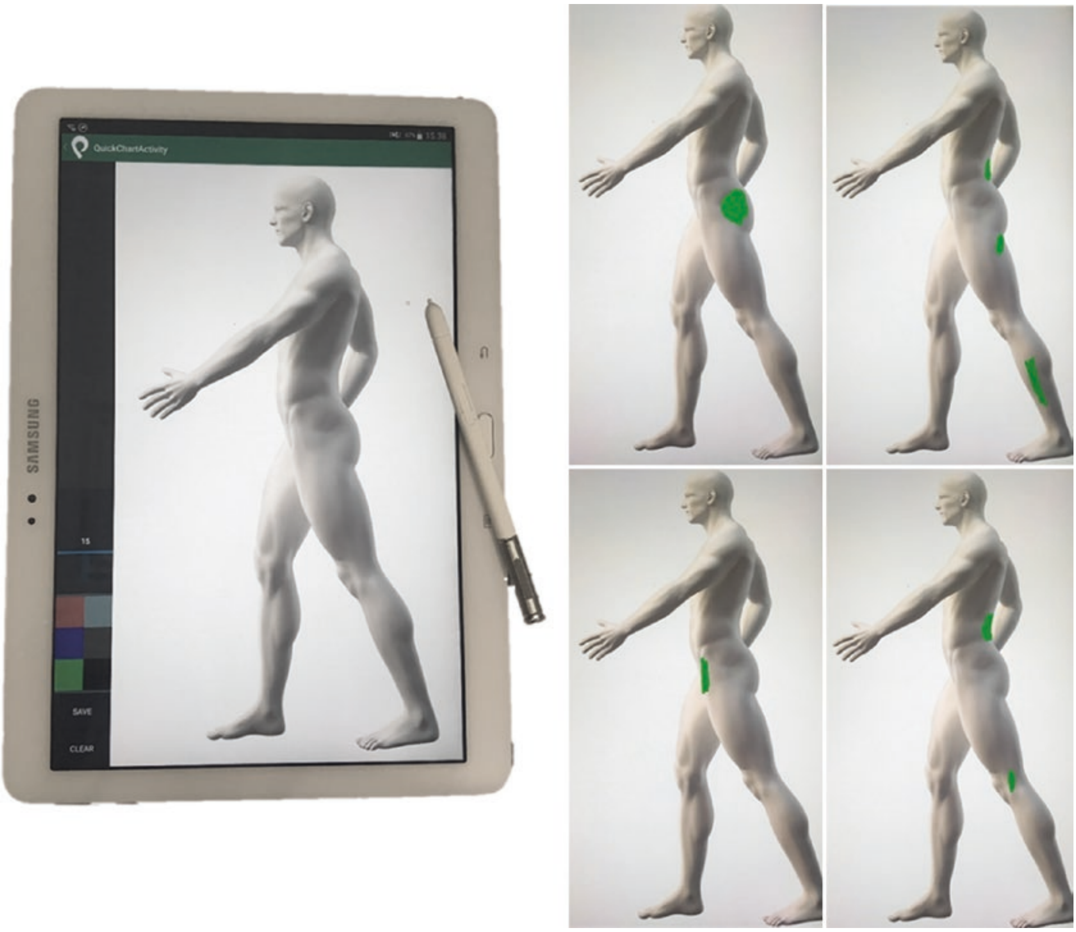

**Fig. 34.6** 'Muscle mapping' recorded by patients using a digital body map (left image) taken from patients when performing hip abduction in side lying. It would be most optimal to use the gluteal muscles of the buttock when performing this movement—as shown in the top left image. However common example areas of effort reported by patients are shown: the area of TFL (bottom left image), lumbar extensors, proximal hamstrings and ankle evertors (top right image) and lumbar extensors and lateral knee (bottom right image)

such testing facilities anyway so simpler testing is required to benefit wider clinical practice.

Once patients could move effectively in single planes, more complex exercises were introduced. Examples included stair climbing, rising from a chair, double- and single-legged squat and lunging. These movements demand more control since movement is occurring at multiple joints simultaneously, challenging patients more. Therefore these are typically introduced most successfully once patients have demonstrated satisfactory single joint control.

## 34.12 Dosage of Exercise

A critical factor to ensure the success of a rehabilitation programme is that accepted exercise prescription principles are applied [78]. This means the treating clinician should carefully consider variables such as the number of repetitions, sets, frequency and rest periods prescribed to ensure targeted gains are achieved. Current research comparing differing exercise dosage in PFP rehabilitation is limited. However, in a randomised trial comparing exercise dose and outcomes in PFP, higher dose (3×/week, 3 × 30 reps, 9 exercises, 60 min) was found to be more effective than lower dose (3×/week, 2 × 10 reps, 5 exercises, 20 min) exercise prescription [79]. During initial rehabilitation low-resistance exercise with frequent repetition and a focus on correct movement patterning is necessary to optimise neuromuscular function [78]. Not until optimal movement patterns are achieved should higher-resistance training be introduced, otherwise there is a risk that patients will simply strengthen and reinforce poor movement patterns, for example, using TFL to compensate for weakness in gluteus medius. In our study therefore patients were initially prescribed four to five low load exercises (typically pelvic tilt alongside flexibility and single plane hip motion) and asked to perform three sets of these five times per week. The number of repetitions was determined by the number they could perform whilst still feeling the 'work' in the correct area. If they reverted to feel the load somewhere else, they were told to stop and rest 30 s then perform the next set. They were progressed to the next stage when they could perform three sets for 90 s with correct movement patterning.

Although exercise prescription should be tailored at the beginning of rehabilitation to prioritise addressing key deficits (e.g. optimising movement patterning and flexibility), evolution of the programme must be guided to ensure all potential deficits are addressed over time. Therefore once correct movement patterning was evident, muscle function was then facilitated through stages from endurance (e.g. low load, 15–20 reps, 3–5 sets, rest 30 s, 3–5 sessions per week) through to strength (e.g. high load, 8–10 reps, 2–3 sets, rest 2–3 min, 2–3 sessions per week) and power training (e.g. moderate load, 3–6 reps, 3–6 sets, rest 3–5 min, 3–5 sessions per week) [78]. There is excellent evidence from strength and conditioning backgrounds to indicate that tailoring variables, including repetition, rest and loading, are key to optimising outcomes of strength training [78]. During rehabilitation load is typically varied by altering the exercise choice. For example, standing hip extension could be commenced initially and then progressed to a double- then single-leg bridge and then a squat, lunge or step-up. Each exercise will target the gluteal muscles, but gradually the complexity of the movement (i.e. from single to multi joint) is increased alongside the load applied.

The concept of tissue homeostasis is widely discussed, in the context of the magnitude of load applied to the PFJ, and is very useful to consider when managing PFP patients. This model considers the load an individual can accept, transfer and dissipate without injury [12]. For example, a high load experienced as a single event may be well tolerated; similarly repetitive smaller loads may also be tolerated; however, if the duration or magnitude of either of these increase, injury may result. This model is helpful to apply clinically to help guide progressions during rehabilitation of PFP patients. For example, as more dynamic and intensive activities are introduced, such as jumping or running, it should be ensured that following these activities patients are permitted sufficient rest to allow their symptoms to recover, before resuming loading of the PFJ again.

The patient's functional goals must also be considered in later-stage rehabilitation. For example, if they want to return to running, given the loads applied to the lower limb during this activity, it must be ensured patients are able to tolerate these. In our experience a guide of this can be achieved by asking patients to perform a short-range single-leg press and quantify the load they can press in relation to their body weight. A patient who is not able to leg press their body weight is unable to have the muscular capacity to absorb and 'dampen' the forces and torques imposed through running effectively without this resulting in excessive loading being placed on the joints and supportive tissue, increasing reinjury risk.

A final crucial point is that short-term rehabilitation programmes will rarely provide additional benefit when evaluated in the long term (beyond a year), since initial benefits typically diminish over time [18]. In our experience, given the high levels of recurrence of PFP, patient's should be advised to continue some flexibility and functional exercise in the long term—albeit reducing the volume of this (e.g. to once a week or once a fortnight). Patients that cease exercise too soon will commonly return to clinic with a recurrence of symptoms.

## 34.13 Study Outcomes

Eighty-five percent of our patients ($n = 41$) reported a significant reduction in their pain at 1 year following commencement of the programme, as measured using the anterior knee pain scale [80] ($P < 0.05$). Follow-up from patients at 1 year following recruitment to the study identified eight patients who reported their symptoms recurred after they stopped the exercises as their pain had resolved. They reported the pain to improve again once they recommenced some of the exercises. Four patients who did not respond to the exercise intervention reported that they went on to consult a pain specialist and found a reduction in their symptoms in response to this, although this was a subjective report and not formally measured. Finally, of interest, we found that patients with increased femoral anteversion ($n = 12$), as measured with a rotational profile from CT imaging, had significantly greater difficulty in sensing the region of the buttock muscles working during hip abduction and extension exercises than those who were not suspected of having rotational malalignment based on clinical examination. These increased femoral anteversion patients were also found to be less likely to respond positively to the rehabilitation programme outlined, perhaps as a result of the previously discussed factors.

## 34.14 Adjunct Treatment Options

In patients failing to respond to movement repatterning as a result of ongoing inability to activate the gluteus medius in particular, we have previously reported addressing this group with an injection of a muscle relaxant, botulinum toxin, into TFL. The aim of this is to relax and inhibit TFL, forcing patients to utilise gluteus medius during hip abduction and thereby allowing them to learn optimal movement strategies. When combined with the movement re-education and progressive rehabilitation outlined, we have found this to be successful, with a significant reduction in pain reported in the majority of patients at 5-year follow-up [81]. This may therefore offer a further option to clinicians who are presented with these challenging patients, who do not improve following initial treatment.

## 34.15 Conclusion

Patellofemoral pain patients present one of the greatest clinical challenges in rehabilitative medicine. By applying biomechanical principles, this chapter has outlined the importance of considering both dynamic and skeletal alignment when designing treatment programmes for this complex population. The musculoskeletal system represents a complex arrangement of vectors where movements can have different trajectories, velocities and muscle activation profiles that combine to give a similar final limb movement. It is currently unknown what determines these relative muscle contributions; however, it is intuitive that ‘optimal’ movement of the body will reduce the forces applied to the skeleton, maximise its efficiency in terms of energy consumption and also reduce injury risk. It has been discussed that even small changes in skeletal or dynamic alignment have the potential to cause significant alterations in muscle effectiveness, altering the forces applied to the limb, which can manifest clinically as PFP. Although complex, we hope that greater appreciation and understanding of the need to change muscle vectors acting on the skeleton will catalyse a change in attitude to rehabilitating these patients, whereby learning movement patterns to optimise muscle efficiency and joint loading is as important as strengthening peripheral neuromuscular function. This requires skilled assessment to ensure the needs of each individual patient are identified and addressed.

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# 35

# Obligatory Dislocators, Dislocation in Flexion

Frederick Weitz

## 35.1 Introduction

Habitual dislocation of the patella or obligatory dislocation in flexion is a relatively rare condition where the patella dislocates laterally in every flexion and extension cycle and the patient has no control over the patella dislocating [1, 2]. The literature concerning obligatory dislocation of the patella is slim due to the rarity of the condition. The presentation of this condition begins mostly when the child starts to walk [3]. The condition is often well tolerated if not painful, although it may present with dysfunction and instability which leads to difficulty in running or frequent stumbling. Mainly habitual patella dislocations start to produce symptoms that are limiting the physical activity of the child at or around the start of school age. The luxation of the patella in flexion is mainly caused by too short extensor muscles, and in some cases contractures are confined to the iliotibial band, vastus lateralis, and the lateral fibers of the rectus femoris muscle [4]. This condition forms a false sulcus to the deep trochlear area that can be seen in preoperative contrast medium-enhanced CT and in the operation.

The difference between habitual patella luxation and permanent patella dislocation is that in the former, the patella dislocates in every flexion cycle and relocates with extension. Permanent patella luxation is a condition where the patella is dislocated laterally in every position of the knee (permanently lateral to the groove and never relocates). These are often congenital and present already at birth. In this chapter we deal with habitual patella luxation.

## 35.2 Treatment

For habitual patella luxation, the literature describes various treatment options. No single procedure has satisfactory results in treating habitual luxation, and the operative treatment should always be a combination of procedures [1, 5, 6]. The lengthening of vastus lateralis tendon is in every case obligatory with adhesiolysis of the lateral scar tissue when present. The reconstruction of MPFL (medial patellofemoral ligament) and MPTL (medial patellotibial ligament) should be also done in combination to recreate the medial soft tissue balance. MPFL contributes 50–60% of the medial restriction during the initial flexion (flexion of between 0° and 30°) [7, 8]. MPTL contributes its medial restriction force in deeper flexion reaching its peak force at 90° of

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flexion [7, 9]. The constant false tracking in flexion movement forms a "false sulcus" to the mid of the lateral condyle. This can be detected in MRI or even better in contrast medium-enhanced CBCT (conical beam computer tomography) (Fig. 35.1a, b). If this false sulcus is clearly present in the preoperative imagining, it should be taken into consideration to elevate the lateral wall of femoral sulcus at this place to prevent the patella from maltracking postoperatively.

Many techniques have been described over the lengthening of quadriceps for habitual patella luxation. The lengthening of the extensor apparatus is the most important part of the combination of procedures. The tightness is normally in the lateral part of the quadriceps tendon. Firstly the lateral adhesions should be carefully released and the tendon properly prepared. A sliding lengthening plasty of the lateral half of the distal quadriceps tendon is performed. The lateral half of the tendon is splitted horizontally about 10 cm long proximally from its patellar insertion. The upper part is cut vertically near the patellar attachment, and the inferior vertical cut is performed proximally. The knee is flexed a bit over 90°, and the two layers are sutured in lengthened position to each other and secured to the medial part of the tendon that is intact (Pictures).

MPFL and MPTL reconstruction should also be done to get the necessary soft tissue medial support during the whole range of motion. If the patient is still an adolescent with open physes, it is necessary to evaluate carefully the techniques used. With open physes MPFL reconstruction with adductor tendon is one option where no drilling near the growth plate is needed. MPTL reconstruction can be done with open growth plates using cortical fixation with suture anchor.

The lifting of the lateral deprivation can be done in every age as it does not harm the growth plates. The lateral deprivation is opened subchondrally and lifted slowly with chisels. The formed clear space is filled with patient's own bone that can be harvested from the distal femur above the sulcus area or with a calcium triphosphate preparate (Fig. 35.2a–c).

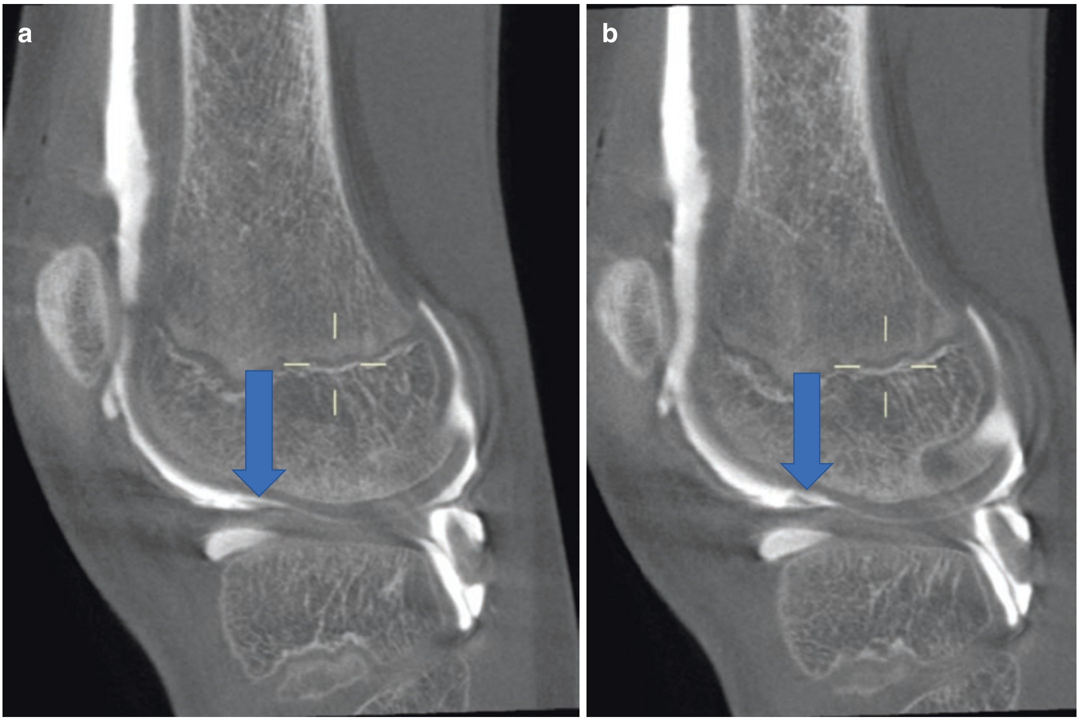

**Fig. 35.1** Contrast medium enchanced CBCT of obligatory dislocator arrow showing the false groowe formed in lateral condyle of femur

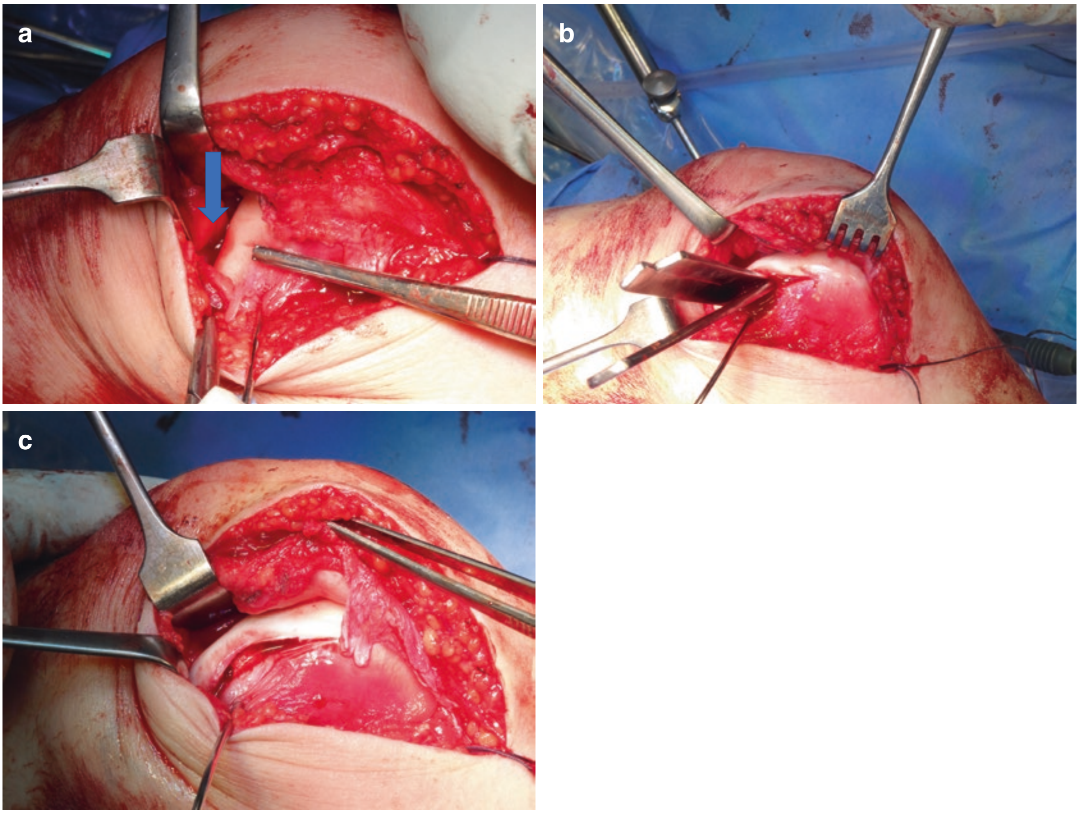

**Fig. 35.2** Intra operative view of lifting the false groove in lateral femoral condyle

## 35.3 Conclusion

Habitual patella luxation in flexion is a very rare condition with operative treatment that demands careful preoperative planning and combination of procedures. The restrictive forces of extensor mechanism must be taken care of. The medial supporting structures have to be reconstructed. If the procedures are done to an adolescent patient, violation of the growth plates has to be avoided.

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# 36

# Is There an Indication for Patella Osteotomies?

Matteo Marullo and David Dejour

## 36.1 Introduction

The patella is a sesamoid bone in a soft tissue complex that originates from the anteroinferior iliac spine and proximal femur and inserts distally on the tibial tubercle. The patella works with this soft tissue complex and not with the femur. The form of the patella and trochlea has a genetic basis; this is clear in comparing the anatomy of the patellofemoral joint among mammals. In horses, the knee is never completely extended, and consequently the trochlea is detached from the condyles. The continuity between the trochlea and the condyles is typical of the primates. The heavy gorilla has a flat trochlea and a flat patella; the fast and light chimpanzee has a narrow trochlea and a patella with only one facet [1].

An asymmetrical patellar groove with a protruding lateral side is a specific mark of bipedal locomotion and is unique in humans. After birth, the development of a bipedal stance and of a complete extension of the knee results in a femoral obliquity and secondary valgus of the extensor apparatus. These epigenetic factors determine the position of the patella in relation to the trochlea and probably affect the patellar and trochlear shape to develop congruent articulating surfaces [2].

In objective patellar instability (OPI), the patella displaces from the trochlear groove due to three main anatomical factors: trochlear dysplasia, patella alta (high riding patella), and excessive lateralization of the anterior tibial tubercle in relation to the trochlear groove [3]. Trochlea dysplasia is recognized as the most important factor for patellar instability; it is present in 96% of patients with objective patellar dislocation [3, 4].

Several surgical procedures, generally named trochleoplasties, have been proposed to correct trochlea dysplasia by fashioning a deeper new trochlear groove [5–9]. Midterm clinical results of these procedures are encouraging. In particular sulcus-deepening trochleoplasty showed excellent clinical and instrumental results [10, 11]. It restored adequate patellar stability and improved knee clinical and functional scores, and it did not caused arthritis progression at a mean follow-up of 7 years [10]. Instrumental evaluation demonstrated an increased trochlear depth, a normalization of the sulcus angle, and an improved congruence between patella and trochlear groove [11].

But patellofemoral dysplasia could also affect the patella. Probably patellar dysplasia is a consequence of the articulation with a dysplastic trochlea during its developmental period; consequently, the patella develops congruent articulating surfaces with the abnormal trochlea [2, 12].

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Wiberg classified the patellar shape in three types, according to the morphology of its medial facet on a skyline radiograph at 30° of knee flexion [13]:

- Type 1: the medial facet is concave and has almost the same area of the lateral facet.
- Type 2: the medial facet is still concave but is smaller than the lateral face.
- Type 3: the medial facet is convex and is almost vertical.

In 1964 Baumgartl added a fourth type of patella, in which the medial facet is absent; he called it Wiberg type 4 [14].

In a magnetic resonance imaging (MRI) study, Fucentese found a smaller medial cartilaginous patellar facet and an increased facet ratio in the majority of trochlear dysplastic knees [12].

Barnett demonstrated that, in the dysplastic patellofemoral articulation, the medial facet of the patella becomes smaller in relation to the lateral facet from proximal to distal. So, the dysplastic patella has a hypoplastic medial facet and a wider lateral facet for both osseous than cartilaginous landmarks [15].

For these reasons, in some cases sulcus-deepening trochleoplasty could led to subsequent mismatch between the reshaped trochlea and the still flat patella, causing persistence of patellofemoral maltracking.

In these rare cases, we proposed a medial closing wedge patellar osteotomy in order to create a congruent patellofemoral joint.

## 36.2 Historical Evidences for Patellar Osteotomies

The topic of patellar osteotomies is not new in literature. The first ones have been proposed in the 1970s in addressing patellar chondromalacia and patellofemoral pain.

In 1977, Deliss presented a case series of 13 patients with chondromalacia patellae treated with a coronal osteotomy [16]. The technique consisted in dividing the patella in a coronal plane, without removing bone or stabilizing the osteotomy. The aim of the osteotomy was to decrease intraosseous pressure of the patella as found after tibiofemoral osteotomies. Overall Deliss reported fair results, in particular, in women, whereas in half the males, the results were excellent.

Several years later, Vaquero and Arriaza published an experimental study about another type of sagittal osteotomy, the "patella thinning osteotomy" [17], in which an intermediate bone fragment is removed, producing a slimmer patella.

The authors proposed it as an alternative to advancement of the tibial tuberosity or patellectomy in cases of severe anterior knee pain. In their study, this technique decompresses the patellofemoral joint with a "Maquet effect" and produces the biological effect of reducing subchondral bone pressure. Anyway, there were no clinical studies about this technique.

In 1978 Morscher was the first to describe a sagittal (longitudinal) osteotomy of the patella [18]; he proposed an open wedge sagittal osteotomy to treat patellofemoral pain in case of dysplastic patella (Wiberg type III and IV).

With this technique he could correct incongruity of the patellofemoral joint by enlarging the area of cartilage contact in the medial facet of the patella. This would improve the nutrition of the articular cartilage and reduce the intraosseous pressure in the patella. Hejgaard and Arnoldi performed this technique in 40 patients with patellofemoral pain syndrome, obtaining significant pain relief in 37 [19]. They point out that the good outcome should be due to the reduced intraosseous pressure, as they previously demonstrated a close correlation between articular pain and elevation of the intraosseous pressure within subchondral bone [20].

In 1980 Griss proposed a modification of Morscher's sagittal osteotomy for the treatment of patellar chondromalacia or incipient osteoarthritis [21]. He developed a sagittal closing wedge osteotomy, in which congruity of the joint was achieved by removing an anteriorly based bone wedge from the patella, allowing the lifting of one of the patella facets. His study was a preliminary report of five cases with good results after 1 year of follow-up.

## 36.3 Patellar Osteotomies in Objective Patellar Dislocation

Reports of patellar osteotomies for treating patellar dislocation are uncommon, and only few of them considered patellar osteotomy in combination with trochleoplasty.

The first description of the Albee's procedure in treating patellofemoral osteotomy included an opening wedge lateral femora condylar osteotomy and a dorsal closing wedge patellar osteotomy [5]. Badhe and Forster used the Albee's procedure to treat four patients suffering from patellar instability [22]. Their results were fair: the patella was stable without sign of necrosis or non-union, but patients experienced residual patellofemoral pain. Actually it is recognized that the elevation of the lateral condyle as described by Albee increases the patellofemoral pressure, so the fair results could be attributable to this type of trochleoplasty.

Paar conducted an experimental study on sheep to combine an open-wedge longitudinal patellar osteotomy, as the Morscher's one, with a deepening trochleoplasty [23]. His laboratory results were good, but there are no clinical studies published about his procedure.

Koch recently published a series of two patients underwent dorsal closing wedge patellar osteotomy in combination with Bereiter trochleoplasty [24]. At the 2 years follow-up, the clinical results of the two patients were good, but one patient needed a mobilization under anesthesia due to postoperative stiffness. The congruence between trochlea and patella was satisfactory, and there were no signs of necrosis or non-union.

In 2012 Saragaglia proposed a patelloplasty in treating objective patellar instability [25]. This technique was not a real osteotomy but actually a removal of a bulge in the distal medial facet of the patella, frequently present in case of patellar dysplasia. The authors reported the clinical results of 22 cases at a mean follow-up of 7.5 years. All procedures were associated with lateral retinaculum release and tibial tuberosity anteromedialization (or lowering). They reported excellent results, with a mean Kujala score of 91.8 and a centered patella on skyline view in 95.5% of cases. Only one patient had recurrence of patellar dislocation.

In 2015 Choufani presented a case report of a lateral closing wedge patellar osteotomy for habitual patellar dislocation [26]. In that patient, the patella was concave with a Wiberg angle of 225°, so, after a trochleoplasty, a tibial tuberosity medialization, a lateral release, and a vastus medialis plasty, the patellar tracking was still abnormal. The authors performed a lateral closing wedge patellar osteotomy to obtain a Wiberg angle of 140° and fixed the osteotomy with nonabsorbable transosseous sutures. At 1-year follow-up, the patient reported no pain or recurrence of dislocation.

## 36.4 Medial Closing Wedge Patellar Osteotomy

### 36.4.1 Preoperative Planning

As medial closing wedge patellar osteotomy has to be considered in association with trochleoplasty, preoperative planning and indication for it are the same for sulcus-deepening trochleoplasty.

Preoperative objective clinical evaluation includes the apprehension test, lateral patellar glide test, and patellar tracking. Subjective findings include the presence of patellofemoral pain and/or feeling of instability. Radiological assessment consists in anteroposterior and true lateral weight-bearing radiographs, axial view at 30° of knee flexion and computed tomography (CT) using the patellofemoral protocol evaluation. Radiological evaluation permits to grade trochlear dysplasia according the Dejour classification and the shape of the patella according to Wiberg and Baumgartl; moreover, it permits to measure tibial tuberosity-trochlear groove (TT-TG) distance and patellar height according to the Caton-Deschamps index [27, 28].

Indications for trochleoplasty were objective patellar instability and high-grade trochlear dysplasia (grade B and D according to Dejour classification). Indications for additional patellar osteotomy were Wiberg type III or IV patella and intraoperative abnormal patellar tracking after trochleoplasty.

Trochleoplasty and patellar osteotomy are often performed as a definitive surgery in previously multi-operated knee.

Performing a patellar osteotomy is technically demanding. The patella is small, poorly vascularized, and with a high proportion of cortical bone. So, each patellar osteotomy has a non-negligible risk of necrosis and non-union [29].

The blood supply of the patella occurs mainly through an anastomotic ring consisting of the anterior tibial recurrent artery and five genicular arteries, which penetrate anteriorly into the bone through vascular foramina [30, 31].

Three main arteries originate from the medial side and three from the lateral side. The patellar and the quadriceps tendons are an additional source of blood supply [32].

### 36.4.2 Surgical Technique and Rehabilitation

The procedure is performed under general anesthesia. The patient is supine with the knee flexed 90°. A tourniquet is applied to the tight. A straight midline skin incision is performed starting 10 cm proximally to the patella till its center. The arthrotomy is performed through a modified mid-vastus approach: the fibers of the vastus medialis are spared by blunt dissection starting 3 cm proximally to its distal end, and the medial border of the patella is sharply dissected. The trochlea is exposed, and a sulcus-deepening trochleoplasty is carried out as described by Dejour [8].

After restoration of the trochlear groove, the patellofemoral tracking is evaluated to rule out any incongruence between the shape of the patella and the new trochlea. This should happen in Wiberg type 3 patellae, where there is a wide, flat lateral facet and a very hypoplastic, convex medial facet, or in Wiberg type 4 patellae, where the medial facet is absent. In these cases patellofemoral tracking should be still abnormal after trochleoplasty; only reshaping a patella with two facet and a Wiberg angle congruent to the newly formed sulcus angle could restore an adequate patellofemoral tracking (Fig. 36.1). The medial facet is created via a medial closing wedge patellar osteotomy.

The medial border of the patella is exposed, and a coronal closing wedge osteotomy is performed for its entire length with a small oscillating saw; the depth of the osteotomy should reach the midline of the patella (Fig. 36.2). Care should be taken not to damage the articular surface, so osteotomy should be performed at least 5 mm below the subchondral bone. The patellar osteotomy is then closed with a fibrous suture: two sagittal full-thickness holes, 1 cm laterally to the patellar medial border, and with 1 cm of distance between them are performed with a 1.7 mm drill; an absorbable No. 2 Vicryl suture is passed in the two holes, and a stitch is done in the dorsal aspect of the patella to close the osteotomy.

Surgery is completed with medial patellofemoral ligament (MPFL) reconstruction using a half-thickness middle third of the quadriceps tendon, leaving it attached to the patella and flipped 90° to the medial epicondyle [28]. The anatomical position of the MPFL on the medial epicondyle is identified with the radiographic method of Schöttle [27]. The joint is then closed with absorbable No. 0 Vicryl suture. No drainage is placed.

Patellar osteotomy does not modify the usual postoperative rehabilitation after trochleoplasty. Full weight-bearing is allowed with two crutches. Continuous passive motion from 0° to 90° is started immediately to model the trochlea and the patella; during the first 45 days, isometric strengthening exercises are performed. After 6 weeks, strengthening exercises in closed kinetic chain and cycling are commenced. After 3 months, light jogging is allowed. Full activity is permitted 6 months after surgery.

## 36.5 Discussion

We believe the indications for patellar osteotomy are very restrictive. Fashioning of the patella is a technically demanding procedure to be reserved for cases of extreme patellofemoral mismatch after trochleoplasty. We consider patellar osteotomy only as an associated procedure to trochleoplasty to produce a patella congruent to the newly

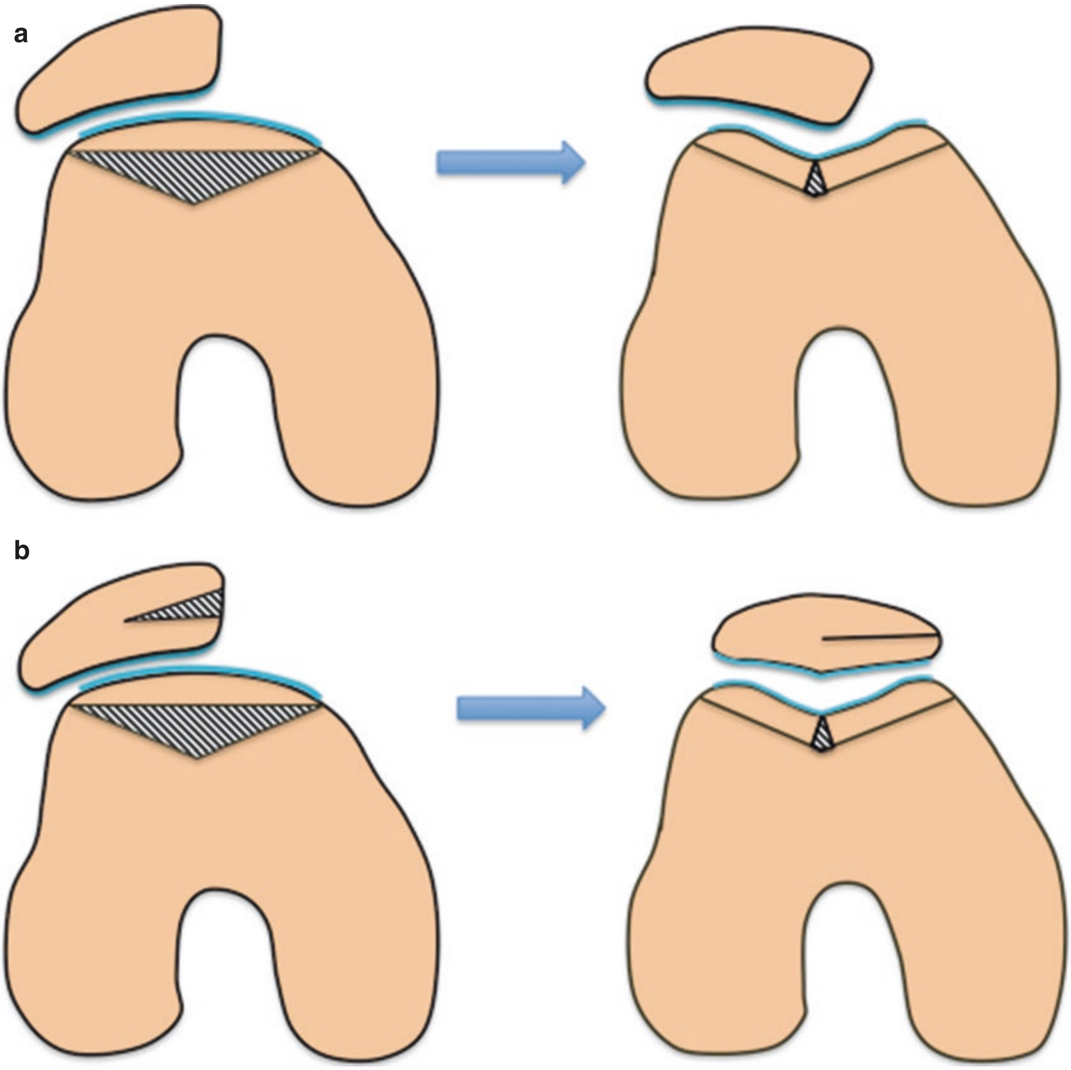

**Fig. 36.1** (**a**) In some cases of high-grade patellofemoral dysplasia, the still dysplastic patella could not adequately match the reshaped trochlea after sulcus-deepening trochleoplasty, leading to persistence of patellofemoral maltracking. (**b**) A medial closing wedge patellar osteotomy reshapes the patella in order to obtain congruence between it and the newly formed trochlea

formed sulcus angle. The decision to perform a patellar osteotomy has always to be taken during surgery when patellofemoral tracking is still unsatisfactory after trochleoplasty.

A medial closing wedge osteotomy has several advantages compared to other types of patellar osteotomies:

- It does not violate the main blood supply of the patella through the anterior vascular foramina.
- The medial border is exposed during the surgical access for trochleoplasty, so the medial blood supply of the patella is already disrupted.
- The eversion of the patella easily permits to control the cut to not violate the articular cartilage.
- The coronal closing wedge osteotomy permits a wide area of contact to prevent non-union and permits a stable fixation with transosseous absorbable sutures.

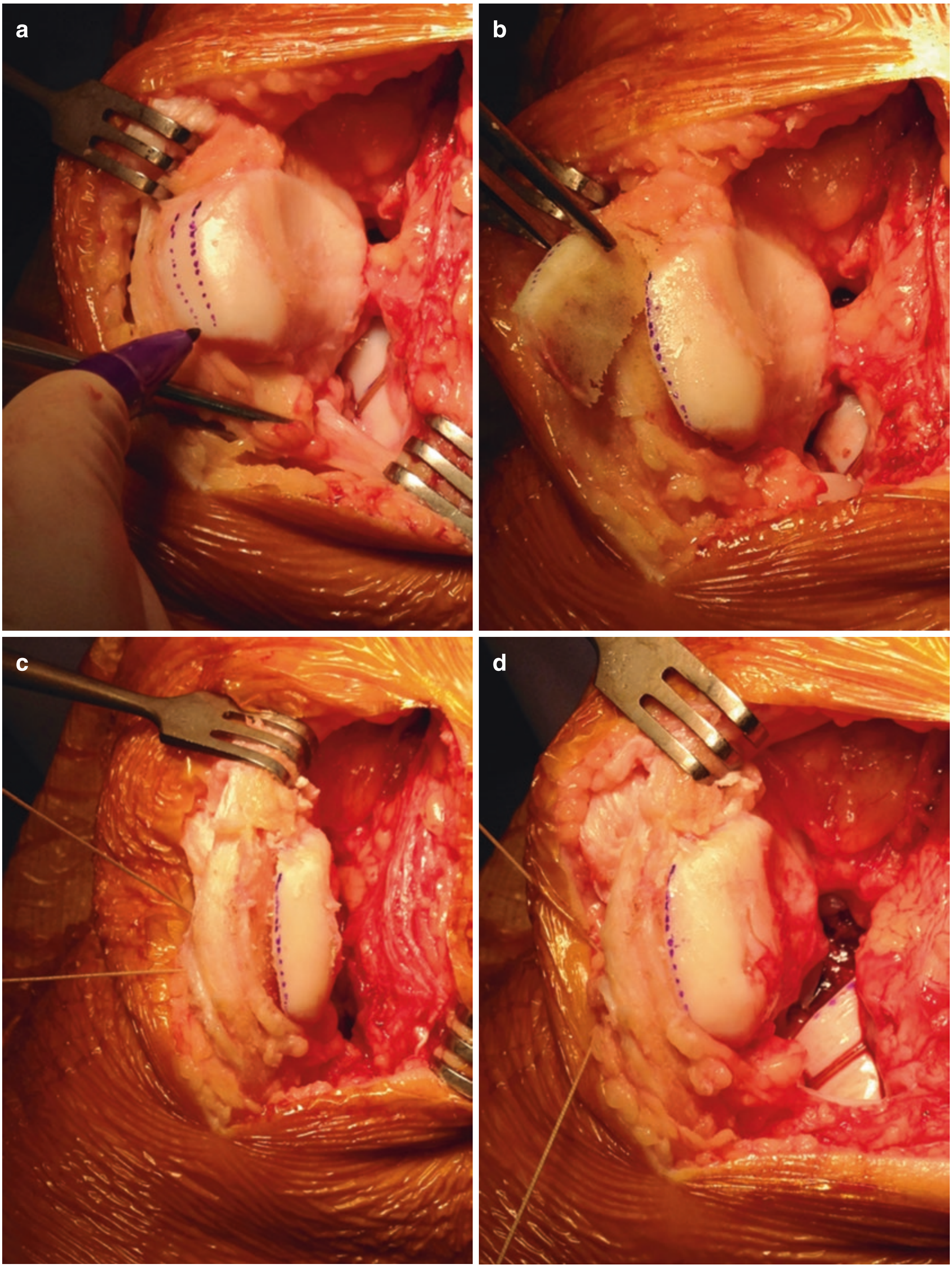

**Fig. 36.2** Intraoperative images showing the patellar osteotomy technique in a right knee. The knee is view from the front, with its proximal part at the top of the pictures. The patella is everted and its medial side exposed. (**a**) The thickness of the wedge is drawn with a pencil. (**b**) The bone wedge is cut with an oscillating saw; the tip of the wedge should end at the midline of the patella. (**c**) Two transfixiant holes are drilled in the medial facet of the patella, passing both sides of the osteotomy. (**d**) The osteotomy is closed and fixed with absorbable sutures

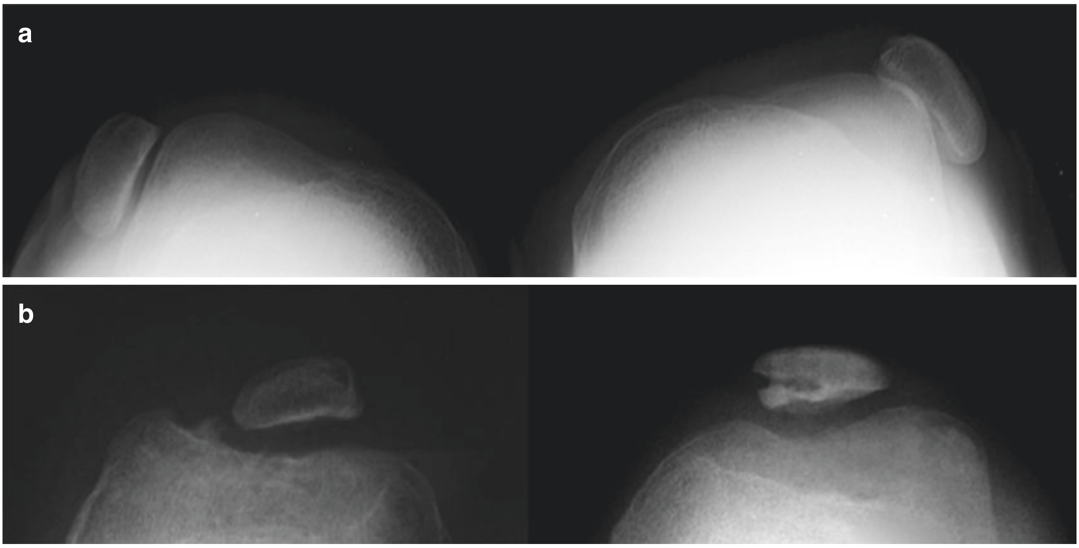

**Fig. 36.3** 20-year-old male with habitual patellar dislocation in both knees. He had type D trochlear dysplasia and patella alta in both knees. (**a**) Preoperative axial view showed permanent patella dislocation and hypoplastic patella in both knees. (**b**) Axial view 6 months after sulcus-deepening trochleoplasty, tibial tuberosity distalization, and MPFL reconstruction in both knees; the left knee (right side of the figure) further had patellar osteotomy. The shape of the patella is more congruent to the newly formed trochlea in the left knee than in the right one

- The coronal cut permits to dose the depth of the cut to recreate a patella with two symmetric facets (to place the ridge correctly) and an adequate subchondral bone thickness (Fig. 36.3).

## 36.6 Conclusions

- Trochlea dysplasia has a genetic basis; patellar dysplasia is a consequence of genetic and epigenetic factors.
- Surgical treatment for objective patellar instability addressed the static and dynamic stabilizer of the patella, not the patella itself.
- Sulcus-deepening trochleoplasty reshape the highly dysplastic trochlea creating a deeper groove.
- In rare cases, the still dysplastic patella does not fit the new trochlear groove, leading to persistence of patellofemoral maltracking. In these cases, patellar osteotomy could reshape the patella leading to a better congruence with the newly formed trochlea.
- Medial closing wedge patellar osteotomy is preferable to other osteotomies because it is highly respectful of patellar vascularization and led to a wide area of contact to prevent non-union.

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# 37

# Is There an Indication for Correcting a Valgus Knee?

Philip P. Roessler and Alan Getgood

## 37.1 Introduction

While most procedures in the treatment of patellofemoral instability address the static or dynamic stabilizers of the patella, there are still other factors that need to be considered during the process of preoperative decision-making. Limb malalignment and its resultant force vectors are one such important factor for normal biomechanical function of the lower extremity. Frontal plane valgus deformity is particularly important, as it may lead to chronic patellofemoral instability and lateral dislocation [1]. Consequently, soft tissue procedures performed with a background of such preexisting deformity show a higher rate of failure [2].

Valgus deformity has been identified as a risk factor for patellofemoral instability [3, 4]. It increases patellar tilt as well as the quadriceps (Q)-angle, which then produces a lateral force vector to the patella during knee flexion [5, 6] (Fig. 37.1). Resultant patella maltracking may cause chronic patellofemoral instability, eventually leading to cartilage injury and early patellofemoral osteoarthritis (OA). For this reason, Frosch and Schmeling also added the entity of genu valgum as a subcategory (3D) to their recently proposed patellar instability classification system [7] (Fig. 37.2).

Treatment options are based on anatomical and biomechanical considerations to counteract the abovementioned effects. Cases of chronic patellofemoral instability with an additional valgus malalignment in the frontal plane thus may require deformity correction by osteotomy, as well as additional soft tissue procedures [8]. The following chapter will explain the biomechanical background, possible indications for deformity correction, as well as a treatment technique and clinical results.

## 37.2 Indications and Contraindications

Valgus malalignment of the mechanical axis in the frontal plane has been shown to have a considerable impact on force vectors and thus patellofemoral stability [9]. Physiological knee valgus angle ranges between 5° and 7°, whereas the *Q*-angle ranges between 10° and 13° in males and 15° and 17° in females [10]. Valgus angles >10° combined with patellofemoral instability should be considered as an absolute indication for distal femoral varus osteotomy (DFVO) [6]. Based on the clinical experience of the authors and due to a lack of literature, valgus angles between 5° and

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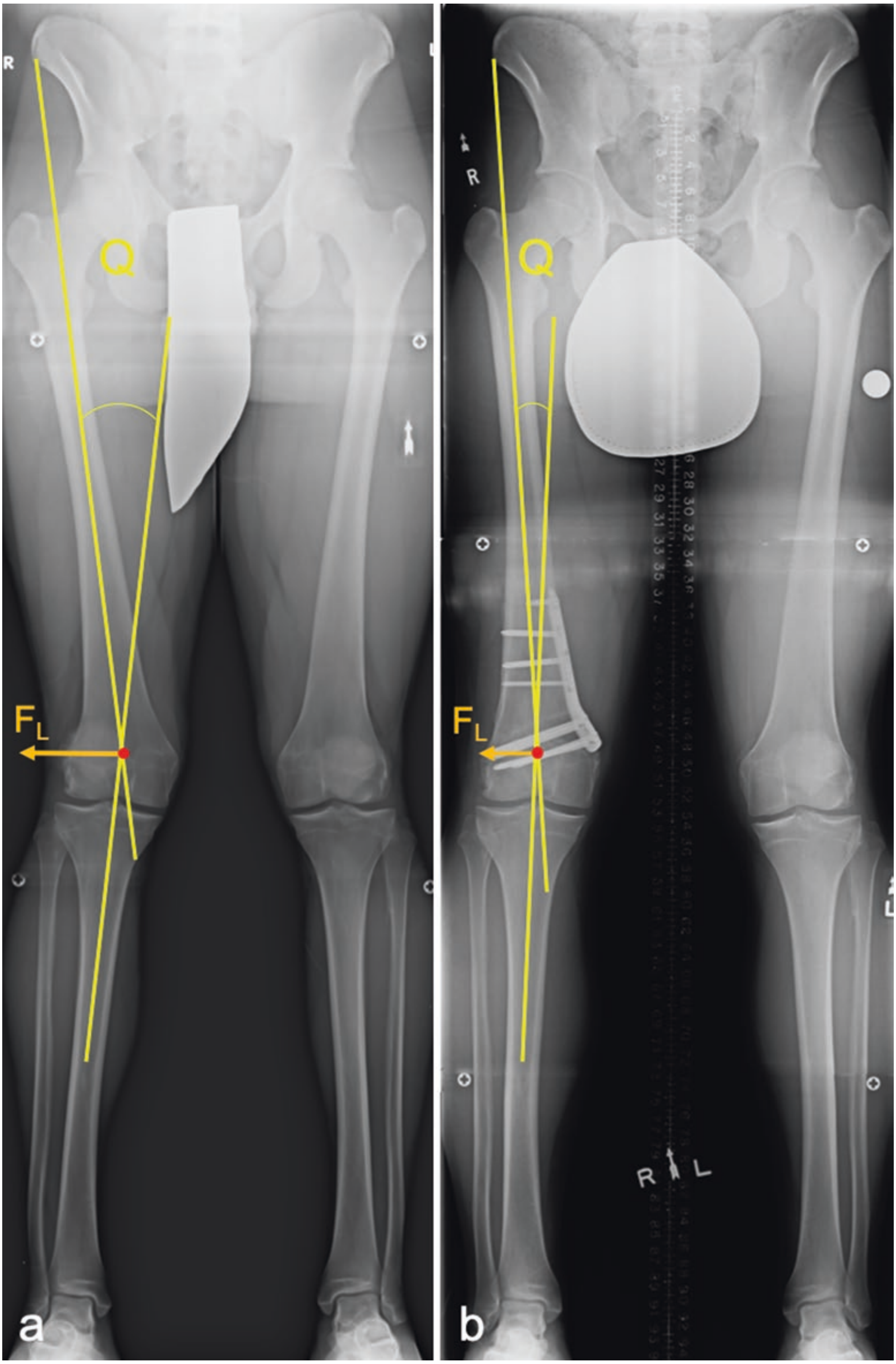


**Fig. 37.1** The quadriceps angle (or $Q$-angle) is dependent on various factors and can only be measured in a true a.p. radiograph. The lateral patella force vector ($F_L$) depends on the magnitude of this angle ($Q$) and is much higher in the valgus knee (**a**) than in a knee with physiologic axial alignment (**b**)

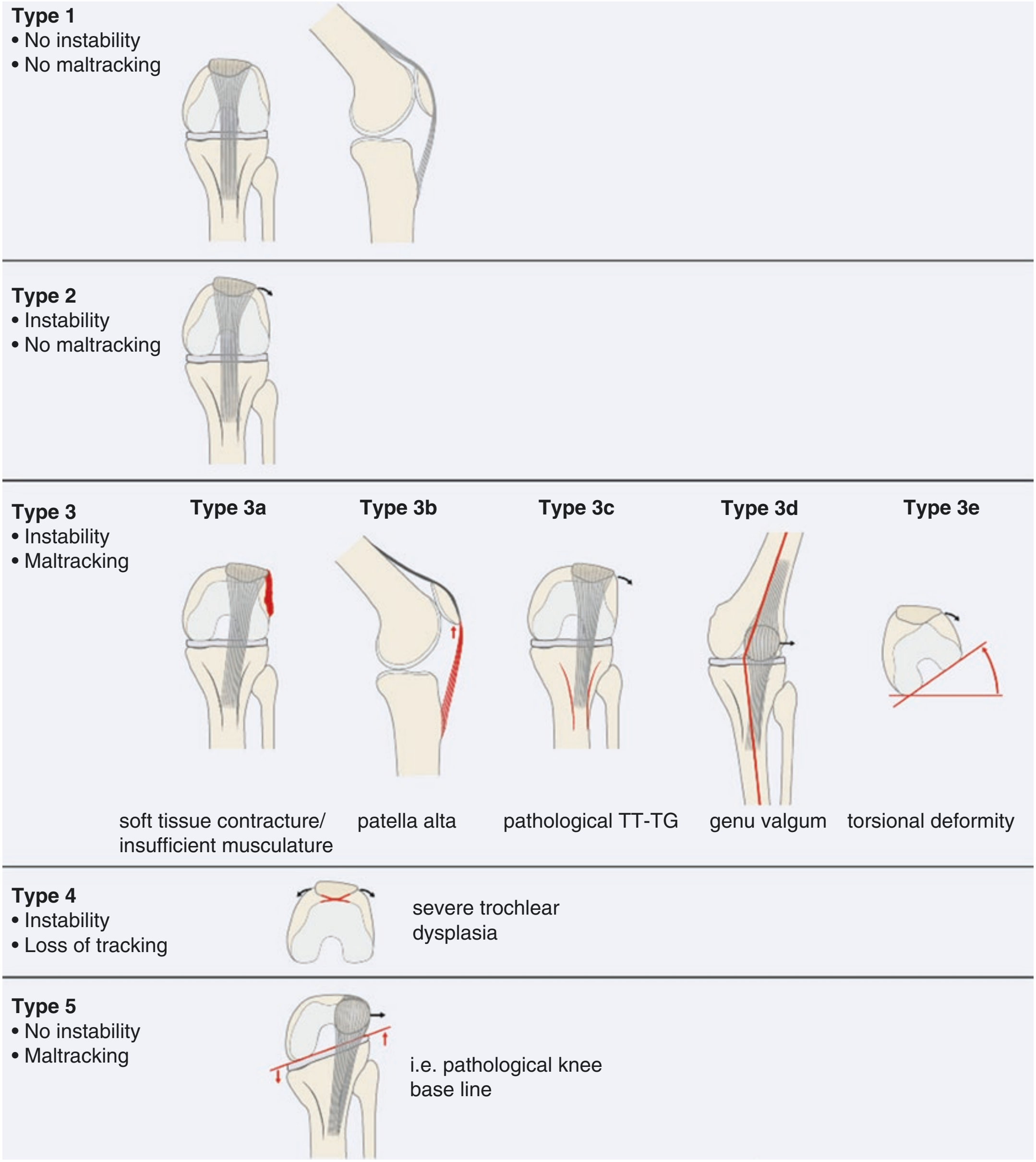


**Fig. 37.2** Proposed classification system of patella instability and maltracking according to Frosch and Schmeling [7]. Grading there depends on the prevailing pathology. In cases of multifactorial genesis, the higher grading is picked

10° should at least be considered as relative indications in cases where other contributing factors are addressed anyway. Soft tissue surgery alone normally does not restore native kinematics of the patellofemoral joint, nor does it provide longevity since the underlying deformity will put any ligament reconstruction or repair at risk of early failure. The main goals of a DFVO in those cases are to normalize the mechanical axis and thus reduce the *Q*-angle, lateral patellar force vectors and restore physiological tracking. Most cases will require additional procedures, depending upon the severity of deformity and coexisting pathology causing the instability. These may include bony procedures such as tibial tubercle osteotomy (TTO) and/or trochleoplasty and soft tissue procedures such as lateral retinacular lengthening and MPFL reconstruction.

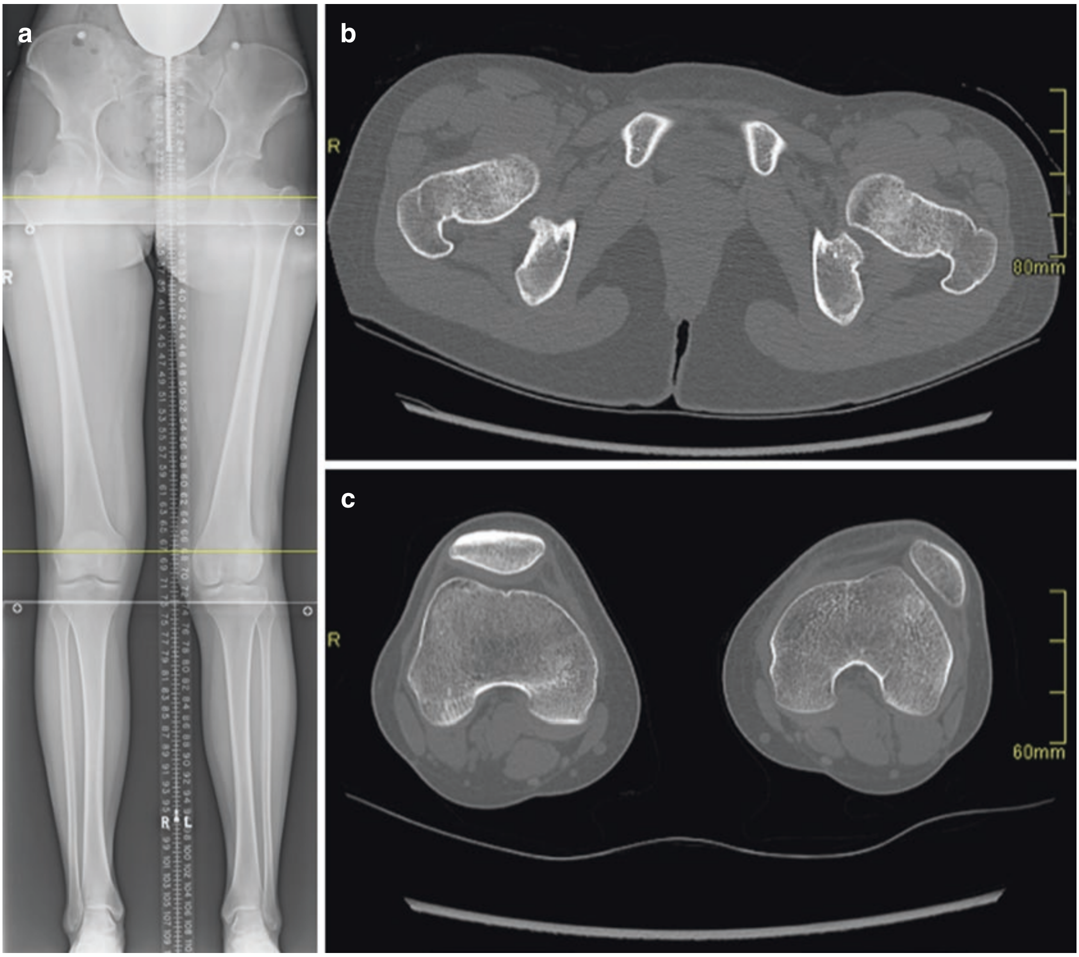


**Fig. 37.3** In this case of a young adolescent female, chronic patellar dislocation in the right knee was caused by a combination of genu valgum (**a**), malrotation (**b**, **c**) and subsequent quadriceps malalignment

As for most forms of bony valgus malalignment, femoral correction via medial closing wedge distal femoral varus osteotomy (MCWDFVO) is the authors' preferred technique. Although lateral opening wedge distal femoral varus osteotomy (LOWDFVO) is also an option, it has been shown to frequently lead to symptomatic hardware below the iliotibial band [11]. Furthermore, when dealing with a patient with a tight/short lateral retinaculum, such as in cases of lateral patella dislocation in flexion, a LOWDFVO increases the tension on the lateral soft tissue envelope and can paradoxically worsen the lateral patella instability.

A femoral approach also opens up the potential of additional rotational correction, if required in cases of combined deformities [12]. It is not uncommon to find cases of combined valgus and femoral torsion, leading to significantly altered pathomechanics of the patellofemoral joint (Figs. 37.3 and 37.4).

Lateral opening wedge high tibial osteotomy (LOWHTO) is also an option to correct a valgus knee [13]. However, in cases of patella instability, it has been reported to be associated with increased external tibial axial rotation and lateral patellar tilt. These factors may add to preexisting patellofemoral instability, despite a possible normalization of the *Q*-angle and extensor force vectors [14]. For this reason, it is believed that only DFVO provides a controllable method of correcting valgus deformities and, subsequently, force vectors in cases of patellofemoral instability.

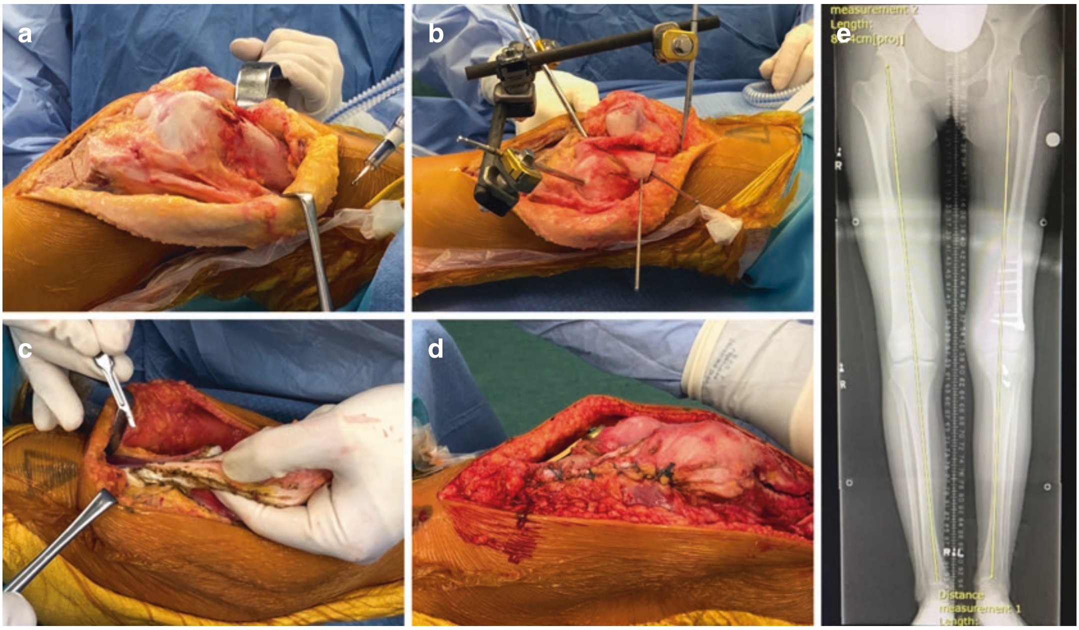


**Fig. 37.4** Various procedures were necessary to correct all underlying pathologies that have been identified by clinical assessment and radiographic imaging (Fig. 37.3). After tibial tubercle osteotomy (TTO) (**a**), a combined distal femoral varus osteotomy (DFVO) and additional rotational osteotomy was performed and temporarily held by external fixation to control the degree of correction (**b**). After fixing the osteotomy with a DFVO locking plate, a modified lengthening Z-plasty of the lateral and medial vastus was performed (**c**) and the tibial tubercle reattached (**d**). The postoperative long-leg standing hip–knee–ankle radiograph confirms the corrected axial alignment (**e**)

Relative contraindications for both DFVO techniques include tricompartmental OA, extreme valgus deformity with concomitant tibial subluxation (here, double level correction may be required), flexion contracture >15°, rheumatoid arthritis and severe bone loss at the lateral compartment [15]. Body mass index (BMI) has also been highly debated as a contraindication over the past few years. Clinical studies mainly focusing on fixed-angle locking plates, however, showed that failure risks of osteotomies were much lower than attributed by earlier publications [16].

## 37.3 Surgical Technique

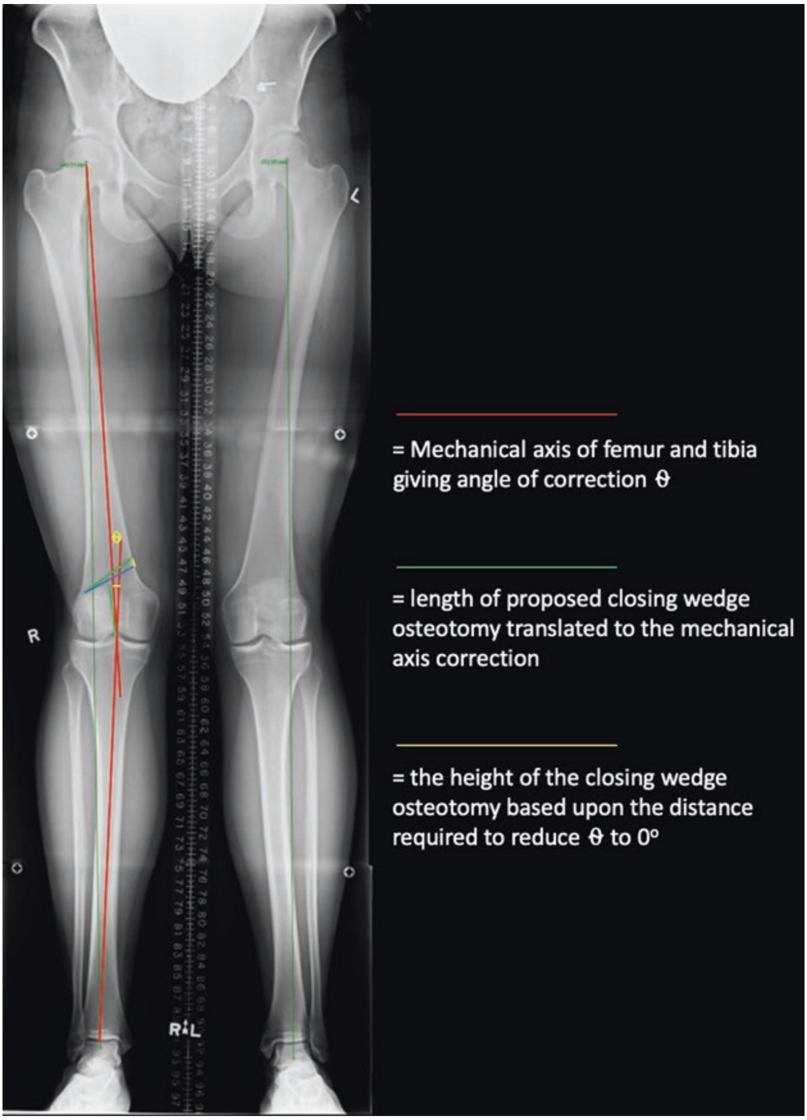
Prior to surgery, DFVO needs to be planned with bilateral long-leg standing hip–knee–ankle radiographs (Fig. 37.3a) to ascertain the existing mechanical alignment and calculate the amount of correction to achieve a neutral mechanical axis. It is our preference to utilize the technique described by Dugdale et al., modified to accommodate the distal femoral correction [8] (Fig. 37.5).

The patient is positioned supine on a radiolucent table, a tourniquet placed on upper thigh with a lateral post and single-foot roll allowing free range of motion of the involved knee that can also be held at approximately 60° of flexion. Following induction of anesthesia, an examination is performed to confirm the preoperative diagnosis and determine the extent of lateral patellar translation, lateral retinacular tension, patellofemoral constraint, presence of J-tracking and general ligamentous stability of the knee.

A diagnostic arthroscopy should be performed to assess intraarticular pathology, particularly focusing on coexisting chondral pathology of the patellofemoral joint and lateral femoral condyle, as well as trochlear morphology.

MCWDFVO starts with an approximately 10–12-cm-long paramedian skin incision from

**Fig. 37.5** Schematic of the planning according to Dugdale



the vastus medialis toward the joint line (Fig. 37.6a). The authors prefer a subvastus approach, where the vastus medialis is elevated off the septum and secured with a blunt Hohmann retractor anteriorly to expose the distal femur (Fig. 37.6b). Subperiosteal dissection is carried out posteriorly, and a sponge gauze is placed posteriorly with a further blunt Hohmann retractor on the bone to protect the neurovascular structures (Fig. 37.6c). Caution must be taken when extending the approach proximally, to avoid the superficial femoral artery and saphenous nerve as they enter the adductor canal outlet, approximately 14.5 cm proximally from the joint line [17].

The DFVO locking plate can be used as a template now to ensure later screw positions prior to osteotomy creation (Fig. 37.6d–f). Guide pins are then inserted at the proximal and distal osteotomy, and their trajectory is checked with fluoroscopy. Since this is a subtractive osteotomy (Fig. 37.6d), care has to be taken not to end up with a cortical mismatch between both proximal and distal osteotomies, especially referring to the length of each

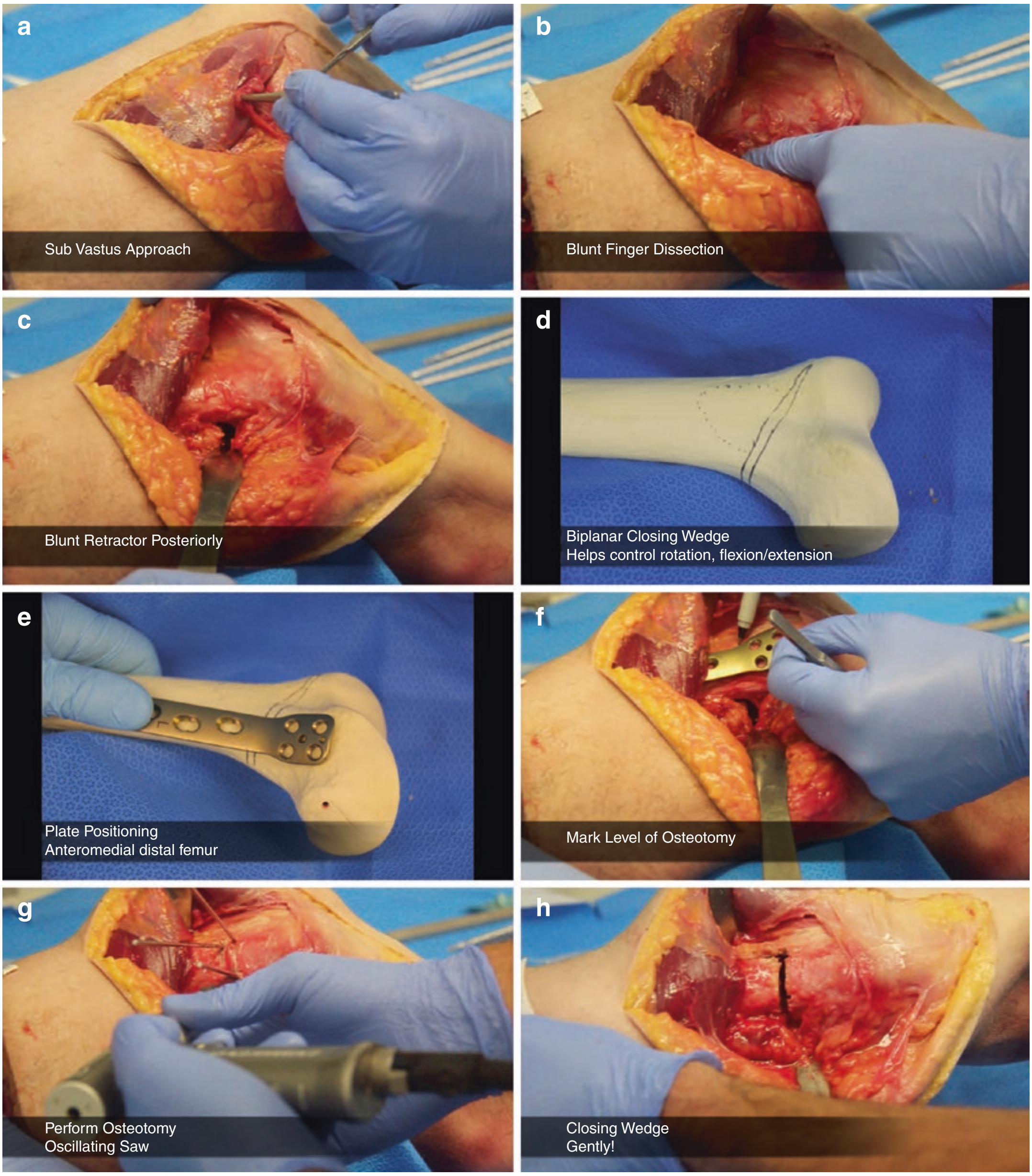


**Fig. 37.6** Subvastus approach to expose distal femur (**a**). Anterior Hohmann retractor and blunt dissection posteriorly with finger or gauze to avoid neurovascular injuries (**b**). Posterior Hohmann retractor (**c**). Model of biplanar closing wedge osteotomy with additional coronal cut (dotted line) to spare the trochlea (**d**). Preliminary plate positioning to define level of osteotomy and mark drill holes (**e**, **f**). Osteotomy is performed after insertion of distal and proximal guide pins (**g**). After subtraction of wedge, osteotomy is closed gently to avoid hinge fractures (**h**)

cut. The more proximal the starting position on the femur, and hence a more oblique cut, will reduce the risk of creating cortical mismatch.

Biplanar femoral osteotomy is then performed with an oscillating saw (Fig. 37.6g). It is the authors' preference to perform the anterior coronal plane osteotomy first. This has the advantage of providing greater control of rotation and flexion/extension of the distal metaphyseal fragment, while providing a greater surface area for bone healing. Next, the axial cuts are made, with the distal osteotomy created first, followed by the proximal osteotomy. Both should be completed with an osteotomy to avoid neurovascular injuries at the opposite side.

After removal of the wedge, the osteotomy is closed slowly to avoid hinge fractures (Fig. 37.6h). In some cases, controlled osteoclasis of the lateral hinge with a 2.4 mm pin may be useful to weaken the cortical bridge without fracturing. The DFVO locking plate is then applied anteromedially below the muscle to reduce later hardware symptoms. Distal locking screws are inserted first, followed by a non-locking screw proximally to compress the osteotomy site. The remaining locking screws can then be applied. Fluoroscopy can be used to verify the degree of correction in the coronal plane; however, it is the authors' preference to work off the preoperative planning. Patella tracking should be assessed directly thereafter with a "no thumb test" or passive flexion-extension. If there are still indicators of subluxation or maltracking of the patella, additional soft tissue procedures could be necessary, such as lateral retinacular lengthening, which is preferred over unselective lateral release in cases of lateral hypercompression symptoms [18]. Deflation of the tourniquet may help to assess soft tissue balances correctly. While MPFL or medial retinaculum imbrication has been described by some authors as optional [19], it is the authors' preference to perform MPFL reconstruction with an autograft in all cases of patella instability, as it is believed to be more reliable in these cases due to the structure being the primary soft tissue restraint to lateral patella translation.

Postoperative rehabilitation includes flat foot touch weight-bearing for the initial 2 weeks postoperatively, followed by weight-bearing as tolerated afterward. A hinged knee brace is prescribed for 6 weeks postoperatively. Deep venous thrombosis (DVT) prophylaxis is advisable at least until full weight-bearing is reached. Range-of-motion exercises should begin immediately postoperatively in the brace, accompanied by gradual quadriceps strengthening. Return to activity can start after 12 weeks postoperatively for low-impact activities and 24 weeks postoperatively for high-impact activities.

Besides the general complication profile, there are few complications specific to DFVO: hinge factures or distal femoral fractures in DFVO, neurovascular injury, hardware failure with subsequent loss of correction, symptomatic hardware, deep-seated infection, and non-union or delayed union at the osteotomy site.

As previously mentioned, a LOWDFVO may be used to correct valgus in cases of patella instability. Care must be taken to ensure that an adequate release of soft tissues is performed, so as not to inadvertently overconstrain the patella and cause a greater amount of lateral patella translation. Therefore, it is our preference to perform a lateral retinacular lengthening in all cases treated with a LOWDFVO.

The iliopatellar band of the iliotibial tract is initially elevated off the vastus lateralis proximally and the deeper transverse retinacular ligament more distally. The transverse retinacular ligament can then be divided approximately 2–3 cm more posterior and thereby provide a lengthening effect when the end is sutured to the side of the iliopatellar band.

In cases of lateral patella dislocation, it is also not uncommon to find combined coronal and rotational malalignment of the lower limb. This should be assessed with full leg axial imaging to provide a rotational profile (Fig. 37.3b, c), so as to determine whether the rotation needs to be addressed and at which level. It is outside the scope of this chapter to look at this in detail; however, Imhoff et al. have described a technique in which coronal and axial malalignment may be addressed with a single uniplanar osteotomy of the distal femur recently [12].

## 37.4 Results

Long-term results for MCWDFVO are good to excellent, as demonstrated by Saithna et al., in a systematic review of 130 pooled patients with various indications of valgus malalignment. At 10-year follow-up, survival rates were between 64% and 82%, with significant (and sustained) improvements in common functional knee scores. Hardware removal was not necessary in most of the cases [20].

So far, most of the results referring to valgus malalignment and patellofemoral instability in particular are either case reports or limited case series only. Purushothaman et al. report the case of a 22-year-old female who was successfully treated with LOWDFVO, lateral release, and MPFL reconstruction, following traumatic patella dislocation on a previously present valgus deformity of the left knee. At 12 months follow-up, the patient had achieved full range of motion and weight-bearing again [21]. Kwon et al. describe the similar case of a 27-year-old female with bilateral knock-knees and congenital patellofemoral instability, who was successfully treated with bilateral simultaneous MCWDFVO, medial reefing, and lateral release. The patient's Kujala score after 12 months was 95 [22].

Swarup et al. report ten cases of LOWDFVO combined with a lateral retinacular release for patellofemoral instability with a mean follow-up of 27 months. The mean Kujala score improved from 53 preoperatively to 77 at the latest follow-up, as did Oxford knee score and VAS. No re-dislocations were reported by the patients [23]. Wilson et al. report 15 skeletally mature adolescent patients who underwent isolated LOWDFVO for genu valgum with concomitant patellofemoral instability. After an average of 4 years follow-up, the Kujala score improved to 84, while the Tegner activity scale was close to 7. Eighty percent of the patients did not show any episodes of re-dislocation or subluxation [24]. Twenty-three cases of MCWDFVO and medial reefing are reported by Nha et al. in 14 patients with a mean follow-up of 31 months. DFVO improved patella congruence angles from 40° lateral to 4° medial and lateral patellofemoral angles from 26° to 9°. Lateral patella shift was reduced by over 10 mm as determined by computed tomography scans. Kujala scores improved from 54 to 92 in this cohort with no reported subluxation or re-dislocation [25]. Another cohort of 20 patients was treated with a combined approach of MCWDFVO and additional Elmslie-Trillat osteotomy and/or MPFL-reconstruction, if indicated. After a mean 16 months follow-up, Kujala scores improved from 40 to 78 with no reported re-dislocations [26].

Despite DFVO as the primary procedure, a number of cases still required soft tissue procedures or even additional osteotomies, as demonstrated by the literature discussed here. Soft tissue procedures proposed are imbrication, reconstruction, or repair of the MPFL and/or medial retinaculum as well as lateral retinacular lengthening. The plethora of techniques only elucidates that no ideal method has been found so far and that there is still a need for a solid consensus.

## 37.5 Conclusion

DFVO provides a tool for dealing with patellofemoral instability in cases of concomitant genu valgum, especially with valgus angles over 10°. It normalizes the Q-angle and thus allows to reduce laterally directed patella force vectors. Although it may be performed in isolation, DFVO usually requires additional soft tissue procedures such as an MPFL reconstruction, or even other osteotomies (tibial tubercle osteotomy or trochleoplasty) to address all underlying factors adding to patella maltracking.

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# 38 Simple to Complex Cases

Elizabeth A. Arendt, Stefano Zaffagnini,
Florian Dirisamer, and Raimundo Vial

## 38.1 Case 1

| | |
|---|---|
| Demographics | 23-Year-old female patient, left knee |
| Presenting symptoms | Lack of knee confidence after a lateral patellar dislocation during a soccer match; trying to get back to being more active |
| History/previous interventions symptoms | Contralateral knee without previous injury<br>No family history of LPD |
| Clinical presentation | Presents 1 week after injury with “catching” episodes, continued knee swelling, reduced knee ROM (10–110°)<br>+++ apprehension |
| *Imaging* | |
| AP/LAT/Axial | – Insall-Salvati ratio 1.3<br>– Caton-Deschamps ratio 1<br>– (+) crossing sign, low-grade trochlear dysplasia |

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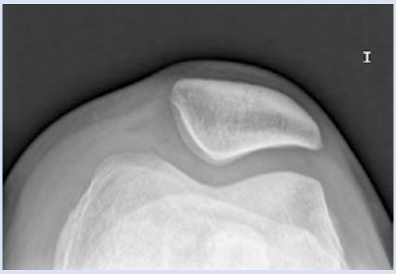

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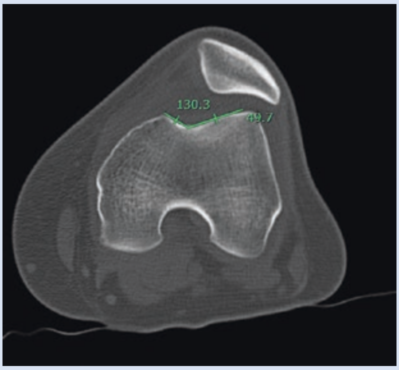
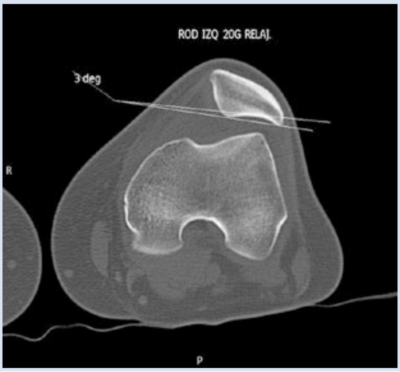
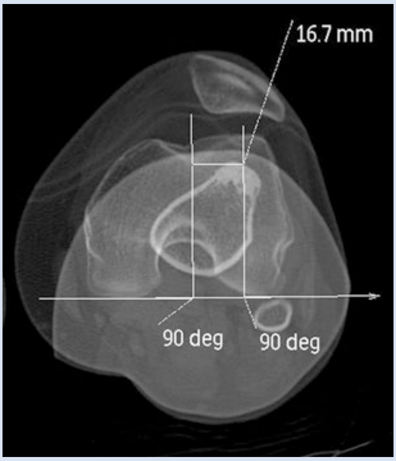
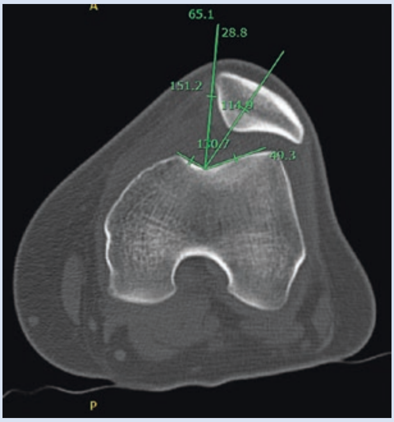
| MRI | – Disruption of the medial retinaculum and MPFL at femoral insertion<br>– 6 mm medial-lateral × 10 mm osteochondral defect on the lateral margin (non-contained) of lateral condyle<br>– Osteochondral fragment of 7 × 8 × 2 mm<br>In posteromedial recess of the knee |
| CT scan | – TT-TG 16.7 mm (left)/12.2 mm (right)<br>– Trochlear depth 6 mm<br>– Sulcus angle 130°<br>– Patellar tilt angle is −3°<br>– Congruence angle is 28° |
|  |  |
|  | 1. |
|  | 2. |

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| Therapeutic concepts | – As the patient has a symptomatic loose body in the knee, she is offered an arthroscopic removal of the loose body<br>– If the osteochondral fragment has enough bone to allow for bone to bone healing, reinsertion is planned<br>– If the fragment has little or no bone attached, the fragment would be excised. As the area was non-contained and lateral to main weight-bearing surface, no further treatment to that area is necessary<br>– Though patient is under-rehabbed due to just starting back to sports, since she is already undergoing surgery and has patella Alta by CD ratio, plan is for MPFL-R with same procedure |
| Operation | – Using arthroscopic posteromedial portal for visualization, the osteochondral fragment was retrieved, inspected, and found to have no reasonable bony surface<br>– MPFL-R using gracilis autograft<br>– Fluoroscopy is used for identification of fixation sites on patella and femur<br>– Suture anchors for patellar fixation<br>– Bioabsorbable interference screw for femoral fixation |
|  | 3. |
|  | |

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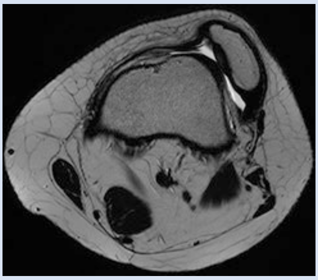
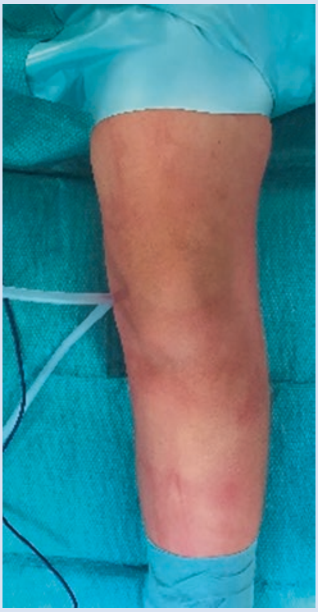
| Clinical result | – Uneventful recovery with no residual knee stiffness<br>– Has full confidence in her knee<br>– At 18 months from surgery, the patient is practicing low-demand sport activities once or twice a week (jogging, physical conditioning at the gym)<br>– Has not returned to soccer<br>– No recurrence of instability to date |
| What can we learn | – Osteochondral fragment is an operative indication<br>– In a first time patella dislocation with minimal risk factors, MPFL-R should be a shared decision between patient and physician<br>– Risk of MPFL-R is knee stiffness if one operates in the face of acute knee swelling |

## 38.2 Case 2

| | |
|---|---|
| • Demographics | • 19-Year-old, female |
| • Presenting symptoms | • Anterior left knee pain<br>• Feeling of left knee instability |
| • History/previous interventions | • First left patellar dislocation at 7 years old during pivoting injury<br>• Subsequently recurrent patellar dislocation of the left knee |
| • Clinical presentation | • Permanent reducible left patellar dislocation<br>• R.O.M. 0–135°<br>• Knee stable under anterior-posterior and varo-valgus stress test |
| • Imaging | • Full length standing AP radiograph of the lower limbs<br> |

|  |  |
|---|---|
|  | - AP X-ray of the left knee<br> |
|  | - Lateral X-ray of the left knee<br> |
|  | - Sagittal section in MRI of the left knee<br> |

| | |
|---|---|
| | - Axial section in MRI of the left knee<br> |
| - Preoperative plan with therapeutic concepts | - Patient presented flat trochlea with trochlear bump ("Type B" according to D. Dejour classification) in a lateral patellar permanent dislocation<br>- The correction of the all concomitant etiological factors is mandatory to achieve patellar stability<br>- Author performed sulcus-deepening trochleoplasty associated with patellar medialization-distalization, lateral release, vastus medialis obliquus plasty, and medial patellotibial ligament reconstruction |
| - Operation | - The entire low extremity was prepared and draped<br> |

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| | • Tibial tuberosity bone plug detachment was performed and lateral release of the wing ligament was performed<br> |
| | • Modified technique of sulcus-deepening trochleoplasty according to masse and Dejour was performed<br>– Trochlea was exposed<br> |
| | – A straight line along the midline of the trochlear groove was incised, and the medial and the lateral limits of the trochlear facet were skeletonized using electrocautery<br> |

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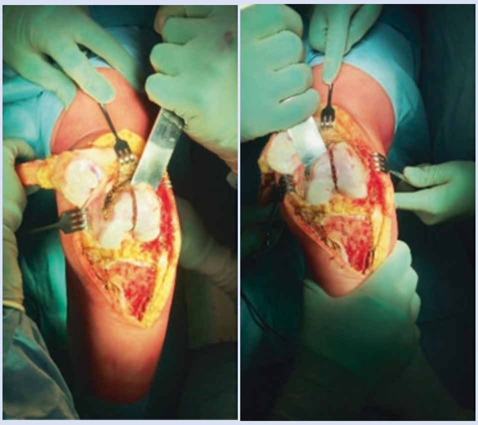
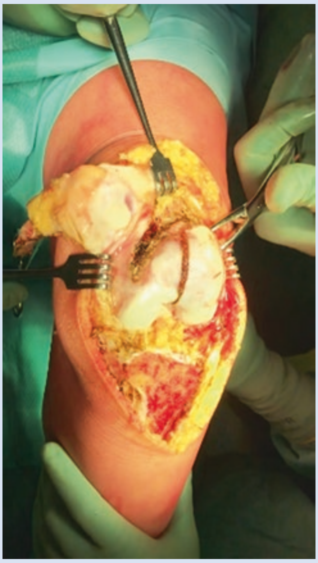
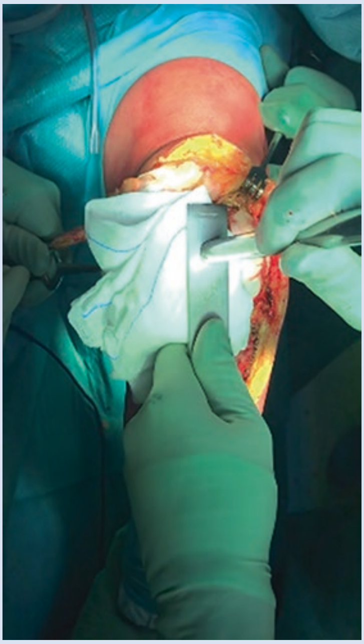
| | – A thin strip of cortical bone from the osteochondral edge of lateral and medial facet limits was removed using gently an osteotome<br> |
| | – Cancellous bone was removed from the under surface of the trochlea using Luer Rongeur to allow the modelling of the new trochlear groove<br> |

- With a light pressure the flaps were molded to the underlying cancellous bone bed in the distal femur

- The bottom of the groove and the external margin of the lateral facet were cut to allow further modelling and was achieved by gently tapping over a scalpel



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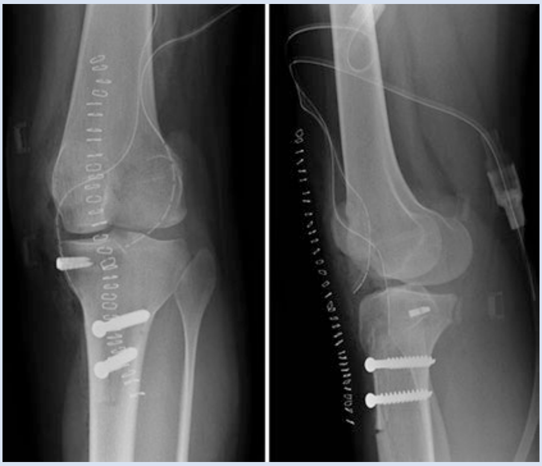
| | – After checking the correction was satisfactory, the new trochlea was fixed with two Herbert resorbable screws<br> |
| | – Subsequently the tibial tubercle was fixed with two cortical screws, VMO plasty was performed, and the medial third of the patellar tendon was detached distally, was medialized, and was fixed to the tibial bone with one staples (MPTL reconstruction)<br> |
| Postoperative imaging | • Postoperative anterior-posterior and lateral X-ray showed the correct deep of the new trochlea and the absence of trochlear bump<br> |

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| Clinical result and follow-up | • At the end of the surgery, patellar stability was achieved |
| | • X-ray at 1 month follow-up documented the obtained correction<br><br> |
| | • At 1-month follow-up patient stopped using crutches and extension brace and achieved a range of motion of 0–100° |

## 38.3 Case 3

| | |
|---|---|
| Demographics | 31-Year-old female patient |
| Presenting symptoms | Recurrent bilateral patella dislocation (permanent dislocator)<br>Mild anterior knee pain |
| History/previous interventions | Lateral release as a child<br>Ali-Krogius procedure when 15 years old<br>Patient never felt that the patella was stable |
| Clinical presentation | Severe symptoms of instability in daily living including avoidance behavior. Positive apprehension test from 0° to 80°. Patella can be centered manually and dislocates in 60° when flexing the knee. Mild patellofemoral crepitus when patella is centered |
| Imaging | Workup done for both knees (similar findings), case showing left knee |

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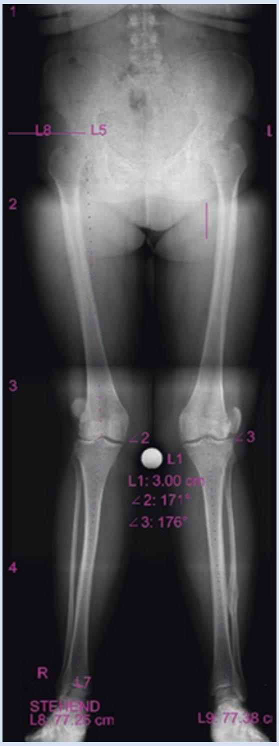
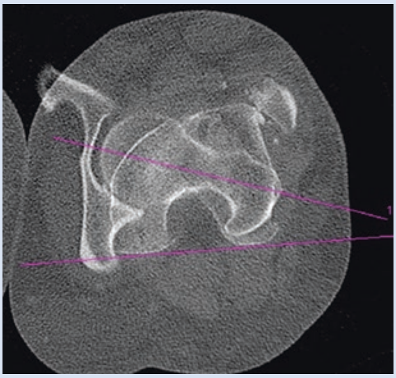
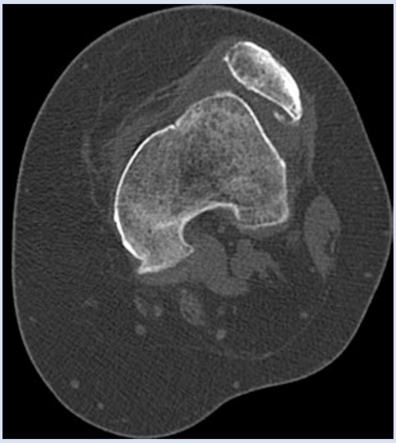
|  | Long-leg standing showing bilateral valgus<br>(R 9°/L 8°)<br>(Note position of the patella) |
|  | Femoral anteversion is R 30°/L 32° |
|  | CT scan showing dysplastic trochlea and signs of patellofemoral arthritis (cortical disruption)<br>TTTG is 26 mm (note medialized trochlea due to dysplastic trochlea; high TT-TG in part due to medialized proximal measurement) |

| | |
|---|---|
| Therapeutic concepts | 1. Correcting the femoral malalignment by 2-plane correction with a distal femur osteotomy<br>2. Normalization of Q-vector with distal extensor mechanism realignment (medializing TTO)<br>3. MPFL reconstruction<br>4. If needed lateral retinacular lengthening<br>The dysplastic trochlea is not addressed due to the degenerative changes. Optional patellofemoral resurfacing as a secondary option if needed |
|  | Postoperative result after complex reconstruction with biplanar distal femoral osteotomy (varization, external femoral rotation), medializing TTO, MPFL reconstruction and lateral retinaculum (scar tissue after lateral release) lengthening<br>The removed bone wedge from the derotation osteotomy was used to fill the osteotomy gap |
| Clinical result | Stable patella in all flexion angles (ROM 0–150°), minor patellofemoral crepitus<br>Significant improvement in ADLs<br>Occasional mild anterior knee pain (not altering ADLs)<br>Overall high patient satisfaction. Right knee was done in same fashion; the FU is meanwhile 7 years with constant subjective and objective performance |
| What can we learn | A patella stabilizing procedure needs to address the relevant pathologies. In such complex cases, a combined soft tissue and bony treatment is necessary. But often compromises have to be made. In this case the trochlear dysplasia was not addressed, so the patient was left with a major risk factor. Nevertheless the patient has a stable patella, because of the high effectiveness of femoral alignment correction |

# 39

# Isolated Patellofemoral Osteoarthritis: Natural History and Clinical Presentation

Marco Valoroso, Giuseppe La Barbera,
and David Dejour

## 39.1 Introduction

PFOA is a common condition in case of global knee OA. More rarely, the PF compartment is involved alone. Several authors investigated PFOA [1–3]. McAlindon et al. [2, 3] studied 2101 patients over the age of 55 years and registered a greater prevalence in females (24%) than in men (11%). Kobayashi et al. [4], in a recent systematic review including 32 studies, concluded that the prevalence of PFOA was 25% in the asymptomatic population (age > 20 years) and 39% in the symptomatic population (age > 30 years).

The etiological factors involved in PFOA are different from tibiofemoral OA (TFOA) and more difficult to identify. Rheumatological conditions, such as chondrocalcinosis, and trauma (patellar fractures) are the best known. Moreover, patients with anatomical abnormalities and/or a history of patellar dislocation or patellar surgery may develop PFOA. However, PFOA is described as idiopathic when these predisposing factors are not identified.

Identifying the etiological factors is important in order to address this condition (preventive, conservative, or operative treatment). This chapter outlines the natural history and clinical presentation of PFOA emphasizing the etiological risk factors for this pathology [5].

## 39.2 Epidemiology

PFOA is found predominantly in females (72%) with 51% of the patients having contralateral symptoms, such as arthritis of the femorotibial compartment. The onset of the first symptoms is 46 years old as average. Epidemiologic studies have shown that 11% of men and 24% of women older than 55 years of age with symptomatic arthritis have disease isolated to the patellofemoral joint [3]. Kobayashi et al. [4] in a recent systematic review, including 32 studies, concluded that the prevalence of PFOA was 25% in the asymptomatic population (age > 20 years) and 39% in the symptomatic population (age > 30 years). PFOA is not statistically associated with the body mass index. However, 29% of patients were obese and 38% were overweight. The weight increases the symptoms, so a relationship between weight and symptoms is supposed. The radiologic evolution is slower to be observed with an average delay of 18 years to pass from stage I IWANO to stage IV [5].

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## 39.3 Patient History and Physical Examination

PFOA is usually well tolerated for a long time. The etiology of the condition affects early manifestations. A meticulous history must be recorded searching for dislocations, trauma, fractures, and previous surgery.

Patients with isolated PF arthritis complain an anterior or retropatellar knee pain, usually correlated with activities that increase the constraint in the PF joint like squatting, ascending or descending stairs, rising from a seated position, or prolonged sitting with flexed knees [6]. The limitations of the activities on flat ground are also important; 80% report that they cannot walk more than 1 km [5]. Additionally, patients can complain for reflex instability due to painful stimuli determining quadriceps inhibition. This condition occurs during light activities like walking. Moreover, patients can denote catching or knee locking. Crepitus and effusion may be observed. Patella tracking must be evaluated throughout the entire knee ROM to assess maltracking or instability [7]. Tibiofemoral joint should be investigated, as well as knee stability, to avoid progressive tibiofemoral OA and/or instability. Furthermore, the neurovascular status, previous scars, and hip and lumbar spine status should be carefully evaluated [6].

## 39.4 Radiographic Analysis of Isolated PFOA

Radiographic analysis is an essential key element in establishing the cause of PFOA and in determining the most suitable treatment modality. Good quality standard knee radiographs are fundamental in investigating PF disorders: AP view, a true lateral view in monopodal stance at 20° of flexion (with posterior femoral condyles superimposition) and a 30° axial view (the lateral trochlear facet should appear with two-thirds of the total trochlear width). In patients older than 50 years old and in those with a history of previous orthopedic surgery, such as meniscectomy, Rosenberg view [8] (weight-bearing AP view in 45° of flexion) should be added.

The 30° axial view allows the study of the patellofemoral joint space: in PFOA can be observed narrowing of the space between the trochlea and the patella, till bone-to-bone contact in most severe cases. Additionally, osteophytes can be detected and can be evidenced whether the patella is well centered or subluxed.

PFOA is graded according to Iwano [9] in four stages (Fig. 39.1):

- Stage I: Remodeling joint line.
- Stage II: Joint narrowing less than 3 mm.
- Stage III: Joint line narrowing more than 3 mm no bony contact.
- Stage IV: Bone on bone.

## 39.5 Etiologies of PFOA

Isolated patellofemoral (PF) arthritis is associated with various etiologies, including objective patellar instability (33%), post-traumatic lesions (9%), and chondrocalcinosis (8%), though most cases remain idiopathic (49%) (Fig. 39.2). Patients with isolated PF arthritis show concomitant signs of trochlear dysplasia in 78% of the cases, and 55% have a type B or D, which could be an underlying cause of cartilage wear [5, 10].

### 39.5.1 Primary PFOA

Primary PFOA tends to occur late in life, around the age of 70. It is often bilateral and usually affects women. Patients have no orthopedic antecedent and especially no history of dislocation [1–3]. This condition tends to be well tolerated for a long time: patients are able to walk almost normally on level ground; however, walking on rough ground and climbing stairs and steep slopes become progressively more difficult. The patients can feel a sensation of instability due to

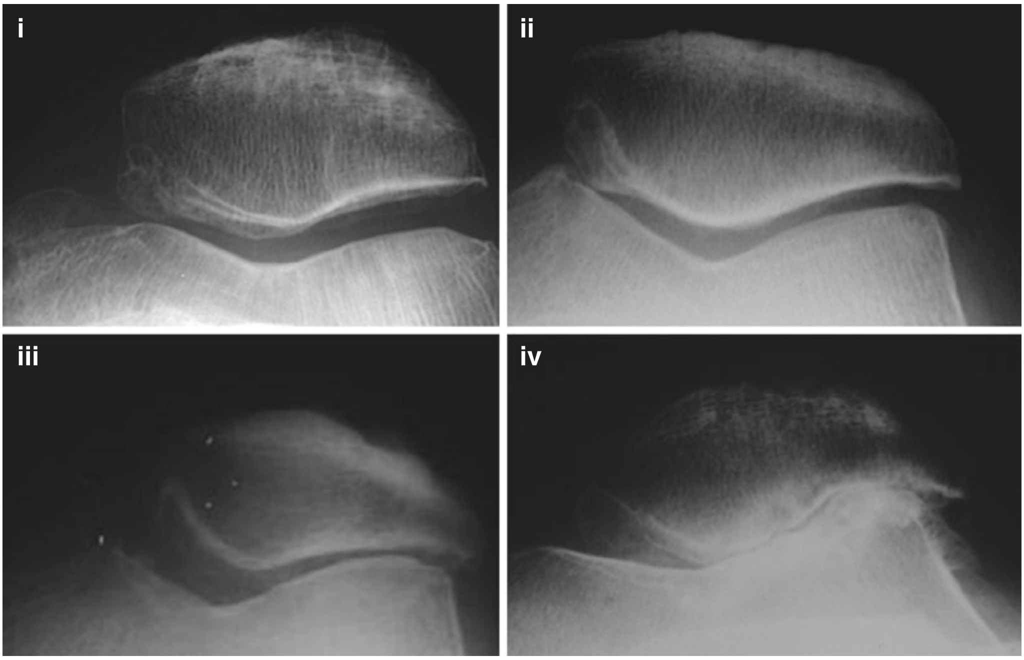

**Fig. 39.1** Iwano classification system based on 30°axial X-rays. Stage I is mild PFOA; the joint space measures at least 3 mm. Stage II is moderate PFOA; the joint space measures less than 3 mm, but no bony contact can be seen. Stage III is severe PFOA; patellar-trochlear bony contact occurs in less than one quarter of the joint surface. Stage IV is very severe PFOA; the joint surfaces entirely touch each other

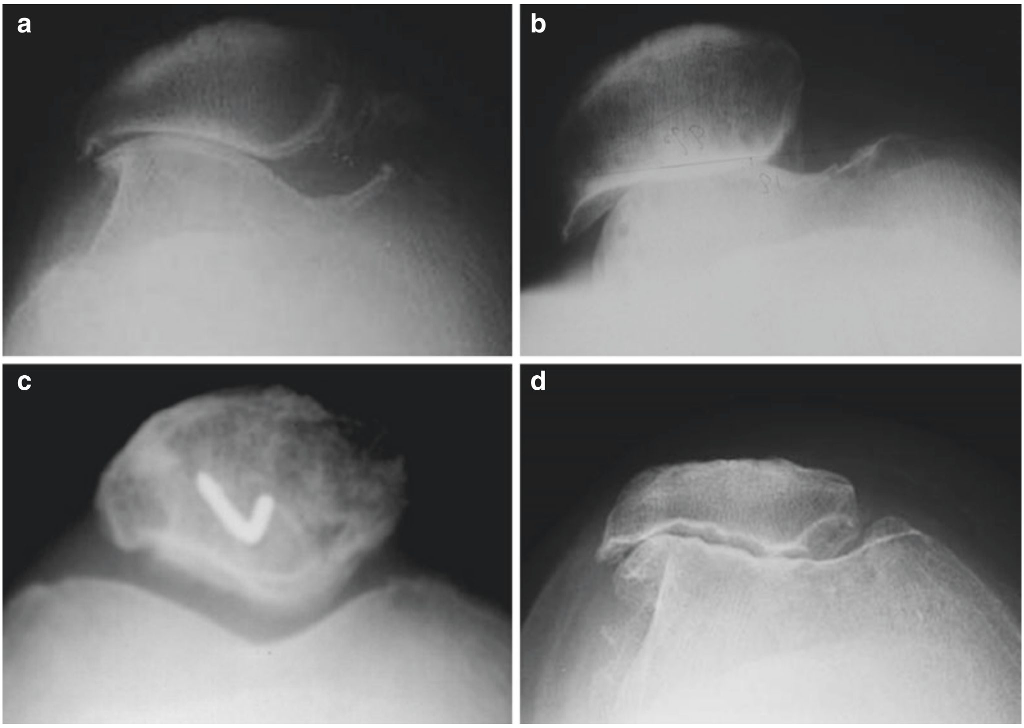

**Fig. 39.2** Radiographic pattern of PFOA. (**a**) Primary PFOA; (**b**) post-instability PFOA; (**c**) post-traumatic PFOA; (**d**) PF chondrocalcinosis

reflex quadriceps inhibition as a result of painful stimuli. Furthermore, patients can complain catching and locking sensations due to patellar osteophytes engaging on the lateral trochlear facet and to the bone spurs on the trochlea during knee range of motion.

#### 39.5.1.1 Radiological Features

This condition affects both knees. The axial view demonstrates loss of joint space with bony contact between the lateral patellar facet and the trochlea. The patella is subluxed as a consequence of cartilage wear, rather than to malalignment of the extensor system. Osteophytes on the lateral border of the patella and on the trochlea can be observed. The lateral view demonstrates osteophytes on the proximal part of the trochlea, joint space narrowing, and subchondral sclerosis of the PF joint (Fig. 39.3).

### 39.5.2 Post-instability PFOA

This condition affects patients slightly younger than primary PFOA group, around the age of 55 years old. Patients sustained previous objective patellar dislocation. In literature, clinical studies on PFA report a percentage of PFOA in patients with a history of documented patellar instability between 8% and 53% of the cases [11, 12]. As the condition of the joint progressively worsens, it becomes increasingly difficult to analyze the causative factors of instability on the radiographs (Fig. 39.4). Dejour and Allain [13] supposed the following biomechanical causes leading to PFOA:

#### 39.5.2.1 Dislocation

When the patella dislocates, its cartilage is damaged; sometimes mirror lesions can be observed on the lateral aspect of the trochlea or even on the lateral condyle [5].

#### 39.5.2.2 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) increasing the dislocating force acting on the patella. Excessively high and asymmetrical pressure peaks occur on the lateral facet of the trochlea and on the lateral facet of the patella [14].

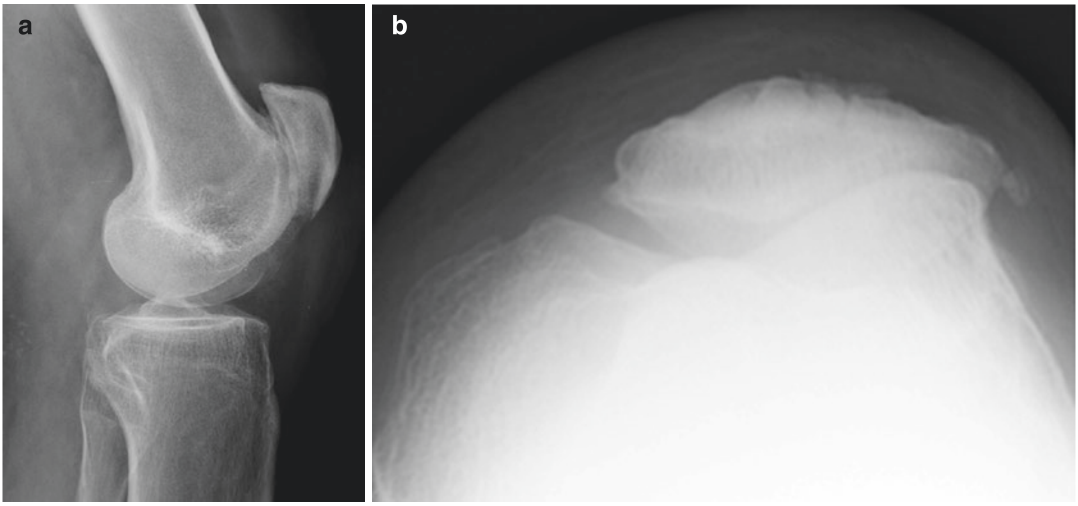

**Fig. 39.3** Primary PFOA. (**a**) The lateral view demonstrates joint space narrowing and subchondral sclerosis of the PF joint. (**b**) The axial view demonstrates loss of joint space with bony contact between the lateral patellar facet and the trochlea. Osteophytes on the lateral border of the patella and on the trochlea can be observed

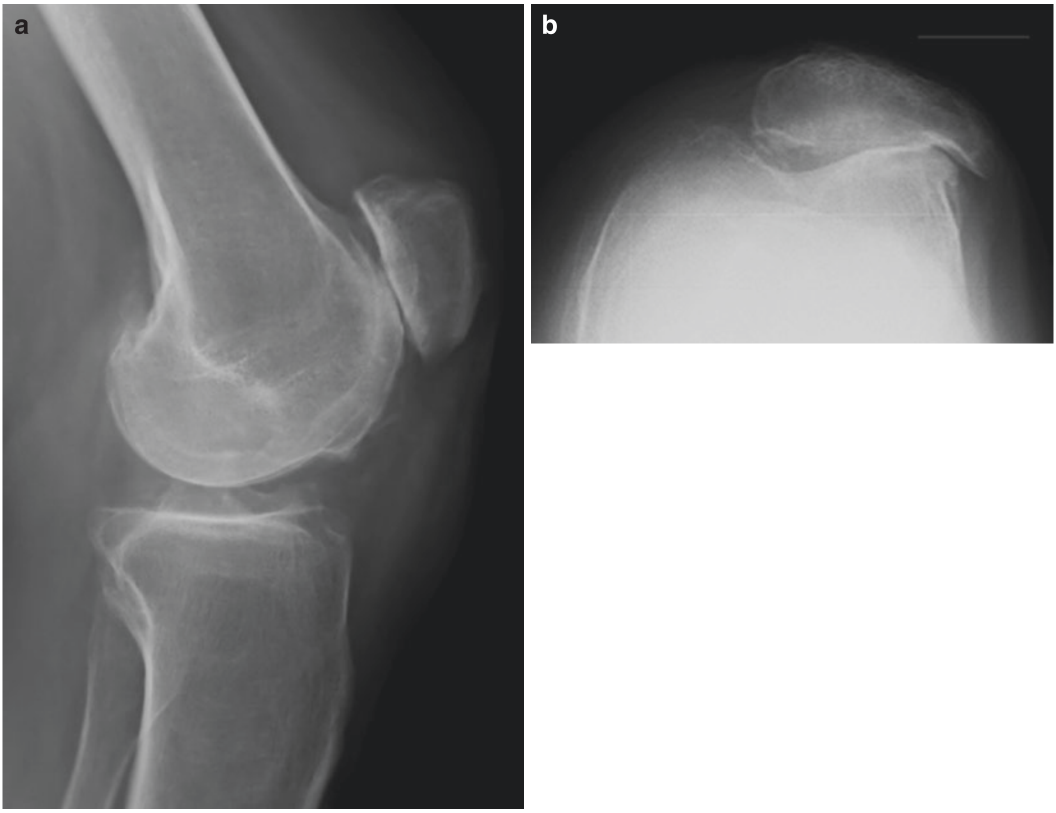

**Fig. 39.4** Post-instability PFOA. (**a**) In the true lateral view, the three radiographic signs of PF dysplasia can be observed: crossing sign, supratrochlear spur, and double contour. Moreover (**b**) bone on bone contact can be observed in axial view

#### 39.5.2.3 Lack of Congruency Between the Patella and the Trochlea

Trochlear dysplasia [15–17] and, to a lesser extent, patellar dysplasia [18] can lead to a lack of congruency between the two articular surfaces: articular pressure is distributed asymmetrically, and the PF joint will become unstable.

Dejour and Allain [5] found it to be the most common predisposing factor, with 78% of patients having radiographic signs of trochlear dysplasia. Higher grades of arthritis have also been correlated to higher grades of dysplasia [9]. In trochlear dysplasia grade B or D, the trochlear prominence determines impingement between the patella and trochlea every time the knee is flexed, increasing PF contact stresses as the angle of flexion increases. Mirror-image chondral lesions (grade 3 and 4) can be observed typically extending the entire length of the patella. These lesions are the *primum movens* of OA [19].

The trochlear facet asymmetry in dysplasia grade C and grade D causes permanent patellar tilting, deteriorating the asymmetrical pressure distribution in the PF joint [15].

#### 39.5.2.4 Patellar Height

The height of the patella is the sole factor that, by itself, could cause objective patellar instability. Normally, the patella enters the trochlea during the first few degrees of flexion and is thus stabilized and guided by the bony groove. If the patella is too high in relation to the trochlea, it will not engage until flexion has advanced further and will be at risk for dislocation. No real correlation between patella alta and arthritis has been proven, but it is still an additional negative factor.

### 39.5.2.5 Radiological Features

#### Trochlear Dysplasia

On the true lateral radiograph, three radiographic signs can be observed: crossing sign, supratrochlear spur, and double contour (Fig. 39.5). Trochlear dysplasia is defined by the crossing of the line representing the deepest part of the trochlear groove with the anterior border of the two condyles [16]. At this crossing point, the trochlea is completely flat. This crossing sign was found in 96% of patients with objective evidence of patellar instability and in 12% of patients with anterior knee pain but was seen in only 3% of the healthy controls [16]. Initially, three stages of trochlear dysplasia were described. A study of 177 cases of proven patellar instability involved a comparison of conventional radiographs and CT scans. This allowed the analysis to be refined and led to the definition of a four-grade system [20, 21]. The supratrochlear spur is formed by a bone bump just proximal to the trochlea. This feature is seen where the entire trochlea projects beyond the anterior cortex of the femur. In OA, this will be the site of an osteophyte. The double contour is produced by the projection of the medial facet of the trochlea. It is abnormal when it runs below the crossing sign. Once PFOA has set in, the crossing sign becomes difficult to discern; however, the supratrochlear spur and the double contour will still be seen.

**Fig. 39.5** In the case of advanced arthritic changes, it is difficult to analyze the causative factors of instability on X-rays

On a 30° axial view, the trochlear angle has been proposed as yet another index of trochlear dysplasia. Bernageau and Goutallier [22] found a mean trochlear angle of 144 ± 6.75°. According to other authors, a trochlea with an angle of >150° on the 30° axial view should be considered as dysplastic.

The trochlea dysplasia is the highest predisposing factor; the incidence is 78% in the isolated arthritis population [5], 55% are a dysplasia with a supratrochlear spur type B and D. The prominence of the trochlea leads to an “anti-Maquet effect” and increases the patellofemoral forces in flexion. The second predisposing factor is the patella dysplasia with an incidence of 42% of patella Wiberg II.

#### TT-TG Distance

The TT-TG distance is a direct measure of extensor mechanism malalignment. It is calculated from a CT scan protocol that superimposes two cuts: one through the most proximal part of the trochlear grove (TG), where the notch looks like a Roman arch, and the other through the most proximal part of the tibial tuberosity (TT). These cuts have to be perpendicular and projected to the bicondylar line. The TT-TG value is defined as the distance between their projections expressed in millimeters. In normal knees, the average value in full extension is 12 mm, while in 56% of patients with at least one episode of patellar dislocation, the value registered is superior to 20 mm. Consequently, the superior limit is considered 20 mm [19].

#### Patellar Height

The Caton-Deschamps patellar index [23] is a reliable yardstick. A normal index is equal to 1; a patella with an index >1.2 is a high-riding patella

(patella alta). An index >1.2 has been found in 30% of patients with proven patellar instability while not being encountered at all in healthy controls [16]. Patellar height may also be specified in terms of the Blackburne-Peel index [24] and the Insall-Salvati index [25].

### 39.5.3 Post-traumatic PFOA

Articular patellar fracture can determine PFOA in the long term [26]. In this population mean age at surgery was 54 years old.

The factors leading to articular degenerative changes are related to the fracture personality (comminuted fractures) and fracture mechanism; moreover, not adequate fracture reduction with gaps >2 mm and/or residual joint incongruity >1 mm is likely to result in OA [27, 28]. Furthermore the risk of OA changes is increased after infections and manipulation under anesthesia to treat a stiff knee that determine diffuse cartilage damage.

#### 39.5.3.1 Radiological Features

The radiographic appearance can be very variable; the usual pattern is a global PFOA. A distinctive pattern is patella magna characterized by an enlarged patella overhanging the trochlea on both medial and lateral sides.

### 39.5.4 PF Chondrocalcinosis

Chondrocalcinosis is a metabolic joint disease that may affect any joint in the body; the knee is one of the most commonly affected joints. The pathological pattern is due to the deposition of microcrystals in various parts of the joint, most frequently calcium pyrophosphate dihydrate (CPPD). Clinical signs and symptoms are similar to primary OA; spontaneous serosanguinous effusions of increasing frequency and severity characterize the clinical presentation [19].

#### 39.5.4.1 Radiological Features

Chondrocalcinosis affects both knees. The joint surfaces are rough and irregular; the patella is thinned out, and its lateral facet is the worst affected; the trochlea is also worn out determining patellar subluxation. In early stages calcium deposits may be observed as a thin linear deposit or, in some cases, as discrete thickness in the patellar cartilage. Chondrocalcinosis must be considered as a disorder affecting the entire joint as well as other joints in the body even in the presence of an isolated involvement of the PF compartment [5, 19].

## 39.6 Predisposing Factors to PFOA

Several anatomic factors have to be investigated on the preoperative X-rays because they lead to the development of patellofemoral arthritis.

### 39.6.1 Trochlear Dysplasia

The main factor is the presence of dysplasia in the patellofemoral joint. A dysplastic trochlea is the principal cause of patellar instability [15, 16]. It is described as a gradual impairment of the trochlear anatomy, leading to the disappearance of the groove that becomes flat or even convex. On the true lateral radiograph, dysplasia is defined by the crossing of the line (crossing sign) representing the deepest part of the trochlear groove with the anterior border of the two condyles [16]. At this crossing point, the trochlea is definitely flat. This crossing sign was found in 96% of cases with objective patellar instability but was seen in only 3% of the healthy controls [16]. Several authors observed also a statistical correlation between the presence of patellofemoral arthritis and the various forms of dysplasia [5, 29, 30]. It is registered high-grade dysplasia in the population of arthritis with instability (66%) than in cases with isolated arthritis (38%). The more the trochlea is prominent, the higher the level of arthritis is noted. The trochlear prominence increases the compressive forces of the patellofemoral joint in a flexion like an "anti-Maquet effect"; the asymmetry of the trochlear facet contributes to an asymmetric kinematic of the patellofemoral joint with a permanent lateral riding of the kneecap [19]. Van Haver et al. [31], in a recent cadaveric study with simulated trochlear deformities, showed that the patellofemoral joint in the trochlear dysplastic group (especially in dysplasia Dejour type B and D) presented increased internal rotation, lateral tilt, and lateral translation; increased contact pressures; decreased contact areas; and decreased stability when compared with the control group. These findings could explain the short-term effects (maltracking, increased pressures, and instability) and long-term effects (osteoarthritis) of different types of trochlear dysplasia. This cadaveric study was the first to demonstrate that a high-grade trochlear dysplasia (Dejour types B and D) leads to higher contact pressures and supports the hypothesis that a pronounced trochlear bump increases patellofemoral compression like an "anti-Maquet effect," which has been reported as a mechanism in the development of isolated PFOA in Dejour types B and D [29, 30, 32].

### 39.6.2 Dysplasia of the Patella

Patellar dysplasia is also a significant factor to the development of patellofemoral arthritis where in nearly 42% of cases patella dysplasia of type Wiberg II is registered ($p < 0.0001$). This finding suggests the presence of a dysplastic patellofemoral joint with a stronger relationship between the incidence of trochlear dysplasia and a dysplastic patella ($p < 0.001$) [19].

### 39.6.3 Other Factors

The patella height is not described as a predisposing factor in the development of patellofemoral arthritis. In literature, no correlation was found between the Caton-Deschamps index and the type of arthritis. However, Luyckx et al. [33], in a biomechanically study, observed that the patellofemoral contact force increased with increasing knee flexion until contact occurred between the quadriceps tendon and the femoral trochlea, inducing load sharing. Patella alta caused a delay of this contact until deeper flexion; consequently, the maximal patellofemoral contact force and contact pressure increased significantly with increasing patellar height ($p < 0.01$). Patella alta was associated with the highest maximal patellofemoral contact force and contact pressure in flexion, and Patella baja significantly increased patella contact pressures in knee extension. A parallel study [5] analyzing 44 CT scans on 44 patients with isolated patellofemoral arthritis did not show any correlation between the femoral and tibial torsion or the epicondylar index. However, Souza et al. [34] noted that individuals with PFPS exhibited significantly increased femoral internal rotation in knee extension and flexion compared with healthy controls. External tibial rotation increased lateral patella shift and tilt in cadaver models and increases PF contact pressure in the lateral compartment [35]. There was no correlation with the axial deformity (varus or varus) of the lower legs. However, several authors reported that valgus alignment was associated with between two- and fourfold increase in odds of lateral PF OA and varus alignment increased the odds of medial PF OA [36]. The quadriceps, hip abductors, gluteals, hamstrings, and iliotibial band (ITB) are implicated in the presence of increased PF joint stress. Hart et al. [37] reported cross-sectional areas of the vastii and rectus femoris were reduced in individuals with PFOA, implying that their force-generating capacity was reduced. These findings have been supported by numerous studies indicating that individuals with PFOA negotiate stairs with decreased quadriceps force [38], that quadriceps weakness was positively associated with lateral cartilage damage and bone marrow lesions [39], and that strong quadriceps reduce the odds of the presence of lateral PF OA [40]. Interestingly, these associations were not found for medial PFOA. Patients with PFOA produce significantly less gluteus medius and minimus force than healthy controls during level walking and descending stairs [38]. They also exhibit significantly reduced hip abductor strength [41]. The potential increase in femoral internal rotation could result from decreased hip abductor strength which may lead to an increase in lateral displacement of the patella in the trochlear groove. Patella flexion also increases with tight hamstrings as the tibia and patella tendon are translated posteriorly, subsequently increasing PF compression forces—even more so when combined with weakened quadriceps [42]. Similarly, a tight ITB can pull on its lateral retinaculum attachment and increase lateral tilt of the patella [43]. In a study of 16 healthy men, those with tight hamstrings exhibited significantly greater lateral PF compartment joint stress and significantly reduced medial PF compartment contact area during a squat task [44].

## 39.7 Natural History and Treatment Implications

Few studies reported on the natural history of PF OA, and those that have been conducted almost solely focus on structural progression assessed with radiographs or MRI.

Progression to radiographic PF OA in a population of middle-aged people with knee pain for more than 3 months was 31% over 6 years [45] and 17% over 3 years in people over 50 years with any knee pain in the last year [46]. In literature, it is reported that structural progression of PF OA occurred less frequently than TF OA, although limited studies report on the progression of PF OA separately from TF OA and combined knee OA. More importantly, no studies so far have reported on the clinical progression of PF OA.

The longitudinal interrelationship between PF OA and TF OA has been described in multiple studies. Having TF OA was found to be a risk factor for onset and progression of PF OA in 3 or more years, and having PF OA was a risk factor for developing TF OA, both in knee pain populations using radiographic definitions [46, 47] and in a female middle-aged population using MRI definitions [48].

In MRI studies reporting the progression of cartilage volume loss in the PF joint, an annual 1.6% loss of cartilage volume was noted in a study population consisting of women (mean age 52 years) without clinical knee OA [49]. In two other studies consisting of patients with knee OA (both mean age 63 years) and radiographic evidence of knee OA (osteophytes and/or joint space narrowing), the annual loss of cartilage volume was 4.5% [49–51]. Women seem to lose patellar cartilage at a faster rate than men [49–51].

Lankhorst et al. [47] in a prospective study observed the rate of isolated PFOA compared to TFOA in middle-aged participants with early osteoarthritis (OA) symptoms of the knee. The sample comprised 845 participants (mean age 55.9 years). At baseline, 116 had PFOA, and none had TFOA or combined PFOA and TFOA (combined osteoarthritis (COA)). Of these 116 participants, 66.3% had developed COA at 5-year follow-up. At 2-year follow-up, PFOA, TFOA, and COA were present in 77 (10.8%), 39 (5.5%), and 83 (11.6%) participants, respectively. These results suggest that OA is more likely to start in the patellofemoral joint and then progress to COA in individuals with symptoms of early knee OA. No differences in TFOA and PFOA phenotypes were determined with respect to signs and symptoms. However, these authors didn't investigate the predisposing factors of PFOA such as trochlear and patellar dysplasia.

Guilbert et al. [52] found 90% of patients were not operated on by a 9-year follow-up, and 71% of patients were satisfied with their medical treatment. He stresses that 50% have a progressive globalization of their arthritis; thus, within this series over 9 years, 37% developed a tricompartmental arthritis, and 23% remodeled the femoral-tibial joint.

Dejour et al. [5] reported a different progression of global arthritis between PFOA post instability (32%) and primary PFOA (41%).

## 39.8 Therapeutic Consequences

Two different scenarios within the patellofemoral arthritis can be identified:

1. PFOA with normal patellofemoral anatomy.
2. PFOA with abnormal patellofemoral anatomy (trochlea/patellar dysplasia).

### 39.8.1 Patellofemoral Arthritis Without Dysplasia/PFOA with Normal Patellofemoral Anatomy

In mild and moderate PFOA, non-prosthetic treatment is possible [53]. Conservative strategies include activity modification, quadriceps strengthening, bracing, nonsteroidal anti-inflammatories, glucosamine–chondroitin, and viscosupplementation [54]. Unfortunately, none of these have been proven to be markedly effective, especially in the setting of advanced arthritis [54, 55]. In the presence of malalignment or symptomatic patellar lateral osteophyte, surgery options such as tibial tubercle osteotomy [56, 57] and a lateral isolated facetectomy are respectively described [58].

### 39.8.2 Patellofemoral Arthritis with Dysplasia/PFOA with Abnormal Patellofemoral Anatomy

In this situation, the partial or total arthroplasty will be more interesting because it will permit the removal of the patellofemoral dysplasia at the time of the turning of the trochlear and on the turned patella [5, 19]. Therefore, if one utilizes a trochlear cutting implant, the prominence due to the supratrochlear spur is removed. Moreover the mediolateral position and rotation of the component could permit the correction of the extenor mechanism malalignment. In selected cases, a slight lateralization of the femoral component reduces the TT-TG distance without performing a distal realigment [5, 19].

The reduction of patellar tilt observed after PFA could be attributed to the more anatomic shape of the prosthetic trochlea and to the lateral patellar facetectomy performed by the surgeon, which decompresses the lateral compartment of the PFJ. The amount of patellar tilt is correlated with trochlear dysplasia in patellar instability, and the PFA acts as a metallic trochleoplasty [30].

Van Haver et al. [31] in a cadaveric study with simulated trochlear deformity investigated the effect of trochlear dysplasia on patellofemoral biomechanics. They noted that patellofemoral joint in the trochlear dysplastic group showed increased internal rotation, lateral tilt, and lateral translation; increased contact pressures; decreased contact areas; and decreased stability when compared with the control group. Within the trochlear dysplastic group, "Dejour type D" showed the largest deviations for the kinematical parameters, and the implants graded as Dejour types B and D showed the largest deviations for the patellofemoral contact areas and pressures. This study is the first controlled cadaveric study demonstrating that a pronounced trochlear bump (Dejour types B and D) induces higher contact pressures. This experimental observation supports the hypothesis that a pronounced trochlear bump increases patellofemoral compression like an "anti-Maquet effect," which has been reported as a mechanism in the development of isolated patellofemoral arthritis in Dejour types B and D [29, 30, 32]. Jungmann et al. [59] evaluating the trochlear morphology using RMN (WORMS scores) in 304 patients selected randomly (aged 45–60 years) observed that knees with a shallow trochlea showed higher patellofemoral degeneration ($p < 0.001$) and lower patellar cartilage volume than controls ($p < 0.001$), indicating more advanced osteoarthritis at the patellofemoral joint. The surgical indication must also include the etiology because this series has shown statistically more global degradation of the articulation when there is no history of dislocation of the patella (primary arthritis population) [59]. In elderly patients, the total knee arthroplasty is giving as good results as in femorotibial arthritis with no specific features in the procedure [60].

The indication must therefore take into account the very slow evolution of this specific arthritis, the etiology is important to analyze because of the natural history differences, and the surgical procedure could change depending on the amount of patellofemoral dysplasia and bony wear.

The goal of PFA is to replace the damaged cartilage and to correct underlying deformities in order to reduce pain and to prevent instability and maltracking. The implant, therefore, serves as a “metallic trochleoplasty,” removing the PFOA and addressing all etiologic factors described in the “menu à la carte” for the treatment of objective patellar instability [30].

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# 40

# Techniques for Cartilage Restoration in the Patellofemoral Joint

Luca Andriolo, Alberto Poggi, Roberto De Filippis, Stefano Zaffagnini, and Giuseppe Filardo

The patellofemoral (PF) joint is a complex structure composed by the femoral trochlea and its counterpart, the patella, the largest sesamoid bone in the human body that serves as a lever arm, centralizing the divergent forces of the quadriceps muscle and improving the effective extension capacity while protecting the tibiofemoral joint by forming a bony shield [1]. As a consequence, the PF joint is subjected to high functional and biomechanical requirements, and the resulting stress often leads to articular surface damage, which can represent a cause of anterior knee pain and joint degeneration.

Malalignment and instability can act as background factors for the onset of patellar and trochlear chondral lesions [2]. Therefore, the treatment of PF cartilage defects should always be accompanied by the assessment of any potential malalignment or instability of the patella and, when indicated, by the correction of the background factors. These corrections are paramount to ensure effective and durable results of cartilage treatments [3]. Once malalignment or instability is addressed, several surgical procedures are available to treat symptomatic PF cartilage damage: microfractures; osteochondral autologous transplantation (OAT); osteochondral allograft (OCA); autologous chondrocyte implantation (ACI); matrix-assisted autologous chondrocyte transplantation (MACT); bone marrow-derived cell transplantation (BMCT); and chondral and osteochondral scaffolds.

Overall indications for these surgical treatments are represented by repair of symptomatic focal articular cartilage defects and failed nonsurgical therapy [4], with contraindications consisting in I–II grade ICRS classification, diffuse cartilage damage, and bipolar articular cartilage lesions (kissing lesions). Other exclusion criteria are severe osteoarthritis (OA), systemic inflammatory diseases, high body max index (BMI), and malignancy [4]. Finally, relative contraindications are early OA and patients over 45 years of age [5]. In the following paragraphs, these surgical options will be discussed in light of their indications, technique, and results.

## 40.1 Microfractures

### 40.1.1 Rationale

This procedure involves the perforation of the subchondral bone to facilitate the release of bone marrow elements such as mesenchymal stem cells (MSCs) and growth factors in the site of the articular defect. These cells can differentiate into fibrochondrocytes and create a fibrocartilage with

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less capacity to resist sheering and compression forces compared to the physiologic one. Main indications are represented by primary repair of symptomatic focal articular cartilage defects, smaller defects (<3 cm$^2$) in patients with failed nonsurgical therapy [4].

### 40.1.2 Technique

The articular cartilage defect is identified arthroscopically and then debrided up to the calcified cartilage layer to expose the subchondral bone. During this step it is important avoiding to damage the subchondral bone because this could promote later osseous overgrowth. The prepared lesion, with a rim of stable perpendicular cartilage and exposed subchondral bone, provides a lodgement to contain the "super clot" of bone marrow elements from the microfractures. This technique involves the creation of small holes throughout the defect to serve as vascular channels allowing the migration of marrow elements to the surface of the lesion. Channels are created first around the periphery of the lesion and then continued toward the center from 3 to 4 mm in depth using an awl, with 3–4 mm space between them without breaking into adjacent holes (Fig. 40.1) [6]. Once completed, the defect will present a uniform rough surface that should be left intact to promote the adherence of the marrow clot and its elements to form the fibrous repair tissue.

### 40.1.3 Results

Although studies specifically focused on microfractures treatment for PF cartilage lesions are missing, Petri et al. [7] performed a study in which they used microfractures as control for MACT in the treatment of isolated PF cartilage lesions. At 3 years' follow-up, the results showed a clinical improvement in both groups without statistically significant differences. Moreover, in a systematic review on the treatment of chondral knee defects, Mithoefer et al. [8] included PF chondral lesions in the overall analysis of knee cartilage lesions: they underlined how 3122 microfracture procedures yielded average knee function scores significantly above the preoperative level over the first 24 months with a short-term clinical improvement rate of 75–100% overall. After 24 months, however, 47–80% of patients reported a subjective decline in the functional outcomes. It could be argued that the fibrocartilage clot has a different composition of collagen than the native hyaline cartilage making it less durable, less resistant, and more prone to wearing out over time, which could explain the symptoms evolution over time.

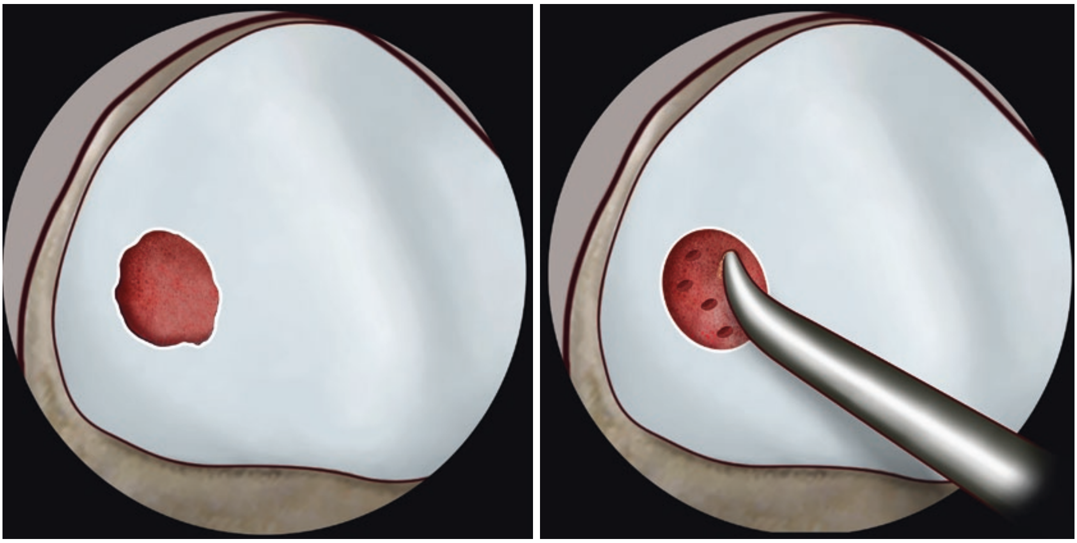

**Fig. 40.1** Microfractures procedure: (left) cautious debridment to remove the calcified cartilage layer and expose the subchondral bone avoiding to damage it. (Right) microfractures penetrations, from 3 to 4 mm in depth, within prepared lesions

## 40.2 Osteochondral Autologous Transplantation (OAT)

### 40.2.1 Rationale

Osteochondral autologous transplantation (OAT) is a technique aimed at restoring a congruent articular cartilage surface, with hyaline cartilage as close as possible to its original status, by transferring osteochondral plugs (one or multiple smaller plugs, also known as “mosaicplasty”) collected from less-weight-bearing surfaces to the damaged area. Donor site availability and the consequent comorbidity represent possible limitations especially in large PF chondral or osteochondral defects [9]. Ideal candidates for OAT are patients with small unipolar lesions, both chondral and osteochondral, particularly those with high physical demands [5].

### 40.2.2 Technique

A longitudinal para-patellar incision is performed from the apex of the patella to its inferior edge. The patella is everted to provide optimized visualization of the articular surface. At that point, the diameter of the chondral injury is measured to determine the size of the osteochondral cylinder required from the donation site. The donor site is chosen within a less-weight-bearing area of the joint (e.g., superolateral or superomedial femoral trochlea). The osteochondral cylinder is implanted paying attention that the surface is levelled with the surrounding articular cartilage (Fig. 40.2), as protruding grafts might jeopardize the overall outcome.

### 40.2.3 Results

The available literature about OAT in PF chondral lesions is smaller than in femoro-tibial lesions. In a prospective study of 20 patients who underwent OAT treatment for PF cartilage lesions, Astur et al. found significant clinical improvements up to 2 years after surgery. Less satisfying results were found by Hangody et al. [10] who conducted a multicenter prospective evaluation in 303 professional athletes treated with mosaicplasty for defect located on femoral condyles in 261, on tibial condyles in 16, and on patella or trochlea in 26 patients. A good to excellent outcome was seen in 91% of condylar defects, in 86% of tibial condylar, and in 74% of PF lesions; 5% of cases showed PF donor site pain related to graft harvest.

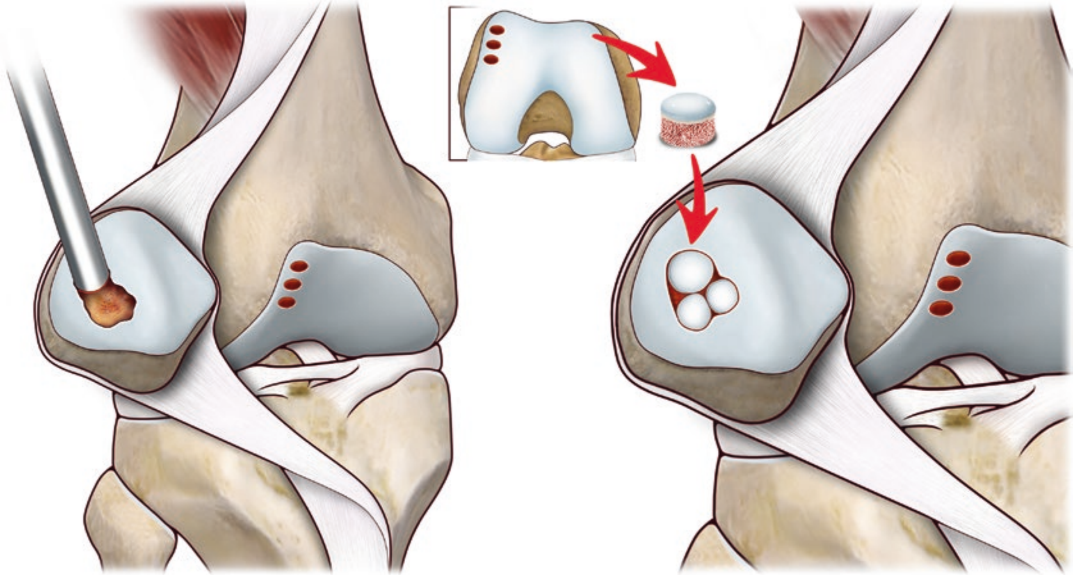

**Fig. 40.2** Osteochondral autologous transplantation (OAT) procedure: (left) preparation of osteochondral bed lesion and grafts harvesting from less-weight-bearing area of the joint. (Right) harvesting grafts placed and fixed by press-fit in prepared lesions

## 40.3 Osteochondral Allograft (OCA)

### 40.3.1 Rationale

Osteochondral allograft (OCA) can restore both articular cartilage and associated subchondral bony damage: moreover, fresh allografts overcome the problems related to the donor site, which can limit the potential of OAT [11]. Beside the indications of this surgery for isolated PF lesions with ICRS grades III and IV, also osteochondral lesions/osteochondritis dissecans or patients who failed previous cartilage surgical treatments (microfractures, ACI, OAT) could be considered, as well as patients who wished to avoid prosthetic arthroplasty. In fact, it is worth mentioning that positive findings have been reported even with the treatment of fresh allografts to address complex bipolar lesions [12].

### 40.3.2 Technique

Two techniques are available for OCA, which could find a different indication according to the location and size of the chondral/osteochondral lesion: a dowel technique for small- (<5 cm$^2$) or average-sized (5–10 cm$^2$) lesions and a shell technique (total graft) for large lesions (>10 cm$^2$ or >75% of patellar surface) [13]. However, the dowel technique is harder to use for lesions involving the median ridge of the patella, regardless of the size of the lesion. Therefore, in such cases the shell technique is the preferred technique: after a complete patellar resection, the total patellar allograft is generally fixed in place using compression screws and/or absorbable internal fixation devices (Fig. 40.3).

### 40.3.3 Results

Gracitelli et al. [13] analyzed 27 patients, treated with OCA for isolated patellar lesions and evaluated at a mean 10 years' follow-up, reporting a statistically significant improvement in clinical scores, with a survival of 78.1% at 10 years and 55.8% at 15 years. Similar positive results were proved even in kissing lesions by Mirzayan et al. [12], who retrospectively reviewed 17 patients (18 knees) who underwent bipolar osteochondral allograft trans-

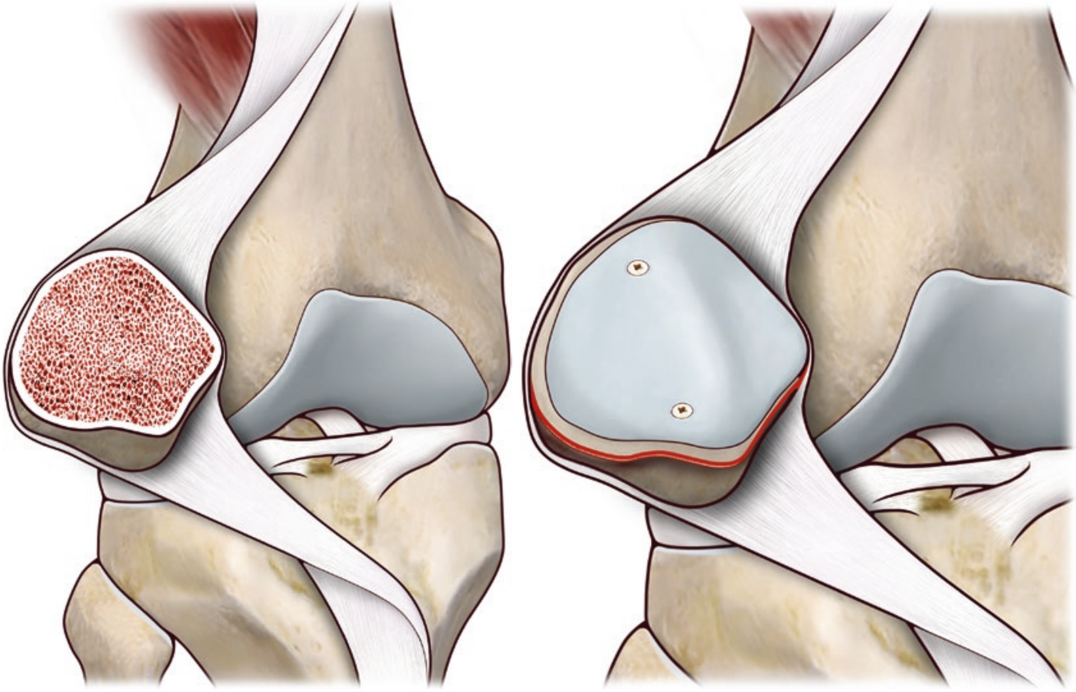

**Fig. 40.3** Osteochondral allograft (OCA) procedure: (left) total osteochondral patellar lesion prepared to OCA treatment. (Right) total patellar allograft in place and fixed with 2 small resorbable lag screws

plantation. At a mean 33.2 months' follow-up, they reported a statistically clinical improvement, and the results were comparable to those of unipolar grafts implanted for defects of the femoral condyle. Torga Spak and Teitge [14] confirmed these results analyzing up to 10 years of follow-up 14 PF osteochondral allografts (12 bipolar and 2 unipolar) implanted in 11 patients with PF OA. They reported that the PF graft delayed prosthetic knee replacement for 8 of the 11 patients, and 10 patients stated that they would have the procedure again.

## 40.4 Autologous Chondrocyte Implantation (ACI)

### 40.4.1 Rationale

ACI has been introduced in the early 1990s as the first cartilage regenerative technique, and until a few years ago, it still represented the only available regenerative technique in many countries. Different from the bone marrow stimulation techniques, the implantation of chondrocytes expanded in culture allowed to obtain a hyaline-like tissue. Moreover, this technique did not present availability limitation nor donor site comorbidity. Although being primarily a chondral procedure, the association with autologous cancellous bone implant allowed to treat also osteochondral lesions.

Patients with large full-thickness chondral defects >3 cm$^2$ [4, 15, 16], minimal subchondral bone involvement, no prior history of cartilage procedures, and a short duration of preoperative symptoms are ideal candidates for ACI.

### 40.4.2 Technique

ACI is a two-step procedure: in the first one, a biopsy of cartilage from a minor weight-bearing surface of the intercondylar notch is harvested and subsequently sent to the laboratory for cell culture. After a least of 2–3 weeks [16], the cultured cells are ready for the implantation or may be cryopreserved for future use. In the second step, by an open approach, the damaged cartilage is debrided avoiding to cause any bleeding from the subchondral bone. The lesion is then covered with a periosteum flap sutured to the margin and filled underneath with a suspension of cultivated chondrocyte and further sealed with fibrin glue (Fig. 40.4). Second-generation

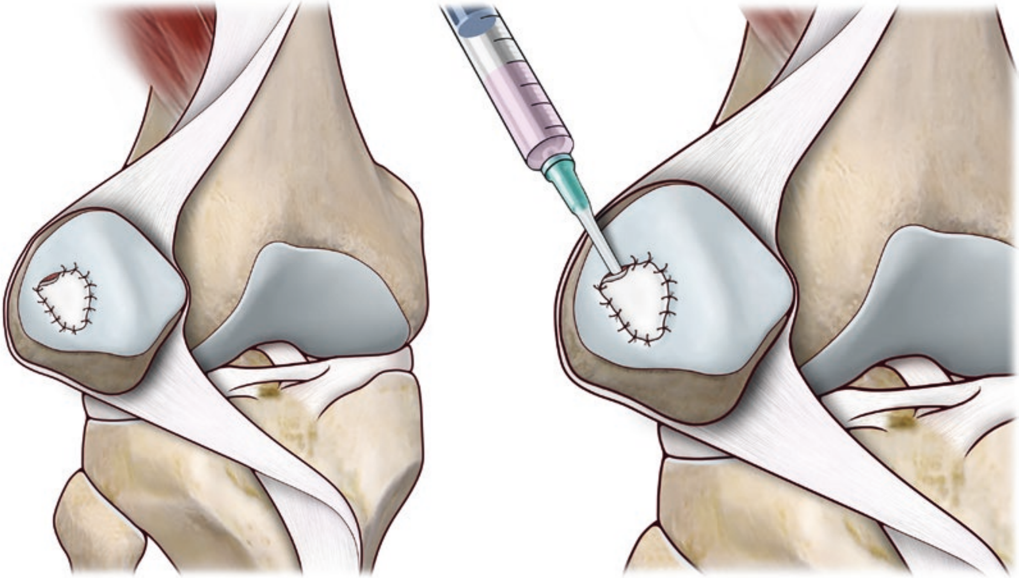

**Fig. 40.4** Autologous chondrocyte implantation (ACI) procedure: (left) preparation of patellar chondral lesion to ACI treatment, creating a patellar pocket for injection. (Right) cultured autologous chondrocytes infiltration in patellar pocket

ACI entails the use of a collagen membrane in place of the periosteum flap [17].

### 40.4.3 Results

In the first study on ACI, Brittberg et al. treated 23 patients, 7 of them for patellar lesions. After 39 months' follow-up, patellar defects resulted in worse outcomes compared to femoral defects, with only two patients obtaining good results. Nevertheless, the excellent clinical and histological results obtained in patients with femoral defects pushed to a spreading of this techniques, and afterward other authors specifically analyzed its use in PF lesions. Minas and Bryant [18] reported 71% of successful results at mean 4 years of follow-up, treating both patellar and trochlear lesions, and these results were confirmed at the same follow-up also by Vanlauwe et al. [19] on 38 patients and by Pascual-Garrido et al. [20] on 62 patients. Also, Vasiliadis et al. [21] obtained good results for ACI in PF lesions but reported a 29% of periosteal hypertrophy, probably caused by the high compression and friction forces that act on PF articulation, which represents the most typical first-generation ACI complication.

## 40.5 Matrix-Assisted Autologous Chondrocyte Transplantation (MACT)

### 40.5.1 Rationale

In order to overcome the drawbacks of ACI, MACT has been developed. The rationale for using a scaffold is to have a temporary 3D structure of biodegradable polymers to allow the growth of living cells. While providing comparable clinical results, MACT can be implanted with a mini-arthrotomic or even arthroscopic approach and was proved to reduce graft hypertrophy related to ACI, with scaffolds providing the support for cell adhesion and proliferation, maintaining the chondrocyte phenotype and matrix production, and avoiding the dedifferentiation into fibroblasts typical of 2D cultures. Hyaluronic acid-, collagen-, or other substrates-based scaffolds have been documented. MACT is indicated in patients with isolated ICRS grades III and IV chondral defects, but it can also be used in osteochondral lesions when associated with autologous cancellous bone implant [22].

### 40.5.2 Technique

The procedure is performed in two surgical steps: the first one consists of a cartilage biopsy, as in ACI, which is then cultured and seeded onto the scaffold. In the second step, the bioengineered tissue is implanted in the PF defect through a mini-arthrotomic approach. Trochlear defects may also be treated arthroscopically (Fig. 40.5). Scaffold fixation can be obtained in different ways, depending on the different scaffolds, by press only or applying fibrin glue to improve scaffold stability [23, 24].

### 40.5.3 Results

MACT has been extensively studied, both for femoral condyle and PF lesions, but the literature provides contrasting findings about their efficacy for the different locations. Ebert et al. [23] treated 194 patients with MACT: 127 lesions were located on femoral condyles and 67 in the PF joint. After 24 months a similar clinical and radiological improvement was observed in both groups. Less positive results were reported in a multicenter study on PF lesions in 34 patients (21 defects on patella, 9 on trochlea, and 4 multiple lesions). After a good clinical improvement for all locations in the first 2 years after MACT, a decrease of clinical outcome from 2 to 5 years of follow-up was found in patients with multiple lesions and patellar defects [25]. The same negative trend was suggested by a long-term update of the same survey [24], which reported worst results in women with patellar lesions requiring realignment. Filardo et al. [26] specifically investigated the differences between trochlear and patellar lesions, documenting how these lesions

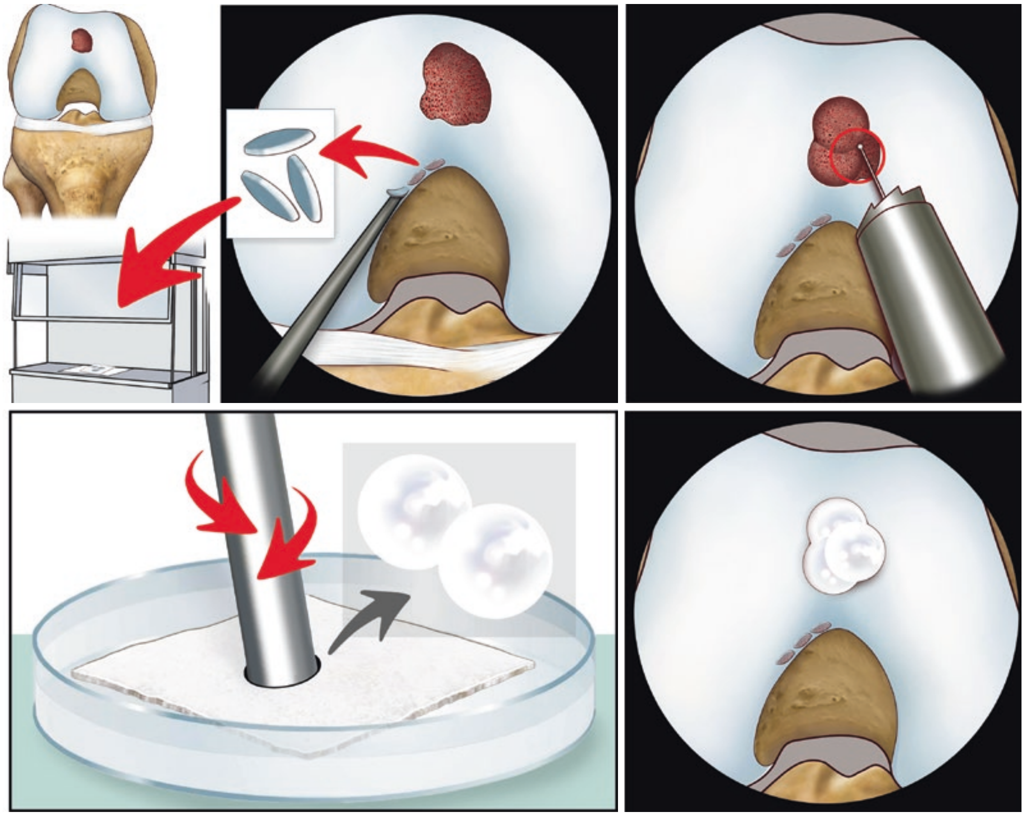

**Fig. 40.5** Matrix-assisted autologous chondrocyte transplantation (MACT) procedure: (above left ) intercondylar notch cartilage biopsy seeded and cultivated onto a scaffold. (Above right) arthroscopically preparation of chondral defect removing all nonviable cartilage to expose the subchondral bone. Below: chondrocyte cultured-scaffold sized and subsequently fixation by press-fit.

generally affect different populations (e.g., patellar lesions are more frequent in women). The lower results reported for patellar compared to trochlear lesions led to hypothesize that, despite being part of the same joint, patellar and trochlear cartilage lesions present a different etiology and a different prognosis.

## 40.6 Bone Marrow-Derived Cell Transplantation (BMCT)

### 40.6.1 Rationale

In the last decade, the use of BMCT for the treatment of chondral lesions has increased. Compared to MACT, this procedure has the advantage to be a single-step procedure. Autologous bone marrow cells (generally harvested from the anterior or posterior iliac crest) can be cultivated or merely concentrated, thus avoiding the need for cell culture and consequently limiting the costs with respect to ACI and MACT. Autologous bone marrow contains not only stem cells and precursor cells prone to differentiate into bone and cartilage, but the entire niche with accessory cells capable of supporting angiogenesis by producing several growth factors. Like MACT, BMCT is indicated in patients with isolated ICRS grades III and IV chondral defects, but it can be also used in osteochondral lesions when associated with autologous cancellous bone implant [27].

### 40.6.2 Technique

After arthroscopic evaluation and debridement of the chondral lesion, the bone marrow is aspirated from the posterior or anterior iliac crest and concentrated with a specific kit. Once the process is finished, the scaffold is immersed in the bone marrow concentrate (BMC). The matrix available for this approach is generally the same as that used in MACT. Finally, the BMC-loaded scaffold is implanted into the prepared lesion, through an arthroscopic or arthrotomic approach, with the possibility of using platelet-rich fibrin as augmentation or fibrin glue for further fixation [27, 28].

### 40.6.3 Results

A limited number of studies on BMCT are available in the literature. Buda et al. [27] treated 28 patients with focal PF chondral lesions with BMCT associated with an anteromedialization of the tibial tuberosity and at a mean 4 years' follow-up reported a significant clinical improvement, higher in trochlear lesions compared to patellar ones. Gobbi et al. [28] performed a comparative study between 19 patients affected by PF lesions treated with MACT and 18 with BMCT. At a mean 5 years' follow-up, a clinical improvement was shown in both groups. Interestingly, MACT showed better results in trochlear compared to patellar defects, while no significant differences were found for BMCT.

## 40.7 Cell-Free Chondral Scaffolds

### 40.7.1 Rationale

A possible limit of microfractures is the loss of bone marrow elements into the joint instead of being contained in the cartilage defect. To overcome this, cell-free techniques based on different materials, like a collagen scaffold (autologous matrix-induced chondrogenesis, AMIC) or other scaffolds or a chitosan-based polymer scaffolding biomaterial (BST-CarGel), have been developed to improve microfractures by retaining the bone marrow element and guiding them toward cartilage formation. Accordingly, the rationale of combining microfractures with scaffolds is to obtain a bio-system where stem cells and growth factors are concentrated to enhance the cartilage restoration potential. Patients with isolated ICRS grade III–IV chondral lesions sized around 2 cm$^2$ are ideal candidates [29].

### 40.7.2 Technique

Cell-free chondral scaffolds are implanted in a single-step procedure. After an accurate arthroscopic or arthrotomic cartilage lesion debridement, microfractures are performed according to the technique described by Steadman, and either a matrix or a liquid bioscaffold is applied to the site of cartilage defect. AMIC fixation is obtained by suturing or pressing the collagen matrix into the defect and can be enhanced with fibrin glue, while for the chitosan-based polymer, autologous blood is added, and the fixation is obtained through the in-site coagulation of the composite [29–31].

### 40.7.3 Results

To analyze the potential of cell-free chondral scaffolds, Kusano et al. [29] performed a retrospective review of 38 patients, 20 of which affected by full-thickness patellar chondral defects, treated with AMIC. After a mean follow-up of 29 months, the results showed a significant clinical improvement for the PF defects, not lower than other joint locations. Sadlik et al. [31] specifically analyzed 12 patients with patellar chondral lesions treated with AMIC, showing a significant clinical improvement at a mean follow-up of 38 months. Finally, Steinwachs et al. recently conducted a retrospective cohort study including 91 patients with 93 knee cartilage lesions (of which 30 trochlear and 14 patellar cartilage lesions) treated with BST-CarGel showing an overall significant decrease in pain and swelling at 6 months' follow-up. Interestingly, the patellar group showed only pain improvement not followed by swelling decrease at this follow-up time [30].

## 40.8 Cell-Free Osteochondral Scaffolds

### 40.8.1 Rationale

Subchondral bone has been recently recognized as a key factor in the articular surface pathology, frequently involved either directly as consequence of trauma or secondarily due to chronic overload and degenerative changes. In this light, osteochondral scaffolds (bi-/three-phasic cell-free biomaterials) have been developed, in order to replace in one surgical step, the entire osteochondral unit, thus treating not only the cartilage layer but also the entire osteochondral unit. ICRS grade III–IV cartilage lesions and not refixable OCD lesions in patients with clinical symptoms of pain, swelling, locking, or giving way represent treatment indications, for primary as well as secondary treatment after failure of other cartilage procedures. Currently, among the different developed products, only one cell-free collagen-hydroxyapatite biomimetic osteochondral scaffold is available in the clinical practice, while preliminary evidence is supporting the potential of a novel aragonite-based scaffold for the treatment of trochlear lesions [32].

### 40.8.2 Technique

A medial para-patellar incision is performed to obtain good visualization of the chondral/osteochondral lesions, and then all the diseased subchondral bone is carefully removed up to 6/7 mm deep. The collagen-hydroxyapatite graft, sized and shaped to obtain optimum fitting into the defect, is implanted by press-fit fixation (Fig. 40.6). The bed of the lesion must have stable shoulders perpendicular to the articular surface to ensure implant stability, and a slight scaffold swelling caused by the subchondral bleeding favors press-fit fixation with further addition of fibrin glue to improve stability [33]. Pre-shaped plugs and specific instrumentation are available for the other osteochondral scaffolds.

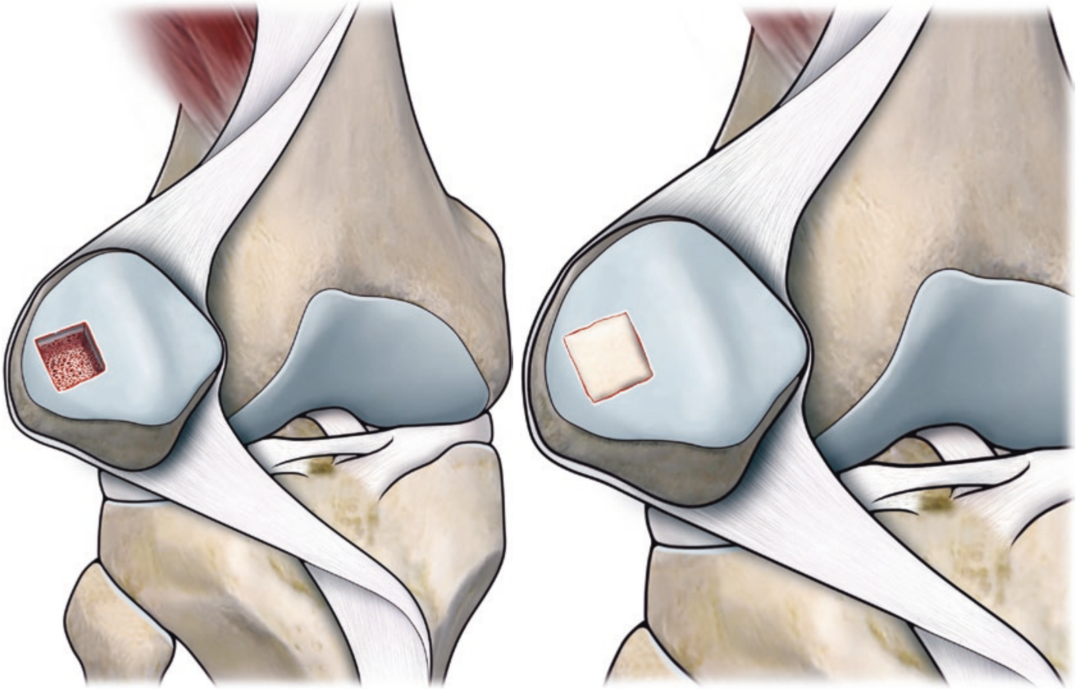

**Fig. 40.6** Osteochondral scaffold procedure: (left) osteochondral bed lesion preparation. (Right) osteochondral scaffold sized and placed into the defect by press-fit fixation

### 40.8.3 Results

Perdisa et al. analyzed 34 patients affected by patellar osteochondral lesions and treated with a biphasic cell-free collagen-hydroxyapatite scaffold, obtaining a significant clinical improvement after 2 years, although underlying that this overall positive short-term outcome was lower in the patella than in other knee locations; moreover, women had lower outcomes, and the need for realignment procedures led to a slower recovery. MRI evaluation showed some abnormal findings with the presence of bone overgrowth, but no correlation has been found with the clinical outcome [34].

The experience with the synthetic polylactide-/polyglycolide-based scaffold is less satisfying: while short-term positive results were reported at 1-year follow-up by Joshi et al. [35] who treated ten patients for patellar full-thickness chondral defects, a subsequent progressive worsening of the clinical improvement was documented, with failure at longer term in restoring the subchondral bone despite the formation of predominant hyaline cartilage with this synthetic resorbable scaffold. Magnetic resonance imaging at final follow-up showed a cylindrical cavity of fibrous tissue instead of subchondral bone restoration. At 18 months of follow-up, all patients except one complained of pain and knee swelling, and final reoperation rate was 70%.

Finally, early positive experience on human implants has been reported for a novel aragonite-based scaffold for osteochondral regeneration: MRI findings revealed graft integration with good bone and cartilage formation and good clinical outcome at 12 months for the treatment of trochlear lesions, especially when the newest tapered implants were tested [36].

## 40.9 Conclusions

The treatment of PF chondral/osteochondral lesions is particularly complex, due to the anatomic, biomechanical, and biological characteristics peculiar to the PF joint. Cartilage restoration in the PF joint represents one of the most challenging conditions for the orthopedic surgeons. Remarkably, different results were reported in patellar and trochlear cartilage lesions, probably because of their differences in terms of cartilage thickness, composition, compressive properties, and anatomic variance, suggesting that these locations should not be considered as the same pathological entity. A proper analysis of the clinical history, signs, and background factors, correcting maltracking when indicated, is paramount to obtain good results. Several procedures are available and have shown to provide good results in terms of clinical and radiological improvement, although with specific indications based on location, depth, and grade of the PF chondral/osteochondral lesions.

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# 41

# Isolated Patellofemoral Unipolar Cartilage Lesions: When to Intervene

Charles A. Baumann, Betina B. Hinckel, Jack Farr, and Andreas H. Gomoll

## 41.1 Introduction

The subset of anterior knee pain that is assigned to the patellofemoral (PF) compartment is multifactorial and may encompass structural chondral/osteochondral lesions, tendinitis, malalignment, maltracking, patella malpositioning, deconditioning, muscle imbalance, and overuse and can coexist with other lesions in the knee (i.e., ligament tear, meniscal injuries, cartilage lesions in other compartments). Chondral and osteochondral defects in the PF compartment are often encountered in clinical practice, on advanced imaging studies, and/or during arthroscopy both in symptomatic and asymptomatic patients. Studies have shown more than half of patients who undergo knee arthroscopy have chondral defects, 5.2% having Outerbridge grade III or IV lesions with 37.5% of these lesions being located in the patella alone [1]. In a review of 31,516 knee arthroscopies, 53,000 cartilage lesions were found in over 19,000 patients; most of the lesions are grade III defects in the patella [2]. In asymptomatic professional basketball players, two studies using magnetic resonance imaging (MRI) revealed the presence of abnormal chondral signal in 57% of all players, with 35% having high-grade patella signal and 25% with high-grade trochlea signal [3, 4]. A recent meta-analysis revealed that on MRI up to 52% of patients with knee pain or symptomatic knee osteoarthritis (OA) are diagnosed with cartilage lesions in the PF joint [5].

While indications continue to evolve, there is no clear role for prophylactic cartilage restoration in the setting of asymptomatic lesions. In fact, assigning symptoms to aneural chondrosis/chondral defect is one of "diagnosis by exclusion." The majority of chondral/osteochondral lesions are asymptomatic and as such should be observed, not treated. Although chondral lesions may progress in size, initial treatment of symptomatic lesion should focus on short-term improvement in objective patient findings (i.e., pain, swelling) and then the patient observed for symptoms [6]. For example, a symptomatic partial thickness chondral flap may resolve with debridement. In contrast, surgical intervention should be considered for large and/or

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full-thickness lesions with localizing symptoms that have failed nonoperative treatment, especially in the setting of abnormal anatomy and/or biomechanics. These abnormalities (i.e., trochlear dysplasia, excessive lateral tilt, malalignment, maltracking, limb coronal and axial malalignment, patella alta [7–11]) predispose patients to PF pain, instability, chondral lesions, and OA [12–24]. Thus, to recommend cartilage restoration surgery, it is necessary to unequivocally determine that the lesion observed is responsible for the patient's symptoms.

## 41.2 Review of Applied Anatomy and Biomechanics

### 41.2.1 Normal Osteochondral Structure, Anatomy, and Dysplasias

The PF compartment consists of the articular surface of the patella and the trochlear surface of the distal femur and continues into the intercondylar notch. The patella is the largest sesamoid bone in the body, with normal dimensions of 4.5 cm (range, 3.8–5.3 cm) in length, 4.7 cm (range, 4–5.5 cm) in width, and 2.3 cm (range, 1.9–2.6 cm) in thickness [25, 26]. Patellar articular cartilage is the thickest in the body, measuring up to 7 mm [27]. The cartilage of the patella does not always follow the contour of its underlying subchondral bone [28]. The articular surface is present except for the "bare area" at the distal pole that is highly variable in dimensions and for the patella tendon attachment. The patella is divided into medial and lateral facets by a longitudinal median ridge on the articular side that is congruous with the trochlear groove (TG) in a "normal" knee. The patella can further be divided into seven total facets. The medial and lateral facets are divided vertically into roughly equal thirds, whereas the seventh/odd facet lies along the medial border of the patella. The lateral facet is more sloped and longer in order to match the lateral FC, whereas the medial facet has a shorter steeper slope and is smaller in size [29]. Furthermore, the Wiberg classification defines three types of patella variations categorized by the positioning of the median ridge [30]. According to the classification, in Type I the medial and lateral facets are symmetrical and concave. In Type II (the most common), the lateral facet is wider than the medial, roughly two thirds of the total patellar width. In Type III, the lateral facet is predominant, while the medial facet is smaller than in Type II and takes on a convex shape. A Type IV was later described by Baumgartl, the "Jaegerhut" patella, with no medial facet and consequently no median ridge [31]. These latter two types are typically associated with trochlear dysplasia (see below).

The trochlea is formed by the anterior aspect of the distal femur. It has a centralized groove (TG) with associated medial and lateral facets. The trochlea is covered by much thinner cartilage layers, 2–3 mm of articular cartilage [32], compared to the patella. As with the patella, the lateral facet is larger and extends more proximally than the medial facet. Following the course of the trochlear groove in reference to the femoral shaft, the more distal aspect of the TG in comparison to the proximal entrance deepens and diverges laterally before terminating at the femoral notch where the PF compartment continues as the patella articulates with the medial and lateral walls of the intercondylar notch [33]. Trochlear dysplasia is characterized by an alteration of the normal concave anatomy and depth of the TG, ranging from a shallow groove to a flat trochlea with highly asymmetrical facets and finally to convexity.

### 41.2.2 Limb Alignment, PF Alignment, and Patella Positioning

The range of nonpathologic knee coronal alignment is an anatomical tibiofemoral angle of approximately 5–7° of valgus [34, 35]. Valgus, as well as rotational malalignment (i.e., increased femoral anteversion, increased tibiofemoral rotation, increased tibial torsion), and lateral insertion of the patellar tendon at the tibial tuberosity increase the lateral quadriceps vector and the stress in the lateral PF joint, increasing the risk of

PF pain [17, 36–38]. The offset between the patellar tendon and the trochlea can be used as a parameter of the quadriceps vector, acknowledging that it represents only the distal vector of forces, as the relationship between the proximal insertion of the quadriceps and the trochlea is not being evaluated.

Patellar malpositioning, such as patella alta, increased lateral tilt, and lateral subluxation also increases PF stress. In a recent study by van Middelkoop et al., patients with a higher Insall-Salvati (IS) ratio (indicating patella alta), greater patellar tilt angle (indicating greater lateral tilt), greater bisect offset (indicating a more lateral patellar position), and greater sulcus angle (indicating a shallower trochlea) had higher odds of having features of PF OA (patellar osteophytes, minor cartilage defects, and high fat pad signal) on MRI [39]. A higher IS ratio, a measure of patella alta, had the strongest association with abnormalities of the PF joint, including patellar bone marrow lesions, patellar osteophytes, and Hoffa synovitis [39].

### 41.2.3 PF Biomechanics, Contact Area, and Pressure

PF biomechanics intimately participate in the function of knee extension and (eccentric contraction) deceleration. While the proximal medial patellar restrains (medial quadriceps tendon to femur ligament (MQTFL) and medial patellofemoral ligament (MPFL) provide the main restraint to lateral translation in early flexion, starting at 15–20° of knee flexion, the trochlea increasingly contributes with flexion. At greater than 30° of knee flexion, the stability of the patella depends largely on the trochlea [40–43]. As flexion increases, the contact area on the patella moves both proximally and laterally. The largest contact area is at 45°, where it forms an ellipse across the central portion of the medial and lateral facets [33]. Progressing to 90°, the contact area shifts to the proximal aspects of the medial and lateral patellar facets. At 130–135° of knee flexion, the patellar facets contact the articular surfaces of the femoral condyles (FCs) (Fig. 41.1). The odd facet only makes contact with the femur in extreme flexion (i.e., squatting) [33].

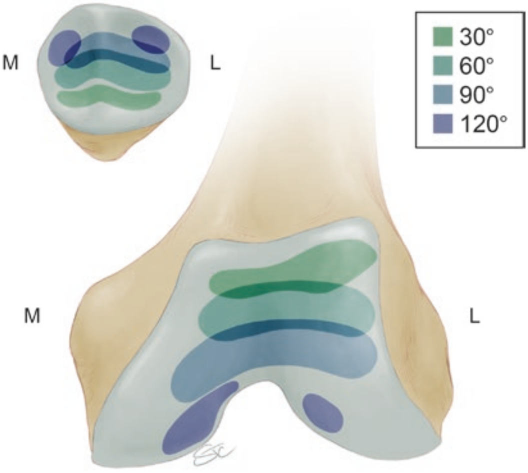

**Fig. 41.1** Schematic demonstrating the patellofemoral joint contact areas corresponding to the degree of knee flexion (© Copyright 2018 by The Curators of the University of Missouri, a public corporation)

In a study by Besier et al. [44] utilizing MRI in asymptomatic subjects, males had mean PF joint contact areas of 210, 414, and 520 mm$^2$ at full extension and 30° and 60° of knee flexion, respectively, in a non-weight-bearing state. Females' contact areas were similar at full extension but had mean values of 269 and 396 mm$^2$ at 30° and 60°, respectively ($p < 0.01$). However, after normalization by patellar dimension, contact areas were not different between genders. In the same study, contact areas increased by an average of 24% ($p < 0.05$) under weight-bearing conditions. In a study performed by Salsich et al. [45] using MRI, progressive increases in PF joint contact area were also observed from full extension to 60° knee flexion in asymptomatic subjects. Furthermore, the lateral facet had an increased percentage of total contact area compared with the medial facet at all knee flexion angles, suggesting increased load-bearing. With contracted quadriceps, the surface area at 0° was 0 and 145.5 mm$^2$, respectively, for the medial and lateral facets, at 20° 21.7 and 162.3 mm$^2$, at 40° 76.0 and 214.5 mm$^2$, and at 60° 103.5 and 243.2 mm$^2$. Heino Brechter et al. [46] showed that MRI assessment of the PF joint contact area is comparable to the established pressure-sensitive film technique, suggesting that this method can be utilized as a valuable and noninvasive tool in quantifying PF joint contact area in vivo.

To obtain the contact stresses in the PF joint, the mean stress (pressure) can be calculated by dividing PF force values by the PF contact area. Studies have extrapolated these measurements to simulate in vivo moments, estimating maximum contact forces of 4600 N, approximately 6.5× body weight, with approximately the same pressure on the lateral and medial patellar facets [47].

### 41.2.4 Etiology

PF cartilage lesions result from a variety of causes ranging from patellar instability, direct trauma, repetitive microtrauma, and malalignment/maltracking to idiopathic. Classifying these lesion patterns (which may overlap) is useful when considering treatment options (Fig. 41.2).

### 41.2.5 Patellar Instability (Fig. 41.3) (Video 41.1)

In patellar instability, there frequently are underlying anatomic risk factors that should be addressed during cartilage repair surgery, such as increased lateral quadriceps vector, medial and lateral soft tissue imbalance, patella alta, and trochlear dysplasia [48]. Patellar instability can cause cartilage damage during the event of dislocation or through the altered loading of chronic patellar subluxation. During a dislocation, cartilage damage to the patella occurs as frequently as 96% [49]. Most commonly, this damage consists of minor injury such as fissuring and/or fibrillation, but chondral and osteochondral fractures may occur. During dislocation, the medial patella strikes the lateral aspect of the distal trochlea, and as the knee collapses into flexion, the lateral aspect of the anterior to the central lateral femoral condyle becomes involved as well. More commonly this lesion is in the far lateral periphery, but it can extend to the central weight-bearing area of the lateral femoral condyle. Although rare, these lesions need to be recognized due to

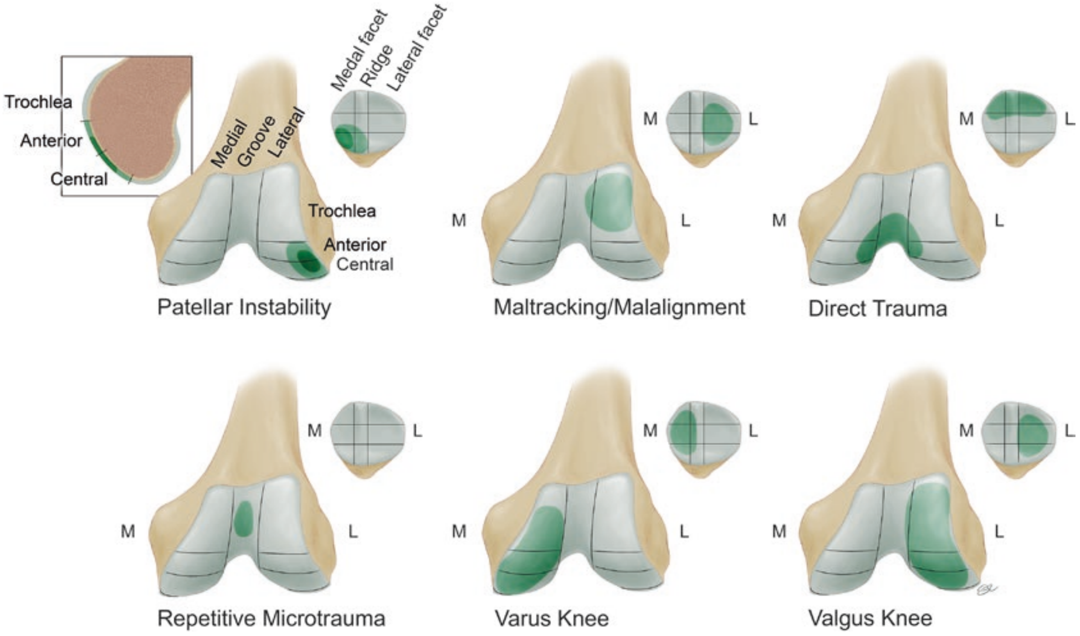

**Fig. 41.2** Illustration depicting the characteristic injury patterns for common causes of PF cartilage lesions (© Copyright 2018 by The Curators of the University of Missouri, a public corporation)

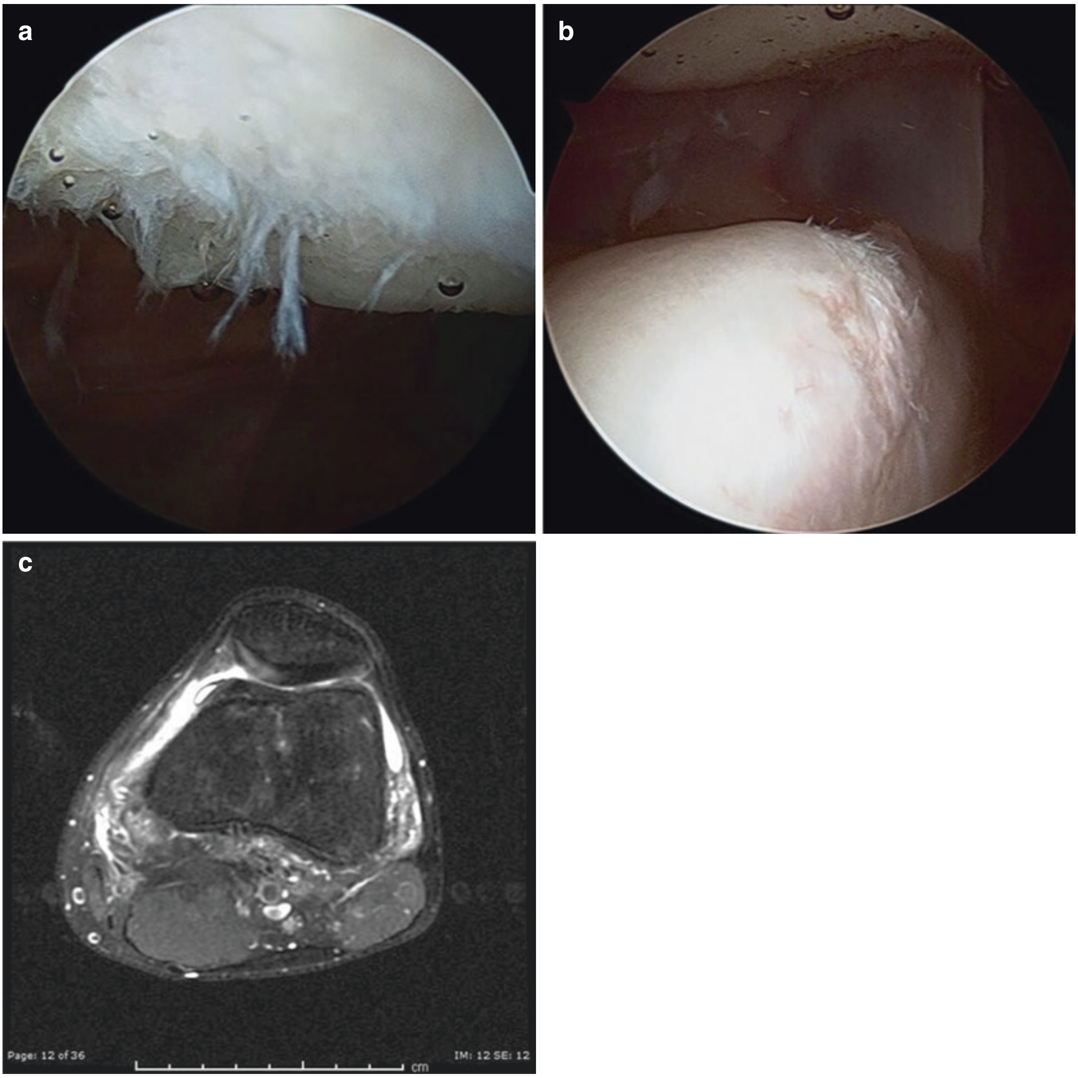

**Fig. 41.3** Cartilage lesions from patellar dislocation. Arthroscopic images showing a distal medial superficial lesion of the patella with fraying (**a**) and a peripheral lesion in the transition of the lateral trochlea to lateral femoral condyle (**b**). Corresponding MRI (**c**) (Courtesy of Jack Farr, MD)

their potential long-term detrimental effects. In the patella, typically the injury is distal medial, occasionally crossing past the median ridge. This can present as a shear type of lesion, which can occur along the subchondral plate or deeper within the subchondral bone. In the osteochondral lesion, the area of cartilage damage is often larger than the bone fracture, and even small fractures visible on X-ray can portend extensive cartilage damage. The amount of cartilage damage is usually related to the amount of energy required for the dislocation and the frequency of events. The more normal a patient's anatomy, the more energy will be required for a dislocation to occur. As such, the likelihood for cartilage damage in a knee with normal anatomy is potentially greater, even in a one-time event. In recurrent patellar dislocation, there is usually less energy involved per event; however, each new event can cause additional injury, and the size of the lesion may increase with the number of dislocations [50]. With lateral patellar subluxation, the lateral patellar facet is relatively unloaded, while the convex median ridge contacts the relatively flat lateral trochlea, thus decreasing the contact area. In high degrees of trochlear dysplasia with a proximal trochlear boss, this effect is even more pronounced with the median ridge convexity contacting the convex trochlear boss. With overall similar PF forces, the decreased contact area results in increased point loading, thus increasing stress and promoting cartilage wear, typically in the median ridge and medial facet.

### 41.2.6 Chronic Malalignment/Maltracking Without Instability

Chronic maltracking is typically related to anatomic abnormalities, which include the same risk factors that may be associated with patellar instability. A common pattern is trochlear dysplasia, increased lateral quadriceps vector, and lateral soft tissue contracture. This creates an environment of lateral PF overload that may progress to lateral PF OA. As lateral PF OA progresses, lateral soft tissue contracture worsens, compounding symptoms of laterally based pain. Lesions in this setting are typically in the lateral PF compartment.

### 41.2.7 Direct Trauma (Fig. 41.4)

During a direct trauma over the patella, all zones of the cartilage and the subchondral bone can be injured in both the patella and trochlea, depending on knee position at the time of impact. This can cause macrostructural damage and chondral/osteochondral fracture or, with a subcritical force, cause microstructural damage and chondrocyte death, leading to subsequent delayed degeneration of cartilage. In the latter situation, the cartilage may look normal initially, until the matrix deteriorates over months to years. Direct trauma usually occurs with the knee flexed (i.e., fall, dashboard trauma). Therefore, these lesions are typically located in the distal trochlea and superior pole of the patella.

### 41.2.8 Repetitive Microtrauma (Fig. 41.5)

Repetitive microtrauma occurs when minor injuries, which by themselves do not result in immediately apparent chondral or osteochondral fractures, exceed the capacity of natural cartilage repair. Common causes include sports that require repeated jumping (i.e., basketball, volleyball) or long periods of time in a sustained flexed knee position (i.e., fencing). Typically, that results in chondral lesions in the central trochlea groove. These may also be associated with other lesions caused by extensor mechanism overload (i.e., quadriceps tendon or patellar tendon tendinitis, fat pad impingement syndrome).

### 41.2.9 Idiopathic (Fig. 41.6)

Idiopathic lesions may be related to genetic predisposition to OA and not restricted to the PF joint. Lesions are frequently not focal, with surrounding cartilage being also abnormal. Sometimes the PF joint is the first compartment to degenerate and the most symptomatic in the setting of what is truly tricompartmental disease. In the varus knee, lesions are usually in the medial PF compartment and associated with medial tibiofemoral compartment degenerative changes, while in the valgus knee lesions are usually in the lateral PF compartment and associated with lateral tibiofemoral compartment degenerative changes. In such cases, treatment of the PF lesion alone can result in functional failure due to progression of the disease in the other compartments. Thus, even mild disease in other compartments should be carefully considered and quantified with TF joint space assessment as well as hip to ankle coronal limb alignment.

## 41.3 Patient Evaluation

Effective treatment hinges on accurate diagnosis, obtained via history and physical examination. Unfortunately, no findings in history or clinical examination are pathognomonic for cartilage

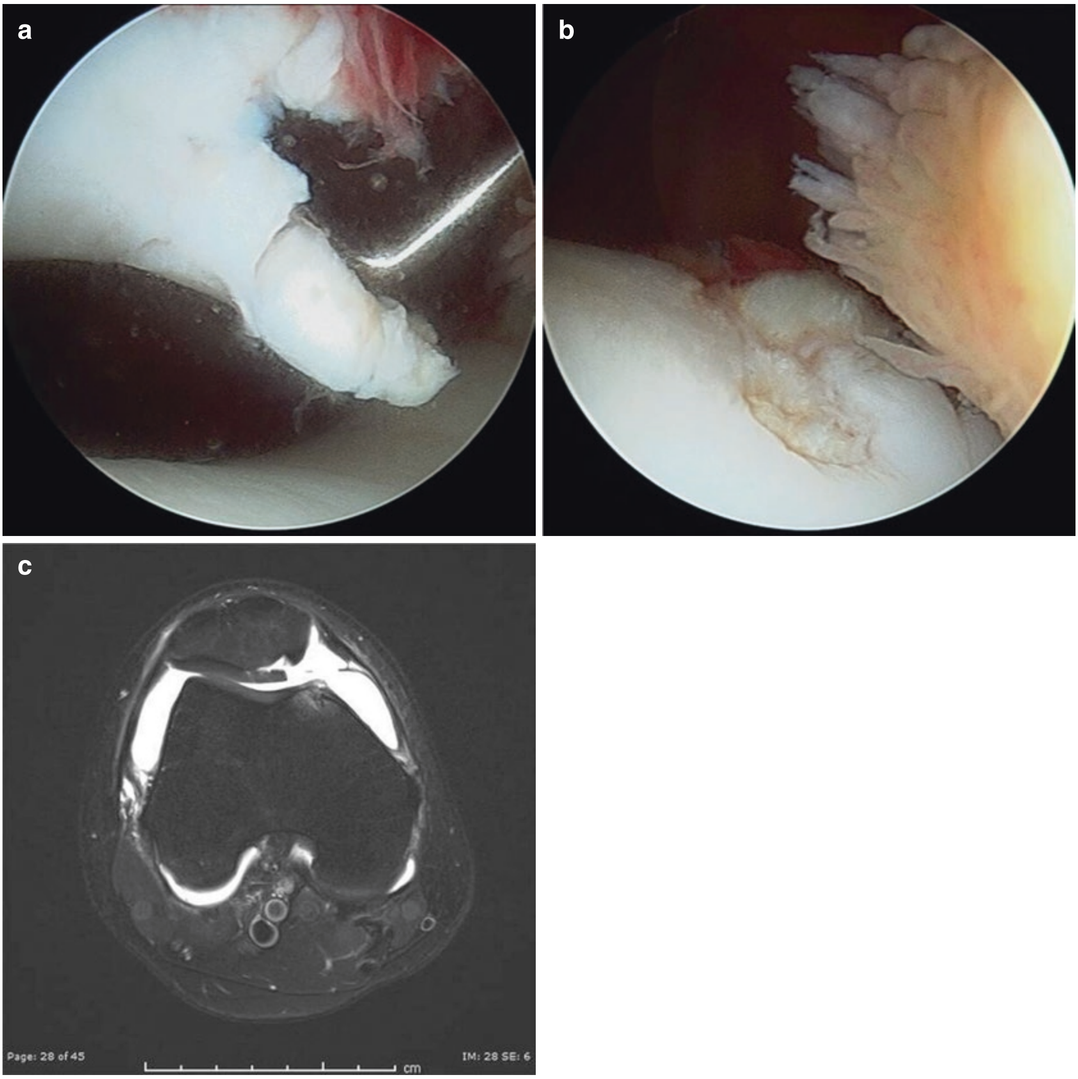

**Fig. 41.4** Lesion from direct trauma to the knee. Arthroscopic images showing a flap of detached cartilage in the patella (**a**) and a full-thickness chondral lesion in the trochlea (**b**). Corresponding MRI (**c**) (Courtesy of Jack Farr, MD)

defects versus other intra-articular derangements (i.e., meniscal tears). Direct traumatic etiologies and patellar instability are often associated with a specific event, such as a fall or twisting injury during sports (i.e., patellar dislocation, ACL tear, direct blunt force trauma). Idiopathic lesions, chronic maltracking, and those associated with repetitive microtrauma may have more of an insidious and progressive onset without an event the patient can recall.

As with all patients, the first step is a comprehensive history. The prototypical patient presents with symptoms of pain with PF loading (i.e., stairs, squatting) and swelling, and a subset of patients will report patellar instability. Typically, symptoms are worsened by walking on downslopes or stairs, especially down. Stairs demand the most knee flexion of all activities of daily living and place the greatest load on the PF joint. Jumping, running, squatting, and kneeling may also worsen one's pain [33]. Additionally, patients may have increased knee pain after prolonged sitting ("movie theater sign"). In the seated position, there is less load

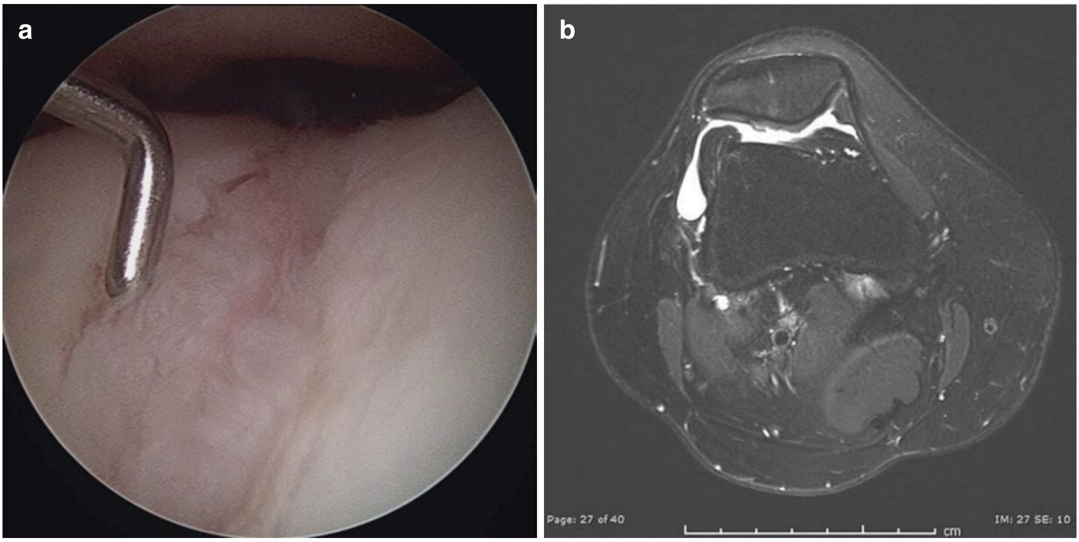

**Fig. 41.5** Lesion from repetitive microtrauma to the knee. Arthroscopic image showing a full-thickness chondral lesion in the central groove (**a**). Corresponding MRI (**b**) (Courtesy of Jack Farr, MD)

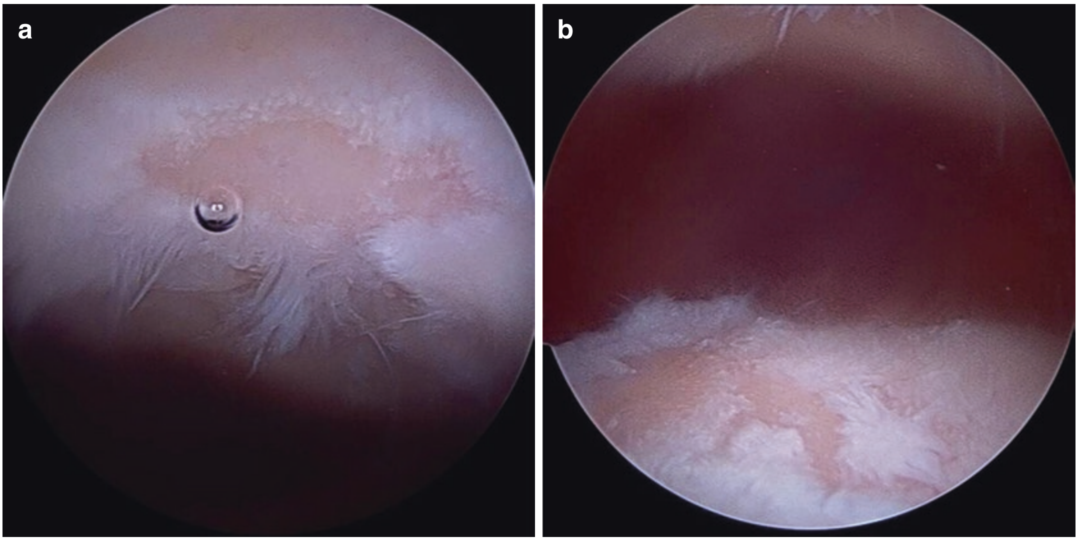

**Fig. 41.6** Idiopathic injury to the patella (**a**) and trochlea (**b**). Full-thickness chondral injury. Note that the surrounding cartilage is also abnormal (Courtesy of Jack Farr, MD)

than during flexed weight-bearing situations; however, the force vector of the quadriceps is perpendicular to the PF joint, and the PF contact is decreased, resulting in increased pressure in one fixed location. Symptoms are characteristically not worsened with walking on level ground [6]. Care should be taken to elucidate whether complaints are primarily related to pain or instability, and if pain, localization is critical. Activities and their relation to pain should also be investigated. Patients should be queried for the presence of activity-related effusions and/or mechanical symptoms of catching or locking. Swelling is common in PF cartilage lesions and more suggestive of the diagnosis than pain alone; it is important to know the degree, frequency, and relationship to activities. The overall mental state of the patient should also be assessed. Studies have shown that patients with a positive mindset and outlook about life measured by Short Form 36 (SF-36) are inclined to have better outcomes [51]. Documenting prior treatments and the response to them is essential to understanding the underlying pathology.

### 41.3.1 Physical Examination

Start by observing the patient's gait. A general knee exam should be performed including evaluation of coronal alignment, muscle bulk and tone, effusion, active and passive range of motion (ROM), and crepitus. The PF physical exam is explained in detail in other chapters. A pertinent PF exam should consist specifically on tenderness to location, PF alignment (quadriceps angle, Q-angle, during ROM), patella positioning (height, subluxation, and tilt), tracking evaluation, and stability testing. Tenderness to palpation should be localized to medial, lateral, distal, proximal, or retropatellar. PF pain is evident in 71–75% of people with tenderness on palpation of the patellar edges [52]. It should be scrutinized whether the presenting pain matches the location of the lesion. The best available test to observe PF pain is anterior knee pain elicited during a squatting maneuver [53]. Studies have shown PF pain is evident in 80% of people who are positive on this test [52]. It is also important, when possible, to ascertain at which degree of flexion the pain is worst and then investigate if the pain matches the location of the lesion (Fig. 41.1). Match between lesion location and pain is more reliable in smaller focal lesions, while a more "general" pain can occur with larger lesions in knees with degenerative changes.

### 41.3.2 Imaging Studies

Imaging should be used to evaluate PF alignment and cartilage lesions and to identify associated lesions (i.e., ligaments, meniscus).

Initial radiographs consist of bilateral weight-bearing anteroposterior (AP), posteroanterior (PA) flexion (45° PA, Rosenberg), 30° flexion true lateral, and low flexion angle axial views such as Merchant [54]. PF OA should be evaluated by the Iwano classification based on axial views. Stage I is classified as mild OA with joint space measures of at least 3 mm. Stage II is classified as moderate OA with joint space less than 3 mm, but no bony contact. Stage III is defined as severe OA with bony contact in less than one quarter of the joint surface. Lastly, Stage IV is very severe OA with the joint surfaces entirely touching one another [55]. Tibial or femoral deformities should be noted. In the tibiofemoral joint, the alignment is evaluated by the mechanical axis on long leg alignment view if needed. Rotational alignment can be evaluated by both CT and MRI [37]. Parikh et al. reported a method for using MRI cuts through the hip, knee, and ankle for measuring femoral anteversion and tibial torsion [56]. Femoral anteversion is the angle formed between the axis of the femoral neck and distal femur. By measuring the angle of the proximal tibia relative to the distal tibia, the degree of tibial torsion can be assessed. Knee rotation of the tibiofemoral joint is given by the angles between the distal femoral condyle line and the proximal tibial posterior condylar line. Normally, the femoral anteversion is 10–20°, tibial torsion is 25–41°, and the knee rotation angle is 5–9° [15, 37, 57, 58]. PF joint alignment is best evaluated by tibial tuberosity-trochlear groove (TT-TG) distance, TT-TG angle, and the tibial tuberosity-posterior cruciate ligament (TT-PCL distance) [59–62]. Values outside of asymptomatic control patients are TT-TG > 15–20 mm, TT-TG angle > 27°, and TT-PCL > 21–24 mm [15, 59–63]. Patella positioning is best evaluated by patellar height and tilt. Caton-Deschamps (CD) or Blackburne-Peel ratios are the standard of care for patellar height measurements as they change with tuberosity surgical movement, while the Insall-Salvati (IS) ratio does not [64]. Patella alta is defined by CD > 1.2 on radiographs [15, 65]. A threshold for patella alta on MRI is controversial but is probably slightly higher than on radiographs. Also important is the engagement between the patella and the trochlea in the sagittal plane. This can be measured by the patellotrochlear index, which does not directly correlate to the patella height measure by radiographs.

MRI should be utilized with cartilage-specific sequences, including standard spin-echo (SE) and gradient-recalled echo (GRE), fast SE, and, for cartilage morphology, T2-weighted fat suppression (FS) and three-dimensional SE and GRE [66]. In assessing cartilage function and metabolism, collagen network, and proteoglycan content in the knee cartilage matrix, consideration should be given to compositional assessment techniques (i.e., T2 mapping, delayed gadolinium-enhanced MRI of cartilage, T1ρ imaging, sodium imaging, diffusion-weighted sequences) [66]. Use of the latter functional sequences is still debatable and they are less broadly available. With these techniques, clinicians can assess joint morphology and assess the progression of cartilage defects and OA. However, the identification and evaluation of deeper lesions (grades 3 and 4) may be more precise than partial thickness lesions (grades 1 and 2) that can be missed (Fig. 41.6). Further, MRI can often underestimate the defect area. On average, defects are ~65% larger than measured by MRI [67]. Most treatment algorithms are dependent on the size of cartilage defects, and as such, imaging misdiagnosis has the potential to adversely affect treatment decisions [67]. Furthermore, it is important to observe the status of the subchondral bone. Bone signal change (radiologists use bone marrow edema, while others prefer bone marrow lesions or bone marrow stress reactions) suggests that the lesion is symptomatic [68]. Also, particularly if surgical treatment is planned, intralesional osteophytes [69, 70], signs of prior failed microfracture [71–73], prior fracture malunion, significant subchondral bone edema or cyst formation, and bone loss due to fracture or osteochondritis dissecans fragment excision [74] should be noted as they are important factors in the treatment decision-making process.

## 41.4 Treatment

When designing a treatment strategy, it is important to know which lesions are symptomatic, which patients have the potential to improve with nonoperative treatment, and which will probably require surgical intervention.

### 41.4.1 Which and Why Lesions Are Symptomatic?

After ruling out other causes of anterior knee pain leaving the diagnosis, PF pain, this still does not assign the pain to the chondrosis. Typically, pain from PF cartilage lesions is stemming from subchondral bone overload and/or synovial impingement. Arthroscopy or MRI can aid in ruling out synovial impingement. Left with chondral associated bone overload pain as the working diagnosis, it is aggravated by activities that increase PF loading. Ideally, the location of pain should be related to the location of the lesion seen on MRI. Deep lesions with underlying subchondral bone stress reaction are more likely to be symptomatic than superficial lesions without bone reaction. Lesion symptoms are related to the forces in that area, which are higher than what the damaged structure can support. As a result, symptom improvement can occur by decreasing the forces in the lesion area through nonoperative treatment (therapy, bracing, activity modification) or unloading surgical procedures and by improving the load-bearing capacity of the local structure through repair of damaged cartilage and bone.

### 41.4.2 Nonoperative Treatment

The initial management for most PF articular cartilage lesions consists of rest, weight loss, activity modification, anti-inflammatory medications, and “core to floor” physical therapy. Most patients will experience pain relief with physical therapy and can therefore avoid surgical treatment [75, 76]. A consensus from the 2016 International Patellofemoral Pain Retreat made recommendations with the aim to guide medical and health practitioners in the treatment of PF pain: (1) Exercise-therapy is recommended to reduce pain in the short, medium, and long term and improve function in the medium and long term. (2) Combining hip and knee exercises is recommended to reduce pain and improve function in the short, medium, and long term, and this combination should be used in preference to knee exercises alone. (3) Combined interventions are recommended to reduce pain in adults with patellofemoral pain in the short and medium term. (4) Foot orthoses are recommended to reduce pain in the short term. (5) Patellofemoral, knee, and lumbar mobilizations are not recommended. (6) Electrophysical agents are not recommended. In addition, wearing a brace or sleeve reduces the lateral translation of the patella; however, braces reduced lateral displacement more than sleeves. Furthermore, braces reduce patellar tilt near full extension, while sleeves have no effect on patellar tilt [77]. These measures are intended to be used in combination with individualized assessments of the specific patient's needs, preferences and presentations, and clinical expertise to inform patient-centered care [78].

These measures should be exhausted (between 3 and 6 months) before proceeding with surgical treatment. The threshold for indicating surgery is lower in traumatic lesions in young patients than in older patients with idiopathic/degenerative lesions. Injections in the form of corticosteroids, viscosupplementation, or platelet-rich plasma (PRP) may help decrease inflammation and improve symptoms in certain patients, specifically older individuals with degenerative disease with the goal of preventing/delaying arthroplasty [79–85]. In younger patients with well-preserved articular surfaces outside the symptomatic lesion, it is reasonable to attempt one or two injections, but repeated injections are not recommended.

### 41.4.3 Operative Treatment

Surgical indications and contraindications are listed in Table 41.1.

**Table 41.1** Surgical indications and contraindications for isolated chondral/osteochondral PF lesions

| Surgical indications | Surgical contraindications |
|---|---|
| Acute chondral or osteochondral injury with displaced fragment | Incidental lesions |
| Symptomatic unstable osteochondritis dissecans (OCD) lesions | Active or recent knee infection |
| Symptomatic full-thickness or near-full-thickness lesions (≥ICRS 3a) | Inflammatory arthritis |
| Normal or nearly normal joint space (Iwano 1 or less) | Significant medical comorbidities |
| Failure of ≥3–6 months of conservative treatment | Body mass index (BMI) ≥35 |
| | Tobacco use |
| | Chronic pain management |
| | Inability to follow postoperative protocol |

A subset of patients fail nonoperative measures, presenting with persistent symptoms despite a comprehensive core to floor rehabilitation program that has provided improvements in flexibility, dynamic strength, and neuromuscular status. A subset of patients may not be able to progress with rehabilitation due to pain. Those patients may be considered surgical candidates. Once again, it deserves emphasizing that incidental lesions found on MRI or arthroscopy should not be treated surgically. Surgical treatment options include arthroscopic chondroplasty, correction of comorbidities, unloading procedures, and cartilage restoration. Simple arthroscopic debridement and chondroplasty can be attempted as a first-line treatment in many cases, specifically in smaller lesions in older patients with more degenerative lesions. Larger lesions in young patients with no significant chondrosis other than the lesion start with an arthroscopic debridement to precisely determine the lesion area and depth in preparation for advanced cartilage restoration procedures, and thus the term "staging arthroscopy" is useful in conveying the expectations after this procedure. Cartilage restoration is indicated for full-thickness or near-full-thickness lesions (≥ICRS 3a) (Fig. 41.7) typically greater than 1 $cm^2$ after failed adequate

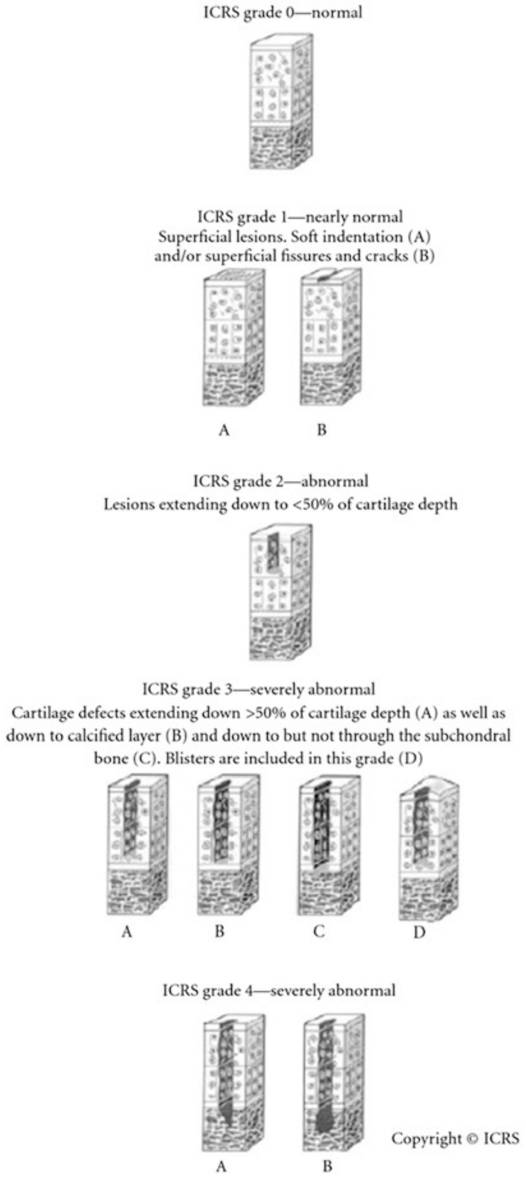

**Fig. 41.7** International Cartilage Repair Society (ICRS) articular cartilage injury classification system. (Image kindly provided and reprinted with permission by the International Cartilage Repair Society)

conservative treatment. Patients with direct trauma, repetitive microtrauma, or chronic maltracking without instability are more likely to benefit from cartilage restoration than patients with patellar instability without maltracking that rarely have symptoms unless in the setting of associated large cartilage defects or patients with idiopathic lesions that are associated with tricompartmental disease and, thus, are not good surgical candidates. Choosing a surgical treatment is based on lesion characteristics, such as the location within the knee joint (i.e., TFs vs. PF), location on the involved articular surface (i.e., distal vs. proximal patellar pole), size, depth (i.e., involvement of the subchondral bone), containment (i.e., contained vs. not contained), as well as on patient characteristics including age, body mass index (BMI), limb and extensor mechanism alignment, and activity level [86].

Optimization of anatomy and biomechanics is critical, as persistent abnormalities lead to high failure rates of cartilage procedures, while correction of these factors results in outcomes similar to those of patients with normal anatomy [87]. The most commonly performed procedures to correct patellar tracking or unload the PF compartment are lateral retinacular lengthening and tibial tuberosity osteotomy (TTO), medialization and distalization to address malposition of tibial tuberosity and patellar height; anteriorization can be added for unloading. AMZ specifically unloads the lateral and distal patella and lateral trochlea, while straight anteriorization unloads the central trochlea and distal patella [88, 89]. The procedures can improve symptoms and function in lateral and distal patellar and lateral trochlear lesions even without the addition of a cartilage restoration procedure [90]. Therefore, in older patients with more diffuse changes, osteotomies alone can provide significant pain relief [91, 92], while associated cartilage restoration is preferred in younger patients with focal cartilage lesions.

Some cartilage repair techniques appear more sensitive to location than others, and there is an increasing consensus that microfracture (MFx) should only be used judiciously in the PF compartment, while other surgical techniques such as autologous chondrocyte implantation and osteochondral allograft have demonstrated adequate long-term results [93, 94]. Very little high-quality evidence supports the use of MFx for the management of PF cartilage lesions [95]. For MFx of the patella, it can be difficult to obtain a perpendicular angle of approach arthroscopically [32].

Moreover, the outcomes following MFx in the PF compartment tend to decline after 18–36 months [93]. Interestingly, in a recent systematic review, the majority of patients were treated with ACI (45.5%) and MFx (29.6%), with a significant increase in the use of the third-generation ACI and decreased usage of MFx from 2013 to 2018 ($p < 0.001$) [94].

The overall complication rate of PF cartilage restoration techniques is 9.2% [94]. When comparing factors that may contribute to poor outcomes between surgical techniques, it becomes controversial and contentious between studies, particularly when comparing between sex, etiology of lesions, bipolar versus unipolar lesions, trochlear versus patellar lesions, location of lesion in the patella, and lesion size. Other factors may be more agreed upon. Several studies have found age (within a common range of 15 and 55, and common mean between 31.2 and 33.3) not to influence clinical outcomes, for example, autologous chondrocyte implantation (ACI) [87, 96, 97], particulated juvenile articular cartilage (PJAC) allograft [98], matrix-induced autologous chondrocyte implantation (MACI), and bone marrow aspirate concentrate (BMAC) implantation [99].

Regarding concomitant TTO, when TTO was performed selectively to correct maltracking, various authors found no differences in clinical outcomes between patients who had TTO or not, associated with ACI [87, 96, 97, 100, 101], scaffolds [102], and PJAC [98]. However, this must be interpreted not that TTO is not necessary, but rather, with the proper indications in select patients, TTO can allow cartilage restoration results equal to patients who do not “need” TTO. (Note that subluxed patella that is not corrected does poorly with cartilage restoration as per Brittberg [103].) Wang et al. [98] additionally found no differences in MRI scores. Tompkins et al. [104] found patients treated with PJAC and concomitant TTO had lower visual analogue scale (VAS) scores, but there were no differences in other scores. Regarding combined factors, Kon et al. [105] found that MACI in women with patellar lesions requiring realignment had a combination of factors that synergistically led to the worse outcomes among PF cartilage lesions. Kreuz et al. [106] also found that female patients with lesions in the PF, specifically in the patella, had worse results compared with male. In male, there were no differences in the results between tibiofemoral and PF compartments.

In summary, careful consideration of indications, as well as the multiple factors involved in surgical decision-making, is critical to achieve successful outcomes.

## 41.5 Conclusions

PF chondral lesions remain a challenging issue, as nonsurgical treatment is frequently unsuccessful, and surgical treatment must carefully consider and correct PF comorbidities [64]. With careful indications and surgical technique, good outcomes can be achieved in a majority of patients.

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# 42

# Partial Lateral Patella Facetectomy and Management of the Lateral Soft Tissues

Seth L. Sherman, Joseph M. Rund, and Jack Farr

## 42.1 Introduction

Isolated patellofemoral osteoarthritis (PFOA) is a relatively common pathology affecting 9–15% of patients older than 40 and 60 years, respectively [1]. However, clinical symptoms do not always correlate with the presence of PFOA on radiographic imaging. When considering symptomatic subjects, the prevalence of isolated patellofemoral cartilage degeneration ranges from 5% to 8% [1, 2]. Although the medial and lateral facets of the patella can each be affected by isolated PFOA, 89% of all isolated PFOA cases initially involve the lateral facet of the patella [3]. The typical presentation of PFOA on radiographs begins with narrowing of the lateral PF compartment joint space. The hallmarks are patellar tilt, indicative of lateral compression and malalignment, often with some degree of lateral patella positioning relative to the trochlea. Over time, the degeneration and excessive lateral patella compression syndrome (ELPCS) worsens [4]. As the joint space narrowing progresses, the lateral facet remodels into a concave shape and begins to impinge at the lateral trochlea/lateral femoral condyle. Untreated ELPCS and/or persistent lateral patella tracking is characterized by increased lateral patella soft tissue fibrosis, medial retinaculum strain, inflammation, lateral retinaculum shortening, cartilage damage, and eventually bipolar PFOA [5]. On physical exam, ELPCS manifests as lateral patella facet tenderness, a negative passive patella tilt test, and painful crepitus into deeper flexion [6]. Advanced lateral patellar tilting and degenerative changes can be seen on radiographs (Fig. 42.1) [5].

Within the isolated PFOA patient population, 78% present with evidence of trochlear dysplasia [7]. Of these, 55% present with moderate to severe dysplasia (Dejour type B or D, respectively) [5, 8–11]. Trochlear dysplasia may lead to altered articular cartilage loading, which over time may be associated with progressive cartilage damage. Patellar tracking is complex and variable due to multiple factors that influence the direction and magnitude of forces at the patellofemoral joint. These factors include trochlear geometry, patellar shape, patellar height, tibial tubercle-trochlear groove/posterior

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**Fig. 42.1** Advanced lateral patellofemoral degeneration and suggestion of lateral patellar tilt

cruciate ligament distances (TT-TG and TT-PCL, respectively), muscle imbalances, and ligamentous structures. Valgus alignment may contribute to increased pressure in the lateral patellofemoral compartment and likewise increase the risk for osteoarthritis in the lateral compartment [4].

PFOA can cause severe disability and have a considerable impact on a patient's activities of daily living, including difficulty with stairs or squatting [2]. Pain is usually experienced during activities that require deep flexion of the knee, resulting in limitation especially in young, active patients [4]. Despite this high incidence, evidence-based medicine offers little guidance on an optimal algorithm for best practices for conservative or surgical treatment and an optimal time to implement [12].

When symptomatic treatment of PFOA is necessary in the healthy middle-aged population, it is very challenging and controversial [13]. Due to unclear causes of pain and poor correlations between clinical symptoms and cartilages lesions, treatment decisions are difficult [14, 15]. Once conservative therapies have failed, surgery is considered, and many different treatment solutions exist. The success of surgical procedures is highly contingent upon patient selection, technique, and compliance with rehabilitation. Relieving pain and preserving the mechanical advantage of the patella for normal knee function are the goals of surgical treatment [13]. Although isolated PFOA can be treated with more aggressive procedures including patellofemoral arthroplasty (PFA) or unloading osteotomy, a partial lateral patella facetectomy (PLPF) is a less aggressive intervention and effective in carefully selected patients. In addition, it does not preclude PFA in the future (noting that the lateral facet is routinely removed during PFA) [16, 17].

PLPF to treat PFOA was first introduced by O'Donoghue in 1972 [18]. Through removing the eroded lateral aspect of the patella, articulation between patellar bone and trochlea cartilage/exposed bone is no longer present. Excising the lateral 15 mm of lateral facet both relieves soft tissue impingement from lateral osteophytes and effectively lengthens the lateral retinaculum, which aids in reducing ELPCS [12]. This technique improves patella mobility and provides relief of anterior knee pain by removing extensive pressure from the lateral facet of the patella. PLPF also provides a relatively fast recovery period and minimal morbidity following surgery [4]. PLPF is a straightforward and effective surgical treatment for isolated PFOA in active middle-aged patients that aids in maintaining pre-morbidity physical activity level [5, 12, 13, 19]. Through improving knee pain and function, PLPF also has the capability of delaying PFA or total knee arthroplasty (TKA) [4].

## 42.2 Concomitant Procedures

PLPF has been employed alone or in combination with other procedures such as anteromedialization of the tibial tubercle [4, 5, 12, 19]. Isolated PLPF does not realign the patella in the trochlear groove [19]. Loss of cartilage at the lateral facet shifts the patella laterally and adds to patellar tilt. The lateral facet/lateral trochlear stress progressively increases [4]. In younger or higher-demand patients with abnormally high TT-TG/TT-PCL and a subluxed patella, anteromedialization of the tibial tubercle may be indicated as a concomitant unloading-type procedure.

If patellar tilt persists after removing the facet, then lateral retinacular lengthening (LRL) is typically performed. PLPF achieves bony decompression, while the LRL improves patella-trochlear engagement through range of motion [20]. Both lateral retinaculum lengthening and release (LRR) are effective in the treatment of lateral retinacular tightness. In the past, LRR quickly gained popularity because of its technical simplicity. However, use of LRR, alone or as a concomitant procedure, has the potential for iatrogenic medial patellar laxity and persistent or chronic pain at the defect site [21]. LRL was introduced to address lateral retinacular tightness while maintaining lateral soft tissue integrity, avoiding risk of over-release and iatrogenic instability [22]. Two prospective randomized studies found that return to athletic activities and functional knee outcomes were superior after LRL compared to LRR [23, 24]. At present, LRL is recommended to address lateral retinacular tightness offering improved outcomes and reduced complication rates as compared with LRR.

Additionally, partial lateral patellar facetectomies have been performed concomitantly with patella-retaining total knee arthroplasties (TKA). Following TKA procedures, the patella is the area of the greatest functional load. Studies have shown that the patella tracked 3–5 mm more laterally following the placement of the prosthesis [25]. Due to lateral maltracking, patellar contact pressures have been demonstrated to be increased in TKAs when compared to normal knees [26–28]. It has been reported that 5–10% of TKA patients had anterior knee pain following surgery [29]. Postsurgical pain reduces patient satisfaction, limits postoperative physical activity, and is a frequent cause of revisions [30, 31]. Among surgeons, resurfacing or patellar non-resurfacing in TKA remains a controversial topic [32–34]. According to the National Joint Registry of England and Wales, 67% of primary total knee replacements were performed without patellar resurfacing. Most surgeons believed that the benefits of patella resurfacing did not outweigh the risks. Patellar complications such as patella fracture, prosthesis wear, and future loosening of the implant could be avoided [32, 35, 36]. However, studies have shown that TKA with patellar non-resurfacing is associated with an increased anterior knee pain incidence and progressive lateral facet degeneration [37–39]. Conversely, concomitant PLPF can reduce the peak patellofemoral contact pressure in patellar non-resurfacing TKA [40]. Through reducing lateral contact pressure, PLPF following TKA has revealed improvements in both the clinical and functional scores of patients [25]. Finally, lateral facet excision is commonly a routine portion of PFA as the patellar button is medialized and downsized, both of which allow a more centrally tracking patella.

## 42.3 Case Study

A 53-year-old male presented with a history of remote traumatic injury to the anterior right knee as a child, which was treated non-operatively. The patient did reasonably well until the past few years when he noted the onset of worsening anterolateral right knee pain. The patient experienced activity-related swelling, mechanical symptoms, and difficulty squatting or going down stairs. The patient's pain occurred at night and interfered with his ability to work. The patient's symptoms were treated with medication, activity modification, bracing, and an exercise program

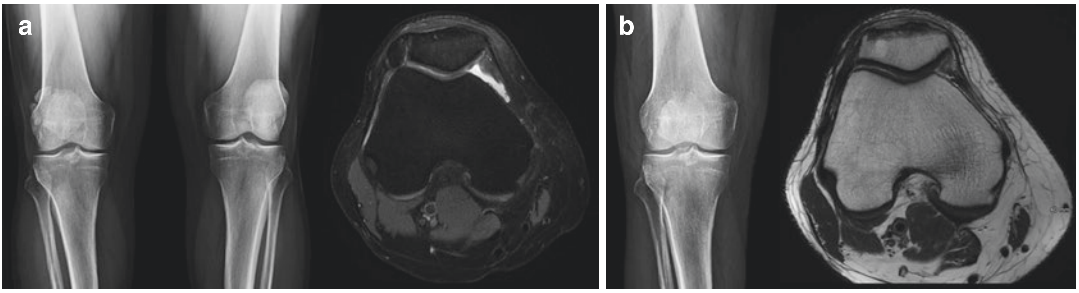

**Fig. 42.2** AP radiograph and axial MRI showing lateral patellar facet non-union on preoperative imaging (**a**) and lateral patellar facet excision at 1-year follow-up imaging (**b**)

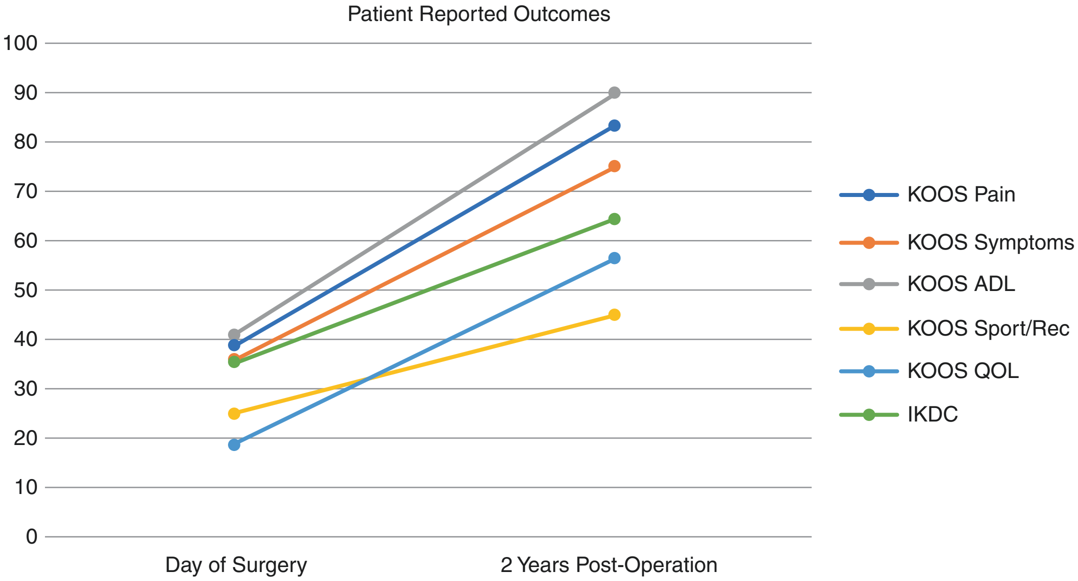

**Fig. 42.3** Patient-reported outcome scores greatly improved from the day of surgery to 2-year follow-up. *KOOS* Knee Injury and Osteoarthritis Outcome Score

without relief. Physical examination and imaging were consistent with ELPCS and lateral patella facet non-union (Fig. 42.2a). Surgical treatment included lateral-based arthrotomy with non-union excision, PLPF, and LRL. Standard rehabilitation protocol was followed including weight-bearing and ROM as tolerated.

Final imaging revealed successful lateral patella fragment excision and a well-balanced patella with normal soft tissue tension (Fig. 42.2b). At 2-year follow-up, the patient was taking no medications for pain, able to work full duty, and could participate in all activities that he desired. He demonstrated marked improvement in all subjective outcome scores (Fig. 42.3).

## 42.4 Treatment Plan

First-line treatment for PFOA is always non-operative. Conservative management includes activity modification, nonsteroidal anti-inflammatory medications, patellar bracing, biologic injections, and “core-to-floor” physical therapy and should be pursued for at least 6 months [13]. Physical therapy for the relief of pain in the patellofemoral compartment focuses on patellar taping; strengthening of core, posterior chain, and quadriceps muscles; and joint mobilization [41]. Even though patellofemoral pain can be significantly reduced after a physical therapy program, for many patients unacceptable pain persists [41]. Patients that do not respond to conservative treatment and continue to exhibit evidence of lateral facet pain and disability, surgical treatment may be required [42].

## 42.5 Surgical Indications and Contraindications

Following failure of conservative treatment, PLPF is indicated in patients with refractory anterolateral knee pain and isolated lateral PFOA, overhanging lateral facet of the patella, and lateral patellar osteophytes [43]. Important correlates upon physical examination are localized lateral patellar tenderness, positive passive patellar tilt test, and excess lateral patellar tilt on imaging (true lateral radiograph or CT/MRI which allows referencing the posterior condyles) [44]. LRL is indicated concomitantly with PLPF if lateral retinacular tightness and lateral patellar tilt persist following bony resection. The combination of PLPF and LRL treats all relevant bony (i.e., prominent lateral facet with osteophytes) and soft tissue pathology (i.e., tight lateral retinaculum). In cases of severe lateral cartilage loss and profound malalignment (Q angle >20°), isolated LRR without facetectomy may lead to suboptimal outcomes. Similarly, PLPF without LRR may lead to persistent patella tilt, soft tissue imbalance, and refractory painful symptoms. Lastly, PLPF can be performed concomitantly with a patella-retaining TKA or PFA [5]. The main relative contraindications are diffuse patellofemoral joint bipolar chondral disease, inflammatory arthritis, patellar hypermobility, and more global tricompartmental degenerative disease [44].

## 42.6 Surgical Technique

The patient is placed supine on the operating table. A bilateral knee examination under anesthesia is performed to evaluate possible concurrent pathology and to assess patella position, patella mobility, and patellar crepitus during knee range of motion [43]. A thigh tourniquet is placed on the upper thigh of the operative leg, as high as possible, and may be inflated after limb exsanguination [13]. Sterile preparation and draping are performed. A sterile bump or leg holder is utilized to comfortably place the knee at 30°.

### 42.6.1 Arthroscopic Technique

Standard arthroscopic portals are established, and a 30° arthroscope is placed. The surgeon may opt to move the anterolateral portal somewhat peripherally and proximally to ease access to the lateral aspect of the patellofemoral joint [43]. Accessory lateral portal may be established through the lateral retinaculum, as necessary. Comprehensive arthroscopic examination of the entire knee is then performed to inspect for and treat any associated lesions (i.e., hypertrophic fat pad, synovitis). An arthroscopic shaver is then inserted into the knee. Chondroplasty is performed for loose and unstable chondral flaps, and any loose bodies are removed [43]. To directly visualize the impingement of the lateral patellar facet against the trochlea, patellar tracking is observed through range of motion arc [43].

Next, a probe is used to measure and outline the area on the lateral patellar facet that is to be resected. After positioning the knee to 20° of flexion, a 5.5 mm burr or power rasp is inserted. The lateral patellar osteophyte and overhanging aspect of the lateral facet is cautiously resected under arthroscopic visualization (Fig. 42.4). Usually, the width of the burr or power rasp is the minimal amount of bone desired to be resected [43]. To obtain adequate visualization throughout the entire resection, it is often preferable to begin resection inferiorly. Following the bone resection, the knee is re-evaluated through flexion, extension, and patellar medial excursion. Patellar tracking is assessed in order to assure improvements in patellar mobility and to verify the absence of remaining impingement and/or catching. If there is residual impingement, it is addressed once again with the burr or rasp [43]. The remaining patella should be parallel to the trochlear surface following resection. If the patellar superolateral aspect is problematic to reach, a

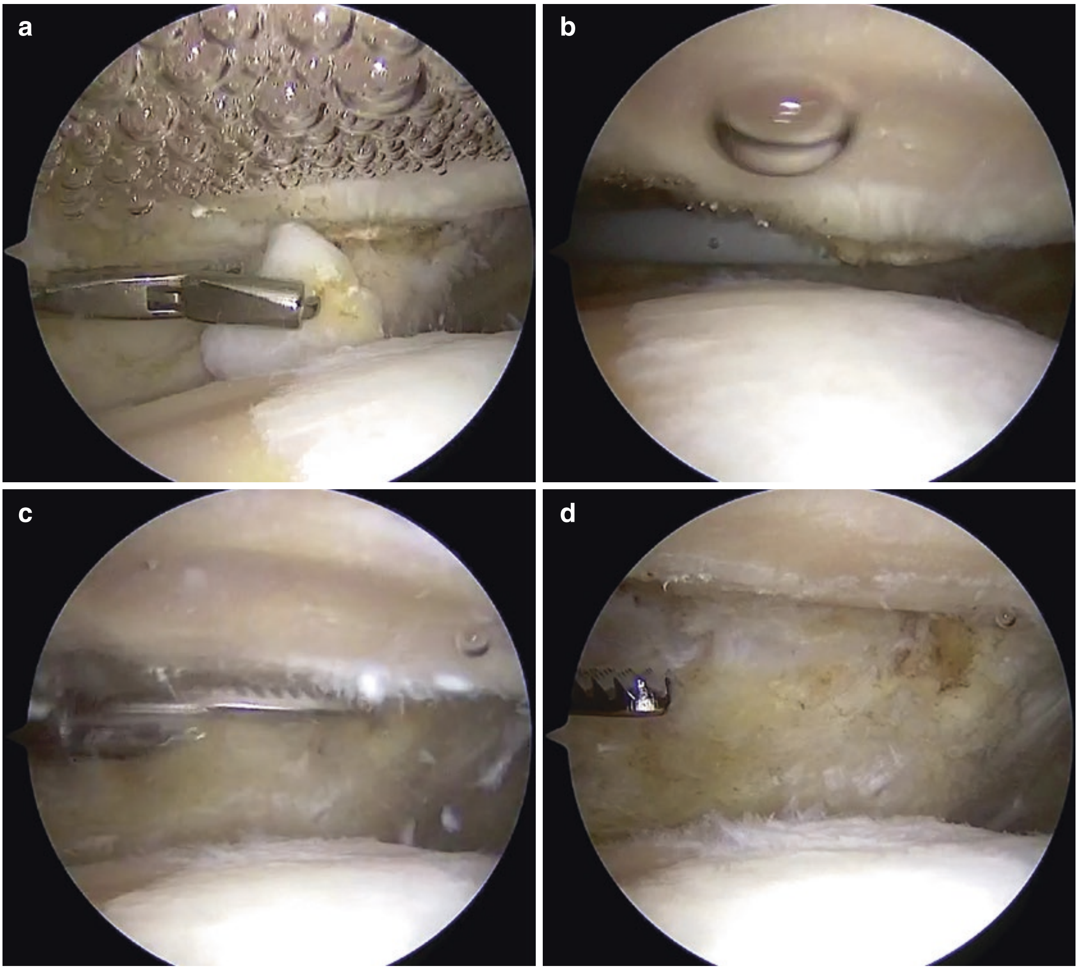

**Fig. 42.4** Arthroscopic partial lateral patella facetectomy technique: With a medial view of the lateral patellar facet, a large broken-off loose body was mobilized and removed (**a**). The prominent lateral patellar osteophyte was then visualized (**b**). Lateral facetectomy was achieved with a power rasp (**c**). The lateral patellar facetectomy was performed (**d**), and the osteophyte removal was completed. The resection goal was to remove any causes of lateral soft tissue impingement and to make the resection plane parallel to the trochlear surface

third portal is established. It is extremely important to carefully resect any remnant osteophytes that could potentially impinge upon the lateral trochlea during range of motion. If there is any question as to the adequacy of the resection, the patella is visualized with fluoroscopy. Following bony resection, lateral retinaculum soft tissue tension is assessed again, and decisions are made regarding the need for combined LRR or LRL. Arthroscopic portals are closed with nylon suture, and a compressive dressing is added to decrease the risk of hemarthrosis [43].

### 42.6.2 Open Technique

For open PLPF, the knee is assessed arthroscopically, and other pathologies are treated as above. From the superior edge of the patella to directly above the joint line, a 3–5 cm anterolateral skin incision is made, which often incorporates the anterolateral arthroscopy portal [5]. The skin incision and subcutaneous layer are mobilized using retractors to expose the lateral facet. The deep incision is through the prepatellar layers of the knee (continuation of quadriceps and patellar tendon and periosteum) to the level of bone directly in line with the planned osteotomy. A subperiosteal elevation exposes the full lateral facet of the patella to allow entering the joint and exposing the full extent of the osteophytes [12, 13]. The patella can then be everted to reassess the articular surfaces of the patella and trochlea as well as associated osteophytes.

The initial osteotomy line is modified to remove approximately 15 mm of the lateral facet and all osteophytes [13]. A saline-moistened sponge is placed under the patella to protect the trochlea. An oscillating or sagittal saw cooled with saline creates the osteotomy. The lateral patellar facet is then excised, and any trochlear/LFC osteophytes are removed (Fig. 42.5). If the edges of the articular surface of the lateral patellar facet are not smooth, a rongeur or rasp can be used [5]. More lateral facet bone may be removed, but at some level, this may compromise a future PFA and should be avoided. Hemostasis is confirmed, and the soft tissue incision is re-approximated [44].

After the deep incision is closed, patellar tilt is reassessed. If the lateral retinaculum remains unacceptably tight, a release or lengthening may be pursued prior to wound closure. For LRR, starting at the distal end of the vastus lateralis, the lateral retinaculum is incised about 1 cm lateral to the patella and extended distally along the lateral margin of the patellar tendon. If tightness in deep flexion persists, further distal extension can be performed to the level of the tibial tubercle. When the lateral tilt is reversed to neutral with the knee extended, the lateral retinaculum is sufficiently released [12]. With the lateral retinaculum remaining divided, the skin is then closed.

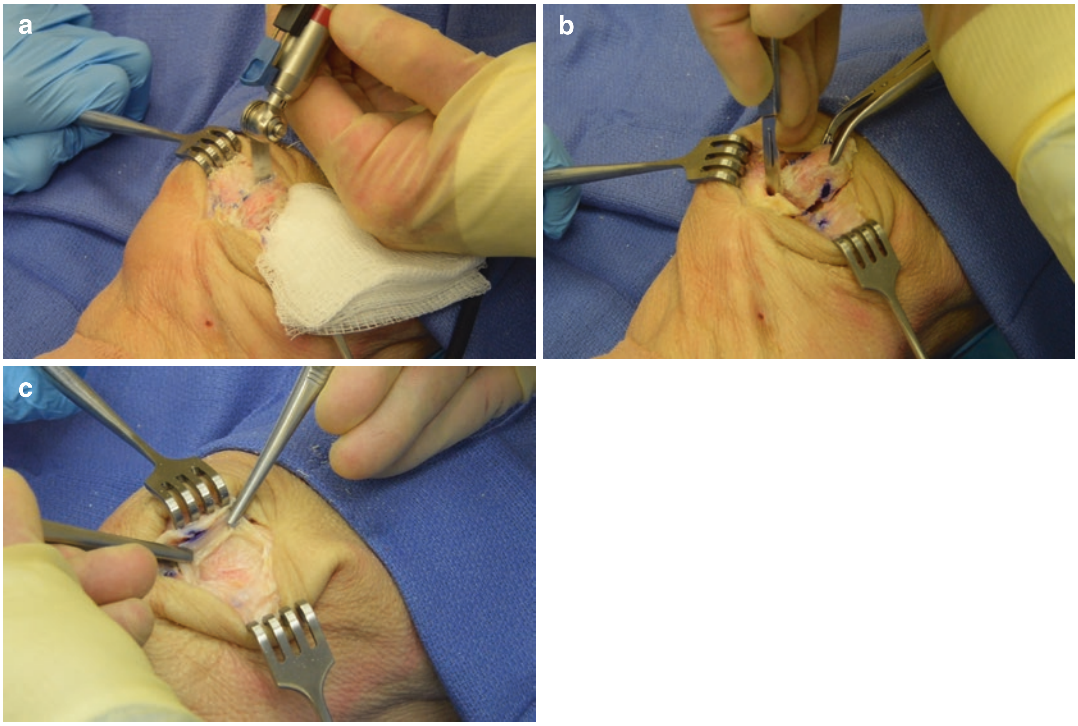

**Fig. 42.5** Open partial lateral patella facetectomy technique (cadaver): The soft tissues anterior to the patellar are incised in line with the planned osteotomy. A subperiosteal dissection exposes the lateral facet dorsum. (**a**) A sagittal saw creates the osteotomy 15 mm from the lateral patella margin (lateral facet). (**b**) Lateral facet and associated osteophytes are then sharply dissected from the quadriceps and patellar attachments. (**c**) The soft tissue incision is repaired at the new lateral margin of the patella. If necessary, a limited lateral release (superficial oblique layer only is shown here) may be performed. Alternatively, the incision may be left open, or lateral lengthening or formal lateral release may be used to effect soft tissue balance

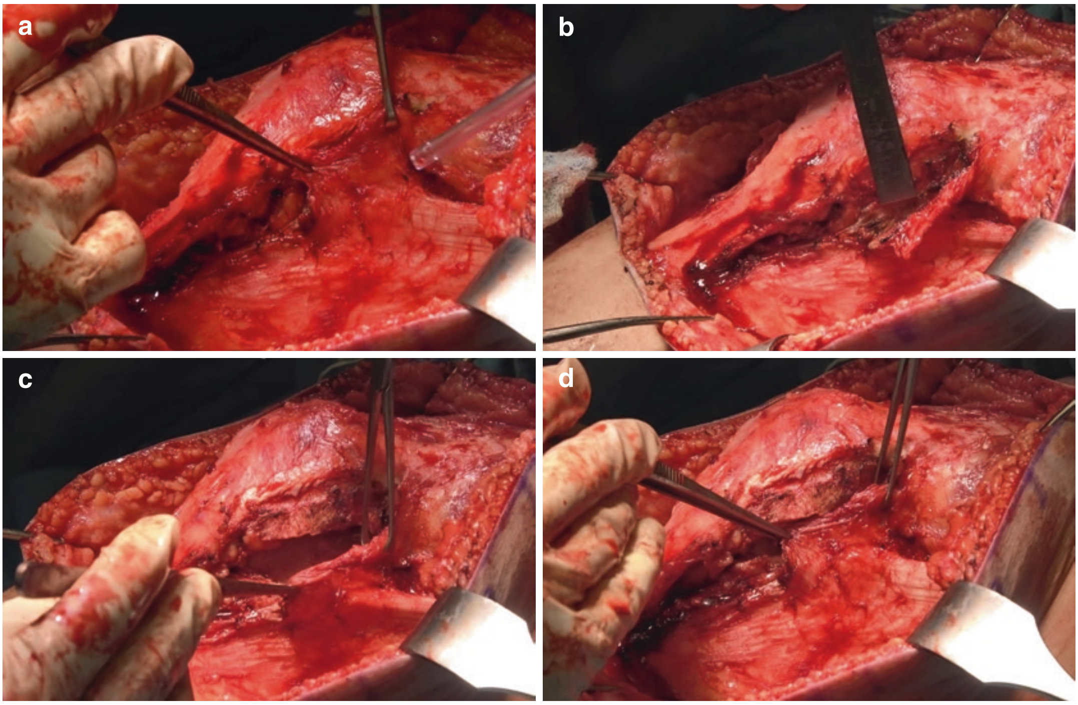

**Fig. 42.6** Lateral retinaculum lengthening technique: The superficial oblique layer is incised near the lateral patellar border and dissected from the deep transverse fibers (**a**). The deep transverse layer is longitudinally incised 2 cm from the patella (**b**). The approximate edges of the superficial and deep layers are visualized (**c**). With the patella centered on the trochlea at 30°, the incised edges of the superior oblique and deep transverse fibers are then sutured together with absorbable sutures (**d**). Approximately 2 cm of lengthening is obtained

For the more preferred LRL technique, the superficial oblique layer of the lateral retinaculum coursing from the anterior iliotibial band is incised at the level of the pre-excision lateral facet margin. The incision begins at the level of the proximal patellar pole and extends distally to the level of inferior patellar pole. This layer is sharply elevated from the deep transverse layer of the lateral retinaculum for 1.5–2 cm [45]. The deep transverse fibers are then longitudinally incised 1.5–2 cm posterior to the initial longitudinal superficial incision. The capsule and synovium are incised at the same level to enter the joint (Fig. 42.6) [21]. Following PLPF, the incised edges of the superior oblique and deep transverse fibers are then sutured together with the patella engaged centrally in the trochlear groove with the knee flexed. To assess for adequate soft tissue balance without overconstraint, the knee is taken through full range of motion arc, and patella tracking is reassessed [20]. Standard wound closure and compressive wrap are placed. Patients are usually discharged home on the same day. The overall result of the combined open procedure is bony decompression of the lateral patellar facet and elongation of the lateral retinaculum (Fig. 42.7).

## 42.7 Arthroscopic vs. Open

Arthroscopic PLPF allows for concurrent diagnosis and treatment of intra-articular pathologies. Through arthroscopic PLPF, the lateral retinaculum is preserved, which results in avoiding the possible complication of iatrogenic medial patellar instability. Minimal soft tissue disturbance with arthroscopy also allows for early mobilization within the rehabilitation protocol. In order to ensure that adequate resection has been performed, patellofemoral articulation can also be dynamically assessed during arthroscopic surgery [43].

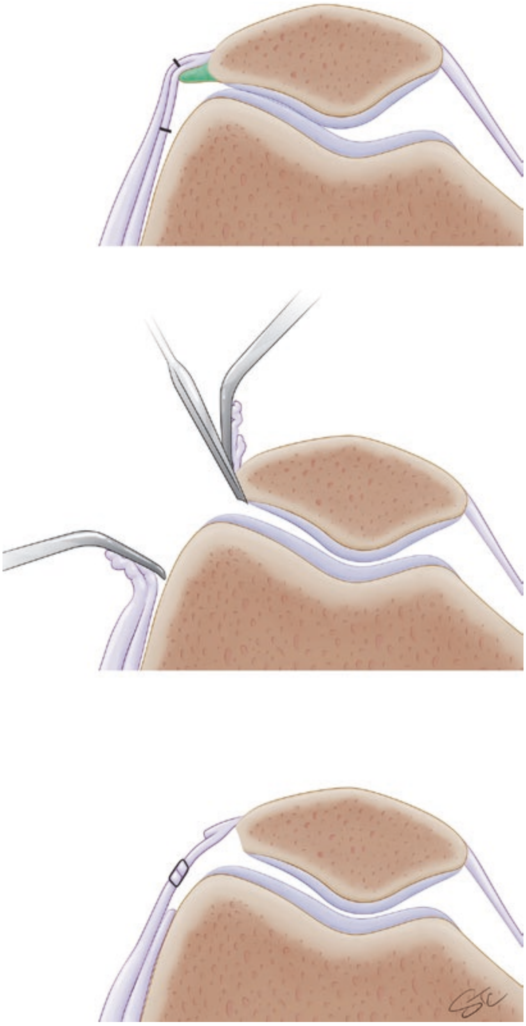

**Fig. 42.7** Open partial lateral patella facetectomy technique: The lateral patellar osteophyte, excessive lateral patellar tilt, narrowing of the lateral patellofemoral joint space, and lateral retinaculum tenting are visualized. The superficial oblique and deep transverse layers of the lateral retinaculum are incised to expose the lateral patellar osteophyte. The osteophyte is excised using an oscillating saw or osteotome. The superficial oblique and deep transverse layers of the lateral retinaculum are then sutured together for an effective lateral lengthening. Following the procedure, the patella is centered within the trochlear groove, and even joint space is achieved

Both the open and arthroscopic techniques provide a reduction in erosion progression of the lateral femoral condyle caused by the osteophyte. However, the arthroscopic approach is more technically demanding. With the open technique, LRL is an option and can be used to treat persistent lateral retinaculum tightness. However, excessive lengthening must be avoided to refrain from iatrogenic medial patellar instability. Additionally, neither arthroscopic nor open PLPF addresses diffuse PFOA [43]. Finally, as there are relatively few Level of Evidence 4 studies, no strong recommendation of one technique over the other is possible. For either technique, adherence to detail results in high levels of patient satisfaction [4, 5, 19].

## 42.8 Pearls and Pitfalls

### 42.8.1 Pearls

- Thorough clinical evaluation and imaging studies to establish a precise diagnosis of ELPCS.
- Be aware of any contraindications (i.e., diffuse patellofemoral or tricompartmental arthritis).
- Ensure adequate bony lateral facet resection to alleviate impingement.
- Following bony resection, assess lateral soft tissue structures for residual tightness to determine whether lateral retinaculum lengthening is required.
- Compression wrap to avoid hemarthrosis.
- Early postoperative rehabilitation to regain patella mobility, range of motion, and core/quadriceps strength [43].

### 42.8.2 Pitfalls

- Incomplete evaluation resulting in imprecise preoperative diagnosis; the procedure is not for ill-defined PF pain or debility.
- Under-resecting the lateral patellar facet or failure to remove all lateral osteophytes.
- Over-resecting the lateral patellar facet resulting in destabilization of the patella and compromise of the lateral soft tissue attachments or future arthroplasty.
- Overlengthening the retinaculum resulting in medial patellar instability.
- Inadequate postoperative rehabilitation resulting in poor patella motion and stiffness [43].

## 42.9 Rehabilitation

Early rehabilitation includes 1–2 weeks of compression to prevent hemarthrosis [5]. A postsurgical brace is not required. Patients can weightbear as tolerated using crutches until they are not limping. Flexion and extension exercises are initiated as soon as possible without restriction [4, 12, 43]. Gravity-assisted ROM exercises or continuous passive motion are utilized. Functional quadriceps exercises progress from isometrics to short arc quadriceps and straight leg raises as tolerated without extensor lag [13, 46]. Early patella and patellar tendon mobilization, hamstrings and posterior chain exercises, ankle pumps, and stationary biking are encouraged [43]. In general, balance exercises can be initiated by week 3. At week 7, swimming and incline treadmill walking can begin. At week 16, exercises emphasizing single limb agility can be started. Through week 20, these agility exercises can gradually progress to multidirectional exercises. Individual patients follow time- and criteria-based rehabilitation protocol with functional clearance for activities based on standardized return to work and/or return to sport testing protocols [43].

## 42.10 Outcomes and Complications

PLPF has produced good clinical results for the treatment of isolated PFOA (Table 42.1) [5, 12]. While improving knee pain and function over the long term, PLPF delays the requirement for major knee surgery [44]. López-Franco et al. [13]

**Table 42.1** Partial lateral patella facetectomy outcomes and complications

| Authors | Number of knees | Concomitant procedures | Outcomes | Complications |
|---|---|---|---|---|
| López-Franco et al. [13] | 39 | Lateral release | 84% reported pain relief and improvement in knee function; KSS improved from 54.5 to 76.3; functional score improved from 71.4 to 83.6 | At 10 years, 32.4% underwent TKA |
| Montserrat et al. [46, 47] | 87 | Insall's procedure | Cumulative survival was 59.3% at 13 years; significant improvement in anatomical, functional, total KSS, and Kujala scores | At 9.6 years, 26.4% underwent TKA; 3 regional pain syndrome, 1 transient extension lag, 1 internal saphenous neuroma |
| Becker et al. [4] | 51 | Lateral release and tibial tubercle medialization | WOMAC pain and function scores significantly improved; 74% reported pain improvement | – |
| Paulos et al. [5] | 56 | Lateral release | 88% were satisfied or very satisfied; Kujala score significantly improved from 45.6 to 72.0 | At 60 months, 16.1% underwent TKA; 2 manipulations |
| Wetzels and Bellemans [12] | 168 | Lateral release | Survival rates of 85% at 5 years, 67.2% at 10 years, and 46.7% at 20 years | At 10.9 years, 35.7% underwent TKA; 1 hemarthrosis, 1 fever, 2 effusions |
| Yercan et al. [19] | 11 | Lateral release | Pain score improved and KSS also improved from 150 to 176 | – |
| Martens and De Ryke [48] | 20 | Lateral release | 90% good-to-moderate results | 2 failures with poor subjective ratings |
| McCarroll et al. [49] | 57 | – | 75% subjectively satisfied | – |
| Cercek et al. [63] | 19 | TKA | Significant improvement in all KSS categories; function improved from 48.7 to 80.0; pain improved from 20.5 to 42.5; total KSS improved from 65.7 to 89.6 | 1 tibial loosening, 1 flexion instability |

**Table 42.1** (continued)

| Authors | Number of knees | Concomitant procedures | Outcomes | Complications |
|---|---|---|---|---|
| Pagenstert et al. [64] | 68 | TKA, medial reefing, and lateral release | 34 had concomitant partial lateral patellar facetectomy, and 34 had secondary patellar resurfacing. Pain relief and function significantly improved in both groups; lateral facetectomy group had a significantly higher KSS, knee ROM, and Kujala score at final follow-up | – |
| Kim et al. [65] | 251 | TKA and patellar resurfacing | 4 groups were divided based upon +/−facetectomy and +/−patellar resurfacing. KSS improved from 51.0 to 85.0, and Kujala improved from 47.8 to 76.2 in the lateral facetectomy without resurfacing group; KSS improved from 49.0 to 83.3, and Kujala improved from 50.8 to 76.7 in the lateral facetectomy with resurfacing group | – |
| Zhang et al. [25] | 63 | TKA and lateral release | 32 had a facetectomy and 31 did not. The facetectomy group had statistically significant less anterior knee pain; facetectomy group had significantly higher postoperative WOMAC pain, WOMAC function, KSS knee, and KSS function scores | – |
| Lakstein et al. [20] | 69 | TKA and lateral lengthening | 23 had a facetectomy and 46 did not. There was not a significant difference in outcomes; post-op KSS pain was 94, and KSS function was 86 in the facetectomy group; scores were fair in 1 patient and excellent or good in 18 patients | 2 subluxations, 1 manipulation, 1 linear exchange and patellar resurfacing |
| Moghtadaei et al. [66] | 51 | TKA and lateral release | 22 had a facetectomy and 24 did not. The facetectomy group had significantly less anterior knee pain; there was not a significant difference in KSS pain and function scores between groups; post-op KSS knee score was 86.1, and function score was 86.0 in the facetectomy group | – |

*KSS* Knee Society Score, *TKA* total knee arthroplasty, *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index, *ROM* range of motion

reported on 39 knees undergoing PLPF. Thirty-three (84%) reported pain relief and improvement in knee function. Mean follow-up was 126 months. The average KSS improved from 54.5 preoperatively to 76.3 postoperatively, and the average functional score improved from 71.4 preoperatively to 83.6 postoperatively. No major complications were detected after the PLPF in their series. The patients were studied for a minimum of 10 years, and at the last follow-up, 11/34 knees (32.35%) had undergone TKA.

Montserrat et al. [46, 47] reported on a total of 87 cases of PLPF and concomitant Insall's procedure for the treatment of isolated PFOA. Mean age was 61.8 years and mean follow-up was 9.6 years. A total of 23 cases were failures and needed a TKA. The presence of tibiofemoral pain, osteoarthritis, and genu flexum were the most essential factors associated with failure. The mean survival time was 13.6 years. The cumulative survival was 59.3% at 13 years. Following the surgeries, there was a significant improvement in anatomical, functional, total KSS, and Kujala scores. Postoperatively, there were three cases of regional pain syndrome, a case of transient extension lag, and a case of internal saphenous neuroma. The main finding from this study was that in long-term follow-up, PLPF plus Insall's procedure was a successful treatment for isolated PFOA from clinical, functional, and radiographic perspectives. Therefore, the combination of these procedures may be effective for the long-term treatment of isolated PFOA, specifically in patients with extensor mechanism impairments [46, 47].

Becker et al. [4] reported on a prospective study of 51 knees in 50 patients who received PLPF with LRR and medialization of the tibial tubercle. The WOMAC pain and function scores considerably improved. Thirty-seven patients assessed their knee as improved, nine as unchanged, and four as worsened with respect to pain. There were not any failures in this case series. However, follow-up was relatively short with a mean of 20.2 months. Although improvement of patellofemoral pain and function was seen in most patients, when compared with other surgical procedures such as isolated facetectomy, the clinical and radiologic results were inferior. Becker et al. did not recommend these combined surgical procedures in isolated PFOA of young or middle-aged patients.

Paulos et al. [5] assessed clinical examinations and radiographs of 56 knees in 53 patients with PLPF and concomitant LRR. The mean age at the time of surgery was 53.4 years and the mean follow-up was 60 months. The mean preoperative Kujala score was 45.6, which significantly improved to 72.0 postoperatively. Within their patients, 88% were subjectively satisfied or very satisfied. There were two cases of stiffness with subsequent manipulation under anesthesia. Nine knees (16.1%) went on to require TKA during the follow-up period. The mean time from facetectomy to TKA was 38 months. Patients in the failure group tended to undergo more concomitant lateral compartment procedures and had a slightly higher preoperative lateral femoral condyle degeneration grade.

Wetzels and Bellemans [12] reported on 168 knees in 155 patients undergoing PLPF with LRR. The average follow-up was 10.9 years, and the mean age at time of surgery was 57.3 years. During the follow-up period, 62 knees (36.9%) had failed with 60 undergoing TKA. With reoperation as the endpoint, survival rates were 85% at 5 years, 67.2% at 10 years, and 46.7% at 20 years. The average time to reoperation in the failure group was 8.0 years. There were two cases of effusion, a case of hemarthrosis, and one patient experienced a fever postoperatively. Wetzels and Bellemans found that the beneficial effects of the PLPF procedure continued to be present at 10 years of follow-up in half of their patients. They also found no significant difference between the patients who had undergone a concomitant LRR and those patients who did not.

Yercan et al. [19] reported on PLPF in middle-aged to elderly patients with isolated lateral PFOA. PLPF and concomitant LRR were performed on 11 knees in 11 patients with a mean age of 62 years. The mean follow-up was 8 years. The average pain score improved, and the total KSS score also improved from a preoperative score of 150 to 176 at latest follow-up. Slowed progression of osteoarthritis in the patellofemoral and tibiofemoral compartments was found on radiographs at follow-up; however, clinical symptoms did not always correlate with radiographic appearance. In this study, the success of the procedure was most contingent on the relief of pain.

Martens and De Ryke [48] published results of a prospective study of 20 cases involving PLPF with concomitant LRR. The mean follow-up was 2 years; mean age, 60 years. Good-to-moderate results were attained in 90% of their cases. There were two failures associated with poor subjective ratings. The main reason for failure in this study was tibiofemoral osteoarthritis, which was advanced at the time of operation. This osteoarthritis progressed throughout postoperative follow-up. Overall, Martens and De Ryke reported considerable improvement in most of their cases and noted only a small degree of risk.

McCarroll et al. [49] reported on 57 patients undergoing PLPF at a mean follow-up of 3.9 years. Satisfactory results were obtained, and 75% of their patients were subjectively satisfied.

### 42.10.1 Concomitant Total Knee Arthroplasty

Total knee arthroplasty (TKA) is an effective and relatively common surgical procedure in patients with painful knee osteoarthritis [50–53]. However, there is a large potential risk of persistent knee pain and poor functional outcomes with patient dissatisfaction up to 30% [54–57]. Patients' expectations undergoing TKA are often not fulfilled with respect to postoperative pain relief and physical activity level [58]. Within the many cohorts of unsatisfied TKA patients, the most frequent cause of dissatisfaction is persistent anterior knee pain [59–62]. Lateral patellar facet syndrome is likely an etiological factor for anterior knee pain.

Cercek et al. [63] reported on 19 TKAs in 18 patients who underwent revision for lateral patellofemoral impingement after their initial TKA. PLPF was performed in 12 of these knees. The mean age was 69.8 years, and the mean time from the initial arthroplasty to revision was 2.5 years. At the latest follow-up, significant improvement was seen in all components of the Knee Society Score. Total KSS scores improved from a preoperative score of 65.7 to a postoperative score of 92.8 at 8 weeks, 91.6 at 16 weeks, and 89.6 at 1-year follow-up. The function score improved from a preoperative score of 48.7 to a postoperative score of 77.6 at 8 weeks, 82.3 at 16 weeks, and 80.0 at 1 year. The pain score improved from a preoperative score of 20.5 to a postoperative score of 46.3 at 8 weeks, 45.4 at 16 weeks, and 42.5 at 1 year. There was a case of tibial loosening and a case of flexion instability.

Pagenstert et al. [64] published a study comparing outcomes of groups of patients undergoing patella-retaining TKA. A total of 68 knees underwent concomitant PLPF or secondary patellar resurfacing with 34 knees in both groups. Medial reefing and LRR were also used as concomitant procedures. Significant pain relief and functional improvement were observed in both groups at latest follow-up (mean, 3.4 years). Patients who underwent PLPF had a significantly higher KSS score, knee ROM, and total Kujala score when compared to the patients who underwent secondary patellar resurfacing. Pagenstert et al. showed that PLPF provided significant postoperative functional improvement and pain relief in patients with patella-retaining TKA.

Kim et al. [65] reported on 251 knees in 208 patients who underwent patella-retaining TKA. These patients were divided into four groups based upon the presence or absence of facetectomy and the presence or absence of patellar resurfacing. There were no significant differences in the preoperative patellar tilt angle or lateral patellar displacement. However, at the minimum of 2-year follow-up, the postoperative patellar tilt angle and lateral patellar displacement were both increased significantly in the group without facetectomy. There were no significant differences found within the clinical results between the patient groups. In the facetectomy group without resurfacing, KSS improved from 51.0 to 85.0, and Kujala improved from 47.8 to 76.2. In the facetectomy group with resurfacing, KSS improved from 49.0 to 83.3, and Kujala improved from 50.8 to 76.7.

Zhang et al. [25] retrospectively reviewed 63 patella-retaining TKAs in 59 patients to compare outcomes of PLPF with knees that did not undergo facetectomy. Minimum follow-up was 3 years, and no major complications were noted. In comparison to the group that did not receive facetectomy, the facetectomy group had statistically significant less anterior knee pain and better postoperative WOMAC pain, WOMAC function, KSS knee, and KSS function scores. The results of Zhang et al. showed that concomitant PLPF improved clinical results in patients undergoing patella-retaining TKA.

Lakstein et al. [20] published results on 23 PLPFs with LRL in 22 patients during TKA as an alternative to lateral release. A control group was composed of 46 patients undergoing TKA without PLPF. The mean age was 70 years, and mean follow-up was 33 months. At the last follow-up, mean KSS pain was 94, and mean KSS function was 86 in the PLPF group. Scores were fair in 1 patient and excellent or good in 18 patients (19 knees). There were no significant differences between the study group and the matched control group regarding patellar scores, tilt angles or patellar translation, KSS, or functional KSS. There were two cases of patellar subluxation without any dislocations, a case of stiffness with subsequent manipulation under anesthesia, and an additional linear exchange and patellar resurfacing surgery.

Moghtadaei et al. [66] reported on 51 knees in 46 patients undergoing primary TKA with 22 undergoing concomitant PLPF and 24 without facetectomy. Four LRRs were also performed between the groups. Final follow-up was at 18 months. The facetectomy group had significantly less anterior knee pain when compared to the non-facetectomy group. However, there was not a significant difference in Knee Society pain and function scores between the two groups. In the facetectomy group, the postoperative KSS knee score was 86.1, and the function score was 86.0.

## 42.11 Conclusion

The optimal treatment of the healthy middle-aged population with PFOA remains controversial [13]. Following failure of conservative treatment, many surgical techniques have been reported for the treatment of PFOA. These range from palliative (e.g., debridement and patellar chondroplasty with or without lateral release/lengthening) to restorative (e.g., cartilage restoration with or without unloading) to PLPF, patellectomy, PFA, and even TKA [16, 49, 67–76]. In younger and high demand patients, restorative and unloading procedures are prioritized. In patients with ELPCS and lateral patella degenerative changes who are not ideal candidates for cartilage restoration and too young for arthroplasty, PLPF +/− LRL provides a rational and safe treatment option [5]. PLPF removes the bony impingement, and LRL manages any lateral soft tissue imbalance. This procedure does not preclude future surgeries including PFA or TKA and should be discussed as a bridging procedure [44]. PLPF has been shown to improve patellar tracking, pain scores, and knee function for extended periods, which can delay the need for arthroplasty [13, 77]. PLPF is a safe, low-cost, and straightforward surgery with expedient recovery and relatively low morbidity.

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# 43

# Arthroplasty Design of the Patellofemoral Joint

Pieter Jordan Erasmus and Kyung Jin Cho

## 43.1 Introduction

The patellofemoral joint (PFJ) is a unique joint that sees the highest loads of any joint; it has six degrees freedom of motion, and this movement is controlled by extensor vectors, soft tissue restraints, and morphology of the trochlea and patella. There is a huge variation in the morphology of the patellofemoral joint, more so than in any other joints in the body as is illustrated in Fig. 43.1. The eventual shape and alignment of the PFJ are the result of genetic and epigenetic factors [1, 2].

Patellofemoral arthroplasty (PFA) is a good bridging procedure for younger patients with isolated patellofemoral osteoarthritis (OA) to delay a total knee arthroplasty (TKA). In some patients, a PFA might even be a finite procedure. PFA is less invasive [3] than TKA, and results after conversion to TKA are comparable to that of a primary TKA in terms of the surgical complexity and outcomes [4, 5]. At present, the outcomes of PFA are much better than to that of the original first-generation designs [6]. Complications and reoperation rates of PFA are however higher than in TKA when treating isolated patellofemoral arthritis [7–9]. Failure in PFA is secondary to progressive tibiofemoral degeneration and pain. Progressive tibiofemoral degeneration, which is the most common failure mode over time, can probably be limited by careful patient selection [10–12]. In the first 5 years of post PFA, the most common reason for failure is pain; this is mostly related to surgical technique and prosthetic design [12, 13].

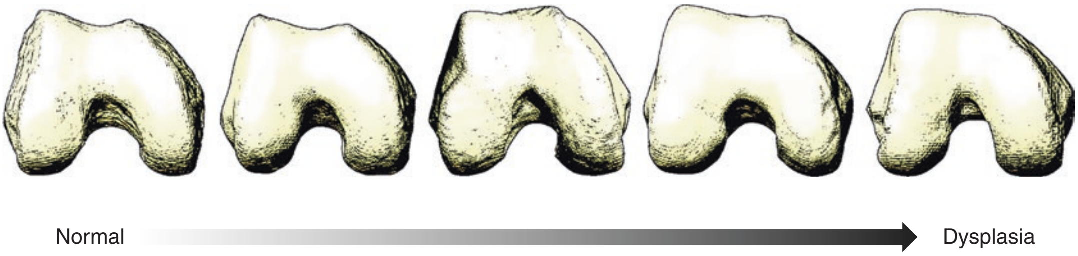

**Fig. 43.1** Wide trochlear shape variations in natural knees

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Patellofemoral joint degeneration occurs over a wide spectrum of trochlea shapes. Iriuchishima and co-workers [14] found that PFJ degeneration was more common in patients with a deep sulcus, while sulcus angle and width showed no correlation. Others suggest that there is a direct relation between trochlear dysplasia and PFJ degeneration [15, 16]. Some authors suggested that absence of trochlear dysplasia is associated with a higher revision rate due to progression of tibiofemoral joint OA [17–20]. The reason might be that in normal knees isolated PFJ degeneration is more likely to be the beginning of progressive degeneration of the whole joint that will eventually affect the tibiofemoral articulation. On the other hand, in knees with dysplastic trochleae, PFJ degeneration is more likely secondary to the abnormal point loading, while the rest of the joint is healthy and normal.

When performing a PFA, the morphology of the distal femur plays a major role in the final position of the prosthesis as there should be a precise fit at the prosthesis articular transition. The axial rotation and the footprint shape of the anterior trochlea have an influence on the eventual coronal groove angle [21]. PFA design should reflect the native geometry of the antero-distal femur and restore normal PFJ kinematics; it should not be to be extrapolated from a TKA design.

Extensive variation exists in current post-first-generation PFA designs [22]. Some have wide distal flanges, and some are narrow. The groove angle also varies widely. This illustrates a lack of knowledge on which design features are desirable for a successful PFA. In order to design the ideal PFA prosthesis, the native PF anatomy and kinematics, as well as the design differences in successful and less successful PFAs, should be examined. We investigated the variations in the natural trochlea and that of commercially available PFA implants; by combining our personal experience and that of others in the literature, we will suggest some design rationales for an ideal PFA.

## 43.2 Design Rationale

As a result of the limb alignment, the extensor vector always has a resultant valgus vector that pulls the patella laterally. This force is restricted by the trochlea and soft tissue constraints around the patella. From full extension to approximately about 30° of knee flexion, the primary restraint is the soft tissues, and the trochlea provides less restraint to this lateral force [23]. This allows the patella to move more laterally from the trochlear groove as the knee extends from 30° of flexion to full extension. Once the patella engages to the trochlea fully, at 30° of flexion, the patella follows the groove line as it moves distally [24]; the PFJ becomes more stable as the groove becomes deeper [25] with progressive knee flexion. The kinematics of the PFJ is the result of a fine balance between the trochlea, the soft tissues, and the extensor mechanism. If any of these are disturbed, then the balance is destroyed, and this can lead to abnormal kinematics and patellar dislocation.

The PFJ can be compared to a belt running over a pulley. In a V-shaped pulley and belt, the friction and the load on the system increase with misalignment; the belt will however be stable. In a flat belt and pulley, friction and load in the belt and pulley do not increase with bad alignment, but the belt can slip off the pulley, just like a dislocating patella in a dysplastic trochlea (Fig. 43.2).

The proximal part of the trochlea component should gradually become shallower allowing the soft tissue restraints, rather than the trochlea, to dictate the patella position in full extension. The distal part of the PFA prosthesis should be able to provide enough stability in flexion, with a relative deep trochlea, while respecting the original tracking and groove line of the patella. We pos-

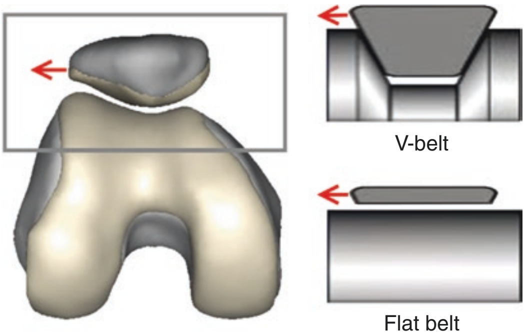

**Fig. 43.2** Patellofemoral joint can be compared to a belt over pulley system

tulate that the direction of the natural trochlear groove is the result of the patient's soft tissue constraints and extensor vector forces. Failing to relatively align the prosthetic trochlea to the naturally developed groove and soft tissue sleeve could increase the risk of wear.

When designing a PFA prosthesis, it is a fine balance to provide stability without over-constraint and at the same time to respect the natural trochlea groove orientation.

## 43.3 The Natural Trochlea

In order to design a patellofemoral prosthesis, it is important to consider the variation in the shape and alignment of the natural trochlea, including in knees with trochlear dysplasia. Trochlear dysplasia is characterized by decreased trochlear depth, and in some severe cases, the trochlea is even convex Fig. 43.1. Patients that undergo primary PFA are more prone to have trochlear dysplasia and patella alta [26]. Poor outcomes of first-generation implant designs have been attributed to failure in accommodating this morphological variation.

Generally, the trochlear groove can be described with a simple circular arc. In an unpublished study on the sagittal radius in 36 asymptomatic knees, we found that the radius ranged between 14 and 32 mm; this result is similar to that of Iranpour et al. [27]. In a study on MRI scans in 25 healthy volunteers, Monk et al. [28] also observed a large variability in the sagittal radius of the trochlea ranging from 17 to 28 mm. There was a strong correlation between the radius of the sagittal trochlea and the knee width. Wang et al. [29] found a strong correlation between the size of the knee and the radius of the trochlea.

Although Monk et al. [28] successfully standardized the sagittal radius of the trochlear groove, they were unable to do the same for the orientation of the trochlear groove. In our published work [30], a wide variation in the coronal and axial alignments of the trochlear groove was observed (Fig. 43.3). The coronal trochlear groove angle varied from 13° varus to 13° valgus and the axial groove angle from 8° internal rotation to 11° external rotation. Trochlea with more dysplastic features had a more internally rotated groove [31]. Other studies also confirmed our findings (Table 43.1) [26, 32].

Van Haver et al. [33] studied the shape variations between the normal and dysplastic knees and showed that trochlear dysplasia proximalized and lateralized the trochlea. The anterior trochlea was most severely affected including the areas

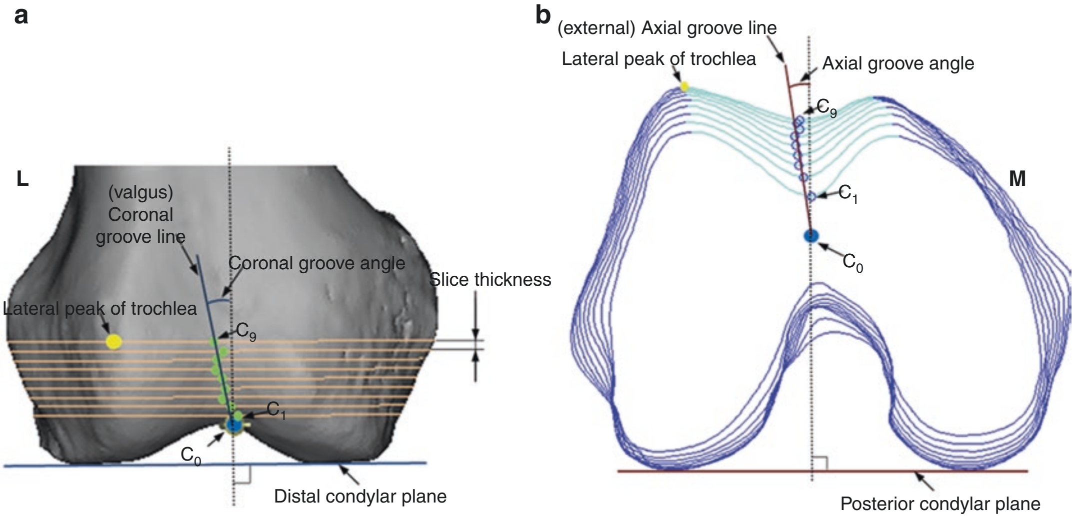

**Fig. 43.3** Graphical representation of groove angle measurements in (**a**) coronal plane and (**b**) axial plane [30]

**Table 43.1** Summary of trochlea morphology measurements

| Measurement | | Mean | Range |
|---|---|---|---|
| Sagittal trochlear radius | (mm) | 23 | 14–32 |
| Axial groove angle | (°) | 3 external | 8 internal–11 external |
| Coronal groove angle | (°) | 4 valgus | 13 varus–13 valgus |

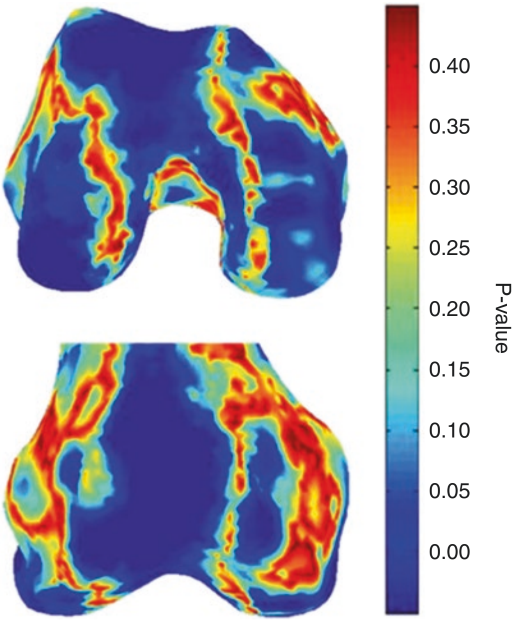

**Fig. 43.4** The shape difference between the normal and dysplastic knees. The least and most deviations are indicated by blue and red, respectively [33]

outside the groove as shown in Fig. 43.4. On the distal side, the affected area was mostly inside the sulcus, and it is extended more laterally from the posterior to anterior. The dysplastic trochlea had decreased medial-lateral (ML) dimensions, suggesting that the ML size of the anterior cut footprint is also affected by trochlear dysplasia.

## 43.4 The Prosthetic Trochlea

Lonner [34, 35] suggested that although poor early results in PFA are often attributed to a bad surgical technique, it is obvious that flawed trochlea designs also played a role. It has been shown by various studies that the trochlea design has a significant impact on PFJ kinematics and clinical outcomes [8, 35–37]. There are two basic designs in PFA prosthesis, namely, an inlay and onlay prostheses. In an inlay design, the original trochlea is basically resurfaced. In this type of prosthesis, the shape and alignment of the original trochlea stay unchanged. In the onlay design, the anterior trochlea is removed and replaced by the prosthesis.

First-generation inlay designs had high failure rates as there was difficulty in fitting them into dysplastic knees [35, 38]. These prostheses were narrow, and the native anatomy of the trochlea had a great influence on their position. They often had to be internally rotated and flexed to fit to the dysplastic knees. This made them prone to patella catching, especially in patients with patella alta, as the patella had to slide on and off the prosthesis at the proximal edge. A further problem was that they were highly constrained designs with a deep narrow grooves. When implanting these prostheses, there was a small margin for error in that slight malalignment of the prosthesis led to unphysiological loading.

Onlay designs significantly improved the clinical outcomes [39]. With the anterior cut, trochlear dysplasia could be corrected, and the component did not have to be internally rotated and flexed. The risk of patellar catching was reduced by a proximally extended anterior flange. This prevented the patella from running off the prosthesis at full extension, even in patients with patella alta. Wider anterior flanges maximized the coverage of the trochlea and became less constraining, making it less sensitive to malalignment by allowing the patella to move more freely. The original second-generation onlay designs such as Avon (Stryker) have a neutral trochlear angle making it possible to use the same prosthesis in a left or in a right knee by externally rotating the prosthesis up to 5° to achieve the desired valgus trochlear angle [21]. Modern onlay designs have an inbuilt valgus groove to accommodate the Q-angle and lateral tracking of the patella at terminal extension.

Recently reported outcomes for a modern inlay design, HemiCap Wave (Arthrosurface), seem to be comparable to that of a modern onlay designs [40, 41]. This modern inlay design has been adapted to be less constraint and wider, covering the medial and lateral aspects of the anterior trochlea. With a patient-specific inlay PFA, KineMatch PFR (Kinamed), a good prosthesis fit with the surrounding articular cartilage, can be ensured, and a good outcome was reported [42]. Doubt still exists whether inlay designs could properly fit in knees with severe trochlear dysplasia, because the whole border of the prosthesis must fit well with the surrounding articular cartilage. In cases of patella alta, it does not extend proximally enough for early engagement of the patella.

When looking at commercially available contemporary onlay prostheses, there is a huge variation in the design of the prosthetic trochlea as is shown in Fig. 43.5. The shape of anterior and distal flanges differs significantly. Table 43.2 lists principal dimensions of different femoral components of comparable sizes. The dimensions were obtained from the manufacturers' brochures and literature [22]. The dimensions provided by the manufacturers were taken if any disagreement existed.

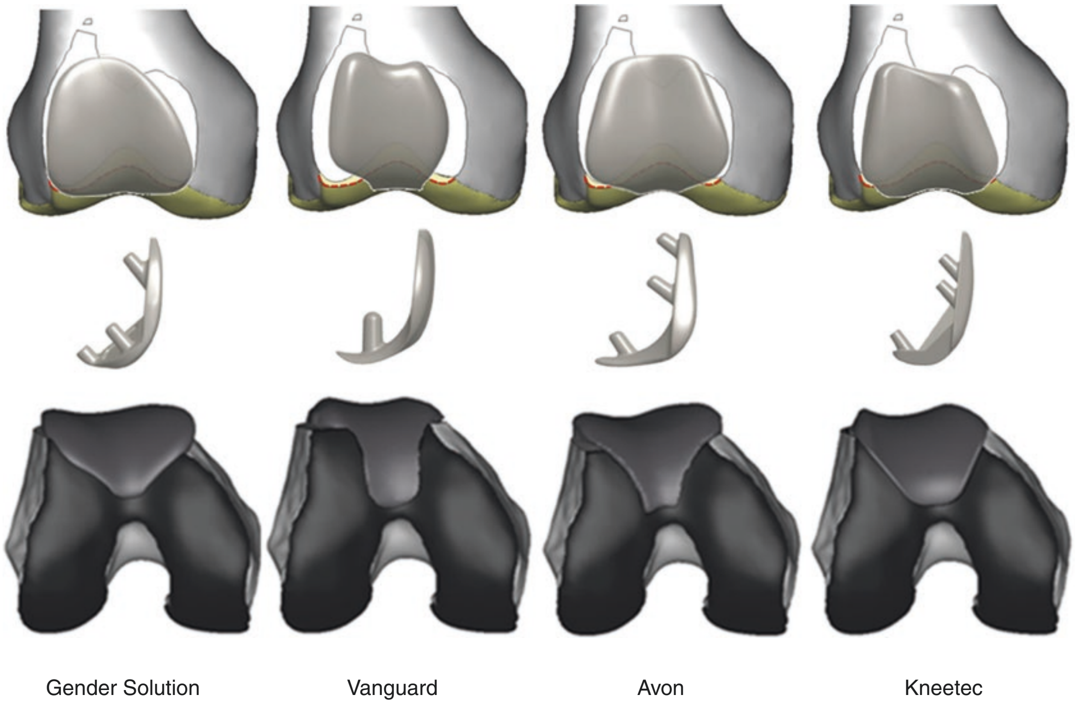

**Fig. 43.5** Four different commercially available onlay type PFA designs. The illustration is recreated with permission from authors [21, 22]. Redline indicates the flush line

**Table 43.2** Principal dimensions of different onlay femoral component designs

| Brand | Manufacturer | Size | ML (mm) | AP (mm) | PD (mm) | *R* (mm) | Coronal groove angle (°) |
|---|---|---|---|---|---|---|---|
| Gender solution | Zimmer Biomet | 3 | 45 | 25 | 43 | 21 | 10 |
| Vanguard | Biomet | M | 46 | 38 | 54 | 23 | 2 |
| Journey | Smith & Nephew | M | 46 | 26 | 40 | 20 | 9 |
| Avon | Stryker | M | 47 | 26 | 45 | 22 | 0 |
| KneeTec | Corin-Tornier | 3 | 48 | 28 | 47 | 28 | 7 |
| Coefficient of variation in % | | | 2 | 19 | 11 | 14 | 78 |

*ML* medial-lateral, *AP* anterior-posterior, *PD* proximal-distal, *R* sagittal radius

We measured the sagittal radii from retrieved implants. The medial-lateral (ML) dimensions of the contemporary prostheses were comparable, but the other dimensions varied more than the ML dimensions. The coronal groove angle showed the greatest variability, having the highest coefficient of variation, of all the dimensions.

The cumulate revision rate (CRR) percentage of primary PFA, by brands, obtained from the British and Australian arthroplasty registries [43, 44] are presented in Table 43.3. Only the modern prostheses, that are still available in the market and had more than 100 cases implanted, are listed. Avon and Gender Solution were the two designs with the highest survival rates at midterm (5 years after the index procedure), in both registries. Vanguard was identified as having a higher than anticipated rate of revision and has been discontinued. There is a marked difference between the design features of the Vanguard when compared to that of the Avon and Gender Solution. The main difference between the Vanguard and more successful prostheses was the size of the anterior-distal flange. Prosthesis with a narrow anterior-distal flange fails to provide full coverage at the flush line, which is the distal border of the anterior cut footprint as can be seen by a red line in Fig. 43.4. In such designs there is a tendency for the patella to run off the prosthetic trochlea in relatively early flexion.

Different CRR was observed for different patella designs when they were used on the same trochlea component design [44]. This shows that the patella design should not be neglected when designing the PFA implants. Although very little is discussed in literature about patellar component in PFA, one could learn from the high failure rate of the constraining designs that the patella component should not be restrained. The patella can be left in place when converting to TKA if the patella design is compatible.

## 43.5 The Ideal PFA Prosthesis

The ideal prosthesis, according to the literature and our own experience, should have the following traits:

The trochlea component should stabilize the patella, fit flush on the anterior femoral cortex with a wide and smooth distal prosthesis articular cartilage transition. It should fit into the soft tissue sleeves with no sharp edges that can cause soft tissue irritation (Fig. 43.6). A valgus sulcus angle is desirable but should be relatively shal-

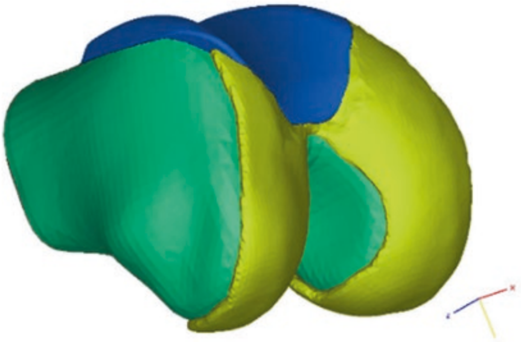

**Fig. 43.6** Flush fit with smooth prosthesis articular cartilage transition

**Table 43.3** Cumulative percent revision of primary PFA by brands

| | | | Time since primary | | | | | |
|---|---|---|---|---|---|---|---|---|
| Registries studies | Brand | Number of replaced joint | 1 year | 3 years | 5 years | 7 years | 10 years | 14 years |
| British [43] | Avon | 5704 | 0.8 | 4.3 | 7.5 | 10.3 | 15.2 | 20.5 |
| | Gender solution | 2138 | 0.7 | 4.8 | 7.4 | 10.9 | – | – |
| | Journey | 1743 | 2.2 | 7.8 | 12.9 | 17.9 | 21.7 | – |
| | FPV | 1619 | 0.9 | 7.0 | 10.1 | 13.9 | 18.0 | – |
| | Sigma | 1310 | 2.6 | 8.7 | 13.3 | 17.4 | – | – |
| Australian [44] | Gender solution | 859 | 1.6 | 6.1 | 9.4 | – | – | – |
| | RBK | 497 | 3.3 | 9.7 | 16.0 | – | 27.9 | – |
| | Journey | 481 | 2.0 | 7.9 | 12.4 | – | – | – |
| | Avon | 378 | 1.1 | 6.4 | 11.7 | – | 25.2 | – |
| | Sigma | 117 | 4.5 | 16.1 | 21.3 | – | – | – |

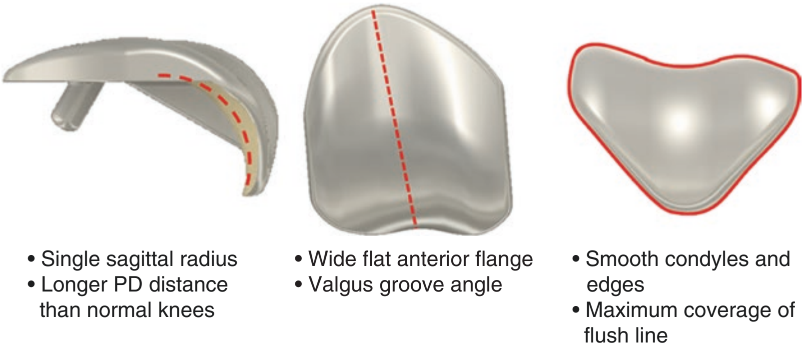

**Fig. 43.7** The ideal prosthesis

low and flat to accommodate the wide variation of coronal trochlea angles found in the population. A longer than natural proximal flange is necessary for an early engagement of the patella in cases of patella alta. Lonner [34] suggested that the prosthesis should maximize the coverage of the trochlea without encroaching on the tibiofemoral articulation; it should also not overhang into the intercondylar notch. The trochlea prosthesis should allow easy conversion to a TKA. In addition, it should be able to accommodate a UKA prosthesis [14].

The patella design should be compatible with that of standard TKA's enabling it to be left in place should a revision to a TKA be necessary. The design should be forgiving for malalignment, and for this reason we suggest a dome or modified dome-shaped patella. The proximal sulcus of the trochlea should have a greater radius than the radius of the patella, while the radius of the patella should match that of the distal sulcus of the trochlea for stability.

A virtual ideal PFA prosthesis was designed trying to incorporate all the requirements as illustrated in Fig. 43.7. Four basic sizes were designed, and to accommodate the wide variations in trochlea morphology, a narrow ML version was added to each size giving a total of eight sizes as can be seen in Fig. 43.8. This prosthesis was then virtually implanted in 45 knees in the range from normal to Dejour type 4 trochlear dysplasia. The fit of the prosthesis to the articular cartilage was graded as excellent with less than 1 mm difference, moderate with less than 2 mm difference, and poor with more than 2 mm difference. Excellent fit was achieved in 22%, moderate fit in 73%, and poor fit in 5% of the 45 knees that had virtual implantations. Even with the prosthesis design with wider size options, it was not possible to achieve a good fit in all knees despite that it was done in a virtual environment where different implant positions could be easily tested for an ideal fit. To further improve the fit, more width variation can be added with an option of having different valgus groove angles to adapt to individual Q-angles; from an inventory point this may not be practical.

## 43.6 The Future

It is impossible to design an ideal prosthesis that would fit into every knee, and the solution to the problem might be to use a basic design that can be adapted to create a patient specific prosthesis using the new technologies that are coming available.

It is already possible to 3D print the prosthesis in metal according to a patient-specific design done on CT and MRI of the knee (Fig. 43.9). With robotic surgery, it has become possible to individually shape the trochlea bone according to a specific design and then implant a prosthesis that matches the bone cut and have the desired trochlea morphology. This will bridge the gap between inlay and onlay prosthesis as it would eliminate the flat anterior cut and allows the proximal extension of the flange to be long enough to accommodate a specific patella height.

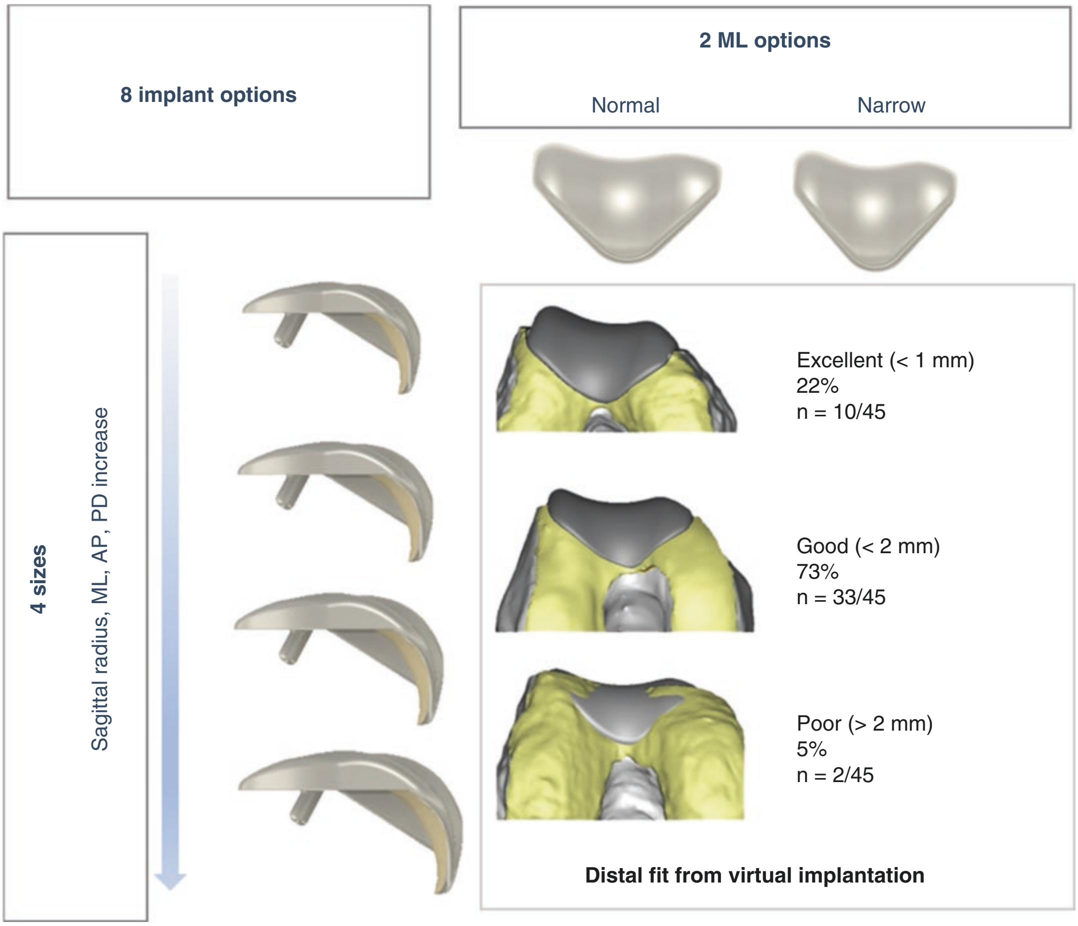

**Fig. 43.8** The ideal prosthesis and virtual implantations

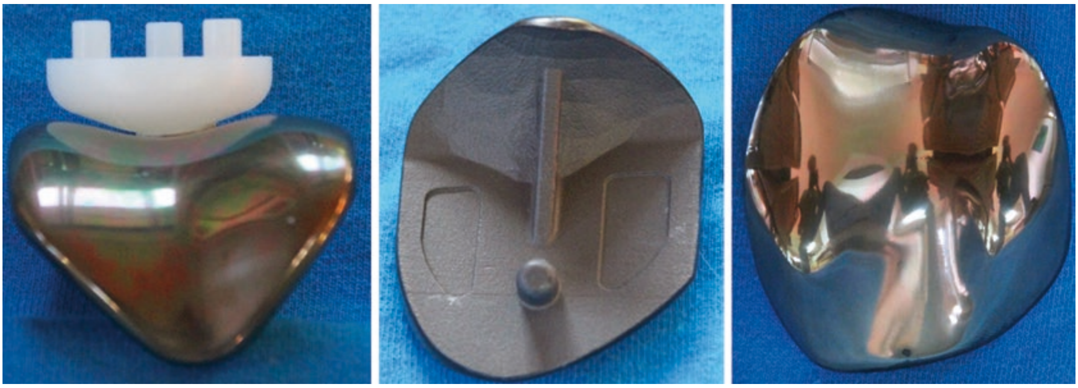

**Fig. 43.9** Patient-specific PFA prosthesis is printed in titanium and heat treated. Distal bone interface matches the patient's anatomy

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# Indications for Patellofemoral Arthroplasty in Isolated Patellofemoral Arthritis

## 44

Daniel Hurwit and Sabrina Strickland

The patellofemoral (PF) joint is a common source of disabling anterior knee pain, and PF arthritis is seen radiographically in up to 36% of the population [1]. Middle-aged, female, and high-BMI patients in particular tend to be more often affected by PF arthritis resulting in pain [2]. These findings are supported by biomechanical studies demonstrating that significant loads, up to seven times body weight, cross the PF joint, especially with prolonged sitting, rising from a seated position, and going up and down stairs [3]. While acute instability events or discrete cartilage injuries can be treated with ligament reconstruction or cartilage restoration procedures, more diffuse degeneration isolated to the PF joint in patients that have failed conservative therapy presents a challenging clinical scenario.

Total knee arthroplasty (TKA) has been commonly used to treat isolated PF arthritis, especially in older patients, but studies demonstrate persistent anterior knee pain in up to one-fifth of patients [4]. PF arthroplasty has emerged as an excellent option for patients presenting with anterior knee pain attributed to isolated PF arthritis. Improved implant design has led to more reliable outcomes and fewer complications [5, 6], and comparative studies have shown PF arthroplasty to yield comparable or better clinical outcomes to TKA with a less invasive approach and possibly fewer complications [7, 8].

While implant choice and surgical technique remain crucial to good clinical outcomes of PF arthroplasty, patient selection and precise indications may be an equally important aspect of surgical management. The ideal patient is one with isolated anterior knee pain felt during activities of daily living, such as climbing stairs or rising from a chair. Kneeling or deeply squatting for these patients may be excruciating or impossible. The patient also may have a history of instability or dislocation events. On physical exam it is important to assess the stability of the patella as well as the knee in its entirety and to palpate and stress the knee carefully to ensure that the patient's pain is localized only to the PF compartment. Weightbearing radiographs, including a Rosenberg view, are important to exclude tibiofemoral disease, and advanced imaging such as MRI may be useful to this end as well. In addition, preoperative imaging can help to identify any existing deformity or dysplasia.

It is essential that conservative management, including treatment with nonsteroidal anti-inflammatory drugs, injections, and physical therapy, is exhausted in these patients before surgery is recommended. While TKA is more often performed in older patients, and PF arthroplasty more often reserved for those who are younger or middle aged, if the tibiofemoral

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joint is unaffected, PF arthroplasty can be a good option regardless of age. This is especially true considering the relatively uncomplicated conversion of PF arthroplasty to TKA and the good outcomes following this operation [9–11].

The etiology of the patient's PF arthritis usually has no bearing on his or her candidacy for arthroplasty. The arthritis may be primary, post-traumatic, or the result of recurrent instability or trochlear dysplasia, as the surgical technique and implants can be adjusted to account for these factors. However, malalignment or stiffness of the tibiofemoral joint is a contraindication to PF arthroplasty, as is any evidence of pain or radiographic arthritis in the medial or lateral compartments. Given that one advantage of PF arthroplasty is retention of the knee's normal kinematics, tibiofemoral ligaments and menisci should be intact, although there is no consensus that prior injury to cruciate ligaments or menisci cause worse outcomes in PF arthroplasty [12]. Inflammatory joint disease is also a contradiction, although good results have been seen anecdotally in those with chondrocalcinosis of the knee.

There is no clear consensus on the effect of body mass index (BMI) on outcomes after PF arthroplasty. Studies have demonstrated that revision surgery is higher in patients with a BMI of 30 or above [11, 13], as these patients may be at higher risk of developing tibiofemoral arthritis. Studies have also demonstrated that a lack of trochlear dysplasia more commonly led to revision surgery, and this has been supported in other studies, leading some to recommend that PF arthroplasty be performed only in patients with arthritis attributable to trochlear dysplasia that has led to patellar maltracking [13–15]. However, PF arthroplasty alone cannot restore proper patellar tracking, which may require additional or concomitant procedures such as a lateral retinacular release.

In conclusion, isolated PF arthritis can be treated effectively and reliably with PF arthroplasty, provided that patient selection is precise. Isolated anterior knee pain without significant evidence of tibiofemoral disease is imperative, while the status of the patient's cruciate ligaments and body mass index has a less clear impact on survivorship.

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# 45

# Complications of Patellofemoral Arthroplasty

Laurel A. Barras and Diane L. Dahm

## 45.1 Introduction

Patellofemoral arthroplasty (PFA) represents an excellent option for the patient with isolated patellofemoral degenerative arthritis. Results upward of 90% survival at up to 10 years have been reported [1–4]. However, in order to avoid complications, careful selection of patients and meticulous surgical technique are of paramount importance. Patient selection is important, particularly due to the well-documented failure of patellofemoral arthroplasty secondary to the progression of tibiofemoral degenerative arthritis. Surgical technique includes optimal choice of implant, as well as the implant's size, position, and fixation.

## 45.2 Indications

Complications can be avoided by choosing the appropriate patient or patellofemoral arthroplasty. The patient should have a history of isolated anterior retropatellar knee pain. The ideal patient will describe exacerbating activities, which include climbing up and down stairs, navigating uneven surfaces, and sitting for long periods of time with the knee flexed. Ideally, the patient will remain asymptomatic or minimally symptomatic when walking on level surfaces. Lower extremity alignment should be grossly within normal limits, and range of motion should likewise be within normal limits, but in particular, without a significant flexion contracture. X-rays should include standing AP, PA flexion, lateral, and low flexion angle axial views. Full-length hip-to-ankle X-rays should also be performed in order to determine alignment. MRI is often utilized to rule out significant tibiofemoral degenerative disease. If diffuse grade 3 to 4 chondromalacia is present at the tibiofemoral compartment, caution should be used when considering patellofemoral arthroplasty. CT scans are rarely required but can be useful in the setting of previous patella fracture and/or chronic dislocation in order to assist with decision-making when contemplating tibial tubercle osteotomy (TTO).

## 45.3 Failure Due to Progression of Tibiofemoral Arthritis

Progression of tibiofemoral degenerative arthritis is a well-documented reason for failure of patellofemoral arthroplasty, requiring revision to total knee arthroplasty (TKA). Revision rates have been reported to be 12–28% at 5- to 6-year follow-up [5, 6]. Several authors have noted less

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progression of tibiofemoral osteoarthritis in patients who exhibit trochlear dysplasia [7–9]. Obesity has also been linked to earlier progression of tibiofemoral arthritis, as well as overall inferior results to those in patients with body mass index (BMI) within normal limits.

## 45.4 Choice of Implant

Two basic design differences include the “inlay” prosthesis, which typically matches a patient’s native trochlear anatomy, and an “onlay” component, which is similar to total knee arthroplasty, which involves an anterior bone resection and allows for optimal position of the new trochlear groove. In general, inlay prostheses perform best when utilized for patients without advanced trochlear dysplasia or patellar malalignment. Such patients might include those with post-traumatic, patellofemoral arthritis, for instance, following patella fracture (Fig. 45.1). Use of an inlay trochlear component in patients with higher-grade trochlear dysplasia can lead to patellar maltracking and a persistent “J sign” in full extension. This can be symptomatic to the point where revision arthroplasty or a patellar stabilizing procedure is required (Fig. 45.2).

## 45.5 Surgical Technique

Careful surgical technique is critical in order to prevent complications of mechanical symptoms and persistent pain in patellofemoral arthroplasty. Specifically, the trochlear component must be properly aligned in the axial, coronal, and sagittal planes. With respect to sagittal alignment, the anterior cut should be performed parallel to the distal anterior femoral cortex. Notching of the anterior cortex should be avoided. Likewise, excessive flexion of the component can lead to complications of notch impingement on the ACL, as well as “catching” from extension to flexion of

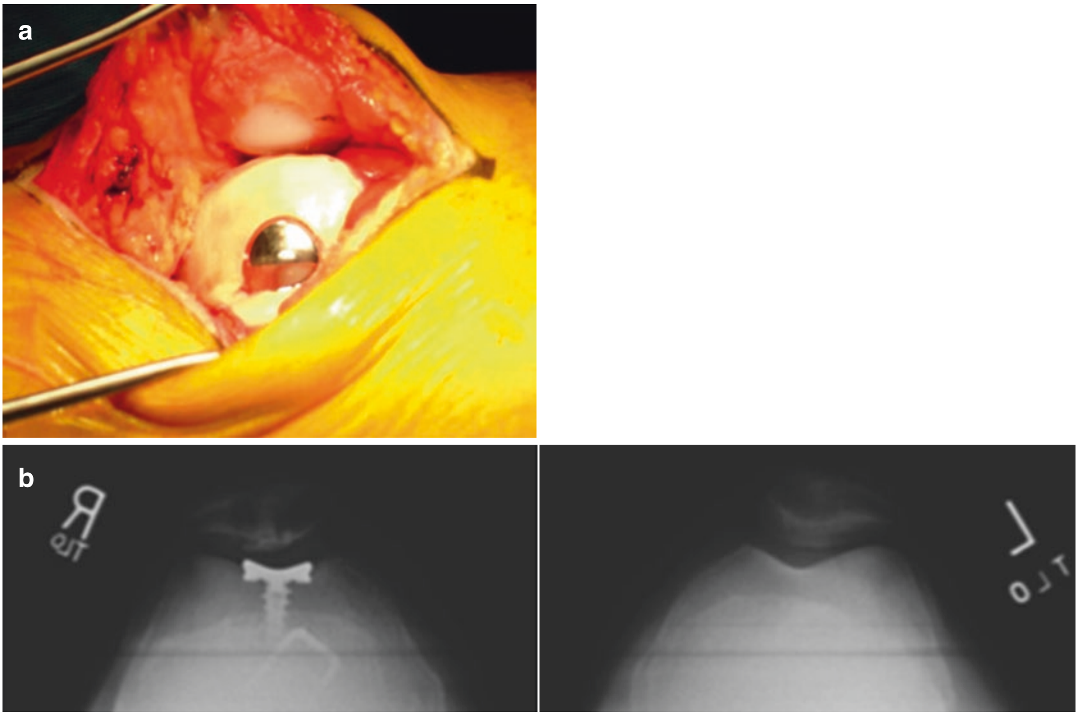

**Fig. 45.1** Surgical (**a**) and Merchant radiographic (**b**) images of a patient without patellofemoral malalignment with an inlay prosthesis

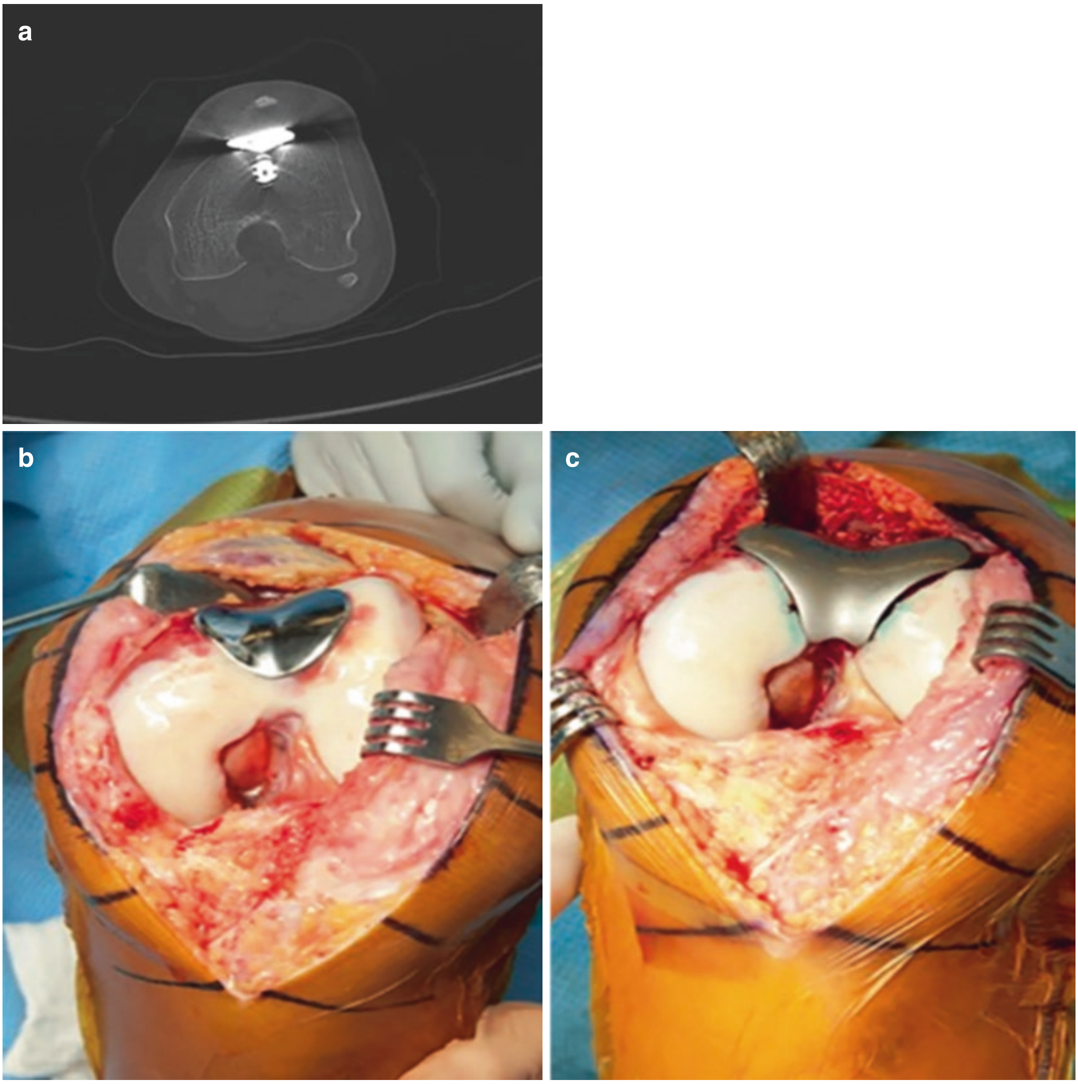

**Fig. 45.2** CT (**a**) and surgical (**b**) images of an inlay prosthesis, which required revision to an onlay design (**c**) due to a persistent "J sign"

the patella on the proximal extent of the trochlear prosthesis (Fig. 45.3). For patients with significant patella alta, tibial tubercle distalization osteotomy may be required to avoid patellar "catching" (Fig. 45.4). With respect to axial alignment, the anterior cut should be parallel or in slight external rotation with respect to the transepicondylar axis. The long axis of the tibia can also be utilized with the cut made perpendicular to this axis. It is important to note that patients with significant trochlear dysplasia have relative internal rotation of the trochlea [8, 10]. In such patients, if the trochlea is placed simply to "match the native anatomy," patients may have difficulty with lateral patellar subluxation, instability, and/or pain, which may lead to the need for additional procedures, such as medial patellofemoral ligament reconstruction and tibial tubercle osteotomy to assist with improved patellar tracking (Fig. 45.5). With respect to coronal alignment (i.e., "varus/valgus"), placement depends primarily on the anterior condylar anatomy. The trochlear edges

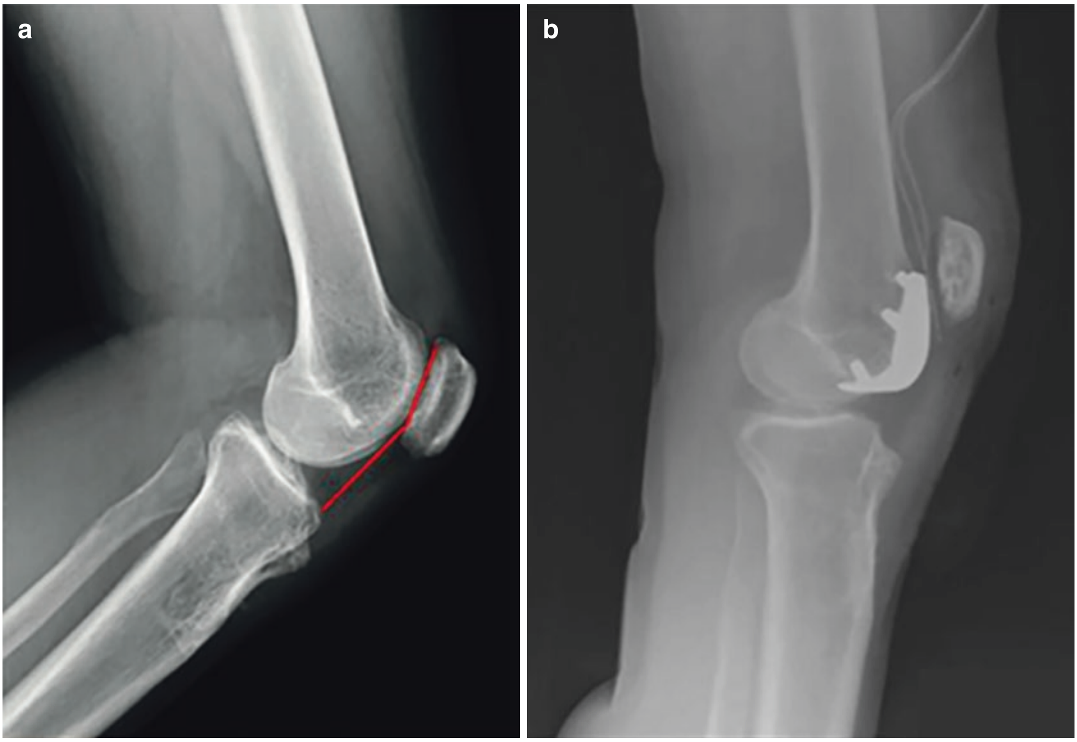

**Fig. 45.3** Lateral radiographs demonstrating factors that may increase the risk of patellar "catching" on the superior flange during range of motion: patella alta (**a**) and flexed positioning of the trochlear component (**b**)

should be "flush" with the articular cartilage, both medially and laterally. Symmetric components have a neutral patellar tracking angle, while asymmetric components typically have a 5–7° lateral tracking angle, in order to improve patellar stability in full extension. Literature has reported lower rates of patellar instability while utilizing asymmetric implants, specifically a 6% rate of slight lateral patellar subluxation [11]. In general, a symmetric prosthesis is placed perpendicular to the long axis of the femur. In contrast, an asymmetric prosthesis is aligned in slight valgus in order to be placed perpendicular to the mechanical axis of the femur. In particular, for asymmetric designs, it is imperative that the implant be placed flush or slightly below the articular cartilage. In general, slight lateral translation of the trochlear component can be performed in the setting of significant lateral patellar tracking. This is often combined with a tibial tubercle medialization procedure. However, lateral overhang of the trochlear prosthesis should be avoided (Fig. 45.6). Conversely, excessive valgus positioning of an asymmetric component may lead to increased pressure between the patella and the lateral wall of the trochlea. This occasionally results in "squeaking" [12]. Preparation of the patella should include an attempt to recreate the original patellar thickness. "Overstuffing" is acceptable at times and even desired in cases of very thin patellae with evidence of significant wear. Occasionally, in instances of severe patellar wear and to avoid possible patella fracture, it may be necessary to leave the patella unresurfaced or perform a staged bone grafting procedure (Fig. 45.7). In order to improve patellar tracking, the patellar component is typically slightly medialized. When necessary, a lateral retinacular release is performed. However, care must be taken to avoid branches of the superior lateral geniculate vessels.

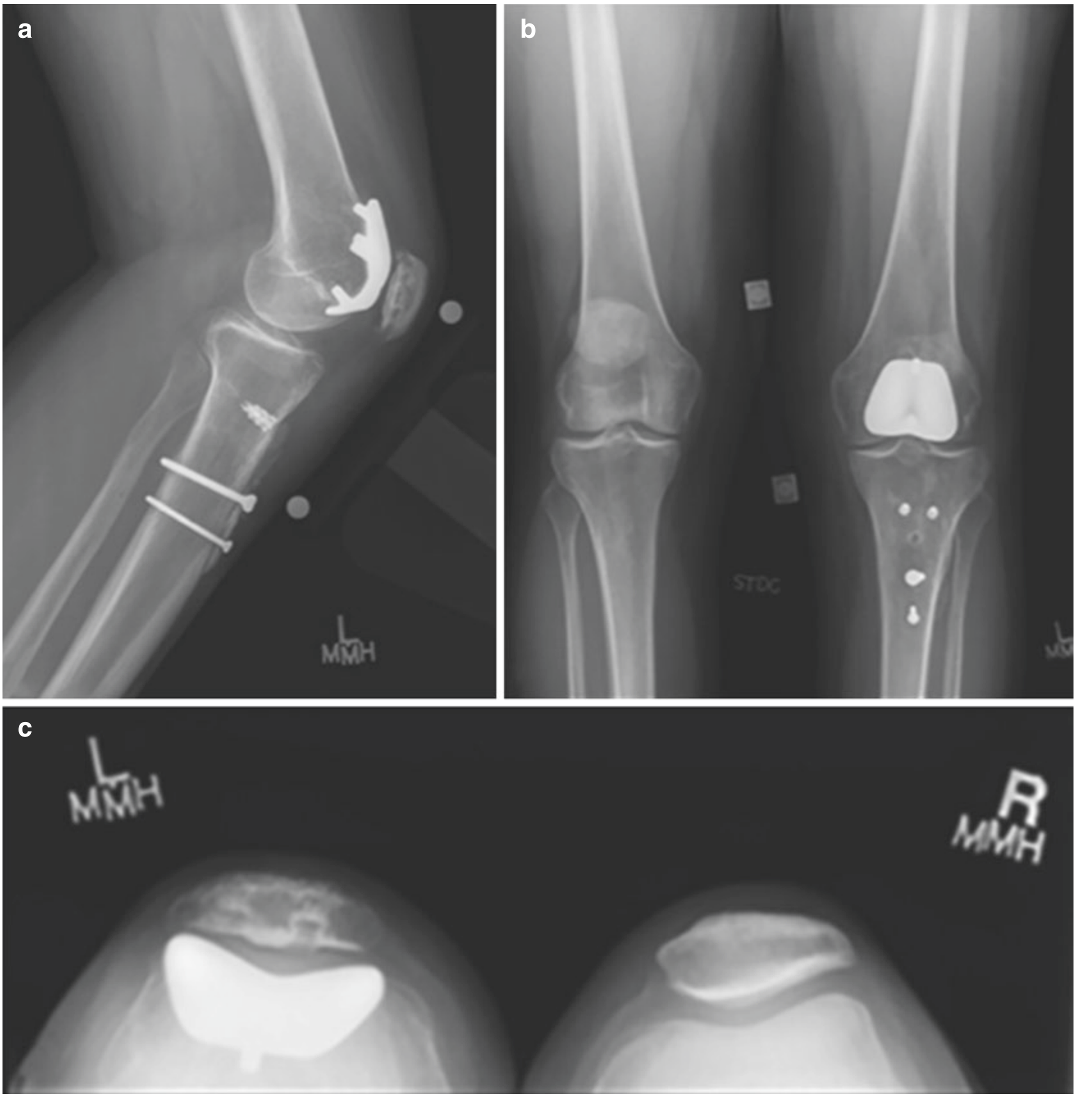

**Fig. 45.4** Lateral (**a**), AP (**b**), and Merchant (**c**) views following tibial tubercle distalization osteotomy for symptomatic patella alta

## 45.6 Revision to Total Knee Arthroplasty

Unfortunately, despite relatively good wear characteristics of modern patellofemoral arthroplasty designs, revision to total knee arthroplasty is often required for progression of degenerative arthritis and/or persistent pain, instability, or mechanical symptoms. In general, revision to TKA yields results that are relatively comparable to primary TKA (Fig. 45.8). However, there have been some reports of inferior results following revision to TKA after PFA in comparison to primary TKA [13–15]. Of note, the patellar component can often be retained when converting to total knee arthroplasty. Patella fracture has been described following patellofemoral arthroplasty, similar to what is often seen in total

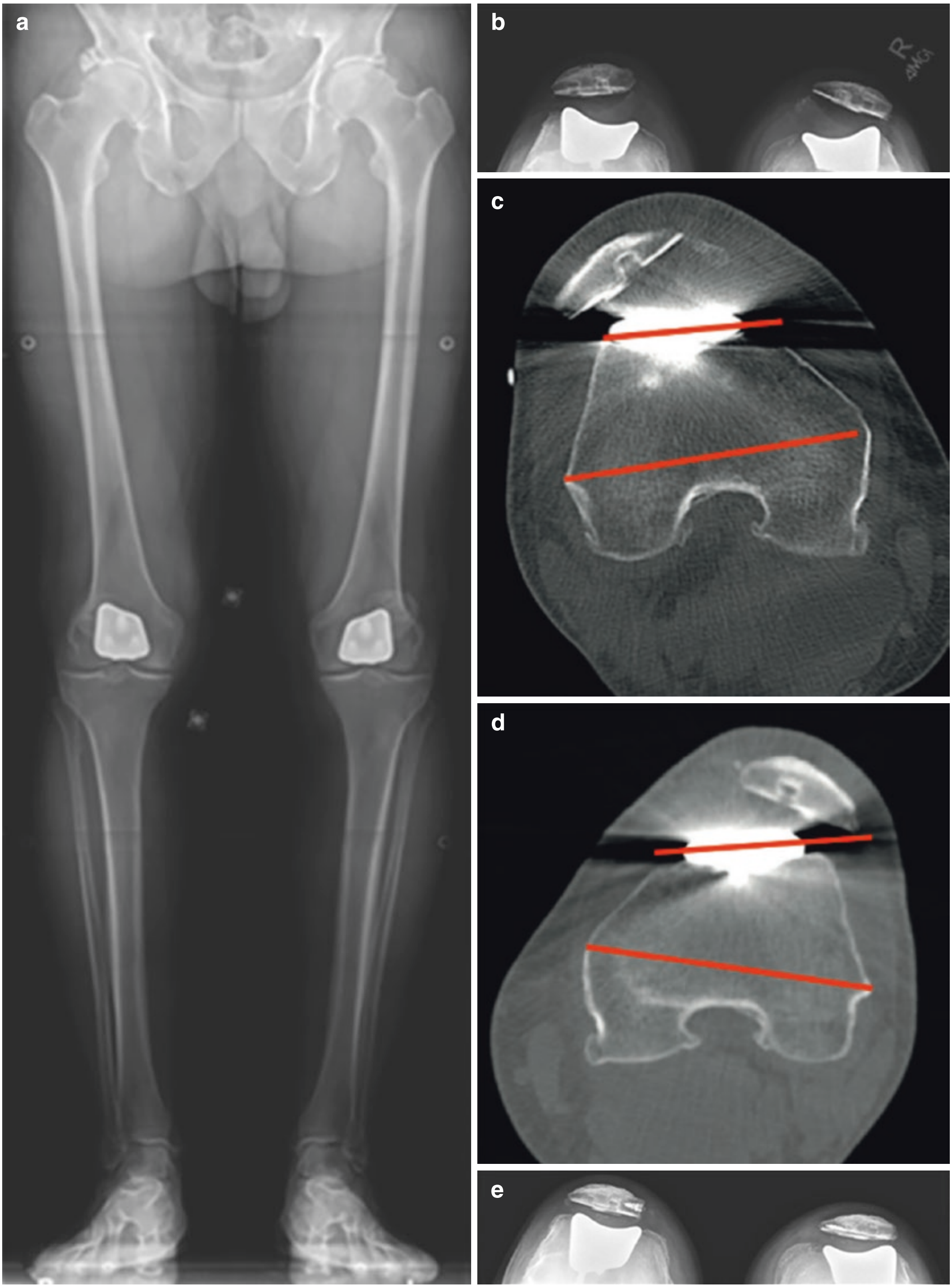

**Fig. 45.5** Full-length hip-to-ankle standing AP (**a**) and Merchant (**b**) radiographs of a patient with patellar instability following bilateral PFA. Axial CT images (**c**, **d**) showing internal rotation of the trochlear components in relation to the transepicondylar axis and evidence of medial patellofemoral ligament (MPFL) insufficiency. Merchant view (**e**) demonstrating correction of patella tracking and alignment following MPFL reconstruction and TTO

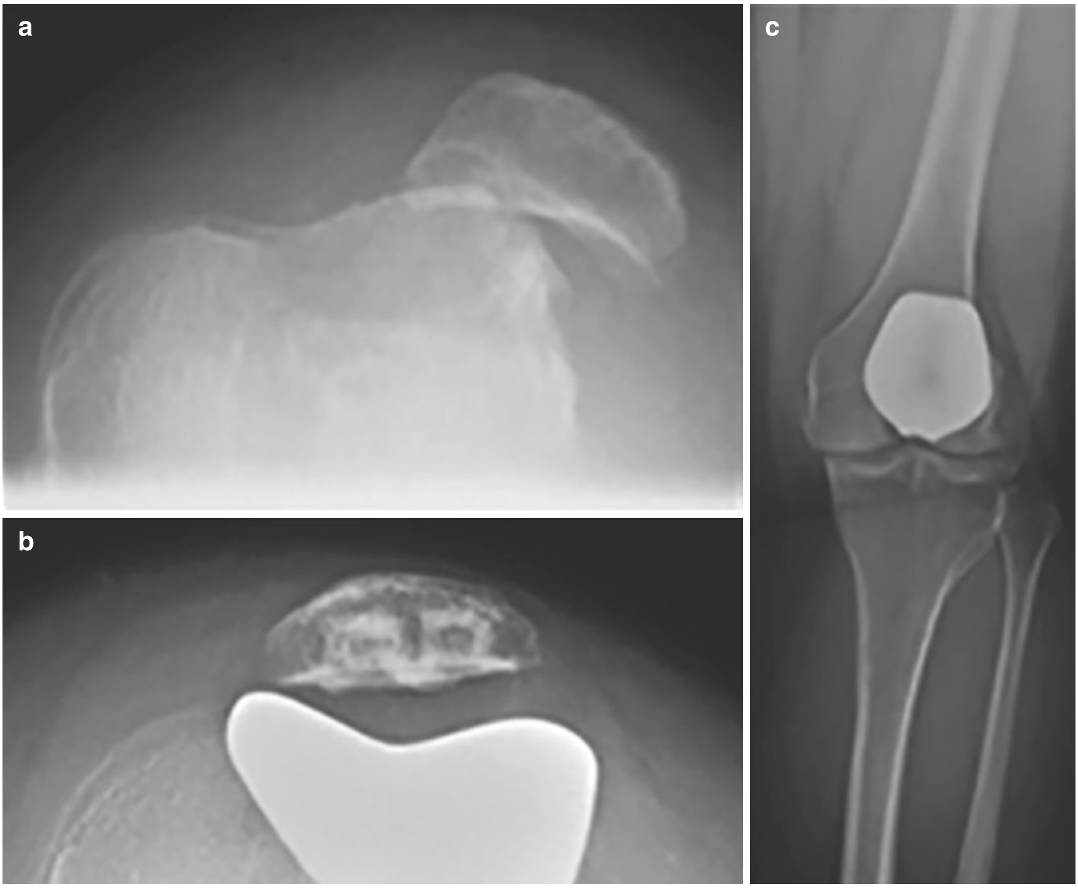

**Fig. 45.6** Preoperative Merchant (**a**) radiograph of a patient with severe lateral patellar tracking. Postoperative Merchant (**b**) and AP (**c**) radiographs in a patient with symptomatic lateral overhang of a laterally placed PFA implant

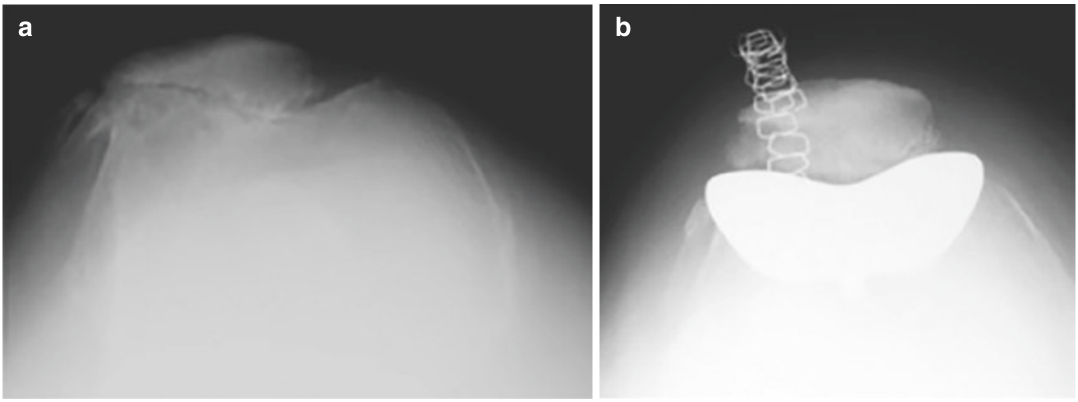

**Fig. 45.7** Preoperative (**a**) Merchant radiograph demonstrating significant wear of the patella. Postoperative (**b**) Merchant view following bone grafting at the time of PFA for severe patellar thinning

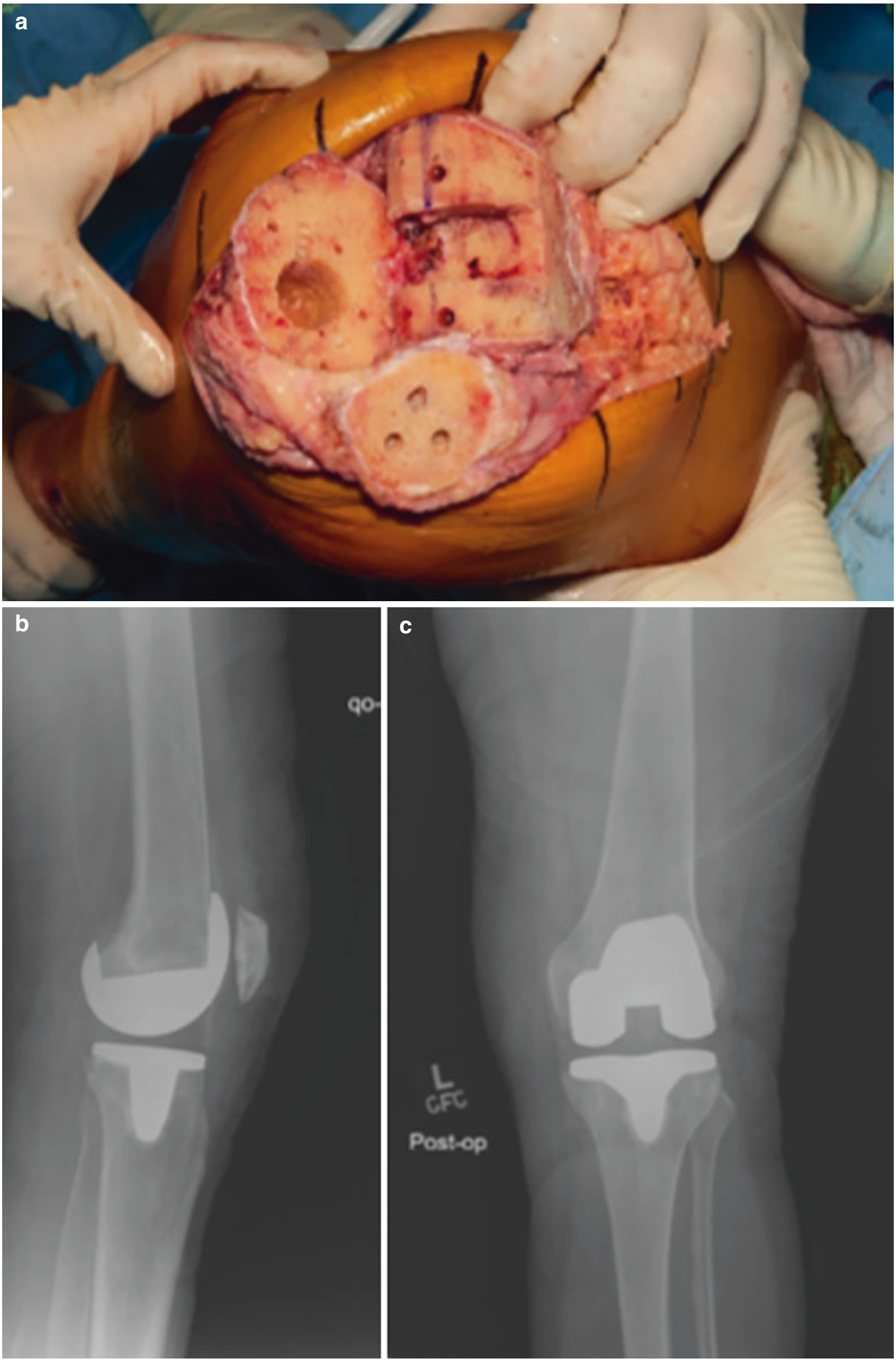

**Fig. 45.8** Intraoperative image of a patient undergoing conversion from PFA to TKA (**a**). Postoperative lateral (**b**) and AP (**c**) radiographs showing conversion to primary TKA implants

**Fig. 45.9** Lateral radiographic image depicting inferior pole patella fracture following PFA

knee arthroplasty when patellar bone stock is insufficient. King et al. found a 9% patellar fracture rate in patellofemoral arthroplasty patients. All of which were type I fractures, treated nonoperatively. Factors that were found to be associated with patella fracture included low BMI, increased bone resection, decreased patellar thickness, as well as larger trochlear size [16] (Fig. 45.9).

## 45.7 Summary

Patellofemoral arthroplasty, using modern designs and techniques, yields satisfactory results for patients with isolated, advanced patellofemoral degenerative arthritis. Careful patient selection and optimal implant position and technique are keys to achieving a successful result.

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# Review of Patella Disorders in Skeletally Immature Patients

# 46

Lindsay Schlichte and Daniel Green

## 46.1 Osgood-Schlatter Disease

### 46.1.1 Nature of the Disease

First described by Robert Osgood in 1903, Osgood-Schlatter's disease etiology is described as repetitive strain and chronic avulsion of the secondary ossification center of the tibial tuberosity [1]. Ehrenborg's work on cadaveric specimens suggested that the patellar tendon fibers attach distally to the fibrocartilage. The high tensile strength of the fibrocartilage results in a traumatic force on the secondary ossification center of the tibial tuberosity causing to fracture [2]. When the bone or cartilage is pulled away, it continues to grow, ossify, and enlarge, and the intervening area may become fibrous, creating a localized nonunion, or may show complete bony union with mild enlargement of the tibial tuberosity [3]. Pathological variants of anatomy have also been suggested as etiological factors. Aparicio et al. [4] and Jacob et al. [5] both describe a cohort of patients with patella alta and OSD, suggesting that the rectus femoris contracture caused the patella alta. In contrast, Lancourt and Christini [6] reported on skeletally immature patient with both patella baja and ODS, suggesting that the increased stress on the tibial tuberosity is caused by the shortened length of the patellar tendon. Other pathogenic factors associated with OSD in adolescents include increased quadriceps and/or hamstring muscle tightness [7]. In a recent perspective cohort of adolescent male soccer players, significant pathogenic factors associated with OSD in the support leg of adolescent male soccer players included height, weight, body mass index, quadriceps femoris and gastrocnemius muscle tightness, soleus muscle tightness, and a higher medial longitudinal arch [8].

Osgood-Schlatter disease typically develops during peak growth (ages 8–12 for girls, 12–15 for boys) with a higher prevalence in athletes (21% of adolescents) than nonathletes (4.5% of adolescents) [7, 9]. Approximately 20–30% of cases are bilateral [3]. Common sports that exacerbate OSD are those that include sprinting, cutting, and jumping.

### 46.1.2 Clinical Findings and Diagnostics

Typically, adolescent patients with OSD will present with a gradual onset of pain, tenderness, and swelling at the tibial tubercle. Upon physical exam, there may be an area of prominence at the tibial tuberosity. Patient's pain may intensify with physical activity, extension of knee against resistance, squatting, and kneeling.

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While diagnosis can generally be made by clinical evaluation, radiographs are recommended in unilateral cases to rule out other differential diagnoses. Suggested radiographs include lateral view of the knee with leg internally rotated 10–20°. Relevant findings include irregularity of the apophysis with separation from the tibial tuberosity in early stages and fragmentation in later stages [3]. While typically not required, MRI can be useful for atypical presentations by identifying bone marrow edema of the anterior tibial tubercle as well as soft tissue changes, which include thickening of the distal patellar tendon, edema of Hoffa fat pad, and edema of the adjacent subcutaneous tissues [10] (Fig. 46.1a, b). It is important to be aware of nondisplaced tibial tubercle fractures as a differential diagnoses. While these fractures may appear similar to OSD on radiograph, the patients typically present with acute and severe onset of pain and the inability to do a straight leg raise.

### 46.1.3 Treatment Options

Conservative management remains the mainstay of treatment. These measures include control of pain with NSAIDS, ice, and activity restriction. Physical therapy for strength and flexibility is also recommended [11, 12]. In a case series of 261 patients followed for 12–24 months, 237 (90.8%) of patients responded well to activity limitation and nonsteroidal anti-inflammatory agents. The 24 patients that did not improve underwent surgical excision of ossicles and returned to normal activities [13]. For the few patients with severe pain, we recommend stopping activity until acute pain subsides. For the majority of patients who present with mild to moderate pain, we recommend continued athletic participation in moderation. Another recommendation is to review the patients' daily activity level of the patient and work with the patients to decrease the overall hours spent

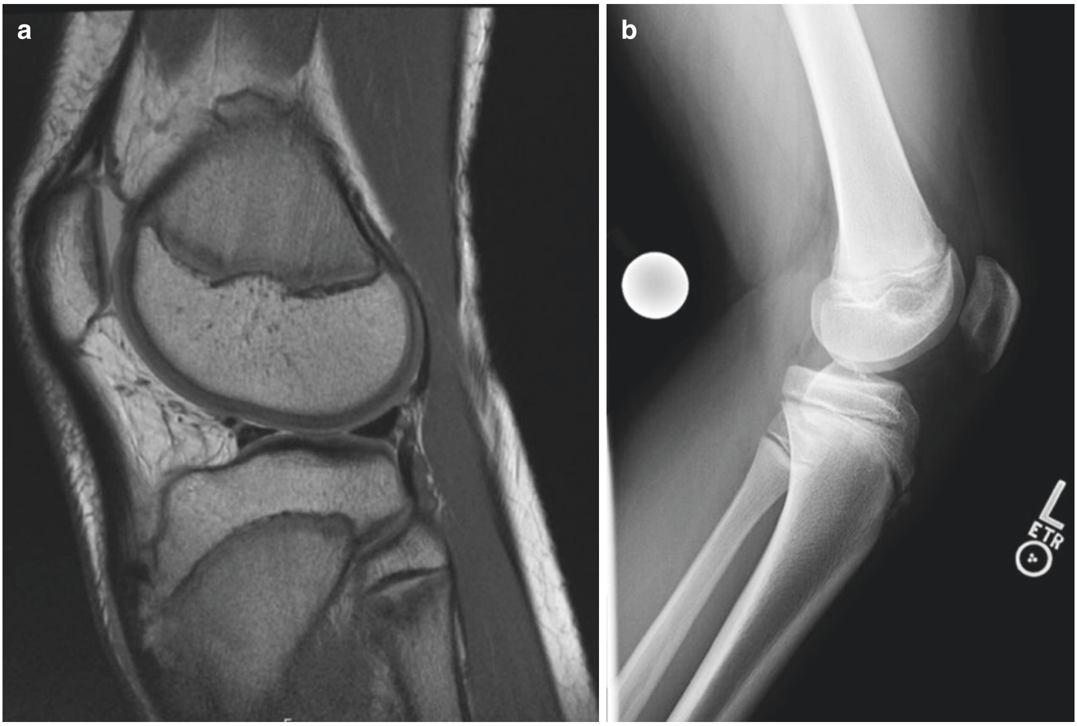

**Fig. 46.1** (**a**, **b**) Osgood-Schlatter disease. X-ray and MRI of a 13-year-old male who presented with pain over the tibial tubercle. Improved with PT, hamstring stretching, and temporary activity restrictions

doing rigorous sprinting and jumping with rest days and flexibility exercises inserted after strenuous activity.

Generally, OSD subsides with the closure of the proximal tibial growth plate at skeletal maturity; however there are reports of patients with ossicles that fail to unite with the tubercle [12, 14, 15]. In these cases, surgical excision has shown positive outcomes. On study of 62 patients with at least 18 months of symptoms underwent resection of an ossicle, 90% of patients were able to return to maximal sports activity without pain, tenderness, or loss of motion at 2-year follow-up [15].

There have been various attempts to study injection options to hasten the treatment time and return to sport; however, few have shown results that surpass traditional conservative therapy [16–18]. Recently, Danneberg described a treatment protocol that includes autologous conditioned plasma injection. The first patient experienced a subjective pain reduction of approximately 50% after one injection and returned to sport pain-free by 3 weeks. The second patient was pain-free after 6 weeks and able to return to sports; he has not experienced a relapse in OSD since treatment [18]. However, we believe larger, multicenter, randomized control trials are needed to compare the efficacy of new injection treatment protocols before we can recommend this or any other new therapeutic option.

## 46.2 Sinding-Larsen-Johansson Syndrome (SLJ)

### 46.2.1 Nature of the Disease

First described by both Sinding-Larsen [19] and Johansson [20], SLJ occurs at the junction of the patellar tendon and the lower margin of the patella and is described as overuse of distal patellar apophyseal traction. While SLJ shares many features, including etiology, of OSD, it develops at the junction of the inferior pole of the patella and the proximal portion of the patellar tendon. In addition, SLJ is much less common, with an incidence of around 2–5%, and occurs in growing adolescents participating in activities that involve sprinting or jumping [21, 22].

### 46.2.2 Clinical Findings and Diagnostics

Patients with SLJ are skeletally immature and present with tenderness and/or swelling at the inferior pole of the patella. Pain is accentuated on physical exam when the patella is loaded during flexion and resistance to quadriceps contraction. There may also be patellar tendon thickening and infrapatellar bursitis [21]. Imaging is not necessary to diagnose SLJ, but plain radiographs are recommended in unilateral cases to rule out patellar fracture or other pathology (Fig. 46.2). It is important to be aware of non-displaced patellar sleeve fractures as they look very similar to SLJ on radiographs. Clinical presentation in patellar sleeve features typically presents after acute trauma, and pain is more severe with active extension.

**Fig. 46.2** Sinding-Larsen-Johansson syndrome (SLJ). An 11-year-old male with 1 month of atraumatic knee pain

### 46.2.3 Treatment Options

Treatment options are generally conservative and include decreased activity, ice, NSAIDs, and stretching. Resolution of symptoms after this conservative generally takes 6–14 weeks [22]. We believe one important risk factor for SLJ is tight hamstrings, so increasing flexibility and incorporating a stretching routine with activity are encouraged.

## 46.3 Bipartite Patella

### 46.3.1 Nature of the Disease

Bipartite or tripartite patella is a congenital anomaly that is typically found incidentally. While a majority of patients are asymptomatic, some may present with painful symptoms in the superolateral or lateral portion of the patella that is exacerbated with activity or began after direct trauma. The overall incidence is around 2–6% and is bilateral in roughly 50% of cases, and it is more commonly found in males than females. [23–25]

The patella typically ossifies between 3 and 5 years of age [26]. As the ossification center enlarges, the expanding margins may be come irregular and associated with accessory ossification centers. The patellar ossification centers are generally superolaterally and are hypothesizes to contribute to bipartite patella [25, 26]. There is a fibrocartilaginous interface between the accessory and main patella, and it is possible that direct trauma or repetitive minor injuries on this fragile interface contribute to a symptomatic bipartite patella [24, 27].

### 46.3.2 Clinical Findings and Diagnostics

Patient history, clinical examination, and squatting skyline radiographs are used to diagnose bipartite patella. Squatting skyline view is more effective for ruling out other causes of patellofemoral pain such as hypoplasia, patellar instability, or abnormal patellar tracking (Fig. 46.3a, b). Of note, bipartite patella is one of the only sources of superolateral knee pain and tenderness at presentation. Symptoms may be worse during knee extension when walking, jumping, climbing stairs, or other activities that require active quadriceps [24].

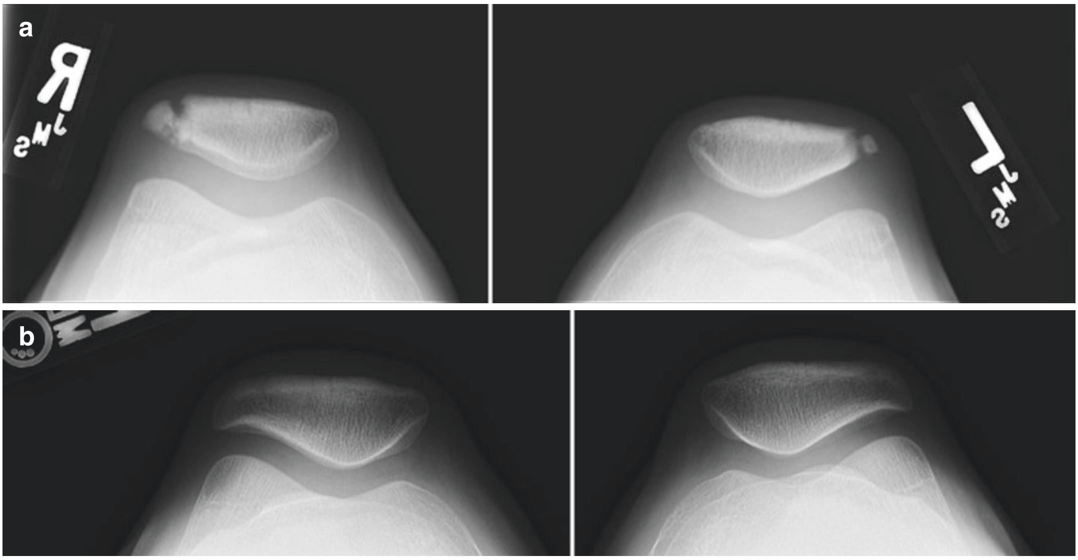

**Fig. 46.3** Bipartite patella. (**a**) A 12-year-old female at initial presentation. (**b**) 2.5 years follow-up

Bipartite patella has been classified into three groups based on the position of the accessory center: type I, at the inferior pole (5% of patients); type II, at the lateral margin (20%); and type III, at the superolateral pole (75%) [28]. On radiographs, a bipartite patella has two smooth, well-corticated borders.

### 46.3.3 Treatment Options

The current standard treatment for bipartite patella is conservative management including NSAIDs, activity modification, local corticosteroid injections, and rehabilitation to increase quadriceps flexibility [25]. Temporary immobilization with the knee based in ≤30° of flexion can offer pain relief by decreasing the mobility of the accessory fragment [24].

In some rare cases, surgical intervention is acceptable for patients who do not respond to conservative treatment. Surgical methods that have been described include excision of the fragment; soft tissue procedures, such as lateral retinacular release (LRR) and subperiosteal detachment of the vastus lateralis; and open reduction and internal fixation (ORIF) of the painful fragment [24, 29–31]. A meta-analysis reviewed 20 articles with a total of 125 patients, in which 100 required surgical treatment. All of the surgical patients returned to sport; however, 9% of them had residual symptoms. A majority of the surgical patients (65%) had excision of the fragment. Those who underwent an excision of the fragment with an additional lateral retinacular release had a 100% asymptomatic return to sport [32].

## 46.4 Trochlear and Patellar Juvenile Osteochondritis Dissecans (JOCD) of the Knee

### 46.4.1 Nature of the Disease

Juvenile osteochondritis dissecans (JOCD) is an idiopathic condition that affects the articular cartilage and subchondral bone in skeletally immature patients. JOCD is a fairly common cause of knee pain in active adolescents with a prevalence between 15 and 29 cases per 100,000 [33]. The etiology of this condition has been widely discussed since the term osteochondritis dissecans was coined by König in 1887. Most authors agree that JOCD of the knee is an overuse injury from repetitive microtrauma. Once injured, loading and stress on the vulnerable area can result in avascular necrosis and potential nonunion [33–35].

OCD lesions on the posterior-lateral aspect of the medial femoral condyle make up 70–80% of the cases. Infer-central lateral condylar lesions are seen in 15–20% of cases. Patellar OCD is a little less common at around 5–10% of cases and is usually located in the inferior pole. Femoral trochlear lesions are least common and account for around 1% of cases [35].

### 46.4.2 Clinical Findings and Diagnostics

Children diagnosed with JOCD are typically active, with a chief complaint of vague knee pain that intensifies with weight bearing or after activity. Other symptoms may include giving away episodes and swelling. In more severe cases, there may also be reports of catching or locking [36]. Some children may also attribute the onset of symptoms to be after an episode of trauma; however this is relatively less common [36]. On physical exam, there may be joint line tenderness, effusion, and crepitation. There may also be a subtle decrease in range of motion [37]. Pain when flexing the knee to 90 degrees, internally rotating the tibia, and extending the knee slowly is known as a position Wilson sign and is a good indicator of OCD. Wilson also noted five symptomatic patients with medial femoral condyle OCD lesions to walk with external tibial rotation [38]. The pain associated with internal rotation is presumably due to tibial spine impingement and results in the positive Wilson sign and external rotation during gait.

Recommended radiographs are AP, lateral, tunnel, and merchant views. In addition, 20–25% of cases have bilateral knee involvement, so it is clinically acceptable to obtain bilateral films [35].

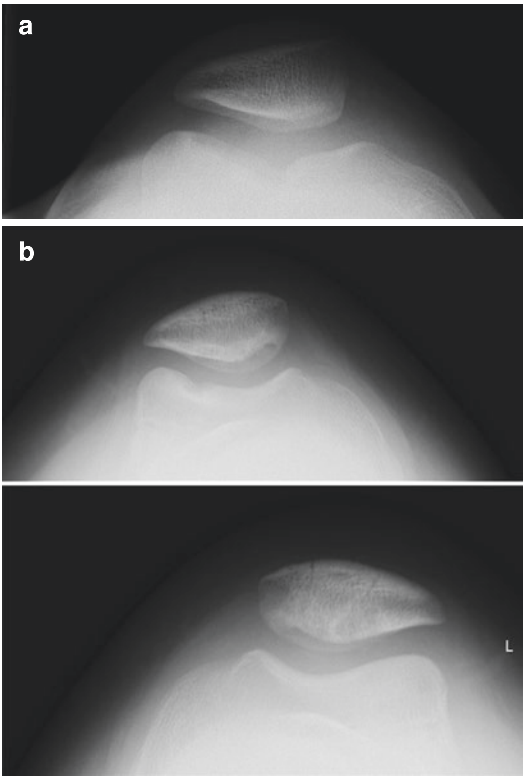

**Fig. 46.4** Juvenile osteochondritis dissecans (JOCD). (**a**) A 13-year-old male athlete with a trochlear OCD lesion. (**b**) A 12-year-old female athlete with bilateral patellar OCD lesions

Once an osteochondral defect has been confirmed on radiographs, MRI can be helpful when it comes to the treatment decision as well as to track progress posttreatment (Fig. 46.4a, b). O'Connor et al. used the MRI classification system described by Guhl to assess OCD lesions, then compared to arthroscopic findings. The authors noted that they were able to improve the accuracy of MRI staging from 45% to 85% by interpreting the high signal T2 line as a predictor for instability only when it was accompanied by a breach in the cartilage on the T1-weighted image. Additionally, Uppstrom et al. demonstrated high inter- and intra-rater reliability for both the Krause and Wall point systems for categorizing the healing potential of JOCD lesions. These nomograms incorporate patient age, lesion length, width, and appearance of cysts into a score and are helpful tools when assessing JOCD lesions most appropriate for earlier surgical intervention [39].

### 46.4.3 Treatment Options

The AAOS Clinical Practice Guidelines systematic review separated skeletally immature patients into two groups: those with stable or unstable lesions. Stable OCD lesions in skeletally immature patients typically respond well to non-operative treatment such as immobilization, non-weight bearing, or activity modification. The reported rates of healing in skeletally immature patients who undergo conservative treatment range from 50% to 90% [40].

Surgical treatment is indicated if non-operative treatment has failed over a sustained period (usually 6 months) or if there is initial radiographic imaging of a loose body. The goals of surgery are to reestablish the subchondral interface and preserve the overlying cartilage and achieve ridged fixation. There are various reported options for surgical intervention including drilling, fixation, and cartilage reconstruction procedures.

JOCD lesions are rarely found on the trochlea, and therefore few studies have focused on the outcomes in skeletally immature patients. In a recent retrospective study of 34 trochlear OCD lesions, Price et al. reported that 21 knees (62%) received operative treatment, 16 of which received repair and fixation with bioabsorbable nails. All of these patients showed radiographic and/or clinical indications of healing at most recent follow-up (mean 21.1 months). Thirteen of the patients who underwent fixation were active, and all of these patients reported successful return to sports [41].

Similar to trochlear OCD, in patellar JOCD, there is a rare lesion location, and there are very few studies that report patient outcomes of various treatment options. Kramer et al. [42] retrospectively reviewed 12 patellar OCD lesions and 17 trochlear lesions that underwent either lesion preservation or excision. At most recent follow-up, 48% of patients were pain-free, and 48% of patients had some residual pain. Although the result was nearly significant ($P = 0.06$), 67% of the patients with residual pain at final follow-up had a longer preoperative pain duration (>12 months). For each 6 month period of preoperative pain, the odds of returning to sports decreased by 68% [42].

## 46.5 Patellar Instability

While several authors have established extensive classification systems of patellar dislocation based on clinical and radiographic presentation and reviews of the literature, Green and his colleagues proposed a more simplified version with three main categories of pediatric patellar dislocation: traumatic (acute or recurrent), obligatory (either in flexion or extension), and fixed lateral [43, 44]. Each category's clinical presentation and treatment options will be described in the section below.

| | Classification of patellar dislocation according to Green and colleagues [44] | |
|---|---|---|
| Type 1 | Traumatic | Acute |
| | | Recurrent |
| Type 2 | Obligatory | In flexion |
| | | In extension |
| Type 3 | Fixed lateral | |

## 46.6 Acute Dislocation of the Patella

The acute traumatic categorization refers to patients who experienced an initial dislocation event due to trauma. Studies report that between 60% and 70% of these acute traumatic dislocations occur as a result of a sport-related incident and can represent 3% of all knee injuries in children and adults [45]. Because this injury is usually traumatic and painful, physical exam can sometimes be difficult. It is important to assess the medial soft tissue complex of the knee. Tears in the MPFL or VMO are very common in acute dislocations, so special attention should be paid to any swelling or ecchymosis in the area [46].

Radiographs of the knee (anterior-posterior, lateral, and merchant views) should be obtained to assess for osteochondral fractures and the status of the physis. Radiographs should also be asses for common risk factors for patellofemoral instability including patella alta and trochlear dysplasia [47]. We believe obtaining an MRI for primary dislocation is valid if there is evidence for osteochondral fracture on X-rays and noticeable joint effusion/hemarthrosis or the history and physical exam is unclear. An MRI will also allow the provider to assess trochlear dysplasia and the tibial tubercle to trochlear groove (TT-TG) distance. Approximately 40% or more of patellar dislocation have an associated osteochondral fracture of the patella or trochlea. Resultant loose bodies will be visible on X-ray or MRI. In this scenario, arthroscopy is recommended for excisions or open repair.

The traditional treatment for initial patellar dislocation without osteochondral fracture has been brief immobilization and subsequent physical therapy. However, recent studies have reported 40–70% of patients sustain recurrent dislocations [45, 48, 49]. There are various risk factors for recurrent dislocation or instability that should be assessed when developing a treatment plan and consulting with the patient. These anatomic risk factors have been heavily described and incorporated into a "patellar instability severity score." [50] This score includes six factors:

- Age (<16 years of age)—1 point
- Bilateral instability—1 point
- Trochlear dysplasia (none, mild, and severe)—0, 1, 2 points, respectively
- Patellar height (IS >1.2)—1 point
- TT-TG distance (>16 mm)— 1 point
- Patellar tilt (>20°)—1 point

When this score was applied to a study population, the odds ratio for recurrent dislocations was 4.88 for the patients who scored 4 or more points [50]. In addition, Magnussen et al. reported that at a mean of 3.4 years follow-up for 111 patients with non-operatively treated primary lateral patellar dislocation, 35 (26.9%) of patients experienced subsequent dislocation events. Significantly, only 26.4% of patients without further dislocations were able to return to desired sport activities without limitations due to the primary dislocation [51].

While recurrent patellar instability is common, it is complex, and each patient will respond differently to initial treatment. Young, healthy, and athletic pediatric patients with multiple risk factors should be advised of their risk for subsequent instability and followed closely.

## 46.7 Recurrent Dislocation of the Patella

Recurrent patella instability involves repeated patella dislocations following an initial incident. Recent studies have reported subsequent dislocations in 15–44% of patients [47, 52]. With these patients, it is important to evaluate their extremities clinically and radiographically to gain a comprehensive understanding of the factors contributing to their instability (Table 46.1).

These tests serve as a supplement to understanding the risk factors discussed earlier. Pediatric patients presenting with recurrent patellar instability require this comprehensive clinical and radiographic exam as they are unlikely to improve without surgical stabilization. Each patient's individual pathoanatomy and athletic goals will guide a tailored treatment plan and permit the best possible outcome. Surgical interventions to address recurrent patellar instability will be further discussed in Chap. 47.

**Table 46.1** Clinical examinations and, if applicable, corresponding radiographic exams

| Clinical exams | Radiographic |
|---|---|
| Foot progression angle during gait | X-ray: Standing AP hip to ankle, lateral, and merchant views<br>• Maturity of physis<br>• Patellar height<br>• Trochlear dysplasia |
| Standing mechanical axis | CT or 3D EOS<br>• Rotational abnormalities |
| Hip internal and external rotation | MRI<br>• TT-TG<br>• Trochlear dysplasia<br>• Damage to the patellar and trochlear cartilage |
| *J*-sign test | |
| Apprehension test | |
| Beighton test [53] | |

## 46.8 Obligatory Dislocation

Obligatory dislocations occur with every episode of either knee flexion or extension, depending on the subtype. Obligatory patella dislocation in flexion typically cannot be manipulated or relocated into the trochlea, while the knee is fixed but does reduce into the trochlea in full extension. Fixed lateral dislocations are rare, irreducible dislocations in which the patella stays dislocated laterally in flexion and extension. Both obligatory and fixed dislocations often present with other congenital abnormalities. Each of these categories can be further specified as syndromic if the dislocation is associated with genetic or congenital conditions including skeletal dysplasia, Ehlers-Danlos, cerebral palsy, Marfan disease, nail patella syndrome, or Down syndrome, Rubinstein-Taybi syndrome, and Kabuki syndrome. These patients generally require surgical intervention. General treatment plan would include a lateral release, quad lengthening, and MPFL reconstruction. These surgical interventions will be explained in detail in Chap. 47.

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# 47

# Specific Procedures for Pediatric Dislocation

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and Marie Askenberger

## 47.1 Evaluation of the Pediatric Patient with Patellar Dislocation

It is well-known that achieving a correct diagnosis in children with acute knee trauma and hemarthrosis through clinical examination is difficult. First and foremost, history is important. Did the injury occur in the setting of trauma, while playing contact versus noncontact sports, or in daily life with little or no force involved? In the young adolescent, the story can be unclear. This is especially true in the setting of traumatic lateral patellar dislocation (LPD), since the patella often relocates spontaneously. If relevant, other important features of the history include the frequency and duration of patellar instability events and personal or family history of ligament laxity and collagen disorders that predispose the patient to patellar instability.

Traumatic intra-articular knee injuries become more common at the age of 9 and peak around the ages of 12–15 years. In children who present with hemarthrosis secondary to traumatic injury, a correct diagnosis is essential to guiding appropriate treatment. Radiography is typically the first diagnostic tool and is used to rule out fractures, but more recently, magnetic resonance imaging (MRI) has become the preferred diagnostic modality. Patellar dislocations are the most common cause of injury in these patients [1–3]. Traumatic patellar dislocation presents with specific MRI signs, including bone bruise at the medial patellar and lateral femoral condyle, hemarthrosis, and edema at the medial patellofemoral ligament (MPFL) injury site. MRI can be used to evaluate chondral/osteochondral fractures and injuries to the medial retinaculum and to identify the various anatomic risk factors for patellofemoral instability that will be discussed in the subsequent section (Figs. 47.1 and 47.2) [4–11]. These risk factors are important in determining the risk of recurrent LPD and in decision-making for the best treatment option.

Understanding the etiology and type of patellar dislocation is also important in guiding treatment decisions. Green and colleagues have proposed three main clinical categories of pediatric patellar dislocation: traumatic, obligatory, and fixed lateral [12, 13]. These are described in greater detail in Chap. 46. Traumatic dislocations are the most common and can be further subclassified as first time (primary) or recurrent. In obligatory dislocation, the patella dislocates spontaneously with every cycle of knee flexion or extension. Fixed dislocation of the patella is permanent and manually irreducible. These three categories of pediatric patellar dislocation can be subclassified as syndromic when associated with conditions such as skeletal dysplasia, Ehlers-Danlos, cerebral palsy,

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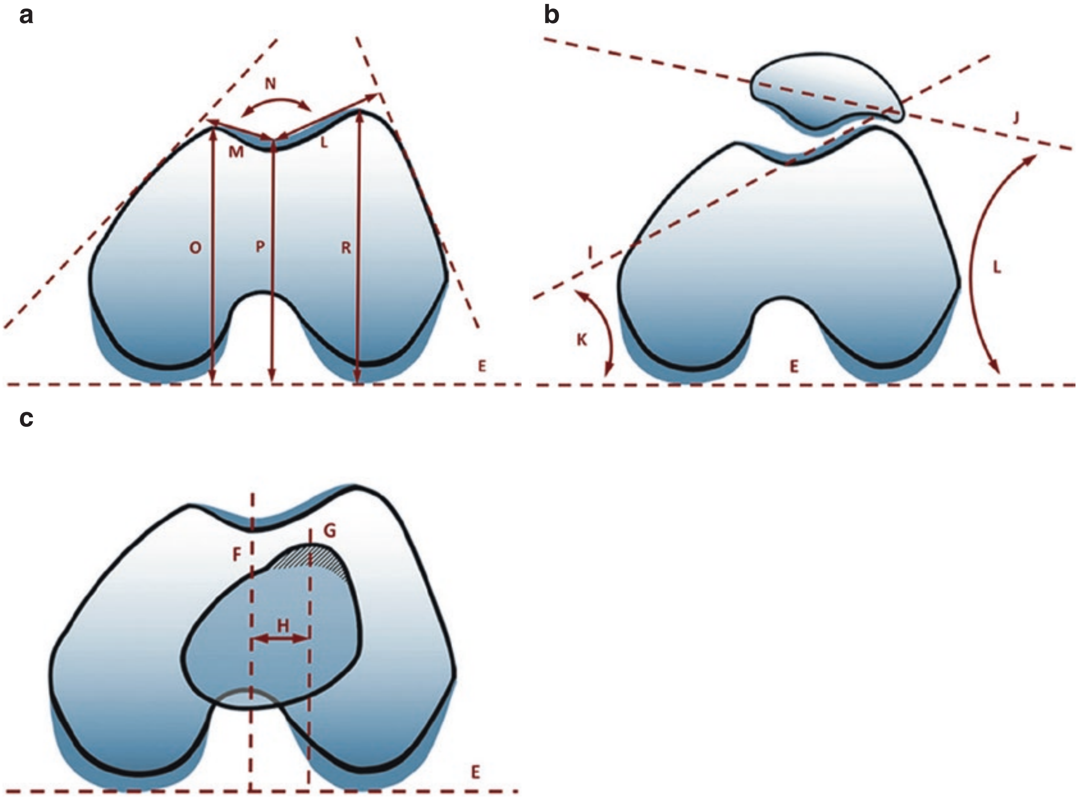

**Fig. 47.1** Axial MRI measurements. The first proximal axial image showing cartilage covering the whole trochlea is used regarding the trochlea and anterior aspects of the femoral condyles. The axial image that shows the most posterior aspect of the femoral condyles is used to define the posterior baseline and posterior landmarks of the condylar height measurements. (**a**) **Trochlear depth** (mm) = $([O + R]/2) - P$. Trochlear dysplasia is defined as trochlear depth <3 mm. **Sulcus angle** (°) = $N$. Trochlear dysplasia is defined as sulcus angle ≥145°. **Trochlear facet asymmetry** (%) = $(M/L) \times 100$. Trochlear dysplasia is defined as trochlear facet asymmetry <40%. (**b**) **Lateral trochlear inclination angle** (°) = $K$. $K$ is the angle between the ($E$) posterior femoral condyle and ($I$) a line across the lateral facet. Trochlear dysplasia is defined as <11°. **Patellar tilt** (°) = $L$. $L$ is the angle between the ($E$) posterior condyle and ($J$) a line at the greatest patellar width (patellar midpoint). Abnormal is defined as ≥20°. (**c**) **Tibial tubercle–trochlear groove distance** (mm) = $H$. $H$ is the distance between ($F$) a line at the most inferior level of the trochlear groove perpendicular to ($E$) the posterior condyle line and ($G$) a line parallel to $F$ at the midline of the patellar tendon insertion into the tibia. Abnormal is defined as ≥15 mm

Kabuki syndrome, Down syndrome, nail-patella syndrome, or Marfan disease. Parikh and Lyssikas propose an alternative four-tier classification system: first patellar dislocation (type 1), recurrent patellar instability (type II), dislocatable patella (type III), and dislocated patella (type IV) [14].

## 47.2 Risk Factors for Recurrent Patellar Dislocation

Specific patterns of osseous geometry have been associated with an increased risk of recurrent patellar instability after primary dislocation. For instance, pathologic genu valgum, increased femoral anteversion, and external tibial torsion can all increase the Q-angle and contribute to patellar dislocations. In a radiographic anatomic study, Dejour et al. also found trochlear dysplasia, increased patellar tilt and patella alta, and increased tibial tuberosity-trochlear groove (TT-TG) distance to be anatomic risk factors [7]. Balcarek incorporated these measurements on MRI into the “patellar instability severity score,” which includes six variables: age (≤16 years of age), bilateral instability, trochlear dysplasia (none, mild, severe), patellar height (Insall-Salvati [IS] ratio >1.2), TT-TG distance

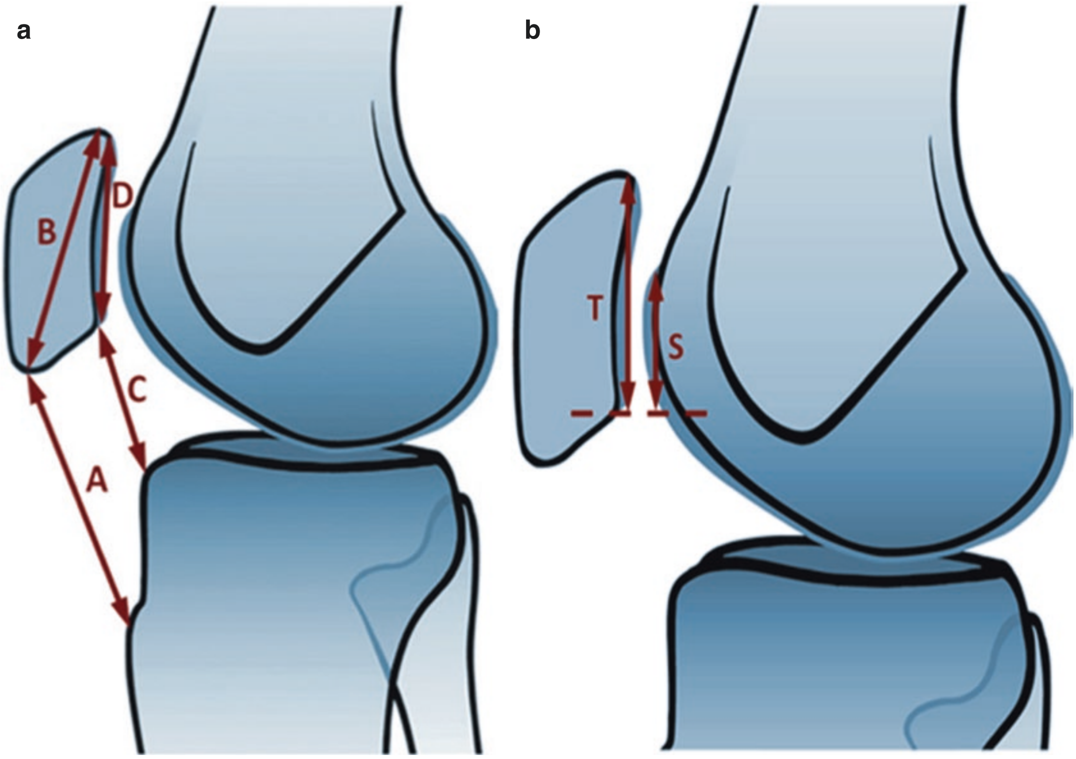

**Fig. 47.2** Sagittal MRI measurements. The sagittal image showing the greatest length of the patella (through the central part of the patellar facet) is used for sagittal measurements of patellar height. (**a**) **Caton-Deschamps index** = *C*/*D*. (*C*) A line from the distal part of the articular cartilage to the anterior corner of the superior tibial joint surface divided by the (*D*) length of the cartilaginous articular surface. Patella alta is defined as ≥1.2. **Insall-Salvati index** = *A*/*B*. (*A*) The length from the caudal aspect of the patella to the proximal insertion of the patellar tendon divided by the (*B*) length of the patella from cranial to caudal. Patella alta is defined as >1.3. (**b**) **Patellotrochlear index** PTI = *S*/*T*. (*S*) A line along the length of the trochlear cartilage overlapping the patellar cartilage divided by (*T*) the length of the articular cartilage surface. PTI is used together with patellar height measurements for evaluation of the patellofemoral engagement

(≥16 mm), and patellar tilt (>20°) [15]. Among patients who scored 4 or more points, the odds ratio for recurrent dislocations was 4.88 in a study population of 61 patients with median age of 19 years.

Anatomical risk factors are frequent in children with first-time traumatic patellar dislocation. Askenberger et al. studied this prospectively [4]. Skeletally immature patients 9–14 years of age with clinical examination, radiographs, and MRI within 2 weeks of the index injury were included. In the final analysis, 103 patients with first-time traumatic LPD were age-matched with a control group of 69 children with traumatic knee injuries that resulted in hemarthrosis. Among the patients with LPD, 74% had trochlear dysplasia (trochlear depth <3 mm), 76% had patella alta (Caton-Deschamps index [CDI] ≥1.2), 50% had patellar tilt (≥20°), and 38% had elevated TT-TG distance (>15 mm) compared to the control group (4%, 36%, 0%, and 9%, respectively). The main divergent risk factor was trochlear dysplasia. High TT-TG distance was only found in combination with other risk factors in the LPD group, and patellar tilt ≥20° was only found in patients with LPD.

Anatomically, trochlear dysplasia has been consistently identified as having the highest independent predictive value for recurrent instability. The largest study to date of children and adolescents with first-time patellar dislocations is by Jaquith and Parikh, who examined 226 knees in 250 patients [16]. Multivariate analysis revealed a strong association between recurrent instability and trochlear dysplasia with an odds ratio of 3.56. Risk of recurrence among patients with both immature physes and trochlear dysplasia in this series was 56%. Similarly, a retrospective study by Lewallen et al. examined 222 knees in 210 pediatric patients and demonstrated a recurrence rate of 69% among those with trochlear dysplasia and skeletal immaturity [17]. Of note, both studies were retrospective in nature, and anatomic risk factors were evaluated on radiographs. Therefore risk factors such as limb alignment and advanced imaging measurements such as TT-TG distance, sulcus angle, and MPFL tear pattern could not be evaluated.

Trochlear dysplasia can be assessed based on lateral radiographic features using the Dejour classification system [18, 19]. Low-grade dysplasia is characterized by the crossing sign (Dejour type A). High-grade dysplasia shows a supratrochlear spur or bump (type B), a double contour line (type C), or the combination of these features with a vertical join or cliff pattern (type D). Lippacher et al. demonstrated that these features on lateral radiographs are sufficient for evaluation of trochlear dysplasia in pediatric patients with open growth plates [20]. However, MRI has recently become the diagnostic tool of choice for assessing patellofemoral instability. In patients with trochlear dysplasia, morphology of the cartilaginous trochlea has been shown to differ markedly from that of the underlying bony trochlea. Therefore, MRI best depicts true patellofemoral geometry and the cartilaginous dimensions of the trochlear groove [21, 22]. On axial MRI, low-grade dysplasia is characterized by a fairly shallow trochlea (Dejour type A). High-grade dysplasia shows a flat or convex trochlea (type B) or demonstrates asymmetry of trochlear facets with either a hypoplastic medial condyle (type C) or with vertical join and cliff pattern (type D). Lippacher et al. showed good to excellent interobserver and intraobserver with the two-grade Dejour classification of low- versus high-grade dysplasia on lateral X-ray but best overall agreement on axial MRI [20].

In patella alta, the patella sits outside the deeper confines of the trochlear groove, making it inherently less stable. Patella alta can be evaluated using a number of different indices. It is often defined as a CDI >1.2 in adults. This index is increased in younger patients when measured on radiographs due to the patella's proximal to distal ossification pattern but adequate when measured on MRI. In the aforementioned study by Jaquith and Parikh, CDI >1.45 was a significant risk factor in univariate analysis [16]. This cutoff of CDI >1.45 closely approached significance in multivariate analysis with an odds ratio of 2.06 ($p = 0.0567$) [16]. Askenberger et al. showed CDI ≥1.2 as measured on MRI to be common in both children with first-time traumatic patellar dislocation (76%) and the age-matched control group (36%) [4]. This finding suggests that patella alta can be a normal variant in the knee and may be well tolerated when not in combination with other risk factors for patellar dislocation.

Like CDI, TT-TG distance and patellar tilt measurements are valuable when combined with other risk factors. The TT-TG distance represents how lateral the tibial tubercle is relative to the center of the trochlea in the axial plane and can be measured on MRI or CT [23]. Patellar tilt is not only associated with MPFL injury and medial laxity, but it can also be a result of other anatomic factors such as trochlear dysplasia, patella alta, and lateral retinacular tightness. In adults, a TT-TG distance of greater than 20 mm, as established by Dejour et al., is often regarded as the threshold to consider a distal realignment procedure [7]. In a recent study based on 618 MRIs from pediatric patients aged 9 months to 16 years, Dickens et al. determined the median TT-TG distance to be 8.5 mm for patients without patellar instability and 12.1 mm in those with recurrent patellar instability [23]. In this cohort, TT-TG distance approached established normal values for adults as adolescents reached skeletal maturity. Similarly, Askenberger et al. determined the mean TT-TG to be 13.9 ± 4.7 in patients aged 9–14 years old with primary traumatic LPD compared to 9.8 ± 3.6 among the age-matched controls [4]. In this prospective study, patellar tilt was measured to be 21 ± 7.2 in the LPD group versus 8.5 ± 4.4 in the control group. Interpretation of TT-TG distance needs to be adjusted depending on the age and skeletal maturity of a child. Patellar height can be difficult to measure on MRI if lateralization of the patella is severe, and in these cases, measurement on radiographs is preferred. In more exceptional cases with rotational malalignment, a CT scan is required.

A high recurrence rate (30–70%) after nonoperative management of a first-time patellar dislocation in the pediatric and adolescent population has been reported in the literature [5, 16, 17, 24–27]. Furthermore, multiple anatomic factors increase this risk of recurrent patellar instability. In patients with history of contralateral patellar dislocation, skeletal immaturity, and CDI >1.45 and trochlear dysplasia as diagnosed on radiographs, the predicted risk of recurrence increased to 88% in the study by Jaquith and Parikh [16]. The presence of any three risk factors had a predicted risk of recurrence of 75%, and the presence of any two risk factors had a predicted risk of 55%. Similarly, Arendt et al. evaluated risk factors for recurrent instability after primary lateral patellar dislocation in a prospective MRI study of 145 patients and identified three statistically significant risk factors: trochlear dysplasia (sulcus angle >154°), patella alta (I/S ratio >1.3), and skeletal immaturity [28]. Stepwise regression analysis demonstrated the probability of redislocation to be 23% with one positive criterion, 51% with two criteria, and 79% with three positive criteria. Thus, an understanding of a patient's risk stratification at time of first dislocation might help differentiate between responders and nonresponders to conservative treatment and determine the need for early surgical intervention.

## 47.3 Pediatric Options for Medial Patellofemoral Ligament Reconstruction

Medial patellofemoral ligament (MPFL) reconstruction has become a mainstay for the operative management of patellofemoral instability. The MPFL is the main stabilizer against lateral patellar dislocation when an outside force is exerted on the knee in extension. Nearly all traumatic patellar dislocations cause MPFL injury. Askenberger et al. demonstrated MPFL injury on MRI and arthroscopy in 73 of 74 skeletally immature patients with first-time lateral patellar dislocations [29]. Injury was at the patellar attachment site in 99% of the cases, either in isolation or as part of a multifocal injury. In a cohort study of 43 children by Kepler et al., MRI scans showed the zone of MPFL injury to be at the patellar attachment in 61%, at the femoral attachment in 12%, at both the patellar and femoral attachment in 12%, and midsubstance in 9% [30]. Only 6% had no identifiable MPFL injury. Early efforts to include the MPFL in treatment of patellofemoral instability focused on primary repair but demonstrated high rates of failure and redislocation postoperatively [31]. More recently, various techniques of MPFL reconstruction have shown good clinical and radiographic outcomes. The goal of MPFL reconstruction is to recreate the anatomic checkrein for the patella. In skeletally immature patients, the greatest concern with MPFL reconstruction is the potential for injury to the distal femoral physis. Hardware fixation or bony procedures of the patella can also lead to patellar fracture or injury of the chondral surface.

Parikh et al. reported a complication rate of 16.2% in a retrospective review of 179 MPFL reconstructions in patients with mean age 14.5 ± 2.6 years [32]. Reconstruction was performed by looping a hamstring autograft through bone tunnels in the patella and fixing the graft at the femoral tunnel with a bioabsorbable interference screw. In patients with open distal femoral physes, either a soft tissue technique without bony tunnels was used, or the femoral tunnel was placed just distal to the distal femoral physis. Eight patients presented with recurrent patellar instability, eight with knee motion stiffness, and five with patellofemoral pain. Additionally, five patients had transverse fractures through the patellar tunnel, and one patient sustained a nondisplaced transverse fracture after direct trauma to the knee. No injuries to the physis were reported in the subset of 28 MPFL reconstructions performed in children ages 12 and younger.

Seitlinger et al. were the first to describe a case of partial growth arrest and subsequent flexion deformity of the distal femur in a skeletally immature female patient 3 years after MPFL reconstruction [33]. This case highlights the importance of radiographic localization of the distal MPFL attachment site and careful socket placement in patients with open physes if a bony attachment is utilized.

In a first-time dislocator, MPFL reconstruction is indicated in the presence of an osteochondral defect or loose body that is amenable to repair [30, 34]. Osteochondral fragments have good healing capacity after surgical intervention with resorbable pins, screw-fixation, and pull-out sutures in the skeletally immature population. A fragment >10 mm in a weight-bearing zone should ideally be refixated within 10 days of the index injury, but good healing has also been demonstrated after refixation within 2 months [35, 36]. Additionally, one of the most common indications for operative management is a history of recurrent lateral patellar dislocations and persistence of symptoms after conservative management. Some centers also consider MPFL reconstruction in first-time dislocators with multiple risk factors for instability, such as those with contralateral instability, trochlear dysplasia, and/or a high patellar instability severity score as discussed earlier.

Of note, isolated MPFL reconstruction may not be sufficient for management of patellofemoral instability in the setting of additional anatomic pathology such as genu valgum, increased age-specific TT-TG, severe patella alta, high-grade trochlear dysplasia, or rotational malalignment. Distal realignment procedures are indicated for bony malalignment, and implant-mediated guided growth is indicated in the setting of genu valgum. Both will be discussed in following sections. In patients with lateral retinacular tightness, lateral lengthening may be performed in conjunction with MPFL reconstruction. In patients with severe trochlear dysplasia, trochleoplasty may also be considered as an adjunctive procedure.

MPFL reconstruction has demonstrated good short-term results in children. Overall failures of MPFL reconstruction in children according to the literature today are due to:

- Failure to consider additional bony risk factors (high-grade trochlear dysplasia, severe patellar alta, rotational malalignment).
- Intraoperative technical errors/decisions (non-anatomic femoral placement and patellar fractures after drilling in small patellas).
- Inappropriate patient selection.

Over 100 different techniques for MPFL reconstruction have been described. This section focuses on the five most common types in pediatrics (Fig. 47.3). One technique uses a double-bundle two-limbed hamstring graft with patellar and femoral sockets or suture anchors. Another hamstring graft technique utilizes the adductor magnus tendon as a femoral attachment site to avoid bony attachment. The adductor tendon and quadriceps tendon have also been described as graft options. The Nietosvaara technique, which involves reconstruction of both the MPFL and medial patellotibial ligament using a hamstring autograft, will be discussed in the distal realignment section.

### 47.3.1 Doubled Two-Limbed Free Hamstring Graft

One technique is to harvest the gracilis or semitendinosis tendon and use a doubled two-limbed hamstring autograft to reconstruct the MPFL (Fig. 47.3a) [37]. Various methods of hamstring graft fixation can be used. Due to the increased risk of patellar fractures associated with osseous tunnels, many surgeons advocate the use of suture anchors or short osseous sockets to avoid this complication. Distally, this technique requires the creation of a femoral tunnel. Therefore, a thorough understanding of the anatomy and radiographic presentation of the distal femoral physis is paramount to avoiding growth arrest. In a cadaveric study, Nguyen et al. concluded that

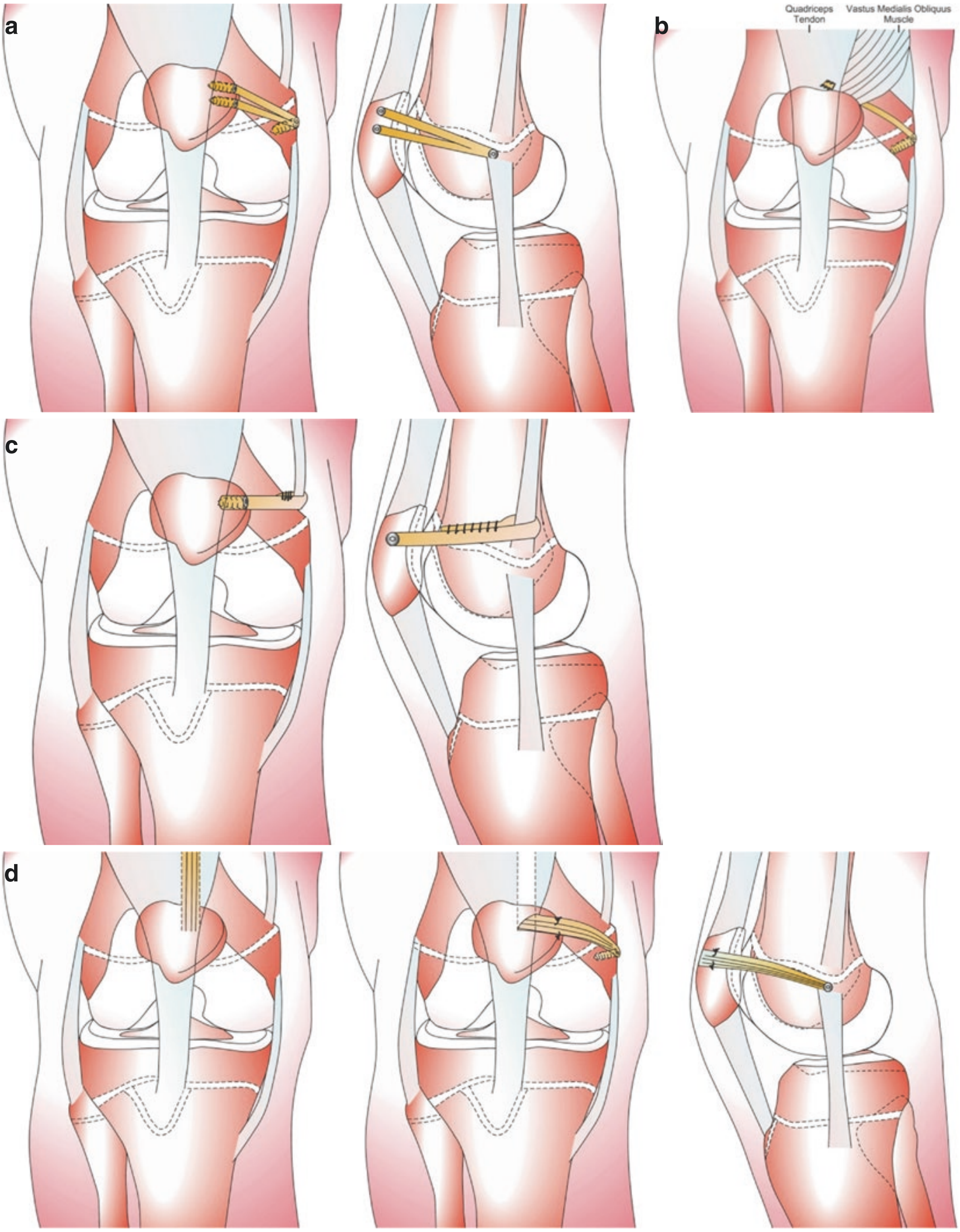

**Fig. 47.3** (**a**) Doubled two-limbed free hamstring graft. (**b**) Medial quadriceps tendon femoral ligament reconstruction. (**c**) Hamstring graft with the use of adductor magnus tendon as femoral attachment site. (**d**) Pedicled quadriceps tendon. (**e**) Pedicled adductor magnus tendon

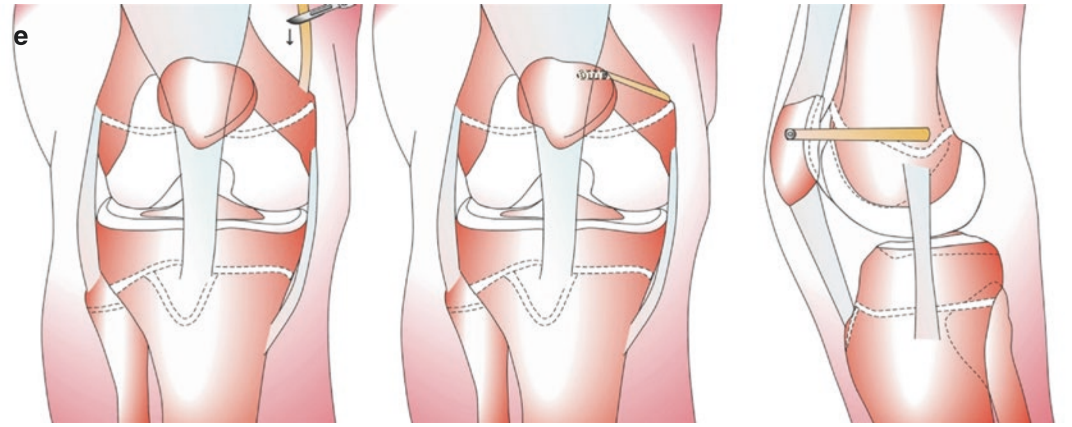

**Fig. 47.3** (continued)

the drill should be angled distally and anteriorly approximately 15–20° in both the sagittal and coronal planes to avoid injury to the physis [38].

Ladenhauf et al. demonstrated favorable outcomes in 41 patients, of whom 23 were skeletally immature, with a free doubled hamstring autograft [39]. In this technique, two ends of the hamstring autograft were docked in the superior medial patella using short sockets. The femoral socket tunnel was carefully placed distal to the physis under fluoroscopic guidance with anteroposterior and lateral imaging. No postoperative instability or growth arrests at mean follow-up of 16 months were reported in this case series. Similarly, Nelitz et al. demonstrated favorable outcomes in 21 skeletally immature patients who underwent MPFL reconstruction with a doubled gracilis autograft [40]. At mean follow-up of 2.8 years, there was excellent improvement in Kujala scores and no postoperative dislocation events.

### 47.3.2 Medial Quadriceps Tendon Femoral Ligament Reconstruction

The MPFL complex is composed of proximal fibers that extend to the vastus intermedius tendon, which have termed the medial quadriceps tendon femoral ligament (MQTFL) by Fulkerson and Edgar. Reconstruction of the MQTFL can also be utilized for the management of patellofemoral instability (Fig. 47.3b) [41]. With this technique, a semitendinosus autograft is docked on the femur at the distal anterior adductor tubercle with socket fixation. However, rather than a patellar attachment, the graft is then brought under the vastus medialis such that it can be woven and attached to the deep distal medial quadriceps tendon. As a result, this technique avoids injury to bony patella. Fulkerson and Edgar reported no recurrence of patellar instability in 17 patients who underwent MQTFL reconstruction.

### 47.3.3 Hamstring Graft with the Use of Adductor Magnus Tendon as Femoral Attachment Site

The adductor magnus tendon lies in close proximity to the MPFL femoral attachment site and has been incorporated as a fixation point for MPFL reconstruction (Fig. 47.3c). In this technique, as first described by Gomes, the hamstring autograft is looped around the adductor magnus tendon [42]. Both parts of the graft are then stitched together and docked to the medial patella. Gomes reported no cases of recurrent instability in 12 patients with mean follow-up of 53 months.

Modifications to the adductor magnus sling technique have since been described in the literature. However, using a soft tissue fixation at the femur in children has been shown to be inferior to bony fixation in adults. Lind et al. had a revision rate of 21% in a pediatric cohort of 24 patients who underwent MPFL reconstruction by looping a released gracilis tendon around the adductor magnus tendon [43]. In this technique, the autograft was fixed at the medial and proximal half of the patella using in a drill hole. Alm and colleagues left the distal insertion of the semitendinosus or gracilis tendon intact, looped the autograft around the adductor magnus tendon, and used suture anchors to fix the graft at the medial patella [44]. This technique showed an elevated redislocation rate of 13% in 30 skeletally immature patients.

### 47.3.4 Pedicled Quadriceps Tendon

In the pedicled quadriceps technique, a full-thickness strip of medial quadriceps tendon is harvested, reflected to expose the posterior surface, and docked at the medial femoral condyle with a suture anchor (Fig. 47.3d) [45]. Modifications of this technique were first described by Steensen et al. [46] and further refined by Goyal [47] and Hennrikus [45]. The advantage to the quadriceps pedicled graft is that bone tunnel drilling and fixation at the patella are not needed, reducing risk of patellar fracture.

Nelitz et al. reported no recurrent dislocations and significant improvements in Kujala scores at mean follow-up of 2.6 years in 25 skeletally immatures patients with mean age 12.8 years who underwent anatomic MPFL reconstruction using this technique [48, 49]. Children with high-grade trochlear dysplasia were excluded. A more recent study by this group reported favorable outcomes in 18 adolescents with open physes and severe trochlear dysplasia treated with thin flap trochleoplasty in addition to MPFL reconstruction with a pedicled quadriceps tendon graft [50]. At mean follow-up of 2.3 years after surgery, there were no reported growth disturbances or recurrent patellar dislocations. Fink et al. developed a minimally invasive technique for harvest of the quadriceps tendon subcutaneously [51, 52]. They reported no redislocations or complications at 1 year of follow-up in 17 patients with mean age 21.5 years.

### 47.3.5 Pedicled Adductor Magnus Tendon

The pedicled adductor magnus technique was first described by Avikainen et al. to augment primary repair of the MPFL [53]. In this method, the adductor magnus tendon is cut proximal to its distal insertion, and the graft is reflected and fixed near the medial border of the patella (Fig. 47.3e). Sillanpää et al. reported one postoperative dislocation and a median Kujala score of 88 at 10-year follow-up in a group of 15 patients treated with the adductor magnus tendon autograft [54]. Malecki et al. had a recurrence rate of 9.3% in a subset of 32 patients treated with the MPFL pedicled adductor magnus technique [55].

## 47.4 Distal Realignment Options

Distal realignment procedures are indicated in patients with an increased age-specific TT-TG distance and large Q-angle. Tibial tubercle osteotomies are generally avoided in growing children as they place the tibial tubercle apophysis at risk and can lead to significant genu recurvatum deformity. Fortunately, there are multiple soft tissue distal realignment procedures that may be safely used in children and adolescents. We will review the common options for distal realignment for the skeletally immature patient below.

### 47.4.1 Nietosvaara Technique

In response to multiple postoperative failures after the Galeazzi procedures, Nietosvaara and Giordano described a modification that aims to reconstruct both the MPFL and the medial patellotibial ligament (MPTL) [56, 57]. The Galeazzi procedure involves a semitendinosus tenodesis to the patella in an oblique manner. In the Nietosvaara technique, a pedicled gracilis and semitendinosus autograft are tunneled longitudinally not obliquely through the medial half of the

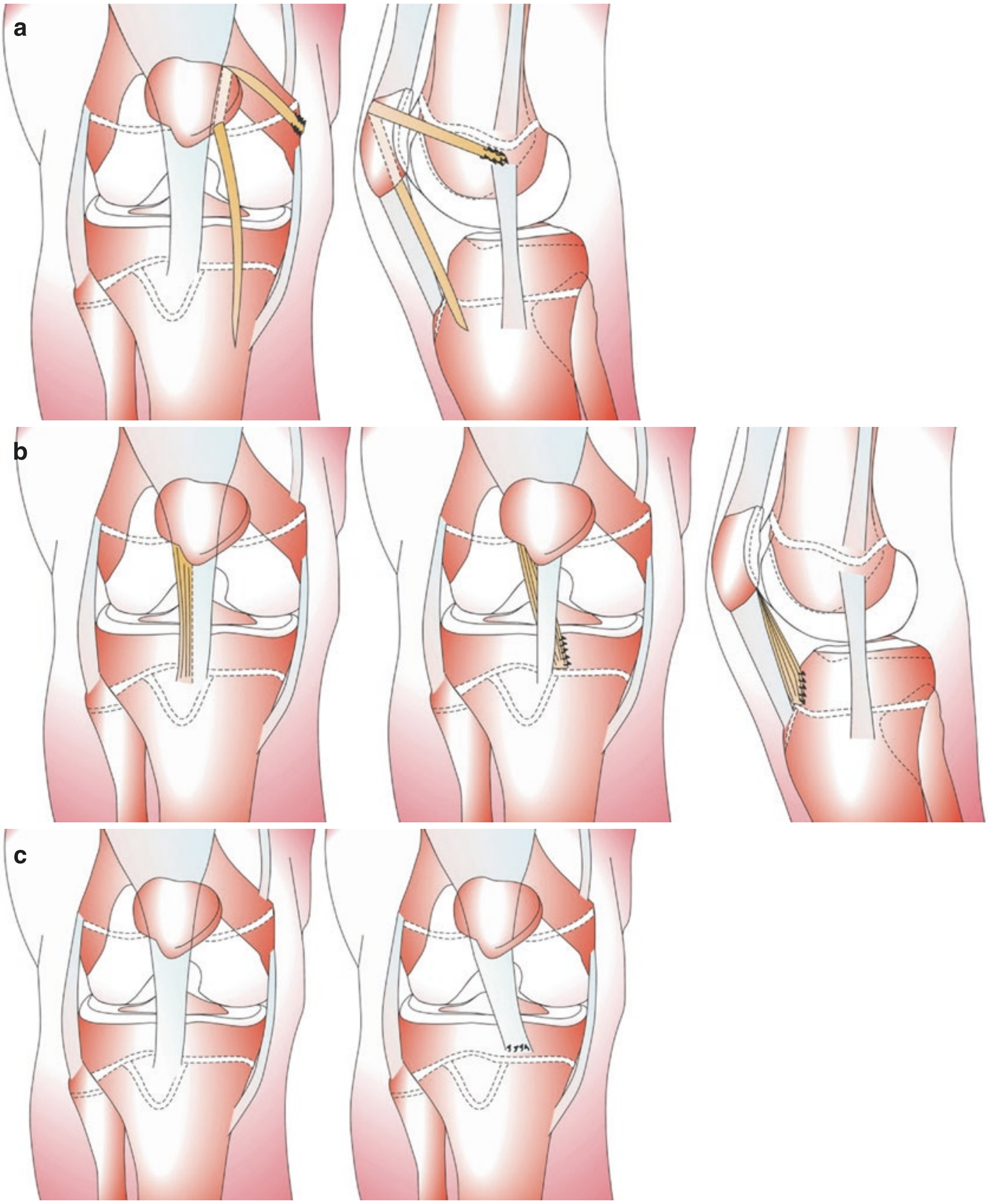

**Fig. 47.4** (**a**) Nietosvaara technique. (**b**) Roux-Goldthwait procedure. (**c**) Patellar tendon transfer

patella (Fig. 47.4a). The graft is then passed subcutaneously to the medial epicondyle where it is secured with fixation at the femur. Long-term studies are needed to evaluate the efficacy of this technique.

### 47.4.2 Roux-Goldthwait Procedure

The Roux-Goldthwait procedure was originally described by Roux in 1888 [58] and subsequently modified by Goldthwait in 1899 [59] and Marsh and colleagues in 2006 [60]. This technique involves creating a longitudinal split in the patellar tendon and detaching the lateral half from the tibial tubercle distally (Fig. 47.4b). This is performed carefully so as not to compromise apophyseal blood supply. The lateral half is then transferred deep to the medial half and sutured onto the periosteum and soft tissues on the medial side of the tibial epiphysis. Marsh et al. performed the Roux-Goldthwait along with a lateral capsular release on 30 knees in 20 pediatric patients with chronic recurrent patellar instability and mean follow-up of 6.1 years [60]. In this cohort of patients, 26 knees had an excellent result, 3 had good result, and 1 had fair result based on Insall's criteria. Vahasarja et al. performed realignment procedures on 57 knees with 3 different operative techniques: lateral release, lateral release and medial reefing, and Roux-Goldthwait [61]. They concluded that lateral release and medial reefing correct patellar tilt most effectively, while the Roux-Goldthwait operation best corrects lateral patellar deviation.

### 47.4.3 Patellar Tendon Transfer

Luhmann, Garin, and Grammont recommend medialization of the patellar tendon in patients with open physes [62–64]. In this technique, the patellar tendon is detached from the underlying tibial apophysis, medialized at least 50% of its width, and then sutured to the periosteum (Fig. 47.4c) [65].

Garin et al. described a case series of 50 knees treated with patellar tendon transfer, lateral retinacular release, and medial reefing [63]. Functional outcome was good in 76% of habitual dislocators and in 86% of recurrent dislocators. There were eight cases of recurrent dislocation and one case of recurvatum deformity after this procedure. More recently, Nepple et al. reported favorable outcomes of medial patellar tendon transfer with proximal realignment in 35 knees belonging to 22 patients [66]. At mean follow-up of 57.8 months, 11% of patients reported recurrent patellar subluxation, while none reported recurrent dislocation.

### 47.4.4 Patellar Tendon Shortening

Patella alta can be addressed with patellar tendon imbrication in the skeletally immature patient as described by Andrish et al. [67, 68]. However, long-term clinical results of this technique in children have not yet been published.

## 47.5 Guided Growth

As previously mentioned, pathologic genu valgum contributes to increase Q-angle and is a common osseous risk factor associated with patellofemoral instability. Therefore, implant-mediated guided growth should be performed to correct malalignment in patient with genu valgum and patellar instability. An eight plate can be used to tether the physis on the medial side while allowing unhindered growth on the lateral. Patients are followed with periodic radiographs, and the implant is removed once full angular correction is achieved. Of note, the plate should be positioned in the posterior one-third of the femur to avoid transection of the MPFL.

To date, two studies have been published regarding the outcomes of hemiepiphysiodesis for surgical management of patellofemoral instability associated with genu valgum. Kearney et al. retrospectively reviewed 26 knees in 15 patients with patellofemoral stability and genu valgum. Twenty-six medial distal femurs and 4 medial proximal tibias underwent selective hemiepiphysiodesis, using Blount staples across 16 physes and 8 plates across 14 physes. In this case series, 69% of patients had complete symptom resolution, while 31% patients reported some patellofemoral instability postoperatively [69]. More recently, Tan et al. reported similar outcomes in 20 knees that underwent isolated hemiepiphysiodesis for recurrent patellofemoral instability. The four knees with postoperative instability were nearing skeletal maturity at the time of operation and had minimal change in the tibiofemoral angle postoperatively [70].

Implant-mediated guided growth can be an effective surgical tool used in conjunction with MPFL reconstruction and/or distal realignment in patients with genu valgum and patellofemoral instability.

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# Trochleoplasty in Children and Adolescents

# 48

Manfred Nelitz

## 48.1 Introduction

The incidence of patellar dislocation is highest among adolescents with a low success rate with nonoperative management [1]. Severe trochlear dysplasia is the most important risk factor of recurrent patellofemoral instability in children and adolescents. It has been shown that the combination of open growth plates and trochlear dysplasia has the highest risk of recurrent dislocation of the patella [2, 3]. A recent study that investigated the results of MPFL reconstruction in adolescents has shown that patients with high-grade trochlear dysplasia were only partially satisfied with the operation [4]. Different authors have additionally shown that MPFL reconstruction as a single procedure is not thought to be the appropriate procedure in patients with high-grade trochlear dysplasia, as it does not address the bony abnormality [5–7]. Therefore, there is a high need of treatment in this age group of adolescents with still open physes and trochlear dysplasia. In patients with open physes, trochleoplasty however has the potential risk of damaging the distal femoral physis with subsequent growth disturbance; therefore most authors do not recommend trochleoplasty in skeletally immature patients [8]. A recent study however has shown that thin flap trochleoplasty performed not more than 2 years before closure of the physes can be performed safely with good clinical results without causing growth disturbance of the distal femur [9]. Performing trochleoplasty earlier in adolescence closes the existing treatment gap of these young patients with still open physes.

## 48.2 Indications

Deepening trochleoplasty can be indicated in patients with open physes, high-grade trochlear dysplasia, and an expected growth of not more than 2 years, who had recurrent dislocations of the patella despite a nonoperative treatment program [9].

Preoperative imaging includes plain AP and lateral radiographs and axial MRI of the distal femur including the supratrochlear region (Fig. 48.1) [10]. A true lateral radiographic view is necessary to assess the radiological signs of trochlear dysplasia, patella alta, and signs of malalignment. On craniocaudal axial MRI scans, trochlear dysplasia must be analyzed along the entire distal femur and also proximal to the cartilaginous trochlea to investigate the different characteristics of trochlear dysplasia and the relationship of the trochlear groove and the distal femoral physis [10].

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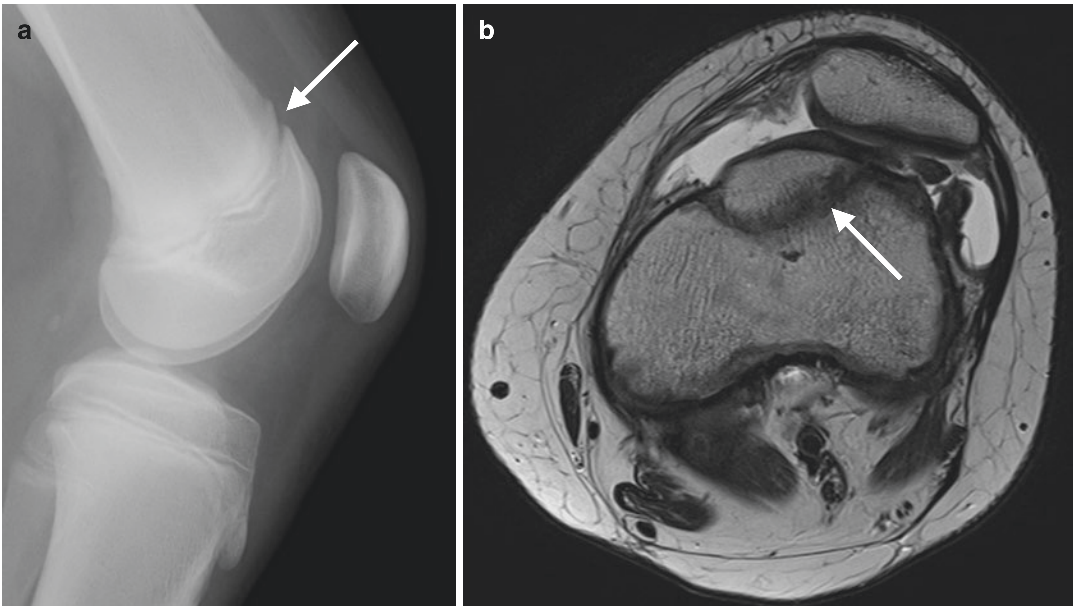

**Fig. 48.1** True lateral X-ray and transverse MRI scan at the level of the physis demonstrate the relationship between the physis (white arrow) and the femoral trochlea (**a**). Severe trochlear dysplasia and a dome-shaped proximal trochlea and lateral subluxation of the patella can be seen on the transverse MRI (**b**)

Bone age and the remaining growth can be determined according the tables of Greulich and Pyle [11] and Bayley and Pinneau [12], using an AP radiograph of the left hand.

For clinical practice the indication for trochleoplasty includes a domed or laterally facing chondral surface. The aim should be to identify all relevant risk factors that may contribute to instability of the patella. Based on the findings, therapy should be individualized on any single patient with correction of the underlying relevant pathologies according to the “menu a` la carte” introduced by the Lyon Group of Dejour.

## 48.3 Contraindication

- Low-grade dysplasia with a flat trochlea or a shallow groove is not considered an indication for trochleoplasty.
- In patients before the growth spurt and an expected growth of more than 2 years, trochleoplasty cannot be performed safely. The growth spurt in adolescents is reaching a peak between 10 and 12 years of age in girls and between 12 and 14 years of age in boys.

## 48.4 Technique

A modified Bereiter technique, in which a thin flexible flap of articular cartilage is raised and molded in the deepened groove, was performed. The thin flap technique was first introduced by Bereiter in 1994 [13]. The typical approach is an anteromedial or anterolateral parapatellar skin incision. The medial skin incision facilitates a concomitant reconstruction of the MPFL. The femoral trochlea was exposed through a lateral arthrotomy (Fig. 48.2a). The articular cartilage was then separated from the synovium. Then an osteochondral flap was carefully raised from the trochlea, extending to the intercondylar notch (Fig. 48.2a). The anterior extension of the growth plate now typically can be seen in the superior part of the osteotomy (Fig. 48.2b). The subchondral groove was then deepened using chisels and a high-speed burr to create a recentralized groove. The subcondral bone of the flap has to

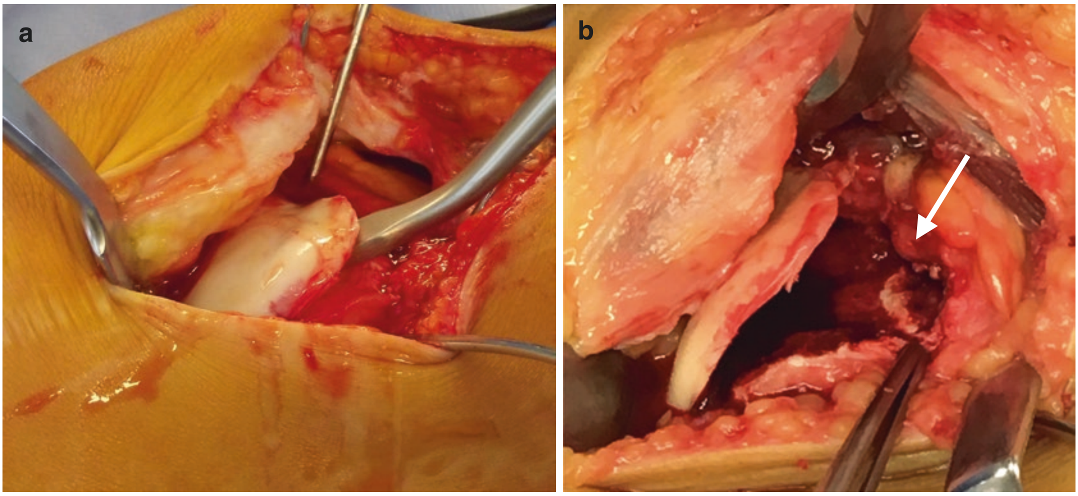

**Fig. 48.2** With a curved chisel, the trochlea is elevated carefully (**a**). Panel (**b**) demonstrates the relationship between the physis and the femoral trochlea. The anterior extension of the physis ends at the cranial part of the trochlea. The distal femoral physis can be seen under the elevated trochlea (white arrow)

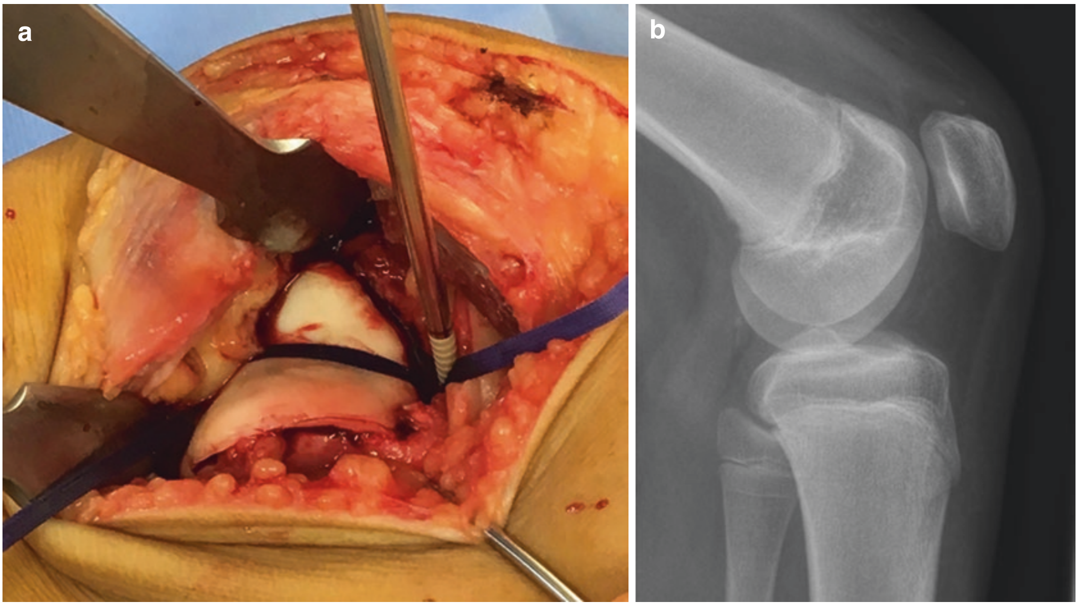

**Fig. 48.3** The elastic osteochondral flap is molded into the newly created groove. Fixation of the flap with 3-mm Vicryl tape lined up with the center of the trochlear groove. If the proximal anchor is placed perpendicular to the surface, it does not interfere with the growth plate (**a**). Postoperative lateral radiograph demonstrates correction of the trochlear groove (**b**)

be thinned carefully with a high-speed burr to allow molding of the flap into the newly created groove (Fig. 48.3a). The osteochondral flap was then pressed into the newly formed groove and fixed with a transosseous 3-mm Vicryl tape and two knotless suture anchors (Fig. 48.3a). If the anchors are placed perpendicular to the surface, they do not interfere with the growth plate. The synovium was then reattached to the margins of the articular cartilage with an absorbable Vicryl suture. If necessary, a lengthening of the lateral retinaculum was performed to achieve a strainless closure. Concomitant reconstruction of the MPFL can be performed to complete stabilization of the patellofemoral joint.

## 48.5 Rehabilitation

Partial weight-bearing of 20 kg, using crutches, is allowed. Physical therapy with flexion and extension exercises of the knee and strengthening of the vastus medialis muscle follows. Full weight-bearing is permitted at 4 weeks, and earliest return to sport is 3 months postoperatively.

## 48.6 Discussion

The ideal candidate for deepening trochleoplasty has no signs of chondral lesions with a smooth and elastic cartilage, which can be molded into the newly created groove [9, 14, 15]. It is known that the risk of fracturing the flap increases with age and cartilage degeneration. Patients with several dislocations often have less smooth and less elastic cartilage during trochleoplasty [14], which can make it difficult to mold the osteochondral flap into the newly created groove. Therefore, early correction of the dysplastic trochlea yields the best clinical results.

Early correction of the dysplastic trochlea is limited due to the fact that the anterior extension of the distal femoral physis is situated under the proximal part of the femoral trochlea. Therefore, patients with open physes have the potential risk of growth disturbance after trochleoplasty.

A recent study however has shown that there is a rapid decrease of growth rates at the end of skeletal growth. The growth spurt of the knee reaches a maximum between 10 and 12 years of age for girls and between 12 and 14 years for boys; thereafter only residual growth of the physis can be expected [16]. It can therefore be assumed that with a skeletal age of 12 years for girls and 14 years for boys, the main growth spurt of the distal femoral physis is over, and there is only residual growth after that. Therefore, even an inadvertent partial growth arrest of the anterior part of the distal femoral physis is not expected to cause clinically significant knee deformity.

Additionally, a study of Seil et al. [17] has shown that growth plates have the potential to generate high distraction forces that are able to break even a small bony bar crossing the physis of children. Similarly, it appears that the physis can resist the violation during trochleoplasty; therefore, no growth disturbance could be seen in the study group after trochleoplasty in adolescents [9].

When performing trochleoplasty in patients with open physes, different issues have to be respected:

1. The osteocartilaginous flap is fixed with a Vicryl tape, which is typically resorbed after approximately 60–70 days. For that reason, there is no permanent anterior transfixation or anterior tension of the physis. A permanent fixation with staples might cause growth disturbance.
2. Different trochleoplasty techniques such as the thick flap osteotomy or the recession wedge trochleoplasty, in which the trochlea is deeply osteotomized in the midline, might more likely cause growth disturbance since the physis is violated to a much higher extent.
3. In patients before the growth spurt and an expected growth of more than 2 years and especially patients under the age of 12 in boys and 10 in girls, trochleoplasty cannot be performed safely. For younger patients with enough remaining growth, remodeling of the trochlea may occur when the patella is stabilized with a soft tissue procedure [18, 19].

## 48.7 Summary

Thin flap trochleoplasty can be performed safely in adolescents with open physes after the end of the growth spurt with good clinical results without causing growth disturbance of the distal femur. Performing trochleoplasty earlier in adolescence closes the existing treatment gap in this group of patients with still open physis and severe trochlear dysplasia. In the author's opinion, deepening trochleoplasty when indicated should be performed as early as possible, as best results can be achieved in this age group.

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# Patellar Tendon Shortening

# 49

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## 49.1 Introduction

Factors contributing to patella instability with recurrent patella dislocations are multifactorial [1–8]. Among those anatomic variances associated with recurrent patella dislocation is patella alta. The exact definition of what actually constitutes an abnormal patella height remains controversial [9–13]. For most, a ratio of the length of the patella tendon to the length of the patella or the length of a distance from the tibial articular surface to the length of the patellar articular surface defines patella height [11–13]. More recently, the relationship of the patellar articular surface contact with the articular surface of the trochlear cartilage can be used to define normal versus abnormal patella height [10]. That said, the further away from the femoral trochlea the patella is positioned while the knee is in extension, the more dependent it is upon the retinaculum and the medial patellofemoral ligament for stability until well engaged within the trochlea. Furthermore, patella alta is also associated with increased patellofemoral contact pressures [8, 14, 15].

When planning surgery for recurrent patella dislocations in patients with patella alta, some method of normalizing patella height is considered. Most often the standard approach is for a tibial tuberosity osteotomy with distalization [16]. Screw fixation is required. Despite the potential complications of delayed union and non-union, often with hardware breakage, and painful prominent screw heads, this method of surgical management for patella alta remains as the standard care [17, 18]. However, in the skeletally immature patient, this is not an option because of the open tibial growth plate. Therefore the traditional management of patella alta in the skeletally immature patient has been to defer surgical treatment until the growth plate has closed. This chapter describes a method of surgical management that shortens the patella tendon by imbrication [19]. Because there is no bony component to the procedure, it can be used safely in the child as well as in the adult.

## 49.2 Surgical Indications

Patients presenting with recurrent patella dislocations and patella alta as measured by one or two of the most commonly validated indices are candidates [6, 10–13]. Because the pathoanatomies are usually multifactorial, the actual procedures included within the realignment most often include proximal patella techniques such as medial patellofemoral ligament reconstruction as well. Additionally, if a medialization of the tibial tuberosity is also required, the patella tendon imbrication can be performed combined with a

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Trillat osteotomy of the tibial tuberosity, rather than a distal-medial transfer of the tuberosity.

Less commonly, this procedure can be used in the management of the patient with significant anterior knee pain associated with patella alta and patella chondrosis involving the distal patellar articular surface. By doing so, this creates a load transfer to the more proximal patellar articular cartilage resulting in load being distributed over a broader surface area, thus lessening contact stress.

## 49.3 Surgical Method

The first decision requires an estimation of the extent of patella tendon shortening required by imbrication. Ideally, we would like to restore normal patella height. But because there is no consensus yet on the best method, I use the Insall-Salvati Index and shorten enough to result in a 1:1 relationship of patella tendon length to patella length. The exception to this is with a patella that has a long non-articular nose. In that case I would estimate the amount of shortening (imbrication) required to normalize either the modified Insall-Salvati index or the Caton-Deschamps index.

An anterolateral incision is made paralleling the lateral boarder of the patella tendon. Extension of this incision proximally is made to accommodate proximal procedures and distally to accommodate tibial tuberosity osteotomy if needed. If a proximal alignment and reconstruction are required, all exposure is performed first, but in the case of medial patellofemoral ligament reconstruction, the final fixation of the graft is performed only after the patella tendon imbrication has been completed. If a tibial tuberosity osteotomy is required, I perform this first followed by the patella tendon imbrication.

Next, the patella tendon is exposed, and the infrapatellar fat pad is released from the posterior aspect of the tendon. A bolster is placed beneath the knee to create tension upon the patella tendon. As depicted in Fig. 49.1, a series of three markings are made overlying the patella tendon. The distance from the most proximal marking to the next marking is one half of the total distance to be imbricated. The third marking is made for the total amount of imbrication to be performed. Dissection is then made beginning from the most distal marking and proceeding proximally to the level of the second marking (Fig. 49.2). Care is taken during the initiation of this dissection to approximate one-half of the thickness of the tendon, but once made the dissection simply follows along the parallel fibers of the tendon.

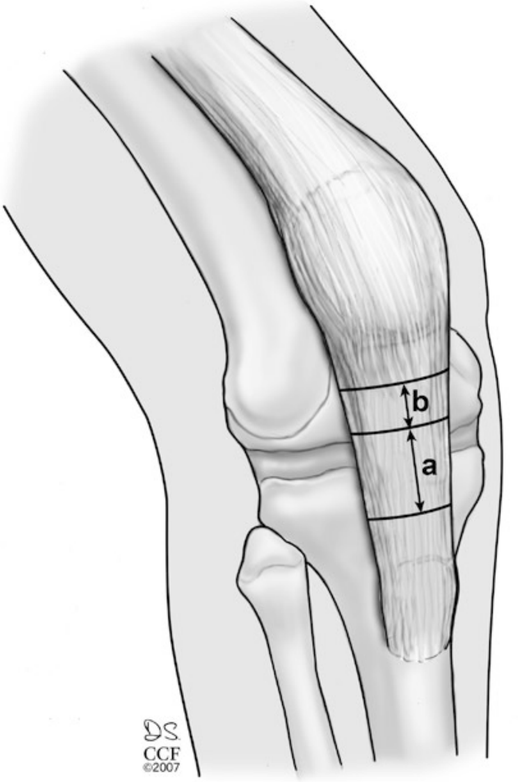

**Fig. 49.1** Following exposure of the patellar tendon and detachment of the infrapatellar fat pad from the posterior surface, three markings are made depicting the amount of shortening to be obtained (*a*) and 1/2 of the amount of shortening (*b*)

Once this dissection is complete, three #1 PDS sutures are placed from the first marking,

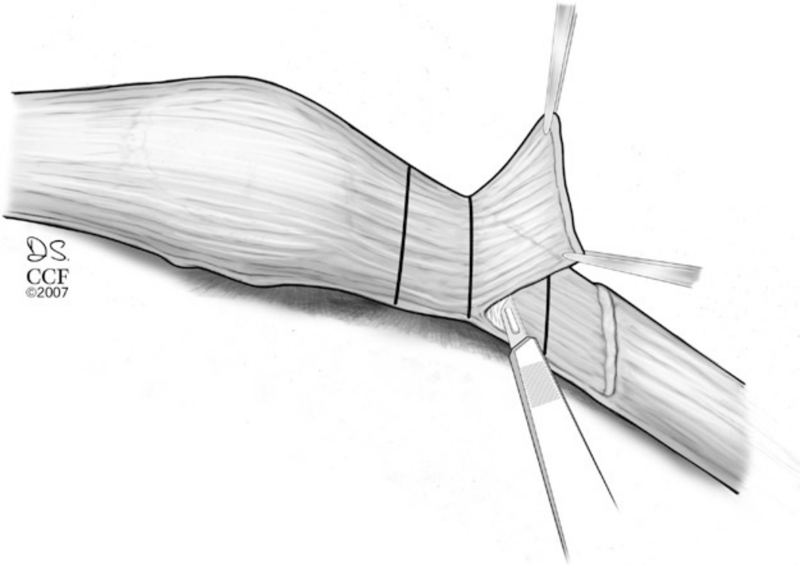

**Fig. 49.2** Dissection is then carried out resulting in a flap of patella tendon estimated to be 1/2 of the thickness of the tendon

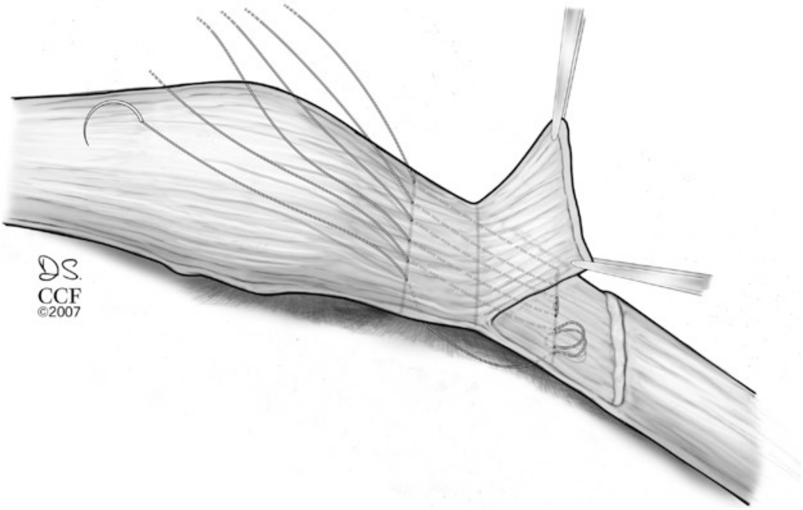

**Fig. 49.3** Three #1 PDS sutures are placed from the proximal line, deep to the tendon, and emerging into the midpoint between the second and third lines and then returning to the first line

passing deep to the tendon and entering the tendon again at the midpoint between the second and third marking. A locking stitch is made and the suture returned deep to the tendon appearing again at the first marking. The sutures are left untied (Fig. 49.3). Next, three #2 FiberWire sutures are placed entering at the second marking and immediately surfacing within the area of prior dissection. The sutures are then placed at the level of the third marking, full thickness, with another locking stitch and then returned to the second marking (Fig. 49.4). The knee is then extended, and the three FiberWire sutures are tied to create the imbrication (Fig. 49.5). Most often, distal traction is applied to the patella with a sharp rake retractor during this stage to facilitate the imbrication. Next, the PDS sutures are tied. In this manner, the redundant posterior

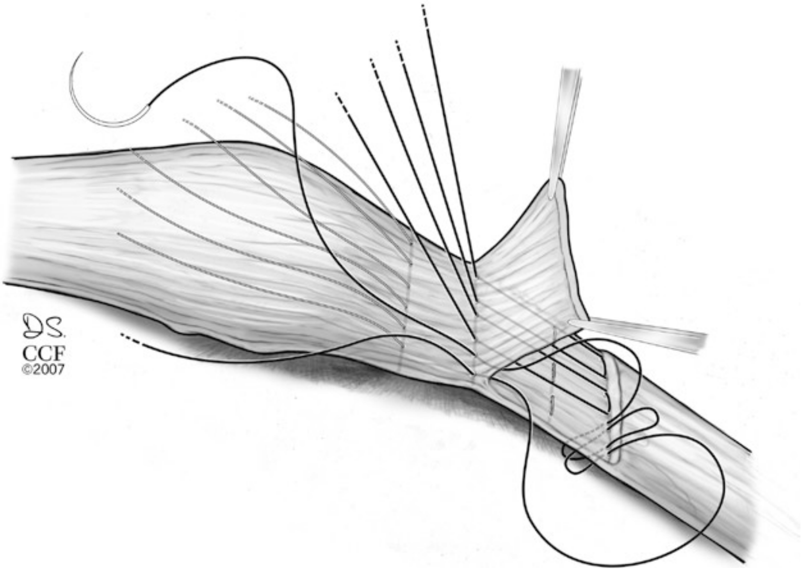

**Fig. 49.4** Three nonabsorbable sutures (#2 FiberWire) are placed from the second line, deep to the dissected flap and superficial to the intact posterior half of the tendon. They are then placed as a locking stitch at the level of the third line and then returned to the original level of entry

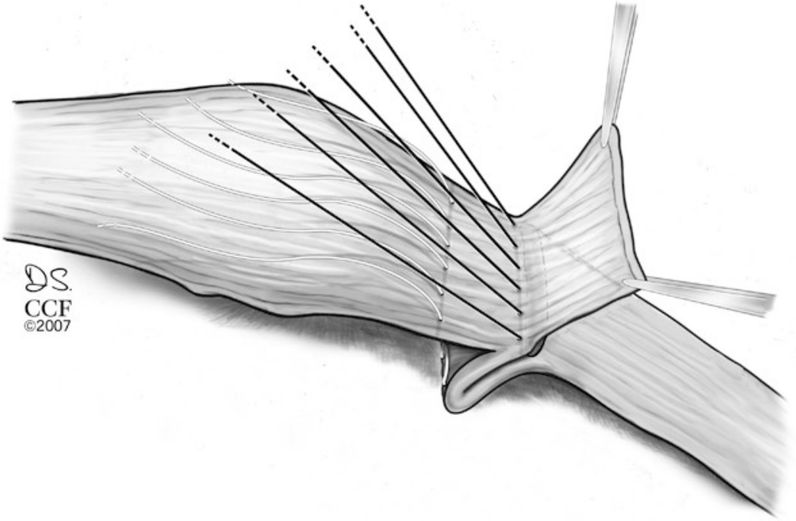

**Fig. 49.5** The FiberWire sutures are tied. Often, distal traction upon the patella with a rake retractor facilitates the ease of imbrication

flap of imbricated tendon is drawn proximally to reinforce the repair (Fig. 49.6). Further reinforcement of the imbrication can be made by placement of O-Vicryl sutures along the medial and lateral boarders of the imbricated tendon (Fig. 49.7).

If needed, the remaining proximal patella alignment and reconstruction is completed, and the wound is closed. The knee is then placed in a motion-controlled double upright brace allowing full extension and limiting flexion to 30°.

## 49.4 Postoperative Care

For the first 6 weeks, the patient is managed with touch-down non-weight-bearing. If full weight-bearing is required during this time, the brace is locked in full extension for weight-bearing and opened for allowable flexion when non-weight-bearing. At the 2–3 weeks' follow-up, the allowable knee flexion in the brace is increased 10–20° per week, by 5 weeks allowing 70° of knee flexion. During the first 6 weeks, the patient is

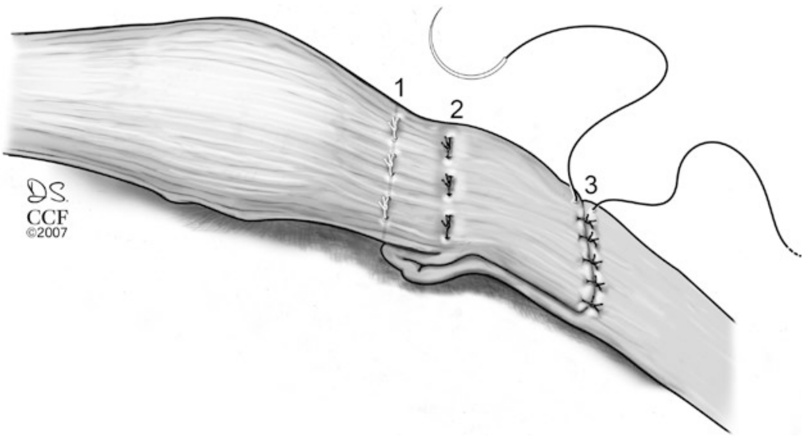

**Fig. 49.6** The proximal sutures are tied, thus creating an imbrication of the posterior, now redundant portion of tendon, to reinforce the repair

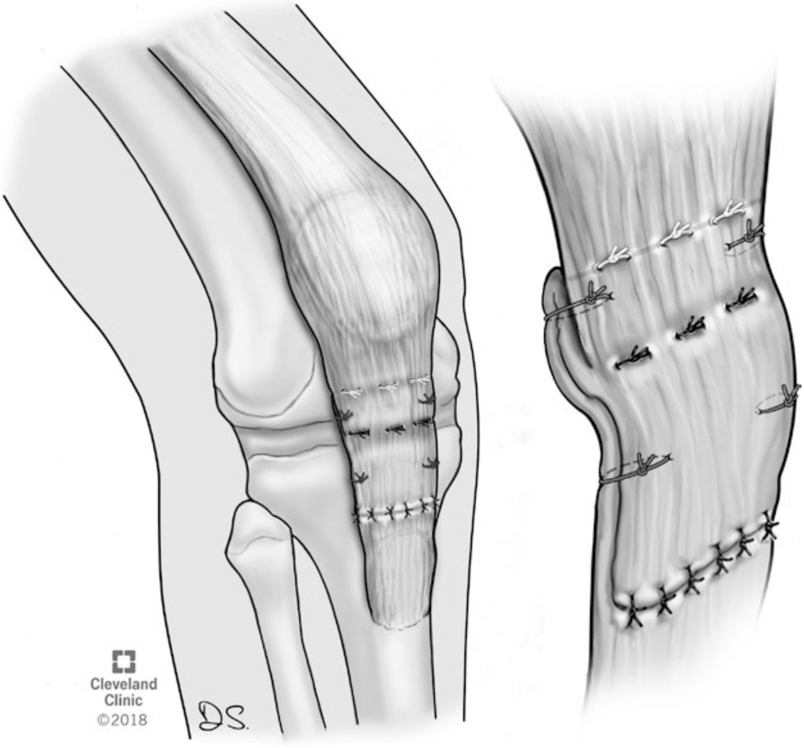

**Fig. 49.7** The imbrication is now complete. A few #0 Vicryl sutures can be placed along the margins of the imbricated tendon

allowed out of the brace for bathing and, as pain and swelling subside, to perform "heel slide" range of motion exercises. The brace is worn, however, for all sleeping and all community ambulation for protection.

Physical therapy during the first 6 weeks is minimal, only to encourage quadriceps isometric exercise to overcome quadriceps inhibition and to instruct in "heel slide" range of motion exercise. By 6 weeks postoperative, progressive weight-bearing is initiated, and more formal pelvifemoral rehabilitation is performed. Open chain resistance exercise, however, is deferred for 3 months. Most have graduated to full weight-bearing without support by 8–10 weeks. Full rehabilitation and return to sport level activity varies but requires at least 6 months from the time of the operation.

## 49.5 Clinical Results

A recent clinical review of a series of patella alignments, which included patella tendon imbrication at a minimum of 2 years postoperative, was performed. The average amount of imbrication was 1 cm with a range of 0–3 cm. There were no complications that could be directly related to the imbrication. Radiographs performed at 3 weeks postoperative and repeated at a minimum of 2 years postoperative demonstrated no significant loss of correction over that time period.

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# Tibial Tubercle Procedure: Old Osgood-Schlatter

# 50

Gerd Seitlinger and Hannah N. Ladenhauf

## 50.1 Introduction

Osgood-Schlatter disease (OSD) describes a traction apophysitis of the tibial tubercle caused by repetitive strain on the insertion point of the patellar tendon. As a result, little avulsion fractures occur at the chondro-osseous tibial tubercle which are followed by sclerosis and fragmentation of the tibial tubercle with soft-tissue swelling and pain. This may lead to nonunion of this secondary ossification center and subsequent bony enlargement of the tibial tubercle. OSD occurs most frequently in children between 8 and 15 years of age who regularly participate in sports [1]. A male to female ratio of 4:1 has been reported [2]. However, due to the increased activity of girls in sports, recent studies show no significant difference in the prevalence between sexes [3]. In approximately 30% of patients, the disease occurs in both knees [3]. Especially, high-impact sports such as soccer, volleyball, and basketball seem to have a high prevalence for OSD [4]. Also tight and strong quadriceps muscles in combination with flexible and weak hamstrings seem to add on to the risk of acquiring OSD [5]. Suspected but not proven was a correlation of OSD and patellar alignment [6].

OSG presents a self-limiting disease and generally resolves as skeletal maturity is reached. Therefore, treatment of OSD is primarily nonsurgical and guided by the symptoms of the patients. Adaptations of sport activity and anti-inflammatory medication are the main treatment options. Unfortunately in some cases, disabling symptoms and pain persist even after physeal closure. For this rather small group of patients, operative treatment may be necessary to alleviate symptoms and help the patient to be able to return to his/her level of activity.

## 50.2 Operative Techniques

Surgical treatment for OSD is occasionally warranted and only indicated when pain relief and return to sports are unsuccessful after conservative treatment. Several operative techniques exist and need to be selected carefully when treating patients with OSD.

When evaluating radiological examinations of patients with persistent OSD, one can often identify signs of irregular ossification around the tibial tubercle. Residual ossicles result from ossification disturbances and can be responsible for chronic inflammation and subsequent pain. Nierenberg et al. showed that patients with

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clinically evident mobile ossicles and radiological confirmation of a free osseous fragment benefited from excision of the ossicle [7]. An additional clinical and radiologic finding in OSD patients is a prominent tibial tubercle. It was shown that 60% of patients with a prominent tibial tubercle complained of discomfort when kneeling [8]. In these patients, a tuberculoplasty is recommended to be successful [9].

Here we give a short overview on different operative procedures and their outcomes presented in the current literature:

## 50.2.1 Ossicle Excision and Tuberculoplasty

### 50.2.1.1 Open Surgery

In 2007 Weiss et al. published a series of 15 patients who were all treated with open ossicle excision and additional tuberculoplasty (Fig. 50.1) for unresolved OSD. All operations were done using a patellar tendon split technique. Twelve patients (75%) were able to fully return to their preoperative level of activity and sport, two patients (12.5%) only partially returned to sports, and one patient (6%) did not return [10].

In 2009 Philajamäki et al. revealed a study of 117 knees treated for OSD with a follow-up of 10 years. Their results showed an excellent or good functional outcome and physical activity level for open ossicle excision. In addition, one of the main complaints of patients, discomfort while kneeling, was resolved in nearly 40% of the patients [11].

In 2010 El-Husseini and Abdelgawad reported results of surgical treatment of OSD in 37 knees. They performed an anterolateral incision to harvest the ossicle. Additionally, a tibial tubercle reduction osteotomy (Fig. 50.1) was done in 85% of patients. They found complete resolution of preoperative pain in 91% of their patients [12].

Nierenberg et al. published their experience including 22 patients with unresolved OSD in 2011. They used a midline skin incision under local anesthesia to excise the ossicle. All patients returned to their previous level of physical activity within 12 weeks postoperatively. All but one was free of pain during kneeling or under direct pressure on the knee joint. In the one patient, who complained of persistent pain, signs of ossicle separation were not clearly visible. They concluded that the key factors for successful surgical treatment were radiological and clinical signs of a mobile ossicle [7].

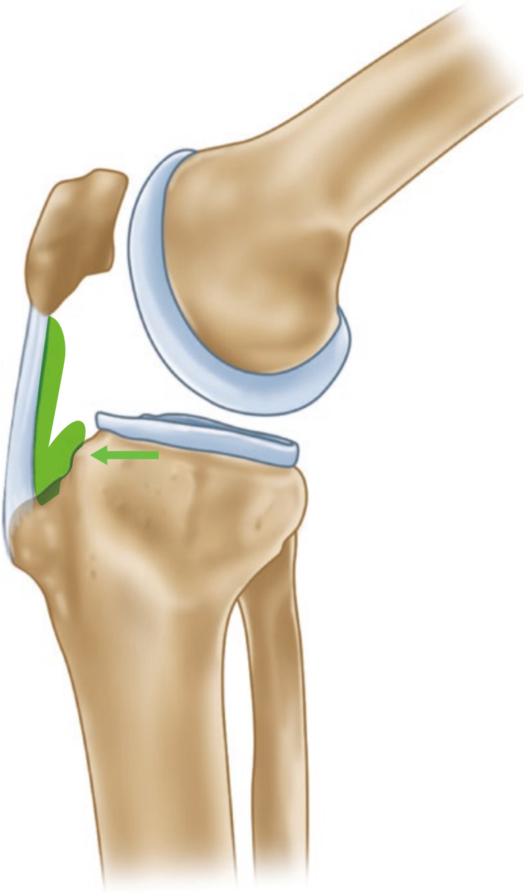

**Fig. 50.1** Sketch of a knee. The green arrows and marker indicate the location of bone resection. Resection of the enlarged tibial tubercle proximal to the insertion of the patella tendon

### 50.2.1.2 Endoscopic Surgery

In 2007 DeBerardino et al. published a technical note on arthroscopic debridement of Osgood-Schlatter lesions through standard knee arthroscopy portals (Fig. 50.1). Their group stated that the advantages of this technique were the avoidance of splitting the patellar tendon longitudinally and the ability to address concomitant intra-articular pathologies [13].

Beyzadeoglu et al. published a case with an arthroscopic excision of an ununited ossicle, debridement of the patellar tendon, and contouring of the proximal anterior tibia in 2008 (Fig. 50.1). They concluded that all of those procedures might be done arthroscopically and sports activity may be allowed earlier [14].

In 2015 Eun et al. reported on a bursoscopic ossicle resection followed by contouring of the proximal tibia (Fig. 50.1) in 18 male patients. Seventeen of 18 patients were satisfied with their surgical outcome; however, 6 patients (33%) did not believe that the prominence of their tibial tubercle had been reduced, and 4 patients were not able to return to kneeling and squatting activities. The conclusion of this study was that their surgical technique showed satisfactory outcomes but had limitations in reducing the prominence of the tibial tubercle [15].

In 2016 Lui published his technique of endoscopic management of OSD. Indicated for this endoscopic technique were cases of symptomatic Osgood-Schlatter disease with avulsed ossicles anterior to the patellar tendon. His technique of ossicle excision and debridement of the patellar tendon is similar to the technique of Eun. However, Lui favors debridement of the tibial tubercle starting distally to the insertion of the patellar tendon (Fig. 50.2), therefore minimizing the risk of injury to the infrapatellar fat pad [16].

In 2017 Circi and Beyzadeoglu investigated 11 athletes who had been operatively treated due to unresolved OSD. This surgical procedure was performed using standard arthroscopic portals. After excision of the ossicle and debridement of the patella tendon, a contouring of the surface of the tibial tubercle proximal to the insertion was done (Fig. 50.1). The mean follow-up was 5.5 years. All athletes showed satisfactory functional recovery. They concluded that arthroscopic surgery for unresolved OSD presents with the major advantage of fast recovery. Also damage to the patellar tendon can be avoided more easily [17].

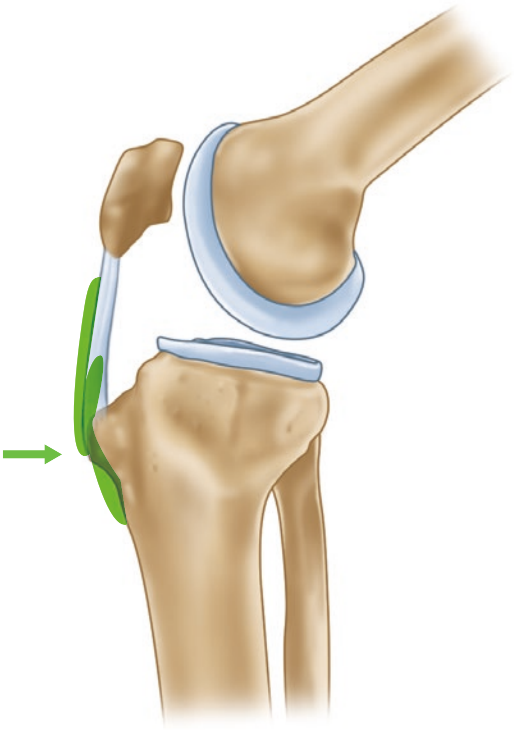

**Fig. 50.2** Sketch of a knee. The green arrows and marker indicate the location of bone resection. Resection of the enlarged tibial tubercle distal to the insertion of the patella tendon

### 50.2.2 Reduction Osteotomy of the Tibial Tubercle

In 2017 Pagenstert et al. published a case series of seven patients who had failed surgical treatment for OSD. After thorough re-investigation with magnetic resonance imaging of the knee, a horizontal osteotomy was performed, and a proximal to distal tapered wedge was removed by using a chisel (Fig. 50.3). The thickness of the osteotomy aimed to be 5–8 mm proximally, reducing the thickness constantly to reach approximately 2–4 mm distally, to build a hinge and allow plastic deformation of the anterior tibial bone. Distally, the osteotomy was left incomplete to prevent dislocation of the fragment. After closing the osteotomy, it was secured by at least two 3.5 mm screws. At follow-up of 2 years, patients showed significant improvement regarding pain scores and function of the knee [18].

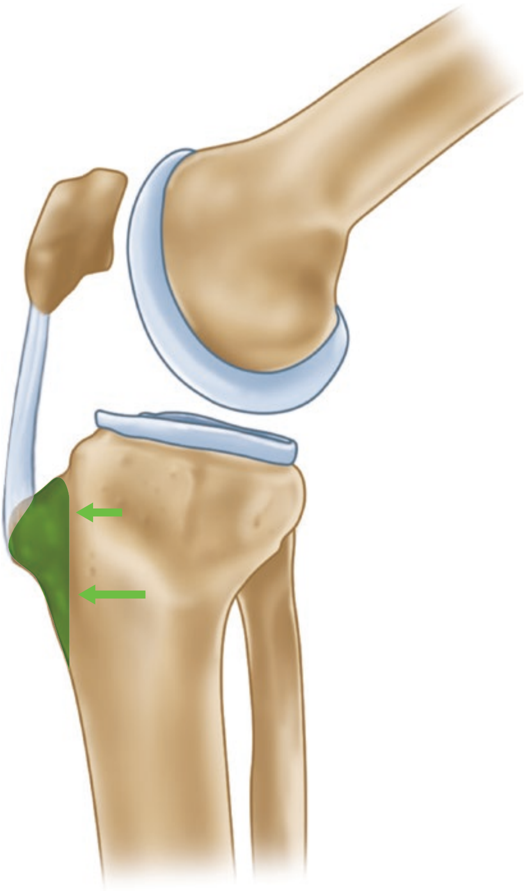

**Fig. 50.3** Sketch of a knee. The green arrows and marker indicate the location of bone resection. Resection of the enlarged tibial tubercle by an osteotomy. In this technique the insertion of the patella tendon itself is reduced

## 50.3 Conclusions

OSD is a self-limiting apophysitis of the tibial tubercle and the adjacent patella tendon in young active patients with open physis. Unfortunately, some patients may suffer from prolonged or persisting knee pain. A mobile ossicle and enlargement of the tibial tubercle seem to be the key factors for ongoing discomfort. Several operative techniques exist. As stated in the literature, open or endoscopic excision of the ossicle results in improvement of symptoms. Reduction of the enlarged tibial tubercle can be performed by reduction of the tibia proximal to the insertion of the patella tendon. One author described an endoscopic technique with a reduction of the tibia distal to the insertion. All of them documented an improvement in pain and function in their studies. One study described a new osteotomy technique. With this technique the authors were able to reduce the prominence of the insertion of the patella ligament itself. They could show improvement of function and pain in a group of patients with failed prior surgery.

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# Derotational Osteotomies in Patella Instability

# 51

René El Attal and Peter Kaiser

## 51.1 Introduction

Derotational osteotomies of the femur and the tibia were first introduced in children to treat torsional deformities leading to disability beyond the age of 8 years [1]. An inwardly pointing knee [2] or a miserable alignment syndrome [3] can be indications for surgical derotational treatment.

Miserable malalignment was defined by Stanley James in 1979 as a combination of femoral anteversion, squinting patellae, genu varum, patella alta, external tibia torsion and compensatory pronation of the feet.

Weber [4] was the first to describe a correlation between an increased internal femoral torsion and patella instability in 1977 which lead to consider derotational osteotomies as an additional treatment option. Cox [5] and Fulkerson et al. [6] recommended derotational osteotomies in cases of increased external tibial torsion and patella instability. Meanwhile, many surgeons included the assessment (and treatment) of lower extremity torsion in the evaluation of risk factors for patella instability as it is now understood that an increased internal femoral or external tibial torsion can facilitate patella instability. The rational can be explained as follows:

> An internal rotation of the body over a planted foot produces a lateral displacement force on the patella, which may end in dislocation or subluxation. An excess of femoral anteversion causes the knee joint and the foot to be pointed medially. Likewise, an increase in external tibial torsion causes the knee joint to rotate internally in the axial plane and the hip to be placed in greater internal rotation if the foot is placed in a position of normal foot progression. If the knee joint is internally rotated in the axial plane more than normal during gait, then excessive laterally directed shear force is created and this results in increased stress in the medial patellofemoral ligaments and increased lateral patellofemoral joint compression forces. Essentially, this results in the trochlea pushing forward and medially against the patella. [7] (Fig. 51.1)

Biomechanical studies proved these theoretical thoughts and showed that an increased internal femoral torsion results in a lateralizing force vector acting on the patella, which can facilitate patella instability [8]. Transecting the medial patellofemoral ligament even increased the effects of femoral torsion on the lateralization of the patella with only 10° relatively increased internal femoral torsion above the norm resulting in a significantly increased risk for instability [8].

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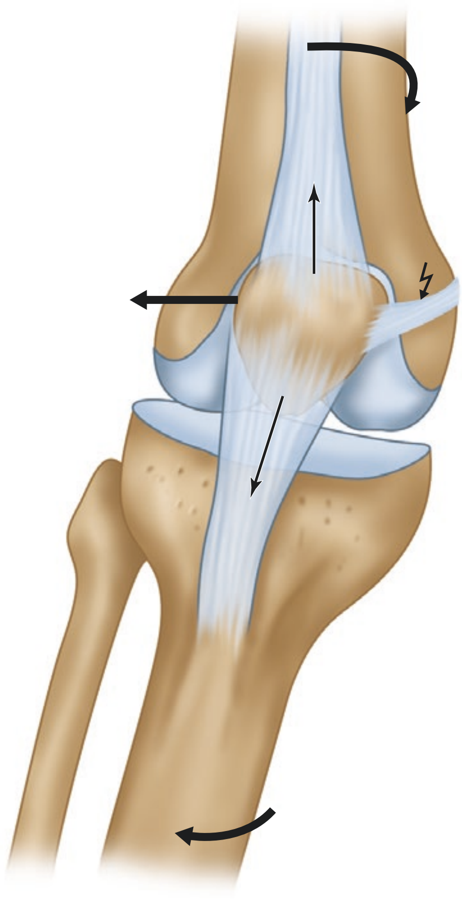


**Fig. 51.1** Patella movement in cases of increased internal femoral or external tibial torsion [7]

Further biomechanical studies demonstrated a nearly 30% increase of patellofemoral contact pressure on the contralateral facets and increased tension of the quadriceps tendon at 30° increased femoral torsion [9].

Patella cartilage stress increased progressively (41–77%) with increased internal femoral torsion, while only a minor increase of stress was observed with increased tibial torsion (10%) [10].

Medial patellofemoral ligament strain was also shown to be increased with excessive femoral torsion especially in a low knee flexion angle of 30° [7, 11, 12].

With a more dysplastic trochlea, the MPFL-stress is increased, while with a more normal trochlea shape, trochlear cartilage stress is increased [11].

Therefore, torsional deformities presumably show a higher effect on patella instability in cases of trochlear dysplasia and an insufficient medial restraint/insufficient MPFL.

Anatomical studies also showed that patients with objective patellar instability had significantly higher femoral internal torsion values [16° vs. 11°] [13] and tibial torsion values [25° vs. 19°] [14] compared to normal controls.

Femoral and tibial lower limb malalignment also clinically correlate to recurrent patella dislocations [15]. At last, an increased internal femoral torsion was seen to be the reason for a failed MPFL reconstruction [16].

In order to address the femoral and tibial torsional malformation surgically, a femoral and/or tibial derotational osteotomy has been proposed in patients suffering from recurrent instability episodes [11, 17–24].

This chapter will describe the measurement of lower limb torsion, discuss the indication of a derotational osteotomy and demonstrate the surgical technique including its aftercare and reported outcome.

## 51.2 Indication

There is scarce data in the literature of when to perform a derotational osteotomy. A derotational femoral osteotomy has been proposed in patients with absolute values of internal femoral torsion of over 15–30° [11, 17–19, 25] or relatively seen app. 5–10° above the norm value [26]. The aim of adjustment is a postoperative absolute value of 15° [11, 17–19, 25]. However, different measurement methods exist and lead to different norm values [27]. Therefore, relative values above the norm should be used and not absolute values. Additionally, many of our patients suffer from multifactorial aetiologies around the knee that potentially cause pain and impairment. The treatment plan has to be individualized. Some authors recommend a derotational osteotomy in symptomatic patients only if the measured torsional value is two standard deviations from the norm on the CT scan [1, #1510].

A derotational tibial osteotomy has been proposed in patients with absolute values of external tibial torsion of over 30–40° [11, 17, 19–21] or relatively seen app. 5–16° above the norm value.

Dickschas et al. [20] published a torsional index, which allows to rate the severity of a torsional deformity (Fig. 51.2). The physiologic range is between 0.8 and 1.2. The authors used the standard norm values published by Strecker et al. [28] for their index (femur 24°; tibia 34°).

The only supportive biomechanical data for a femoral derotational osteotomy showed that a single MPFL reconstruction seemed to just be sufficient in cases of 10° relatively increased internal femoral torsion but not for higher degrees of femoral torsion [26, #1505].

Therefore, the authors don't conduct a femoral derotational osteotomy in cases of 10° relatively increased internal femoral torsion but mainly in cases of app. 15° or more. Tibial derotational osteotomy is performed in cases of 40° relatively increased external tibial torsion (Fig. 51.3).

$$\text{Torsional index} = \frac{\text{Torsion}_{\text{Femur}} + \text{Torsion}_{\text{Tibia}}\ (\text{Patient})}{\text{Torsion}_{\text{Femur}} + \text{Torsion}_{\text{Tibia}}\ (\text{Norm})}$$

**Fig. 51.2** Calculation of the torsion index (REFERENZ)

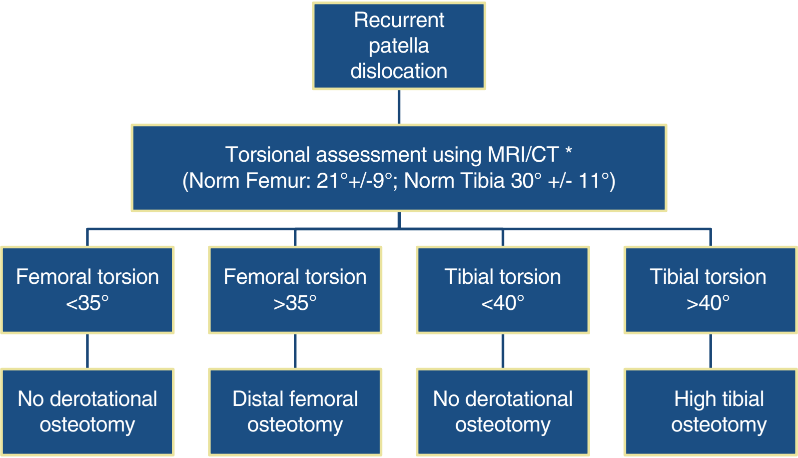
## 51.3 Measurement

Clinical assessment of torsion of the lower extremity should point the way to further radiologic examinations. Alignment of the lower extremity in the frontal and sagittal plane has to be evaluated. The position of the patella and the position of the feet are of special interest. But not only the alignment of the patella but also the hip joint as well as the foot and ankle has to be carefully examined. Analysis of the gait pattern is important and position of the foot at the moment of touchdown.

The patella can point inwardly while standing because of an increased internal femoral torsion which is also called "squinting patella". Lying prone, patients with an increased internal femoral torsion show an excessive internal hip rotation and reduced external hip rotation. Additionally, femoral torsion can be estimated in a prone position by the technique described by Ruwe et al. [30]: The examiner palpates the greater trochanter of the femur and rotates the hip with the knee flexed 90° until the greater trochanter is felt most prominent laterally. The angle between the long axis of the tibia and a vertical line represents femoral torsion.

Tibial torsion can also be estimated in a prone position with the knee and ankle flexed 90°. While looking on the heel from above, the angle between the malleolar axis and condylar axis and/or the angle between the foot and the thigh

**Fig. 51.3** Indication for derotational femoral or tibial osteotomy (chartflow); *femur torsion is assessed by Waidelich's method [29] and tibial torsion by the bimalleolar method



axis can be estimated. If any of these findings is positive for increased torsion, further radiologic torsional examinations seem necessary.

However, in cases of recurrent patella instability episodes, the authors conduct a routine torsional assessment using MRI (or CT) independently of these clinical findings.

Various imaging techniques, including radiography [31], ultrasound [32], low-dose biplanar radiography [33], computed tomography (CT) [18, 29, 34–38] and magnetic resonance imaging (MRI) [39–41], have been used to assess lower limb torsion. With their speed, precision and ease of use, cross-sectional imaging modalities, such as MRI or CT, are regarded as the gold standard nowadays.

Descriptions of various measurement techniques have been published, using transverse or oblique and single or superimposed image slices. These techniques use different anatomical landmarks for measurement. As a result, a wide range of the standard values for femoral torsion (7–24° internal torsion) has been reported in the literature [28, 29, 38–44], without a significant difference between ethnic groups [43, 45].

Various measurement methods of femoral torsion on the same specimens showed significant differences with a maximal difference of up to 16° in single femora [27]. Because norm values cannot be compared to each other and lead to confusing results if different measurement methods are used [46], only one single measurement method should be used to assess lower limb torsion throughout a patients' treatment career.

Because of a high inter- and intraobserver agreement (mean 1–3°) and reported norm values (mean norm 21°± 9° [29]), the authors use the technique described by Waidelich et al. to measure femoral torsion. This technique is displayed and explained in Fig. 51.4.

There are also different measurement methods to assess tibial torsion. The mean norm value ranges from 22° to 35° [28, 29, 47–49] and shows a significant ethnic difference [47].

Because of its high inter- and intraobserver agreement (mean 1°) [50] and simplicity, the measuring method using the bimalleolar axis is widely used to assess tibial torsion (Fig. 51.5). The norm value for this method seems to be 5° lower than for Waidelich's method and 8° lower than for Jend's method leading to an approximated norm value of 30° ± 11° (if Strecker's norm values for Waidelich's method are applied) [28, 29, 50, 51].

Both the femoral and tibial norm values are reported for adults and differ during childhood as femoral torsion diminishes and tibial torsion increases until app. The age before puberty [52].

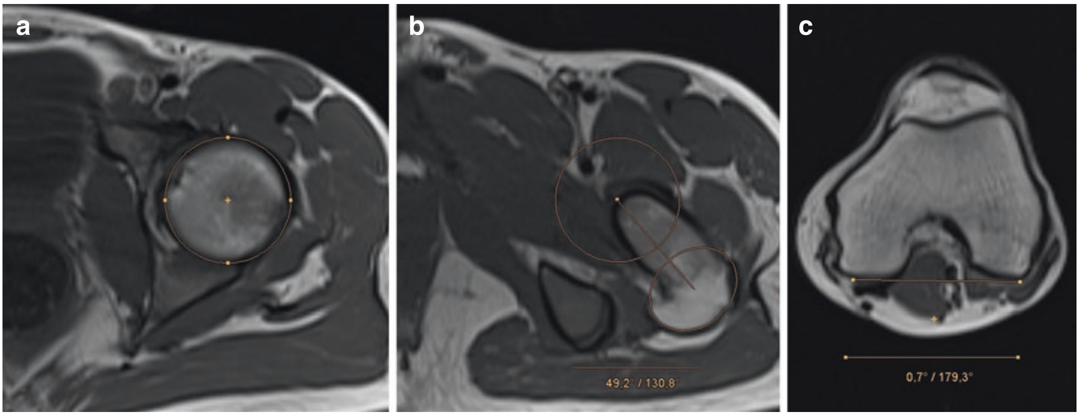


**Fig. 51.4** Femoral torsion measurement: A circle is drawn around the femoral head on its greatest diameter on one slice (**a**). An ellipse is drawn around the greater trochanter on another slice, and both centres are connected representing the proximal axis (**b**). The distal axis is the posterior condylar axis on a slice showing the widest extension of the condyles (**c**). Both axes (**b**, **c**) can be measured to the horizontal axis and are added or subtracted to each other depending on the direction of torsion (e.g. 49.2° – 0.7° = 48.5° internal femoral torsion in this example), or both axes are drawn and measured directly to each other

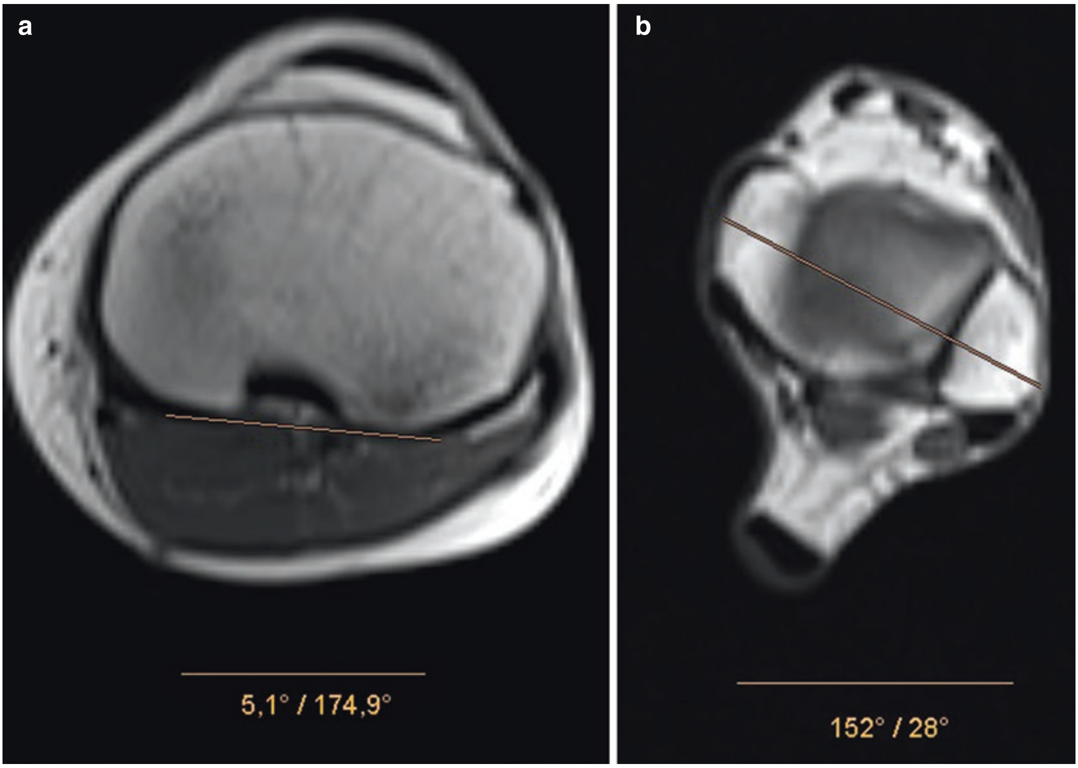


**Fig. 51.5** Tibial torsion measurement: The posterior tibial condylar line is drawn on one slice and represents the proximal axis (**a**). A line bisecting the medial and lateral malleolus is drawn on another slice (**b**). Both axes (**a**, **b**) can be measured to the horizontal axis and are added or subtracted to each other depending on the direction of torsion (e.g. 5.1° − 28.0° = 22.9° external tibial torsion in this example), or both axes are drawn and measured directly to each other

After the age of 9 years, no more change of torsion can be expected.

The measurement is demonstrated in detail in Video 51.1.

The tibial tubercle-trochlear groove (TT-TG) distance also has to be measured (see Video 51.2). It is not a value of torsion but indicates the relative position of the tibial tubercle to the deepest point of the trochlear groove. High values indicate a high Q-angle. There is only minor change of this value to be expected after distal femoral derotation. Therefore it is important to know in forehand if this parameter is pathologic (>20 mm) and has separately to be addressed. If a proximal tibial derotation above the tibial tubercle is planned, significant changes of the TT-TG are to be expected. This can be calculated in forehand by a mathematical geometric formula. Therefore, an internal rotational correction of 20° will lead to a medialization of the tibial tubercle of 7.2 mm [53].

An osteotomy below the level of the tibial tubercle will not change the TT-TG.

Patella height can be measured by different techniques. The author’s preferred measurement is the Caton-Deschamps index (Fig. 51.6).

As a derotational osteotomy can unintentionally change leg axis, it is important to have a whole-leg standing view, in which the entire axis of the lower extremity can be measured [56].

The knee angle (lateral distal femoral angle, LDFA; medial proximal tibial angle, MPTA) and joint line can also be assessed. The modified Q-angle (the angle between the tibial tubercle and the highest point on the intercondylar notch and anterior superior iliac spine, normally up to 26°) can only be measured using this type of view.

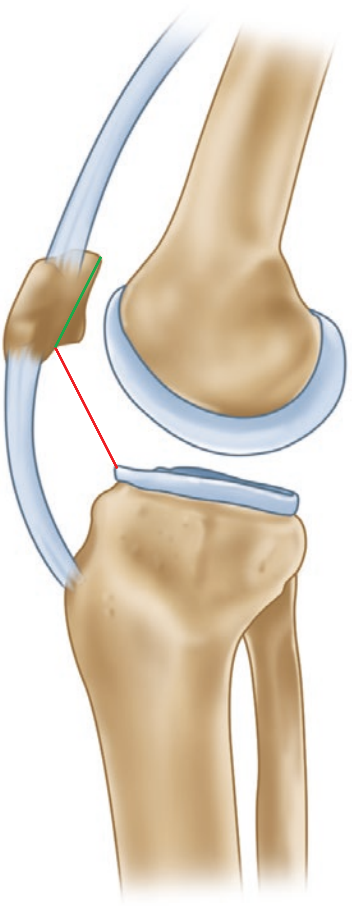


**Fig. 51.6** The Caton-Deschamps index: The distance from the most distal part of the retropatellar joint to the anterior edge of the tibia is divided by the length of the retropatellar joint facet. A quotient of >1.2 is defined as a patella alta, and if the quotient is >1.3, a distalization of the patella is recommended [54, 55]

## 51.4 Surgical Treatment

As a derotational osteotomy was regarded to be challenging and risky, it was not a standard surgical procedure to treat lateral patellar instability up to now. With a standard technique and higher numbers, this procedure can be performed in a safe and reproducible way. It should only be limited to cases with excessively increased internal femoral or external tibial torsion as the clear cause of instability [20, 57]. The surgical technique of femoral and tibial derotational osteotomy is explained in the following.

### 51.4.1 Distal Femoral Derotational Osteotomy

Femoral osteotomies can be conducted at the proximal intertrochanteric region, the middle shaft region or the distal supracondylar region with good results. There is no evidence to support decisions regarding surgical technique or the level of osteotomy [25].

The authors usually perform a derotational osteotomy on the distal supracondylar region from the lateral side, because of necessary additional surgical treatments like lateral lengthening, trochleoplasty, tibial tubercle osteotomy or MPFL reconstruction (with two medial incisions). Other authors prefer a medial subvastus approach because of better soft tissue coverage and less tractus irritation by a plate. However, MPFL reconstruction with a medial plate is not always possible, as the Schöttle point is covered by the plate.

It has to be stressed that the authors perform a MPFL reconstruction in every case. Derotation osteotomy as trochleoplasty is a bony procedure that guides the patella in a correct way at 20° of flexion and beyond. Between 0° and 20°, the MPFL is the most powerful and important restraint against lateral forces and needs therefore to be reconstructed to avoid redislocation of the patella.

Femoral derotational osteotomy is conducted via a lateral distal femoral subvastus approach in a supine position.

Prior conducting an osteotomy, two Schanz screws 5.0 or K-wires 3.0 are inserted parallel in the femur to assess the amount of derotation ventral to the desired plate position. The osteotomy is planned app. 1 cm proximal to the medial epicondyle which should be confirmed under fluoroscopy. Care needs to be taken to ensure that the osteotomy plane is parallel to the mechanical axis in order to avoid any varus/valgus misalignment [22].

If the osteotomy plane is perpendicular to the femoral shaft, frontal plane alignment can change. Proximal femoral external derotational osteotomies can result in an increased varus angulation (0.8–2.6° for 10°, 1.6–5.1° for 20°

and of 2.3–7.9° for 30°), while distal femoral external derotational osteotomies can result in an increased valgus angulation (0.1–1.7° for 10°, 0.2–3.7° for 20° and of 0.7–6.9° for 30°) [58].

Recently, a Pillar-Crane-Model was introduced to either avoid unintended valgus alignment in distal femoral derotational osteotomies or correct frontal alignment using an oblique, single-cut osteotomy [59–61]. These mathematical calculations are not easy to adopt. As a rule of thumb, it can be stated that your osteotomy in the lateral view should head a little bit towards the distal femoral condyles if you want to avoid or correct valgus alignment in distal femoral osteotomies (Fig. 51.7).

In the future, the osteotomy in the sagittal plane can be planned by Medicat Ltd. software. To really transfer this plan onto the bone during surgery, patient-specific cutting guides will be necessary.

However, an additional frontal plane malalignment can also be corrected by a biplanar supracondylar femoral derotation osteotomy. In these cases the technique consists of a perpendicular osteotomy in the axial plane and a wedge osteotomy in the frontal plane [62] (Fig. 51.8).

In either case the osteotomy is stabilized using an angular stable implant, e.g. a TomoFix plate.

The step-by-step surgery is shown in Video 51.3.

Patient lies in a supine position with both legs washed and draped with the ipsilateral leg on a pad and the contralateral leg flat. A sterile tourniquet can be applied.

We use a lateral subvastus approach (approx. 10 cm) to the femur. After splitting of the iliotibial band, the vastus lateralis is elevated and retracted with a Hohmann retractor (Fig. 51.9).

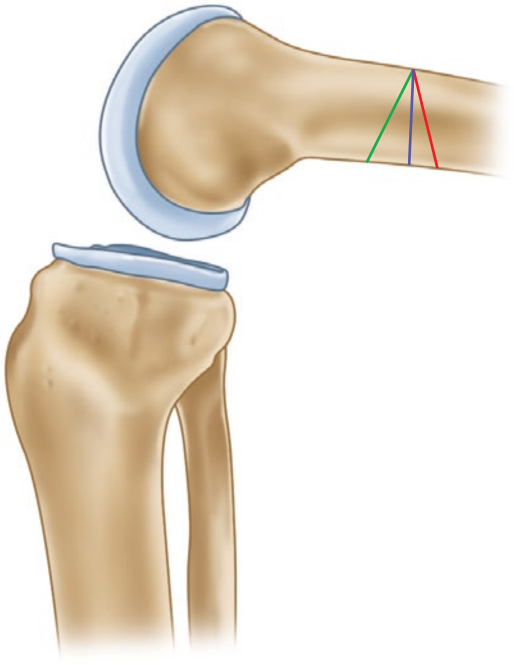


**Fig. 51.7** Frontal plane changes depending on the osteotomy plane. The blue line represents an osteotomy perpendicular to the axis of the femur. Little change of the axis of the leg in the frontal plane should be expected. To correct or prevent varus, the osteotomy can be directed to the posterior condyles like demonstrated with the green line. A direction of the osteotomy demonstrated by the red line will produce a valgus alignment

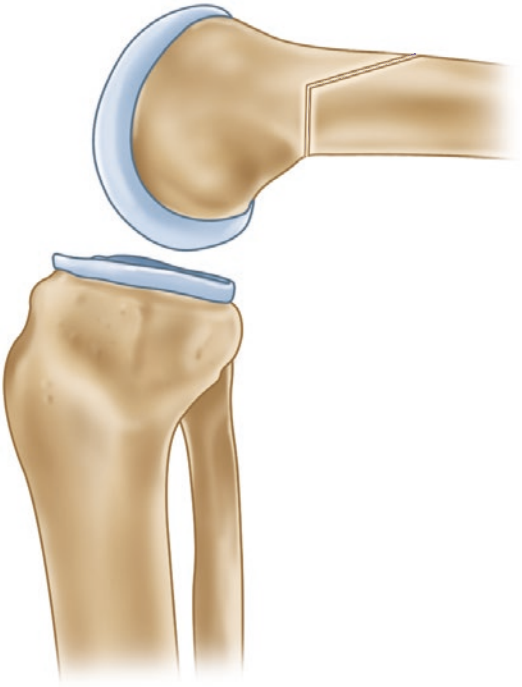


**Fig. 51.8** The principal of the biplanar distal femoral osteotomy in the sagittal view. This represents the author's standard technique. The wedge provides control throughout the procedure, and unintended complete loss off reduction can be avoided. To make rotation possible, the lateral border of the wedge needs to be removed

**Fig. 51.9** Lateral subvastus approach with two parallel K-wires to mark the osteotomy

The level of the osteotomy is marked under fluoroscopic control and should be as low to the condyles as possible for good bone healing. Do not detach the periost.

Two Schanz screws 5.0 or K-wires 3.0 are placed depending on the desired amount of derotation with one in the distal (knee) side of the osteotomy and one in the proximal (femoral) side of osteotomy.

The desired angle of correction can now be defined with the placement of the two wires/screws. To measure the angle, a surgical goniometer (Fig. 51.10), a wedge or an iPhone with a goniometer app can be used (draped sterile).

It is important to place the screws/wires wisely. There must not be soft tissue stress, and they should not hinder the surgical procedure.

For the osteotomy it is important to get a real AP view of the knee using fluoroscopy. Two K-wires of 1 cm distance are placed so that they perfectly superimpose on the AP view.

Now the lateral view is checked. It should be rectangular to the axis of the femur. If a slight valgus alignment is present, the osteotomy can be slightly directed towards the distal condyles of the femur. If a varus should be corrected, the osteotomy can be directed towards the hip. Higher degrees of varus/valgus can be corrected after performing the biplanar osteotomy.

Next the wedge is marked at the femur so that it runs out at the anterior cortex and cut with a 0.8 mm saw. The lateral edge of the wedge is removed to facilitate rotation (Fig. 51.11a, b).

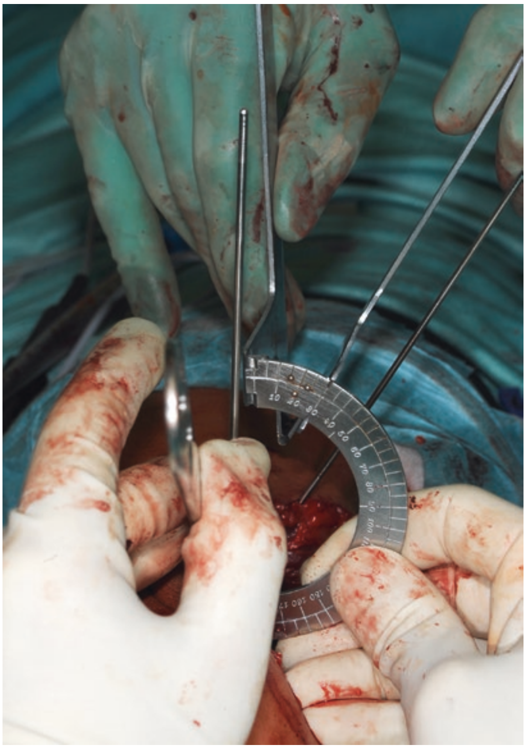


**Fig. 51.10** The correction angle is measured with a goniometer between two K-wires proximal and distal to the planned osteotomy

Before performing the osteotomy, it is *mandatory* to place a Hohmann retractor under the femur at the level of the osteotomy to protect the popliteal vessels. Injuries are reported

Next the osteotomy is completed and checked under fluoroscopy. The situation is now very instable but can be controlled due to the wedge. With the help of the Schanz screws, the knee is rotated laterally as soon as the Schanz screws are aligned and parallel (Fig. 51.12).

If indicated, varus/valgus alignment can now be corrected either by a closing wedge technique or more often by an opening wedge technique. The beauty of the biplanar osteotomy is now again that the wedge stabilizes the osteotomy and that it is still possible to open the osteotomy with a spreader and keep the rotational correction.

A big reduction clamp is placed over the wedge around the femur.

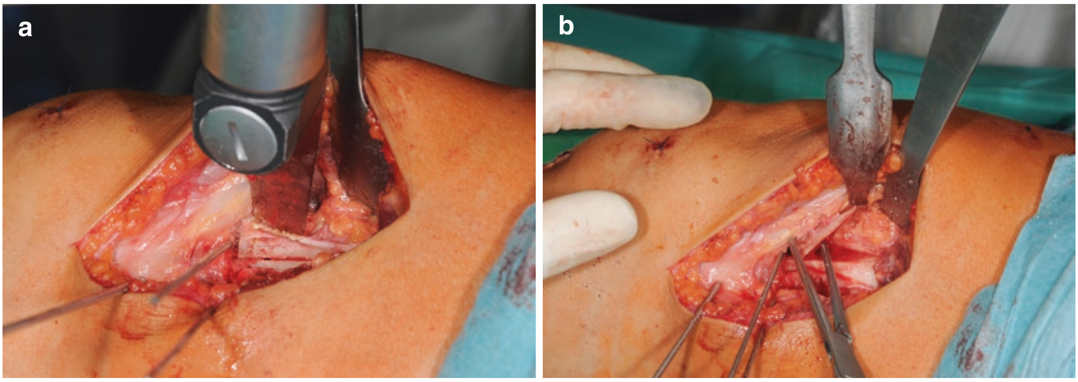


**Fig. 51.11** (**a**, **b**) The lateral edge of the wedge is cut and removed to facilitate rotation

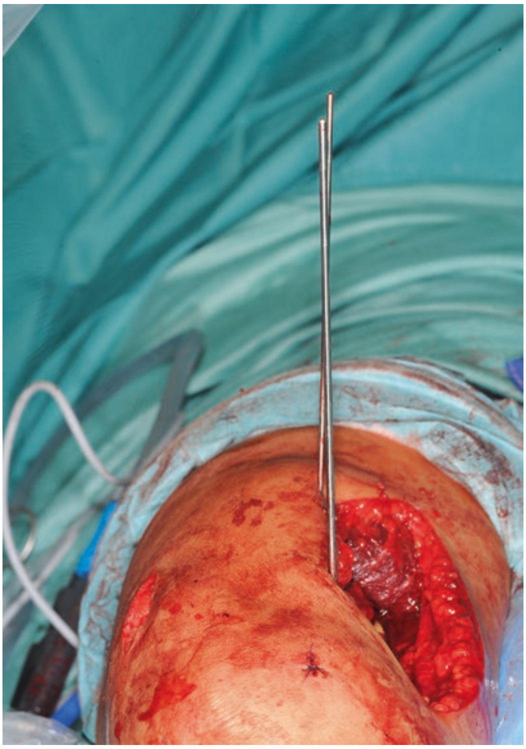


**Fig. 51.12** K-wires are aligned as the knee is rotated externally

A lag screw is now placed anteriorly and tightened. The osteotomy is now stable, and the clamp can be dismissed.

The leg axis should now be checked with an alignment rod. The knee has to be fully extended. First place the rod so that it aligns with the centre of the femoral head and fix the rod in this position. Next check for centre of the ankle joint and fix the rod manually. Next get a perfect AP fluoroscopic view of the knee with one-third of the fibula head overlapping with the lateral tibia and a perfect joint line view. This is the axis you produced. Fine-tuning is still possible as the lag screw works as an angle point and correction of up to 3° are possible. Work until the desired axis is achieved.

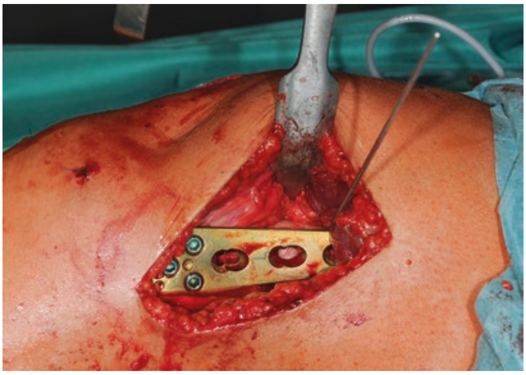


**Fig. 51.13** Final construct with plate inserted and fixed

Finally a TomoFix plate can be inserted and fixed without any issues of instability. First the distal screws should be inserted. If there is any AP translation left, this can be corrected with a conventional screw to guide the femur to the plate. Now the angular stable shaft screws are inserted with eccentric drilling to compress the osteotomy gap. Therefore, the conventional screw has to be loosened before (Fig. 51.13).

Further procedures can be performed at that stage. Most often this will be a MPFL reconstruction from the medial side. Although the plate is placed laterally, the Schöttle point can still be identified precisely. The direction of the drill pin has to be pointed upwards nearly anteriorly to pass the plate laterally. This can be checked directly from the lateral wound.

The use of a subcutaneous drain remains at the surgeon's preference. After irrigation the wound is closed. There is no orthosis required.

### 51.4.2 Tibial Derotational Osteotomy

Tibial osteotomies can be conducted at the level above or below the tibial tubercle, the tibial shaft or the supramalleolar region.

As mentioned before, there is a big difference if the level of osteotomy is applied above or below the tibial tubercle (Fig. 51.14).

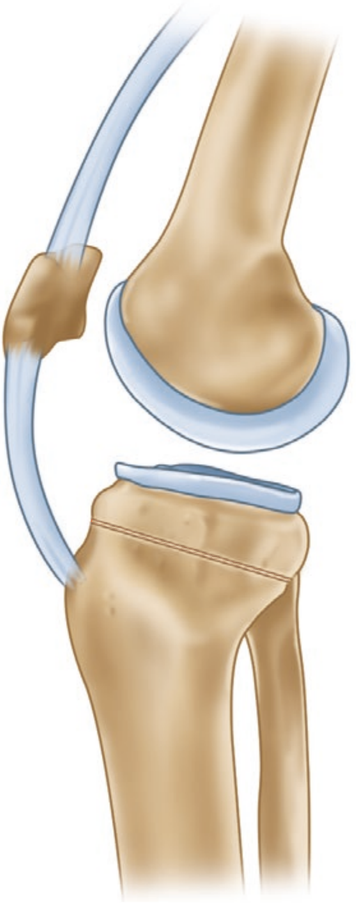


**Fig. 51.14** Schema of an above the tibial tubercle osteotomy

Cutting above the tibial tubercle will lead to a change of the TT-TG as the tibial tubercle moves medially if the tibia is rotated internally and the other way round for lateral derotation. This has to be anticipated and planned, as it is possible to end up with pathological values of the TT-TG with negative consequences for the patellofemoral joint, i.e. elevated cartilage pressure und maltracking of the patella.

Another issue with an osteotomy above the tibial tubercle is the challenge to securely fix the short proximal tibia segment with an implant.

Osteotomies below the tibial tubercle do not change the TT-TG. This can be obtained by a straight cut below the TT, below the TT with an ascending cut behind the TT or with a descending cut below the TT. Another option at the proximal tibial is to do a complete osteotomy of the TT additional to the derotating osteotomy at the level of the TT. This offers all options of TT positions. The TT position can stay the same, one is free to place it medial or lateral or address a patella alta/infera. After derotation, the TT is fixed with at least two additional screws from anterior which improves stability after placing a lateral plate (Fig. 51.15a–c).

Other options for derotation include derotation at the level of the shaft with an intramedullary saw and distal supramalleolar derotation techniques [63, 64].

If the amount of derotation exceeds 20° at the tibia, impairment of the peroneal nerve has to be expected. A release of the peroneal nerve before derotation is possible but implicates a risk of damage to the peroneal nerve. Therefore a distal supramalleolar derotation with fibula osteotomy is a good alternative.

The author's preferred technique is a derotation at the level of the TT with prior osteotomy of the TT (Fig. 51.15c).

The step-by-step surgery is shown in Video 51.4.

The patient lies in a supine position with both legs washed and draped with the ipsilateral leg on a pad and the contralateral leg flat. A sterile tourniquet can be applied.

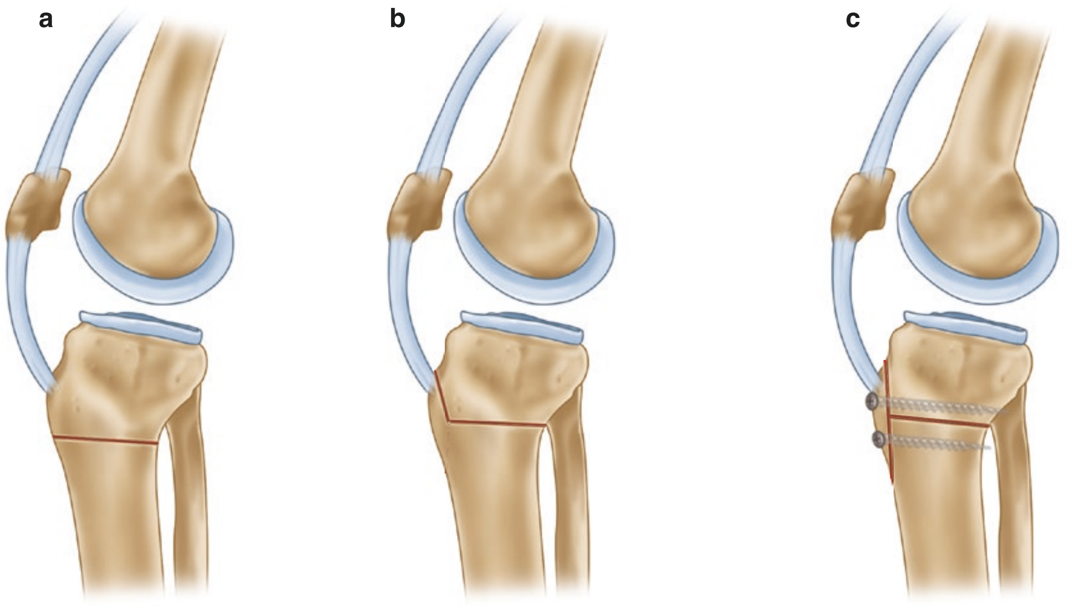


**Fig. 51.15** (**a**) Osteotomy level below the TT. (**b**) Osteotomy at the level of the TT with either ascending or descending cut of the TT. (**c**) Osteotomy at the level of the tibial tubercle and complete TT osteotomy. This is the author's preferred technique

A lateral approach to the knee is applied, either straight or in a hockey stick fashion.

The fascia of the tibialis anterior muscle is split 1 cm lateral to the anterior edge of the tibia; the muscle is bluntly removed from the bone.

The tibial tubercle and the ligamentum patellae are identified. A Langenbeck retractor is placed beneath the ligamentum patellae and the tibial bone.

The tibial tubercle is now osteotomized with a 0.8-mm-short saw blade parallel to the anterior tibial edge resulting in an approximately 6-cm-long bone block.

Before performing the osteotomy, the medial collateral ligament has to be identified and mobilized with a curved rasp to prevent damage. This can be done via the same lateral approach or with an additional small medial approach to stay less invasive.

Two Schanz screws have to be placed proximal and distal of the planed osteotomy in an angle that represents the desired correction. To measure the angle, a surgical goniometer, a wedge or an iPhone with a goniometer application can be used (draped sterile).

The osteotomy should separate the TT osteotomy in two equal areas proximal and distal of the derotational osteotomy to enable secure and stable refixation of the TT at the end of the procedure (Fig. 51.15c).

A 0.8-mm-thin saw blade should be used to perform the osteotomy with a Hohmann retractor protecting the dorsal structures of the tibia and a Hohmann retractor to protect the MCL on the medial side. The osteotomy should be performed perpendicular to the mechanical tibial axis. This has to be performed with great caution. Eventually a chisel can be used to complete the osteotomy in the dorsolateral part to avoid injury to nerves and vessels in that area.

Next the Schanz screws are aligned in the frontal plane. A lateral angular stable plate is introduced and the derotation fixed temporarily with a proximal and distal screw.

The result should now be checked clinically and fluoroscopically. The changed rotation should be compared to the contralateral side. The TT can be positioned as planed and fixed with two K-wires. Patella tracking should also be evaluated at that point.

If the desired correction is achieved, all screws are introduced in the plate, and the TT is fixed with at least two cortical small fragment screws proximal and distal to the level of the derotational osteotomy.

The use of a subcutaneous drain remains at the surgeon's preference. After irrigation the wound is closed. There is no orthosis required.

### 51.4.3 Combined Procedures at the Femur and Tibia

Distal femoral and tibial derotational osteotomies have to be combined in special circumstances. If there is a combination of high femoral internal torsion and high tibial external torsion, correction of only the femoral rotation would lead to an excessive lateralization of the foot (Charlie Chaplin gait). Therefore the rotational osteotomies have to be combined. Surgery to the tibial tubercle (as described above) can also be performed in the same setting [20–23].

In these complex cases, detailed preoperative planning is paramount. Every step of the procedure should be checked before continuing with the next step. Especially the achieved rotation of the femur and tibia should be checked several times and the consequences for patella tracking as well as the long-leg axis. The above described techniques allow a maximum of control and correction of the plan throughout the surgery (Fig. 51.16).

**Fig. 51.16** Example of a two-level osteotomy at the distal femur in a biplanar manner and a tibial derotation with an osteotomy of the tibial tubercle and refixation with two cortical screws above and below the osteotomy level

## 51.5 Aftercare

After surgery, patients need to be controlled for 24 h to exclude any potential compartment syndrome. A drain should be removed after dressing changing on the first postoperative day if there is less than 80 ml exudation within the last 6 h, and an X-ray image should be conducted during the first days after surgery. No orthosis is needed for the osteotomy itself. Mobilization is conducted with partial weight-bearing (20 kg) without any restriction of the range of motion. Lymph drainage can be conducted early including passive and active flexion-extension exercises and a continuous passive motion machine. Additionally, strengthening of the vastus medialis muscle and straight-leg raises are recommended. Medical prophylaxis against thrombosis should be administered until full weight-bearing. Weight-bearing can be increased after the 5th–6th postsurgical week after X-ray control. Cyclic ergometer training can be performed after the third postsurgical week in tibial osteotomies if the wound healed and knee flexion of 90° can be achieved. Femoral osteotomies need patience, and consolidation should be visible on X-ray images, usually after the sixth postsurgical week, until the beginning of cyclic ergometer training. Return to sports is possible after osseous healing, earliest 3 months postoperatively. Implant removal is possible after at least 6 months and consolidation of the osteotomy. Plate removal was conducted in 70–80% of patients after a mean of 13.5–17.0 months (range 6–38 months) postoperatively [20–23].

## 51.6 Complications

Although a derotational osteotomy seems to be a major operation with potentially severe risks, reported complications are rare in the literature. An analysis of 1003 patients undergoing any corrective osteotomy of the lower limb showed a low intra- and perioperative complication rate of 3.5%. Only 1.7% needed a revision surgery mainly because of a vascular lesion ($n = 4$), a compartment syndrome ($n = 4$), hematoma ($n = 2$) or deep infection ($n = 7$). 1.9% could be treated conservatively in cases of a superficial infection ($n = 16$) or deep vein thrombosis ($n = 3$). Two cases of a high tibial osteotomy resulted in a nerve lesion in cases without a protective peroneal nerve release or proximal fasciotomy of the ventral compartment and one case because of a high closing angle over 15° and postoperative compression because of a hematoma [65].

There were no infections in derotational osteotomies performed mainly in cases of patella instability or anterior knee pain [20–23, 25].

Table 51.1 shows the complications which occurred after a distal femoral or high tibial derotational osteotomy in these cases.

A non-union occurred mainly in the distal femur in cases with an increased risk because of obesity, smoking and a long-term therapy with psychopharmacological medication. All cases healed after revision surgery with autogenous bone grafting and additional plating [20–23, 25].

**Table 51.1** Complications of a distal femoral or high tibial derotational osteotomy [20–23, 25]

| Distal femoral derotational osteotomies | High tibial derotational osteotomies |
|---|---|
| Non-union (0–7%) | Non-union (2–5%) |
| Loss of correction (2%) | Peroneal nerve palsy (2–5%) |
| Flexion deficit (17%) | Compartment syndrome (2–5%) |

One reported case showed a loss of correction because of an increased BMI of >30 kg/m$^2$. After revision surgery 8 weeks postoperatively, the bone healed uneventfully using a more stable and longer plate [23].

Two patients needed prolonged physiotherapy because of a knee flexion deficit after 6 weeks with a full range of motion at final follow-up [25].

Another patient developed a peroneal nerve palsy immediately postoperatively after a high tibial osteotomy, which resolved without surgical interventions at final follow-up [20, 22].

One last patient needed a fasciotomy because of a compartment syndrome which also healed uneventfully with complete recovery [20, 22].

In summary, the reported complication risk seems quite low for such a major surgical intervention.

## 51.7 Outcomes

Clinically, a derotational osteotomy shows excellent results with a redislocation rate of 0% during a mean follow-up of 16–44 months (range 6–131 months) [20–23, 25]. However, there are only few clinical reports with few cases of patella instability. Table 51.2 shows the clinical improvement of functional scores and pain of these reports.

Mean femoral torsion was 31°–41° (range 28–66°) before derotational femoral osteotomy

**Table 51.2** Clinical improvement pre- to postoperatively [20–23, 25]

| | Preoperatively | Postoperatively |
|---|---|---|
| VAS | 4.0–7.3 | 1.5–2.6 |
| Japanese Knee Society score | 66–72 | 87–90 |
| Lysholm score | 46–66 | 71–90 |
| Womac score | 80 | 88 |
| IKDC | 54–60 | 65–85 |
| Tegner activity score | 3.57–4.0 | 3.75–4.5 |

in these cases, and correction was conducted by a mean of 11–14° (range 5–26°) [20–23, 25]. Mean tibial torsion was 47° (range 37–66°) before high tibial derotational osteotomy, and correction was conducted by a mean of 9–11° (range 5–18°) [20, 22].

Patients were mainly satisfied and reported a better cosmetic alignment with reduced squinting of the patella and improved squatting of the knee after a distal femoral derotational osteotomy [25].

Biomechanically these subjective impressions can be supported by the findings of Kaiser et al. [66] who showed that a distal derotational femoral osteotomy changes the patella tilt, patella axial engagement and the TT-TG significantly. For example, in cases of an increased internal femoral torsion, a femur derotation of 5° (towards an absolute norm value of 20°) decreases PT by a factor of ~1.3 and increases AEI by a factor of ~0.012. Additionally, the TT-TG diminishes by a factor of ~0.6, which needs to be taken into account, if an additional tuberosity transfer is planned in order to avoid a potentially increased retropatellar pressure.

## 51.8 Summary

This chapter illustrates the measurement method of lower limb torsion, reports on the indication for a femoral or tibial derotational osteotomy and demonstrates the surgical technique including its aftercare and reported outcome. It is very important to measure torsional malalignment with always the same method and according to normal values given by this method. Radiological measurement should be performed by the surgeon for planning of correction. Correction at the level of the femur and tibia can be necessary if excessive internal torsion of the femur and external torsion of the tibia is present. In many cases it is useful to use a lateral distal approach especially as a lateral lengthening is often necessary and a MPFL reconstruction is recommended in all cases of recurrent patella dislocation.

Be aware that derotation potentially changes your leg axis. This should be checked and corrected to prevent reoperation and failure. Derotation and correction of varus/valgus alignment can reproducibly be performed with a biplanar technique as described above. The level of the osteotomy on the femur should be as low as possible in the metaphysical bone to prevent bone healing problems. For the same reason, compress your osteotomy with your plate. The popliteal vessels must always be protected by a Hohmann retractor at the posterior border of the femur at the level of the osteotomy. On the tibial side, the medial collateral ligament has to be protected from the saw. With a correct measurement and a standardized controlled technique, excellent results can be achieved with a low rate of complications.

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# 52 Guided Growth Surgery

Petri Sillanpää

## 52.1 Introduction

In skeletally immature population, patellar dislocation is a very common condition. During growth spurt in adolescence, distal femoral and proximal tibial growth plates can affect significantly on axial alignment of the lower limb. One of the predisposing factors for patellar dislocation includes valgus alignment of the lower limb. "Genu valgum" increase lateralizing forces to the extensor mechanism of the lower limb and can be one of the significant risk factors for patellar dislocation in skeletally immature population. Genu valgum increase lateral patellar displacement and may present as higher Q-angle and elevated tibial tubercle-trochlear groove distance, which have been described as predisposing factors for patellar dislocation [1]. Valgus alignment can be measured in long-leg axial radiographs, by calculating femoral and tibial angles on coronal plane. If malleolar distance exceeds 10 cm, which indicates clinically relevant genu valgum, guided growth surgery can be considered to correct the weight-bearing line of the lower limb. Hemiepiphysiodesis is a surgical technique used to straighten the leg by slowing unilaterally the growth plate for a certain period of time. Usually a small tension plate implant (eight-plate) with screw proximal and distal to the growth plate is used to slow the growth in controlled way [2]. Amount of correction is monitored in 3-month interval by long-leg axial radiographs. When correction is complete, the implant is removed. Guided growth surgery is simpler and more convenient to the patient than correction osteotomies in adults, and therefore hemiepiphysiodesis is a viable option in skeletally immature patellar dislocation population [3].

## 52.2 Planning for Surgery

When abnormal valgus alignment is suspected in physical examination, long-leg axial plain radiographs, from both lower limbs, are required. From the radiographs, coronal plain alignment is measured by drawing a line from the center of the hip joint to center of the talus. Roughly 5–8° of valgus, i.e., mechanical axis deviation lateral to the center of the knee joint, is normal during early phase of the growth before age of 10 years [4]. In physical examination, a rough indicator is more than 10 cm intermalleolar distance, when knees are in contact (Fig. 52.1) [4]. In other words, significant valgus alignment is usually diagnosed in physical examination, by obvious clinical presentation of genu valgum. Preoperative assessment also includes measurement of limb lengths and rotational deformities. The surgeon

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**Fig. 52.1** Malleolar distance exceeds 10 cm, indicating clinically relevant genu valgum. Guided growth surgery can be considered to correct the weight-bearing line of the lower limb

should be aware of the principles for radiographic assessment of lower limb deformities.

When mechanical axis exceeds 8–10°, especially unilaterally, and the patient has had recurrent patellar dislocation, hemiepiphysiodesis surgery can be considered for the treatment. Planning for surgery follows the same basic rules as in adult correction osteotomies. First, limb alignment is measured using single-limb standing anteroposterior radiography of a lower extremity with the patellae facing forward. The weight-bearing line is defined as the line drawn from the center of the femoral head to the center of the proximal talus joint surface. In skeletally immature valgus alignment, the majority of the abnormal growth is in the distal femoral growth plate, indicating decreased distal lateral mechanical femoral angle. Pathological angular deformity can be corrected gradually with growth by performing temporary hemiepiphysiodesis surgery using tension band plate [2] (Fig. 52.2). Alternatively, staples or physeal ablation can be used. Most commonly, temporary hemiepiphysiodesis is used for a period of time that angular correction has been achieved, and it allows the physis to resume growth after hardware removal [2]. Sometimes proximal tibial growth plate may need to be addressed, with a similar principle, if medial proximal tibial angle is increased indicating tibial pathological angular deformity. Understanding the principles of lower limb osteotomies is necessary to precisely analyze the location of angular deformity, and timing of surgery is typically before or at the growth spurt of a teenager with at least 5–10 cm excepted growth remaining.

Physiological valgus in younger kids less than 10 years of age generally resolve by time [4], and therefore, if patellar dislocation is not intolerable condition or valgus alignment is not severe, observation for 6 months is recommended to reassess the natural history of the deformity during growth. Too near to the growth plate closure, hemiepiphysiodesis may not be enough to correct limb deformity, and correction osteotomy needs to be performed as in adults, once skeletally mature [5]. In a case with recurrent patellar dislocation, skeletally immature patient with genu valgum typically requires correction of valgus deformity first, and at the time of plate removal, medial patellofemoral ligament reconstruction (MPFLR) can be performed. In author's own experience, MPFLR simultaneous at the time of hemiepiphysiodesis is technically difficult [6–8] but might be considered with adductor magnus autograft technique with soft tissue fixation without any bony tunnels [7, 8]. If the patient has had MPFLR before planned hemiepiphysiodesis surgery, meticulous surgical technique needs to be used not to damage the graft on

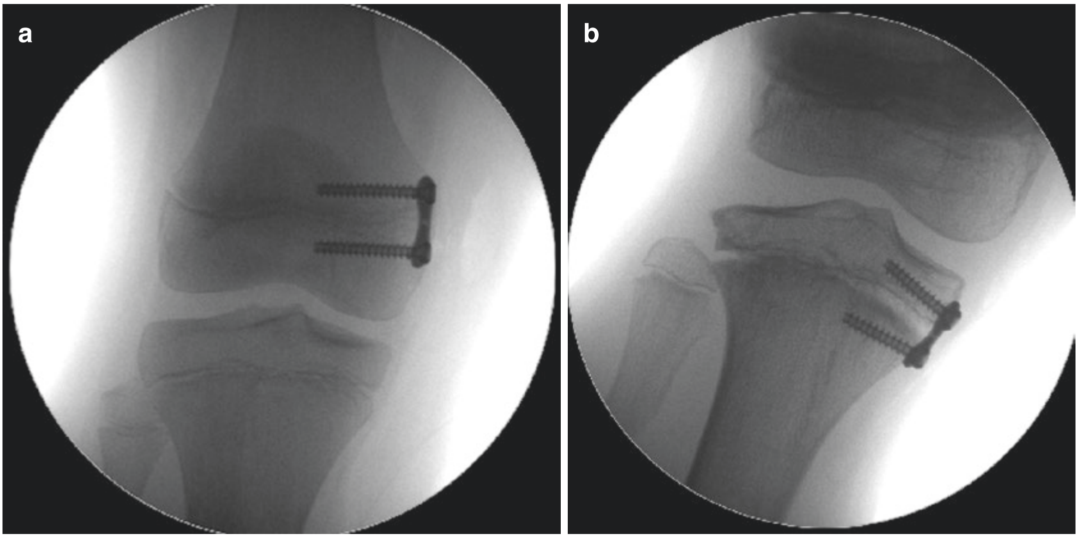

**Fig. 52.2** Pathological angular deformity can be corrected gradually with growth by performing temporary hemiepiphysiodesis surgery using tension band plate, located at distal femur (**a**) or proximal tibia (**b**), depending on axial deformity in coronal plane

femoral side. The MPFL femoral attachment is located near to the distal femoral physis, and therefore hemiepiphysiodesis plate fixation should be performed by dissecting the superficial soft tissues from proximal direction to distal and locate the plate over the femoral periosteum.

## 52.3 Surgical Technique

Fluoroscopy is used to verify precise location of the distal femoral physis and plate positioning in anteroposterior and lateral planes [2]. Patient is supine, and a 3 cm skin incision located at the adductor tubercle-medial femoral epicondyle is made. The plate is placed in a subfascial plane, proximally partly submuscular (vastus medialis obliquus). The MPFL femoral attachment is located near to the distal femoral physis, and therefore hemiepiphysiodesis plate fixation should be performed by dissecting the superficial soft tissues from proximal direction to distal and locate the plate over the femoral periosteum, which should be protected.

The following surgical details have been described by Stevens [2]. Once the plate is in correct soft tissue layer, the plate is centered by using a needle and fluoroscopy. Two 1.6 mm K-wires are inserted into the screw holes, and self-tapping cannulated screws are inserted. To avoid sagittal plane misplacement, the plate should be in or just posterior to the midsagittal plane. Too anterior plate location could lead to genu recurvatum during growth. Care should be taken not to penetrate the physis during screw placement. Screws placed parallel to the physis have been shown to provide more efficient angular correction than divergent screws [9]. The effect is more evident shortly after surgery, which is important in patients close to the skeletal maturity.

Postoperatively immediate full weight-bearing and free range of motion is allowed. Patient can usually walk without crutches within 2 weeks, which makes recovery period much easier than correction osteotomy in adults. Follow-up radiographs every 3–6 months are necessary, and plate should be removed when full correction of the valgus deformity is obtained. Follow-up should continue 1–2 years postoperatively to monitor for subsequent under- or overcorrection.

Complications include under- or overcorrection, premature physeal arrest, iatrogenic limb length inequality, and hardware migration or failure. Complications appear to be lower using the two hole extraperiosteal plate method compared with staple method [10, 11]. After plate removal, rebound period of accelerated growth [12] may occur and can be treated by repeat hemiepiphysiodesis if skeletal maturity has not yet been reached. In skeletal maturity, under- or overcorrection can be treated with open or closed wedge osteotomy.

## 52.4 Results for Guided Growth Surgery

Plate method (eight-plate) has been reported to have generally lower complication rate than staple method [5, 10, 11, 13]. Regarding the correction potential of the deformity, both plate and staple methods have been reported to have relatively similar results [5, 14, 15]. It has been found that the correction potential decreases with increasing age at the implantation [5]. Majority of the studies report results for the angular correction of the deformity for genu valgum. Some studies have reported skeletally immature patellar dislocation as secondary diagnosis for genu valgum correction [5], and there is some yet limited evidence in specific patellar dislocation population cohort study regarding the effectiveness of genu valgum correction for patellar stability [3]. Growth modulation by hemiepiphysiodesis to correct genu valgum is, however, an effective procedure to reduce lateralizing forces to the patellofemoral joint and is viable option in skeletally immature patellar dislocation population.

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