James V. Bono
Richard D. Scott
Editors

Revision Total Knee Arthroplasty

Second Edition

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Preface

Revision Total Knee Arthroplasty was initially created as a "how-to" text for the diagnosis and management of the failed total knee arthroplasty, with step-by-step descriptions of surgical techniques of revision total knee arthroplasty. The text has become a practical reference for students, residents, fellows, and attending surgeons engaged in the treatment and follow-up of patients who have undergone knee replacement surgery.

Part I covers the evaluation and diagnosis of the failed total knee arthroplasty including an update on the current incidence and reasons for the need for reoperation after total knee arthroplasty.

Part II emphasizes the general principles of revision surgery technique, including management of skin, surgical exposure, and removal of femoral and tibial implants at the time of revision. The fundamental aspects of the restoration of deficient bone stock, proper alignment, and adequate fixation are thoroughly discussed.

Part III discusses special considerations including the topics of infection, periprosthetic fracture, and stiffness and discusses the complexities of total knee arthroplasty after failed high tibial osteotomy, after fractures about the knee, and after prior unicompartmental and hinged knee replacement. The topics of insert exchange, aseptic synovitis, and the economics of revision total knee arthroplasty are discussed individually. The final chapter discusses the role of arthrodesis as a salvage procedure.

We feel fortunate to have received the support of so many well-known master surgeons who have contributed to the text. We are grateful to all of them and are honored to have been able to present their combined experience in the ensuing pages.

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I

Diagnosis and Evaluation

Reoperation After Total Knee Arthroplasty

1

Richard D. Scott

The specific incidence of and causes for reoperation after total knee arthroplasty (TKA) continue to change with time. In the early experience with hinge and condylar knees, reoperations were most frequently required for prosthetic loosening, knee instability, and sepsis. Twenty-five years ago, patellofemoral complications accounted for up to 50% of reoperations [1]. With improved prosthetic designs and better surgical technique, reoperations became less frequent. In the decade between 2000 and 2010, polyethylene wear (often associated with lysis) was a leading cause of failure [2]. With improvements in polyethylene fabrication, sterilization methods, and modular locking mechanisms, this failure mode has become less common.

In this chapter, the arthroplasty literature from 2013 to 2015 will be reviewed for updated reports of the current modes of failure of TKA [3–11]. These reports will highlight the reasons for revision, but most of them cannot give an incidence or annual failure rate since they do not include the size of the population from which the failures occurred.

To address the issue of incidence and annual failure rate, my personal incidence and causes of reoperation after 4993 consecutive posterior cruciate ligament (PCL)-retaining primary TKAs followed for a mean of 15 years are presented. Among these, there were 264 knees requiring reoperations. Some causes are obviously prosthesis specific. Nevertheless, this experience will help to give an overview of the incidence and causes of reoperation likely to be seen today in a total knee arthroplasty practice and also provide a calculated annual reoperation rate.

Literature Review

According to published reports between 2013 and 2015, the reasons for TKA reoperation have continued to evolve. All reports note a decreasing incidence of polyethylene wear as a causative factor [3–11]. Some studies separate failures into early and late, with "early" defined as within 2 years of the arthroplasty implantation and "late" as any time after that date.

Le et al. reviewed all first-time revisions performed at one institution over a 10-year period [3]. These included both referred cases as well as those originally operated at their institution. Forty-six percent of the revisions were in the "early" group, while 54% were operated beyond their 2-year anniversary. In the early group,

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reasons for revision in decreasing frequency were instability (26%), infection (24%), stiffness (18%), and poly wear (2%). In the late group, reasons were infection (25%), instability (18%), stiffness (14%), and poly wear (9%).

Zmitkowski et al. reported an 8-year experience at one institution with 10,188 primary TKAs documenting only those cases that required an operating room anesthetic but did not require a component revision [4]. Follow-up was 1–9 years with a median of 4 years. Four percent of knees required a "surgical intervention" for a rate of 1% per year. Reasons in decreasing order of frequency included manipulation for stiffness (58%), patellar clunk (12%), infection (12%), incision complications (6%), and hematoma (4%). If the manipulations for stiffness were eliminated, the reoperation rate was slightly less than 0.5% per year.

Thiele et al. conducted a retrospective study that included all first revisions performed at two high-volume arthroplasty centers between 2005 and 2010 where at least one prosthetic component was replaced [5]. Of 358 revisions, 20% were performed within the first year. The most common indications for reoperation within the first year were infection (27%) and instability (24%). Between 1 and 3 years, malalignment (29%) and instability (23%) were most frequent. Beyond 3 years, aseptic loosening (35%), instability (19%), and polyethylene wear (19%) were most common.

Sharkey et al. reviewed 781 revision cases and compared the reasons for reoperation to a report from the same institution 10 years prior [6, 12]. It was noted that besides wear being less frequent, infection was the most common cause for early failure while aseptic loosening predominated in late failures.

Schroer et al. and Lombardi et al. both reported on 844 revisions performed between 2010 and 2011 at several centers [7, 8]. Thirty-five percent of revisions occurred "early" and appeared to be surgeon dependent. Overall failure reasons included loosening (31%), instability (19%), infection (16%), stiffness (10%), and malalignment (7%). They also noted that unexplained pain accounted for some revisions in their as well as most reported series.

Dalury et al. studied 820 revisions performed between 2000 and 2012 [9]. Loosening, infection, instability, and wear accounted for approximately 20% each of reoperations, but they noted that wear-related failures were less frequent in the more recently operated patients.

It is difficult to collate the above-noted series because of variability in the time intervals in which the reoperations are reported, but some general trends can be noted. It would appear that approximately one-third of first-time revisions take place within the first 2 years after index surgery. About 25% of early failures are due to infection and a similar number are due to instability. Stiffness is the third most common cause in the first 2 years. Infection and instability persist as reasons for late failure but prosthetic loosening has recently become the leading cause. Polyethylene wear is also still a factor, but with much less frequency than its role a decade ago.

A Single Surgeon's Reoperation Experience from a Computerized Database

In November of 1984, a database was established to follow consecutive posterior cruciate-retaining primary knee arthroplasties performed by one surgeon. Data was maintained in a computerized database. Patient demographics, operative details, follow-up examinations, and reoperations were monitored and documented. As of January 2016, 4993 knees were included in the database with 264 knees requiring a reoperation (Table 1.1). The following is a review of the causes and incidence of first-time reoperations including a calculated annual reoperation rate. Patients were urged (and constantly reminded) to report any surgical interventions performed elsewhere. Despite this, it is possible that an occasional reoperation performed elsewhere has not been included in the statistics.

Infection

Early operative infection should be a rare occurrence today with the use of improved sterile technique, more efficient surgery with shorter operating times and perioperative antibiotics. Most surgeons should experience an early operative infection rate between 0 and 0.3%. Infection is most likely to occur in the multiply operated, diabetic, or morbidly obese patient or when there has been a wound healing issue. Many factors likely accounted for the low (0%) primary infection rate in this series [12].

Late metastatic infection from a remote focus can occur throughout the life of the patient. Common sites that can cause a bacteremia that seeds the joint are the oral cavity, gastrointestinal and urinary tract, or skin site (usually cellulitis). Some of these cases are inevitable despite education of patients and treating physicians about their possibility. They are currently responsible for about 12% of reoperations (32 among the 264 knees reoperated in this series) and may eventually become the leading cause as other issues are minimized. The incidence of late metastatic infection was 0.6% at mean follow-up of 15 years with an occurrence rate of 0.04% per year of follow-up.

Patients must be educated as to the prevention of late infections Dental prophylaxis has become optional. Some surgeons recommend dental prophylaxis for 2 years following the arthroplasty while others recommend lifetime coverage.

Table 1.1 264 reasons for reoperation on 4993 knees (mean 15-year follow-up)

94 insert wear with lysis (most implanted in mid-1990s)
37 insert wear with synovitis
8 insert wear without symptoms
32 late metastatic infections
13 stiffness (8 treated with arthroscopy)
9 metal-backed patellar wear (10% at mean 28-year FU)
8 broken porous femoral components (none since 1996)
8 atraumatic laxity (involving insert exchange)
7 un-resurfaced patellar pain (4% at mean 20-year FU)
7 loose cemented femoral components (among 3448 = 0.20%)
6 recurrent rheumatoid synovitis (among 244 rheumatoid knees)
6 loose cemented tibial components (among 4953 = 0.12%)
5 recurrent hemarthrosis
4 shear-off patellar lugs
4 loose cementless tibias (10% at mean 25-year FU)
3 traumatic laxity (involving insert exchange)
3 ganglion cysts
3 patellar loosening (among 4815 = 0.06%)
2 loose cementless femoral components (among 1378 = 0.15%)
1 patellar clunk
1 rotating bearing spinout (among 820)
1 traumatic fracture of tibial bone involving need for revision
1 traumatic fracture of femoral bone involving need for revision
1 fractured resurfaced patellar bone involving component removal

Femoral Component Loosening

Isolated femoral component loosening has been very rare in this series whether the component was cemented or cementless. Failure of either femoral fixation method accounted for approximately 3% of reoperations. The incidence of femoral loosening was 0.2% at mean 15-year follow-up occurring at a rate of 0.01% per year.

The success of a cementless femur could be dependent on the quality of primary fixation at the time of the arthroplasty. In this series, suitability for cementless fixation was subjectively determined by testing the difficulty of removing the femoral trial using an extractor with a slap hammer.

Both cemented and cementless femurs are vulnerable to late loosening in the presence of severe osteolysis, and this data is included in the section on wear and lysis.

Tibial Component Loosening

Isolated cemented tibial component loosening is also infrequent and also accounts for approximately 2% of reoperations. It also has an extremely low incidence of 0.01% per year failure

over the first 15 years. As seen on the femoral side, tibial loosening is more prevalent in the presence of wear debris-induced osteolysis.

Cementless tibial components are more likely to loosen than cemented components with the incidence dependent on their design and the accuracy of implantation. Components fixed with screws or those using metals with high in growth potential are more likely to enjoy long-term success. In this series, there were only 40 cementless porous titanium tibias implanted, none with screw fixation. At mean 25-year follow-up, four had loosened for an incidence of 10%. Conclusions about the success of cementless tibial fixation using current designs cannot be judged by the results in this series of this outdated design.

Patellar Complications

As mentioned earlier, patellar problems were the leading cause of reoperation some 25 years ago. These complications included worn metal-backed patellar components, patellar fracture when large central fixation lugs were in vogue, and patellar loosening when fixation was via a small central fixation lug. Since the mid-1980s three-pegged all-polyethylene patellar components (as were used in this series) became the state of the art. Metal-backed patellar components were abandoned in this series in 1986. Of 87 implanted, nine have worn through and required revision [13].

With this fixation method, both loosening and fractures were rare. Of 4699 all-poly 3 lugged patellas implanted, there have been three reoperations for loosening, one for a fracture, and one for a patellar clunk. Shearing off of the three lugs occurred in four cases with an early design. Its etiology required the presence of an abnormal shearing force caused by imbalance in the quadriceps mechanism. The conformity of the prosthetic articulation tended to keep the patella located in the trochlear groove, while the soft tissue imbalance pulled the patella toward the lateral side, resulting in the shear forces. Once the junction between the lug and the patellar component was reinforced by manufacturers, this complication has not been seen.

A few traumatic fractures of the body of the patella occurred, but were treated conservatively and did not require surgery. Small avulsion fractures that usually involved a few millimeters of the superior pole of the patella were also seen, often as rare incidental findings noted at routine follow-up. Occasionally, they were symptomatic for approximately 6 weeks during which time the patients should be advised to avoid high forces across the patellofemoral articulation such as ascending stairs and arising from a sitting position without arm support.

Early in this series, patellas were selectively left un-resurfaced based on the findings of noninflammatory arthritis, less than grade III cartilage degeneration and congruent tracking with the trochlear flange [14]. Approximately 20% of osteoarthritic patients met these criteria. In the last two decades, the long-term success of three-pegged all-poly patellar components led to almost universal patellar resurfacing except for the rare, young, heavy, and active male patient. Using these criteria, 178 un-resurfaced patellas have a mean follow-up of 20 years. Of these, 7(4%) have required secondary resurfacing. Overall, patellar problems account for 6% of reoperations and occur at a rate of 0.4% per year.

Polyethylene Wear and Lysis

A decade ago, polyethylene wear (and its consequences) was the most frequent cause of reoperation after TKA. Wear can present as an isolated radiographic finding or can produce symptomatic wear-debris synovitis and eventual osteolysis that can compromise prosthetic fixation. Polyethylene wear complications accounted for a little over 50% of reoperations in the early 2000s [2]. Of these, approximately two-thirds were associated with lysis, one-third with synovitis only, and between 5 and 10% presented with asymptomatic radiographic wear at a routine follow-up that was severe enough to warrant an elective insert exchange. The chance of requiring an operation for a wear-related problem ran approximately

0.25% per year of follow-up for the first 27 years. Almost all wear-related problems were seen in modular tibial components. All-poly non-modular tibial components when used in elderly patients have few if any wear-related issues and tend to outlive the patient.

Osteolysis was extremely rare in knees implanted in the 1980s. Its incidence began to slowly climb in the early 1990s and may have peaked in knees implanted in the late 1990s. The reasons for this are multifactorial. Inserts implanted in that era were still gamma radiated in air (the state of the art at that time). In addition, more conforming articulations started to be used to decrease topside wear. These conforming articulations can transfer stresses away from the topside to the insert-tray interface possibly leading to increased backside wear and the fine debris particles that incite the lytic process [15]. The confounding issue of dealing with topside wear via increased conformity but precipitating backside wear because of force imparted to the insert-tray interface can be addressed by rotating bearing components or by the use of non-modular metal-backed or all-polyethylene components. Modern systems also tend to have better locking mechanisms, and many have polished trays to minimize backside wear caused by micromotion. Polyethylene, itself, also continues to undergo fabrication modifications to eliminate oxidation and improve wear characteristics.

In this series, there were 139 wear-related failures accounting for 53% of the reoperations. Ninety-four were for lysis, 37 for synovitis, and eight showed asymptomatic wear on routine follow-up radiographs. Their incidence diminished yearly as a result of the fabrication and prosthetic design improvements noted above.

Miscellaneous Causes of Reoperation

There are a number of miscellaneous causes of reoperation after TKA that together account for approximately 15% of reoperations (Table 1.1). These include ankylosis that doesn't respond to closed manipulation, traumatic and atraumatic instability, recurrent hemarthrosis [16], recurrent rheumatoid synovitis, and symptomatic ganglion cysts that tend to arise from the proximal tibiofibular joint [17].

Summary

In summary, PCL retaining fixed-bearing TKA is a highly successful operation with the need for more surgery occurring at the rate of approximately 0.35% per year over the first 30 years. The most common cause for revision surgery was related to polyethylene insert failure 10 years ago, but recent reports note that wear-related problems are less frequent while loosening, instability, stiffness, and late infection now predominate.

Although there are more young and more very elderly patients undergoing TKA today, the mean age of patients having this surgery remains at about 68 years. Actuaries tell us that people this age die at the rate of 2.7% per year while we have noted that their arthroplasty will fail at the rate of 0.35% per year. It is a sobering thought that the 68-year-old TKA patient has an 8 times greater chance of dying than of ever undergoing another operation on their total knee.

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Implant Bearings in Total Knee Arthroplasty

2

Christine S. Heim and A. Seth Greenwald

The Enduring Goal

The enduring success of the low-friction arthroplasty, advanced by Sir John Charnley as a solution for hip arthrosis, may be appreciated by the fact that in 2016 almost 1.4 million primary and revision hip and knee arthroplasty procedures were performed in the United States, a number more than doubling on a global basis [1] (Table 2.1). Improvements in surgical technique and implant design over the last four decades have resulted in total knee arthroplasty (TKA) being deemed one of the most successful, contemporary orthopaedic procedures to effectively relieve pain and allow patients to resume the activities of their daily lives. The prevalence of aseptic loosening attributed to ultra-high molecular weight polyethylene (UHMWPE) wear debris-induced osteolysis is in the single digits in most knee series, with some reports describing prosthesis survival beyond 20 years [2–25]. Despite this obvious success, UHMWPE wear is an inescapable consequence of total joint articulation and is of contemporary concern particularly as our population grays and lifestyle demands increase [26–44]. Appreciating an orthopaedic triad where patient outcomes are not only dictated by the implant but are highly dependent on patient factors and technical proficiency assists the goal of avoiding total knee arthroplasty revision.

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The Triad: The Implant

The Evolution of UHMWPE

The UHMWPE used in joint arthroplasty components results from polymerization of ethylene gas into a fine resin powder of submicron and micron size distribution. A number of resin mixtures exist, but GUR 1020 and GUR 1050 are the prevalent polymers utilized in contemporary devices. They are consolidated with the use of ram extrusion or compression-molding techniques. Structurally, UHMWPE is made up of repeating carbon-hydrogen chains that are arranged in ordered (crystalline) and disordered (amorphous) regions [45]. While UHMWPE has remained the tibial insert and patellar component bearing material of choice over the last four decades, researchers are continually striving to increase its in-vivo longevity through alterations to processing and/or sterilization techniques.

Short- to mid-term clinical reports of UHMWPE damage in the 1990s led to a review

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Table 2.1 Hip and knee arthroplasty procedures performed in the United States in 2016

	Primary	Revision	Total
Knees	759,600	89,000	848,600
Hips	492,900	58,400	551,300
Total	1,252,500	147,400	1,399,900

Data from *Orthopaedic Network News* [1]

Fig. 2.1 A 5-year retrieval of a failed poly-II tibial insert demonstrating a high component wear rate with infiltration of carbon fibers and polyethylene debris into surrounding tissue

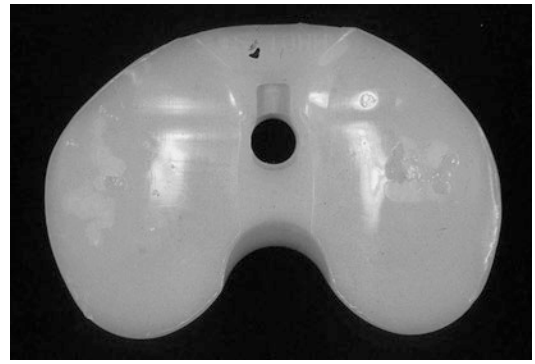

Fig. 2.2 A 3-year retrieval of a failed Hylamer-M tibial plateau demonstrating an unexpectedly high wear rate with corresponding wear and debris-induced inflammatory tissue response

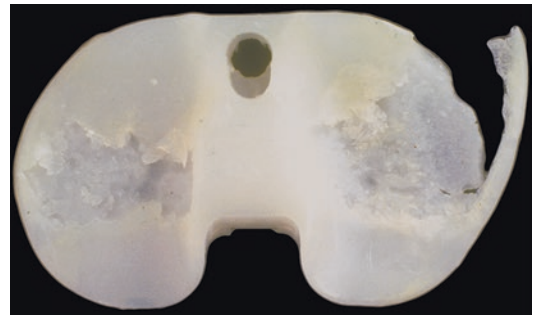

Fig. 2.3 A 6-year retrieval of a heat-pressed tibial component associated with polyethylene fatigue and early delamination

of manufacturing processes and determined that inadequate quality control resulted in fusion defects arising from incomplete polymerization, voids, and foreign body inclusions [46–48]. Recognizing the direct impact of these variables on the in-vivo degradation of the final parts, orthopaedic device manufacturers addressed the allowable tolerances for these components, and these issues have not reappeared in the peer-reviewed literature.

Previous attempts to improve UHMWPE performance have included carbon fiber reinforcement (Poly-II) [49] and polymer reprocessing by hot isostatic pressing (Hylamer) [50]. The former was withdrawn from the market because of an unexpectedly high wear rate [51] (Fig. 2.1), while the latter has been linked to debris-induced osteolytic response, especially when sterilized by gamma irradiation in air [52] (Fig. 2.2). Heat pressing was yet another attempt to improve the finish of the articular surface, but was associated with UHMWPE fatigue and early delamination [53] (Fig. 2.3). These material innovations had checkered pasts as they moved from the laboratory to clinical application.

Gamma irradiation in air was the predominant method of UHMWPE component sterilization, and, to this day, represents the long-term standard against which contemporary material improvements are measured. In the early 1990s, an increasing prevalence of tibial component failures associated with debris-induced osteolysis raised concerns over the long-term durability of contemporary devices [54, 55]. A clinical follow-up study reported by Bohl et al. suggested that this may be accounted for by the prolonged shelf storage prior to implantation of UHMWPE components gamma irradiated in air [56]. A 12–20% reduction in in-vivo survival was noted for shelf storage ranging from 4 to 11 years with a mean in-vivo time to revision of 2.5 years (Figs. 2.4 and 2.5).

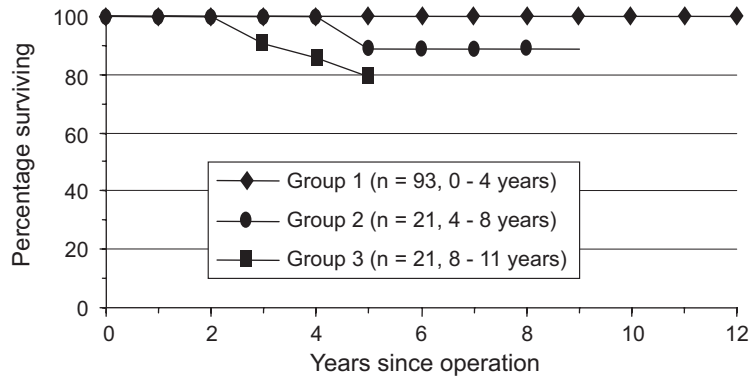

Fig. 2.4 The influence of shelf storage on survival of a prosthetic knee plateau following gamma irradiation in air (from Bohl JR, Bohl WR, Postak PD, et al. The effects of shelf life on clinical outcome for gamma sterilized polyethylene tibial components. Clin Orthop Relat Res. 1999;267:28–38, with permission)

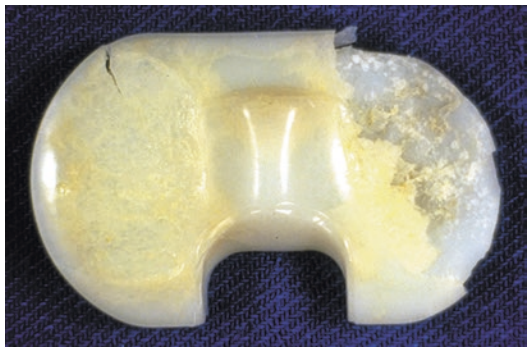

Fig. 2.5 A group 2 plateau implanted after 7.6 years of shelf storage and retrieved 3.8 years after implantation. Gross delamination and pitting, characteristics of fatigue failure, are observed (from Bohl JR, Bohl WR, Postak PD, et al. The effects of shelf life on clinical outcome for gamma sterilized polyethylene tibial components. Clin Orthop Relat Res. 1999;267:28–38, with permission)

Further, laboratory studies indicated that as shelf storage increased, the amount of UHMWPE exposed to high surface stresses during articulation increased dramatically and was a contributing factor to early in-vivo polymer failure [57–59] (Fig. 2.6).

The explanation for these observations lies in the mechanics of the sterilization process, which facilitates breakage of polymer chains by the incoming gamma radiation, creating free radicals, which preferentially combine with available oxygen [60, 61] (Fig. 2.7). The onset of mass UHMWPE component production and device modularity resulted in extended component shelf storage before use. This was not a previous consideration, but ongoing shelf life oxidation offered an explanation for mechanical compromise of the polymer in-situ [58, 60, 62, 63] (Fig. 2.8). It was also noted that in-vivo component oxidation occurred, but to a lesser degree [64].

At this point, attempts to remove oxygen from the sterilization process included the use of inert gas and vacuum environments or by avoiding gamma irradiation altogether through the use of ethylene oxide (EtO) or gas plasmas [65–67]. Acetabular components sterilized by these techniques demonstrated a reduction in UHMWPE wear in hip simulation studies (Fig. 2.9). Today, orthopaedic device manufacturers avoid the use of an air environment when packaging UHMWPE components, and sterilization dates are standard on device package labeling.

It is now also quantitatively appreciated that increasing the gamma radiation dose above the 2.5 Mrad level used in conventional UHMWPE component sterilization encourages free radicals to combine, creating cross-links between the molecules of adjacent chains, which is further enhanced in an oxygen-free environment [68–70]. Figure 2.10 from McKellop and coworkers [69] is descriptive of this phenomenon in a simulator comparison of acetabular cup components with the volumetric wear per million cycles dramatically reduced with increasing gamma radiation exposure.

There are clinical reports attributed to Oonishi and Grobbelaar, which describe in-vivo UHMWPE wear reduction in acetabular components realized

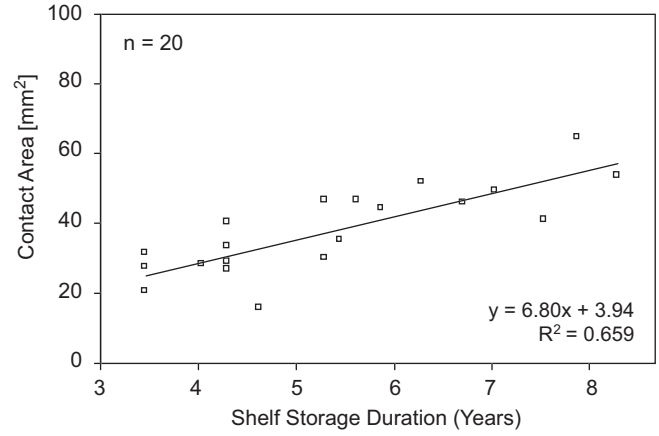

Fig. 2.6 Tibial-femoral contact area for a 5.6-mm thick tibial plateau carrying >20 MPa stresses during articulation dramatically increases with lengthening shelf storage periods

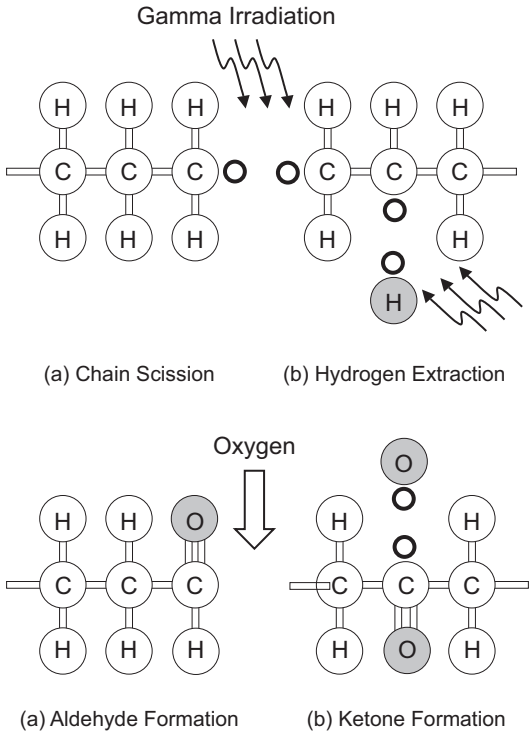

Fig. 2.7 Depicted polymer chain breakage following irradiation in air and combination with oxygen facilitating oxidative degradation of UHMWPE

through increased cross-linking [71–76]. However, these studies employed large doses of gamma radiation (>50 Mrad), which are known to cause polymer embrittlement and yellowing. Wroblewski, employing a chemically enhanced cross-linked polymer, achieved similar findings both in-vivo and in-vitro, when coupled with an alumina articulation [77].

These isolated studies pointed the way to a new class of UHMWPEs, whose common denominator was an appreciation of the importance of increased cross-linking while minimizing oxidative degradation to reduce wear. Initial methods used to manufacture these moderately to highly cross-linked UHMWPEs included (1) heating above or below the melt temperature of the polyethylene, (2) the type of radiation employed, (3) the radiation dose level, (4) the sequence of stepwise application, and (5) the endpoint sterilization. The one common factor is that radiation was integrated into the manufacturing process. All received U.S. Food and Drug Administration 510[k] clearance, allowing commercial distribution for both hip and knee components (Table 2.2).

However, changes in the mechanical properties of these materials, particularly in their reduced resistance to fatigue crack propagation (fracture toughness), raised concerns about their long-term suitability in hip and knee components where locking mechanisms offered foci for stress risers [78–81] (Figs. 2.11, 2.12, and 2.13). Short-term clinical reports for total hip arthroplasty demonstrated a significant reduction in wear volume and rate for these polymers [82–87], which supported the impressive preclinical hip simulation laboratory data [88–92]. However, the negative impact of extreme component positioning on outcome was also demonstrated through case and retrieval reports at this time [80, 93, 94].

An appreciation of the differing modes of hip (abrasion and adhesion) and knee (pitting and delamination) failure, confirmed through

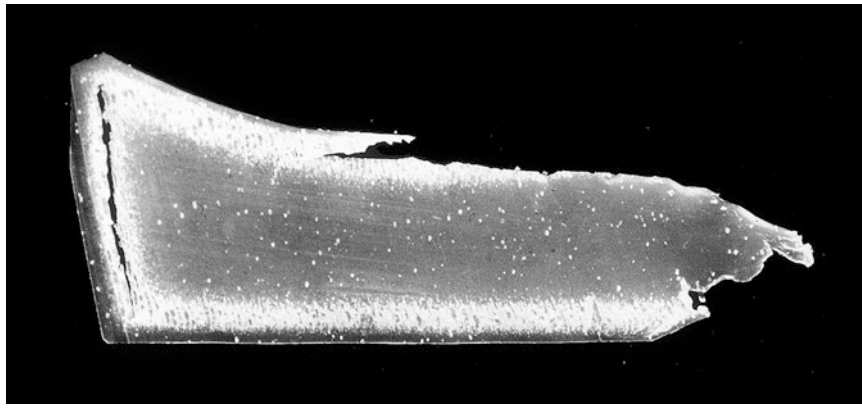

Fig. 2.8 A 3-year retrieval of a fully oxidized, gamma irradiated in air, UHMWPE tibial component demonstrating a circumferential white band indicative of polymer embrittlement after prolonged shelf life. Fusion defects from incomplete consolidation are noted

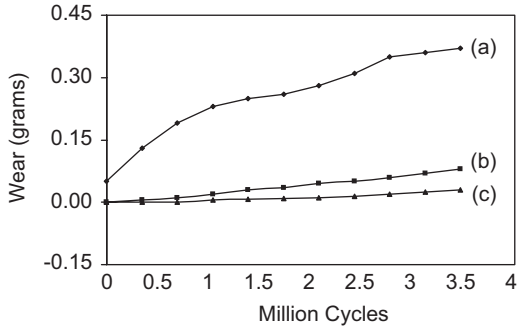

Fig. 2.9 Hip simulator weight-loss comparison for aged (25 days at 78 degrees Celsius in O_2) compression-molded cup components: (**a**) gamma irradiated in air; (**b**) sterilized with ethylene oxide; and (**c**) gamma irradiated in a vacuum environment and use of barrier packaging. (From Greer, Schmidt, Hamilton,[66] by permission of *Trans Orthop Res Soc.*)

Table 2.2 Moderately to highly cross-linked UHMWPEs

Manufacturer	UHMWPE trade name
Biomet	ArComXL
DePuy/J&J	Marathon AltrX
Smith + Nephew	XLPE
Stryker	Crossfire X3
Zimmer	Durasul Longevity Prolong

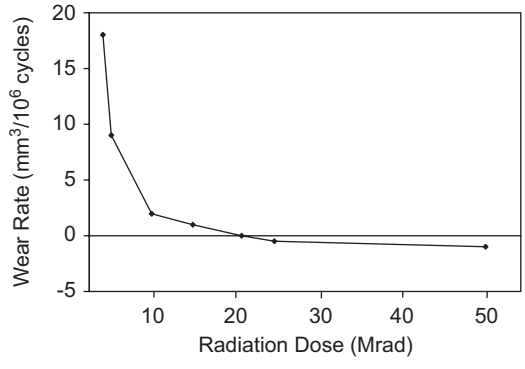

Fig. 2.10 Mean acetabular cup wear rates versus gamma dose level (from McKellop H, Shen FW, Lu B, et al. Development of an extremely wear-resistant ultra-high molecular weight polyethylene for total hip replacements. J Orthop Res. 1999;17(2):157–167, with permission)

Fig. 2.11 A 1-year conventional UHMWPE, primary acetabular liner demonstrating crack initiation and propagation. Failure initiated at a sharp edge of a locking point (from Tradonsky S, Postak PD, Froimson AI, et al. A comparison of disassociation strength of modular acetabular components. Clin Orthop Relat Res. 1993;296:154–160, with permission)

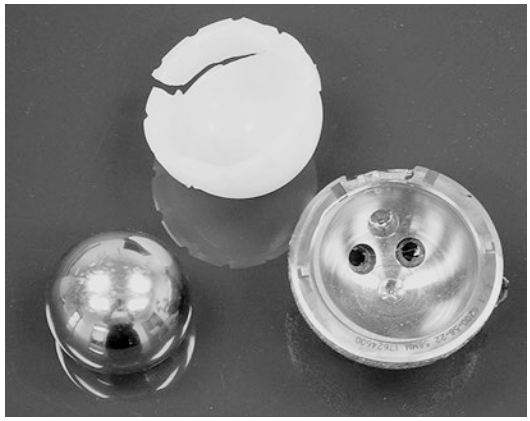

Fig. 2.12 A 10-month cross-linked UHMWPE, revision acetabular liner demonstrating crack initiation and propagation. The decision to retain the acetabular shell in an almost vertical and anteverted position contributed to this early failure, which was compounded by the decision to use a 40-mm femoral head and a correspondingly thin liner (from Halley D, Glassman A, Crowninshield RD. Recurrent dislocation after revision total hip replacement with a large prosthetic femoral head. J Bone Joint Surg Am. 2004;86(4):827–830, with permission)

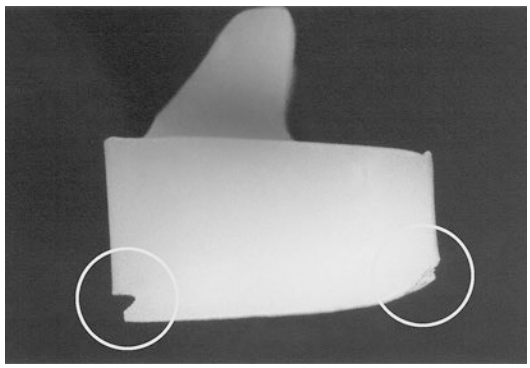

Fig. 2.13 A 3-year failure of a constrained condylar conventional UHMWPE tibial insert. Failure of the posterior locking mechanism resulted in posterior component lift-off (from Ries MD. Dissociation of an ultra-high molecular weight polyethylene insert from the tibial baseplate after total knee arthroplasty. J Bone Joint Surg Am. 2004;86(7):1522–24, with permission)

conventional UHMWPE component retrieval [95–97], also suggested that a universal, moderately to highly cross-linked polymer may not be appropriate. To counter the reported degradation in material properties, "enhanced" UHMWPEs now have antioxidants, predominantly vitamin E, infused or blended into the resin powder during the manufacturing process (Table 2.3). Laboratory studies have confirmed the maintenance of UHMWPE mechanical properties and wear resistance in addition to prevention of oxidative degradation for these polymers [98–105].

Table 2.3 Contemporary antioxidant-infused UHMWPEs

Manufacturer	UHMWPE trade name
Biomet	E1
Corin	ECIMA
DePuy Synthes	AOX
DJO global	E+
StelKast	EXp
Zimmer	Vivacit-E

Contemporary peer-reviewed literature for the moderately to highly cross-linked UHMWPEs in total hip arthroplasty is reporting dramatic reduction of wear rate when compared to conventional UHMWPE in mid- to long-term follow-up studies with metal femoral heads [106–121]. Total knee arthroplasty clinical reporting focuses on aseptic loosening and mechanical failures rather than wear rate, but again, in short- to mid-term studies, these UHMWPEs are demonstrating efficacy [122–126]. While short- to mid-term clinical studies supporting the further advantages of the antioxidant-infused UHMWPEs in total hip arthroplasty are increasing [127–131], reporting for total knee arthroplasty has just begun [132]. While the overall clinical gains of these enhancements have been questioned [133], the passage of in-vivo time will be, as has always been, the defining factor in the continued use of these moderately to highly cross-linked UHMWPEs with or without antioxidants.

The Femoral Side

While the predominant focus for increasing the in-vivo longevity of total knee arthroplasty is alteration of the UHMWPE tibial insert, there are alternative bearing options for the femoral component as well. As example, oxidized zirconium, marketed under the trade name Oxinium (Smith + Nephew, Memphis, TN) in the United States, has the strength of metallic cobalt-chromium

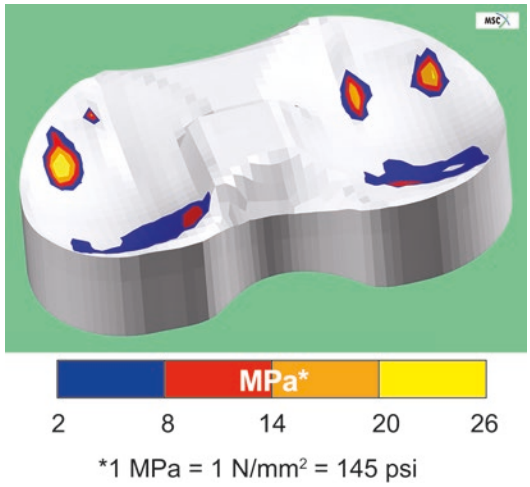

Fig. 2.14 Finite element analysis of tibial-femoral contact areas and surface stresses of a contemporary mobile bearing knee design at 0° extension. Poor mating of the articulating surfaces is observed resulting in peripheral contact with damaging stress levels

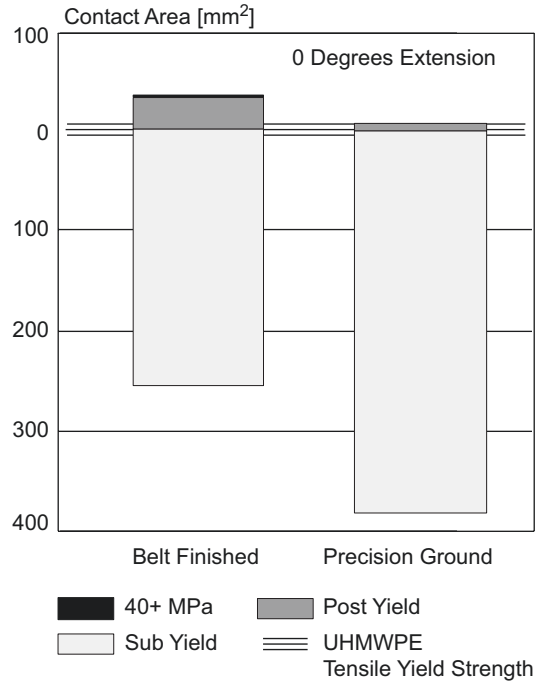

Fig. 2.15 A comparison of tibial-femoral contact areas by surface stress range for belt finishing and computer-aided precision grinding techniques of a single femoral component design at 0° extension. The overall bar height depicts the total contact area (from Heim CS, Postak PD, Greenwald AS. Factors Influencing the longevity of UHMWPE tibial components. In: Pritchard D, editor. Instructional Course Lectures, vol 45. Chicago, IL: American Academy of Orthopaedic Surgeons; 1996, with permission)

femoral components with the wear characteristics of ceramics [134], as has been shown in laboratory simulators for pairings with both conventional and highly cross-linked UHMWPE [135, 136]. The uniqueness of this material is that it offers patients with metal hypersensitivity, particularly to nickel, an implant option that has been shown to be clinically equivalent to cobalt-chromium femoral components [137–142].

The Tibial-Femoral Geometries

As knee designs have evolved, a growing appreciation of the avoidance of round-on-flat geometries through the ranges of knee flexion in favor of round-on-curved surfaces emerged [54]. The ability of a given design to minimize contact stresses during walking gait contributes to UHMWPE tibial component longevity [143]. With this, the trend toward more conforming design geometries also has associated with it the expectation that femoral component tolerances be maintained during the manufacturing process. Failure to achieve this can dramatically decrease contact surfaces, elevate peak stresses, and, concurrent with articulation, is the harbinger of material damage [144] (Fig. 2.14).

The attainment of femoral component tolerances has markedly improved with the use of computer-aided precision grinding as a standard finishing technique for metallic femoral knee components. This is particularly beneficial where small variations in surface contours have large effects on contact areas and surface stresses (Fig. 2.15). The implications of this technique have potentially far-reaching consequences. As design specifications are produced with tighter tolerances, the need for precision manufacturing is imperative (Fig. 2.16).

The Wear Particles Produced

Conventional wisdom and our experience particular to hip arthroplasty suggest that osteolytic response is associated with both particle size and

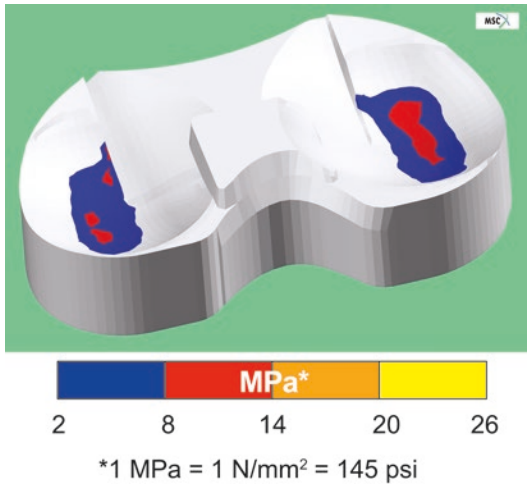

Fig. 2.16 Finite element analysis demonstrating the optimization of tibial-femoral contact areas and surface stresses resulting from quality controlled finishing of the component demonstrated earlier in Fig. 2.14. It is apparent that use of the conforming geometries has been achieved with the resulting diminishment of peak contact stresses

debris volume. Laboratory hip simulator experiments have shown that UHMWPE particle volumes in various size ranges are dependent on radiation dose [145] (Figs. 2.17 and 2.18). The greatest potential for cytokine release, the first step in the sequelae leading to osteolysis, following macrophage debris encapsulation is at the <1 μm level. Ingram et al. suggested that highly cross-linked UHMWPE debris obtained from scratched surface articulation was bioreactive when placed in culture medium and appeared to be volume dependent [146].

The influence of surface roughness was further investigated by Scott et al. in a hip simulator comparison between conventional, EtO, and 10 Mrad UHMWPE components [147]. As one appreciates from Fig. 2.19, roughened surfaces have a negative influence on particle production where highly cross-linked UHMWPEs are employed. This was challenged by Muratoglu et al. in a study in which retrieved femoral components were articulated in

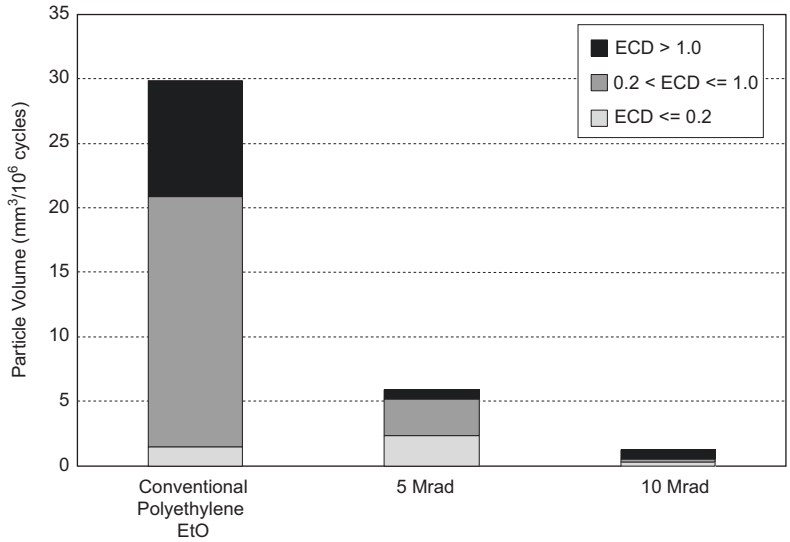

Fig. 2.17 Comparative volumes of acetabular particle generation for different size ranges per million cycles for conventional and highly cross-linked UHMWPEs at 5 and 10 Mrads resulting from hip simulation. ECD, equivalent circular diameter (from Ries MD, Scott ML, Jani S. Relationship between gravimetric wear and particle generation in hip simulator: conventional compared with cross-linked polyethylene. J Bone Joint Surg Am. 2001;83(Suppl 2, Pt 2):116–122, with permission)

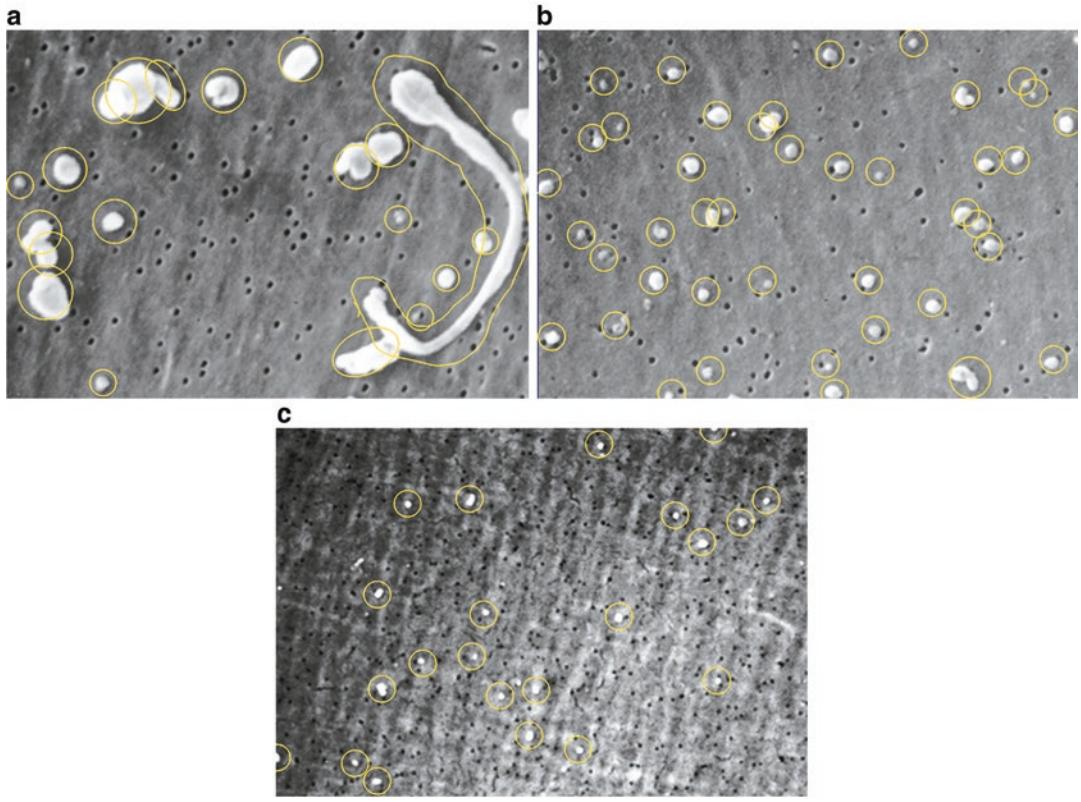

Fig. 2.18 Corresponding SEM visualization (10000×) of particle distribution for (**a**) conventional and (**b** and **c**) highly cross-linked UHMWPEs at 5 and 10 Mrads, respectively, employing a 0.05-μm filter. The particles are highlighted for appreciation (from Ries MD, Scott ML, Jani S. Relationship between gravimetric wear and particle generation in hip simulator: conventional compared with cross-linked polyethylene. J Bone Joint Surg Am. 2001;83(Suppl 2, Pt 2):116–122, with permission)

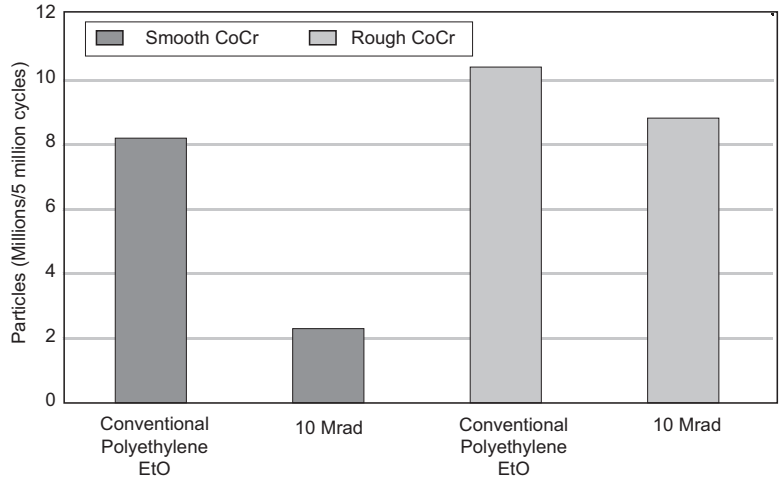

Fig. 2.19 The influence of smooth and roughened femoral head surfaces on particle generation for conventional and highly cross-linked UHMWPE acetabular components resulting from hip simulation (from Good V, Ries M, Barrack RL, et al. Reduced wear with oxidized zirconium femoral heads. J Bone Joint Surg Am. 2003;85(Suppl 4):105–110, with permission)

knee simulation against a highly cross-linked UHMWPE [148]. Further, retrieved oxidized zirconium femoral components have demonstrated decreased surface roughness with time in-vivo, suggesting another benefit of this cobalt-chromium alternative for improving the long-term viability of knee articulations [149–152].

The Triad: The Patient

Overenthusiastic patient use following total knee arthroplasty has been cited as a factor influencing failure [153–155]. Its occurrence, however, has generally been described in singular case reports in much the same way as failure attributed to obesity. Series reports do not support a relationship between increased body mass index and device failure following arthroplasty [156–161]. Surgical preference, however, weighs in favor of the lightweight patient as the ideal arthroplasty candidate [162]. It is also known from both physical laboratory testing and finite element analysis that load magnitude in combination with displacement are factors influencing UHMWPE damage [163–170]. While a recommendation for patient weight loss before surgery may be justified from these laboratory investigations, the clinical reality of achieving this does not lie in the patient's or surgeon's favor [171].

With the patient population pursuing total knee arthroplasty getting younger and living longer, it is imperative that contemporary implant bearing materials address these increasing demands [172]. Clinical studies are now focusing more on patient-reported outcomes and relating them to comorbidities in an effort to align expectations for both the patient and the surgeon [173–175].

The Triad: The Surgery

The forces and torques that occur during walking gait, particularly during toe-off, promote articulation in the posteromedial quadrant of tibial inserts [176–180]. Retrieved components of failed knee arthroplasties demonstrate UHMWPE damage patterns in this area [181–185] (Fig. 2.20). Notwithstanding poor component design, causal factors include overloading the medial compartment, improper surgical correction or alignment of the bony structures, insufficient soft tissue balance and release, polyethylene cold flow near the edge of the tibial plateau, and surgical malrotation of the components [181–185]. In addition, the dynamic effects of lift-off and subsequent impact loading and unusual patient kinematics further increase the potential for posteromedial failures [186]. The influence of surgical malrotation may be appreciated in Fig. 2.21a, b, which demonstrate dramatic changes in location, contact area, and peak stresses for a PCL preserving knee in a laboratory investigation [187].

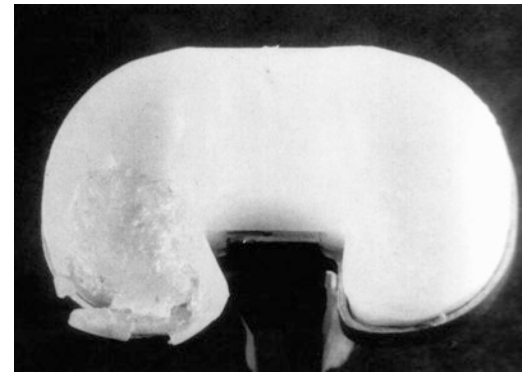

Fig. 2.20 UHMWPE tibial component retrieval showing deformation and wear in the posteromedial portion of the insert (from Swany MR, Scott RD. Posterior polyethylene wear in posterior cruciate ligament-retaining total knee arthroplasty: a case study. J Arthroplasty. 1993;8:439–846, with permission)

The continual emphasis on templating and the technological advances in computer-assisted and robotic navigation systems, intraoperative sensors as well as patient-specific instrumentation offer the promise that component malalignment may ultimately be minimized and patient satisfaction increased [188–194]. Eliminating the outliers in component placement will contribute to diminishing UHMWPE material damage in knee arthroplasty, however, the best technology to utilize in the achievement of this goal, is yet to be defined [195–197].

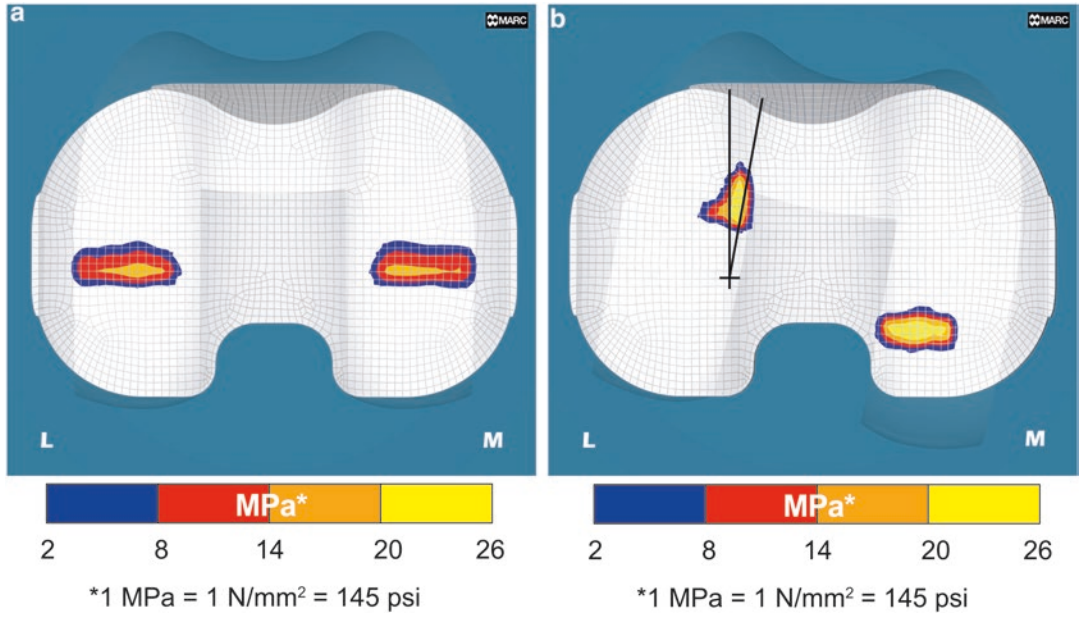

Fig. 2.21 The distribution of contact stresses at the toe-off position of walking gait for a left knee, PCL preserving design at (**a**) neutral rotation and (**b**) after the application of a 16 N-m external torque, simulating deliberate component malalignment. A dramatic increase in peak contact stresses is observed, which is contributory to component damage (from Morra EA, Postak PD, Plaxton NA, et al. The effects of external torque on polyethylene tibial insert damage patterns. Clin Orthop Relat Res. 2003;410:90–100, with permission)

The Enduring Promise

The previous remarks have attempted to define problems, solutions, and unknown performance factors of bearing materials currently utilized in total knee arthroplasty as they relate to the implant, the patient, and the surgery. What is important for the reader to appreciate is that this is a continually evolving experience, which will find advocacy or limitations, with the passage of in-vivo time.

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The Painful Total Knee Arthroplasty

3

Nigel M. Azer, Thomas S. Thornhill, and Abraham D. Kim

Total knee arthroplasty is one of the most successful operations performed, with 95–98% good to excellent results reported at 10–15 years [1–3]. Up to 20% of patients, however, report dissatisfaction with their outcomes due to persistent pain [4]. A thoughtful and systematic approach to these patients can help elucidate the mechanism of failure and develop an appropriate treatment paradigm. The results of exploration for debilitating pain of unknown etiology in a total knee replacement remain poor, with only 59% fair or poor results reported after surgery [5]. Thus, it is paramount to consider all potential causes of pain about a total knee arthroplasty before considering intervention. We shall consider the diagnosis and treatment of the painful total knee replacement from an anatomical perspective, stratified into intra-articular, periarticular, and extra-articular/systemic causes (Table 3.1).

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Intra-Articular

Infection

Infection *must* be considered in the evaluation of every patient with a painful total knee replacement. It is a most devastating and feared complication that often threatens the function of the joint, the preservation of the limb, and the health of the patient. Deep infections occur in 0.39–3.9% of primary total knee replacements and, on average, three times higher in revision cases [6, 7]. Body mass index ≥35, diabetes mellitus, male sex, American Society of Anesthesiologists (ASA) score ≥ 3, diagnosis of osteonecrosis, and a diagnosis of posttraumatic arthritis have been shown to increase the relative risk of deep infection [8]. The most common organisms are *Staphylococcus aureus* and *Staphylococcus epidermidis.* Methicillin- and vancomycin-resistant organisms have become increasingly prevalent and difficult to treat. The diagnosis of infection should start with a thorough history and physical examination. Persistent pain is the only consistent finding with infection, although a draining wound or history of wound problems or any erythema must also raise the suspicion for infection (Fig. 3.1) [9]. Serum studies including white

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Table 3.1 Differential diagnosis for painful total knee arthroplasty

Intra-articular
Infection
Patellofemoral
Resurfaced vs. unresurfaced patella
Maltracking
Fracture
Avascular necrosis
Loosening
Patellar fibrosis
Overstuffing joint
Wear
Osteolysis
Instability
Valgus-varus
Axial including midflexion
Malalignment
Arthrofibrosis
Recurrent hemarthrosis
Popliteus impingement
Loose bodies
Persistent synovitis
Overhanging component
Gout/CPPD
Periarticular
Neuroma
Fracture
Heterotopic ossification
Bursitis
Extra-articular
Complex regional pain syndrome
Hip/spine pathology
Vascular etiology
Unrealistic expectations
Psychological profile

blood cell count, erythrocyte sedimentation rate, and C-reactive protein are useful, particularly in following the course of treatment. In patients undergoing revision knee arthroplasty, erythrocyte sedimentation rate >30 mm/h has a 63% sensitivity and 55% specificity for infection, whereas C-reactive protein >10 mg/L had a 60% sensitivity and 63% specificity [10]. Bone scans are also helpful, with sensitivities and specificities of approximately 84% [11]. Aspiration of the knee should be performed, and the fluid should be analyzed for cell count with differential and culture. Cell count and neutrophil differential both below

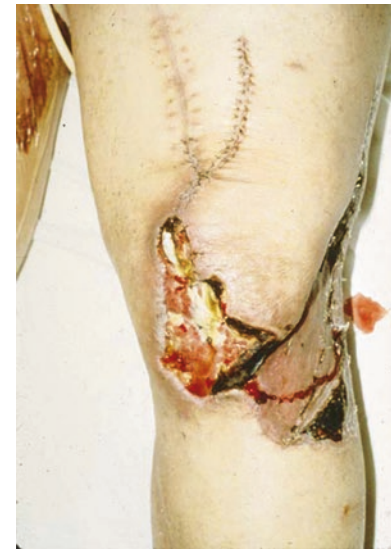


Fig. 3.1 Infection must always be excluded

a cutoff value of >1100 cells and >64%, respectively, yield a negative predictive value of 98.2% [12]. However, the existing diagnostic criteria for periprosthetic joint infection in the literature vary widely, and even when the results of the aspirate are combined with serum inflammatory markers, there remains a large variance in sensitivity (54%–100%) and specificity (39%–100%) [13]. Finally, tissue taken intraoperatively may be sent for frozen section pathological examination. Greater than ten polymorphonuclear leukocytes per high-power field is implicated in infection with a sensitivity of 84% and a specificity of 99% [14]. Hence, the diagnosis of infection must be made based on careful history and physical examination using all available data, rather than basing the diagnosis on one particular test.

Treatment of a total knee infection is often based on the timing and duration of the infection as well as the implicated organism and the status of patient's overall health. Decisions must then be made whether to attempt prosthesis retention, one-stage exchange, or two-stage exchange. A glycocalyx layer formed around the prosthesis may prevent antibiotic penetration to the prosthesis, rendering antibiotic treatment alone ineffective. Surgical treatment remains the mainstay. Aggressive treatment for *superficial* wound

infections is recommended, as many of these infections actually involve deeper tissues. Primary debridement within 10 days of symptom onset has a reported success rate of 56% in patients with low-grade organisms, but the success rate is diminished to 8% in the presence of *Staphylococcus aureus* infections [15]. Even lower rates of success are reported for using this approach for chronic infections. Arthroscopic debridement has only seen moderate success in the eradication of acute (within 4 weeks of surgery) infections, providing eradication in 52% of patients [16].

Prosthetic exchange is the primary mode of treatment when eradication of the infection is the goal. Single-stage exchange may be considered when an acute infection with a relatively low-virulence gram-positive infection is encountered in a competent host. One study showed 89.2% success with single-stage exchange in which there were gram-positive infection, absence of sinus tract, antibiotic-impregnated cement in the new prosthesis, and 12 weeks of adjuvant antibiotic treatment [16]. The most widely accepted approach, however, is the two-stage exchange in which aggressive irrigation, debridement, synovectomy, and prosthesis removal are performed, followed by reimplantation after a period of intravenous antibiotics. During the interim, a spacer of antibiotic-impregnated methyl methacrylate is often used. With this technique, overall infection-free survivorship was shown to be 85% at 5 years and 78% at 10 years [17]. Up to 97% eradication rates are reported with this technique [12]. The use of a PROSTALAC functional spacer made of antibiotic-laden cement with a small metal-on-polyethylene articulation is of interest because of its potential for enhanced function and maintenance of good alignment and stability of the knee. This facilitates second-stage procedures. Using this technique in a two-stage exchange with a mean 4-year follow-up, cure rates of 91% have been demonstrated [18]. Although this is promising, further outcome-based studies are necessary.

It is critical to always maintain a high index of suspicion for infection and to treat infections aggressively. All painful total knee replacements must be evaluated for the possibility of an indolent infection.

Patellofemoral Problems

Anterior knee pain is a relatively common complication after total knee arthroplasty and is often attributed to the patellofemoral articulation. It is, however, important to exclude other causes of anterior knee pain, such as peripatellar tendinitis, bursitis, Sinding-Larsen-Johansson disease, residual from Osgood-Schlatter disease, neuromas, and complex regional pain syndrome. The prevalence of anterior knee pain after total knee replacement has been reported as high as 25.1% in knees with unresurfaced patellae and 5.3% in resurfaced patellae [19]. Overall, approximately 10% of patients with total knee replacement may be expected to have anterior knee pain [20]. Analysis of 8530 total knee arthroplasties at an average follow-up of 7 years found an incidence of patellar component loosening of 4.8% and patellar fracture 5.2% [21]. Problems with the patellofemoral articulation in a total knee may be referable to malalignment and maltracking of the patella, osteonecrosis, fracture, loosening, component failure, tendon rupture, and peripatellar fibrosis. Evaluation of this pain must first identify whether the patella has been resurfaced, as unresurfaced patellae have been shown to have a significantly higher incidence of pain. The patella should be resurfaced in obese patients, patients with inflammatory arthritis, preoperative maltracking, significant loss of cartilage and exposed subchondral bone on the patella, gross surface irregularities, and those with significant anterior knee pain preoperatively [22]. When anterior knee pain is diagnosed in a patient with an unresurfaced patella, consideration to revision to a resurfaced patella must be given after other etiologies have been excluded. With newer three-lugged, cemented, all-polyethylene components available and careful attention to technical detail, the authors advocate patellar resurfacing in all total knee arthroplasties.

Patella maltracking is evident when the patella fails to maintain a congruent articulation with the trochlear groove of the femoral component (Fig. 3.2). Failure to achieve adequate tracking

Fig. 3.2 Merchant radiographs permit diagnosis of patellofemoral dislocation

may cause pain and crepitus as well as wear, failure of the patellar component, loosening, and fracture. Maltracking is most commonly caused by an imbalance of the extensor mechanism, especially with tightness of the lateral retinaculum and weakness of the vastus medialis. It may also be attributed to malposition of the femoral, tibial, or patellar components themselves. Placing the femoral component into excessive valgus increases the Q-angle and elicits an increase in the lateral force vector, tending to displace the patella laterally. Likewise, internal rotation or medial shift of the femoral component also displaces the patella laterally. Internal rotation of the tibia causes lateralization of the tibial tubercle, also detrimentally increasing the Q-angle. Lateral placement of the patellar component also contributes to maltracking. It is essential to perform diligent intraoperative assessment of patellar tracking to avoid patellofemoral instability. Alteration of the joint line itself may result in patella alta or infera, which could exacerbate abnormal tracking, impingement, or recurrent dislocation. An asymmetrical patellar resection may also contribute to patellar maltracking. The medial facet is thicker than the lateral facet. Thus, it is essential to resect the same amounts of bone from the medial and lateral facets to maintain this orientation. An oblique resection, taking too much bone off laterally, results in maltracking. The diagnosis of patellar instability can usually be made by physical examination, but may be evident on Merchant radiographic views. Computed tomography may provide essential information in determining the rotational alignment of the femoral and tibial components. Treatment of patellar subluxation begins with aggressive quadriceps rehabilitation, patellofemoral bracing, and avoidance of deep squatting exercises. Malrotated components should be revised as necessary. Additional soft tissue procedures, such as lateral release and medial advance as well as tibial tubercle osteotomy, may be added as indicated.

Fractures of the patella are generally rare, with reported rates ranging from 0.5 to 5.2% [21, 23, 24]. Fractures include occult stress fractures as well as intraoperative and postoperative fractures (Fig. 3.3). They may be associated with trauma, patellar subluxation, inadequate resection, excessive resection, thinning the patella to less than 15 mm, and operative disruption of the patellar blood supply, particularly when median parapatellar exposure is accompanied by lateral release [25]. Treatment typically depends on the competence of the extensor mechanism, the degree of displacement, and the integrity of prosthetic fixation. Nonoperative treatment has been successful in non-displaced fractures with a well-fixed component and a competent extensor mechanism. Surgical fixation with tension band and/or revision of the component is indicated in the more severe injuries. Patellectomy should be avoided whenever possible.

Loosening of the patellar component is rare, with a reported rate of 0.6–4.8% of cases [21, 26]. It is associated more with metal-backed designs, which have largely fallen out of favor. Risk factors for failure of the patellar component include excessive body weight, recalling that the patellofemoral articulation can bear up to seven times body weight during squatting, increased knee flexion, and a high level of activity. The diagnosis is usually apparent with symptoms of effusion and crepitus, which are more pronounced with activities that load the patellofemoral joint. Plain radiographs confirm the diagnosis, and treatment involves revision.

Patellar fibrosis or *patellar clunk syndrome* occurs when a fibrous nodule forms at the junction of the posterior aspect of the quadriceps tendon and the proximal pole of the patella (Fig. 3.4).

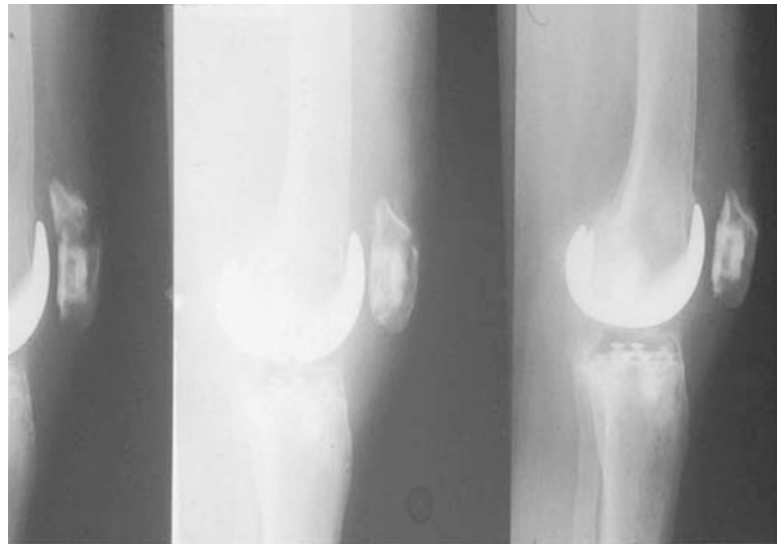


Fig. 3.3 Fractures of the patella are generally rare and include occult stress fractures as well as intraoperative and postoperative fractures

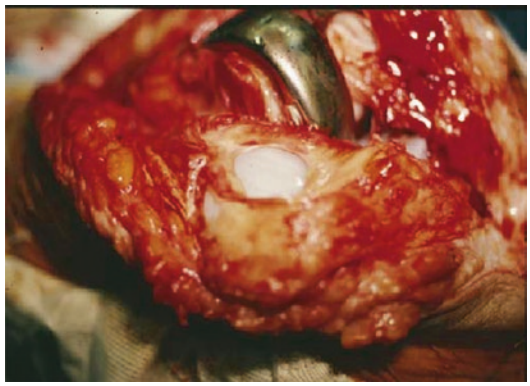


Fig. 3.4 Patellar fibrosis occurs when a fibrous nodule forms at the junction of the posterior aspect of the quadriceps tendon and proximal pole of the patella

With flexion, this nodule enters the intercondylar notch. Then, as the knee is extended from 30 to 60°, the fibrotic lesion *clunks* out of the notch. This syndrome is classically associated with posterior stabilized components but has been reported in cruciate-retaining designs, as well as in cases in which the patella remains unresurfaced [27, 28]. Extensive excision of the synovium in the suprapatellar region may prevent this. Treatment involves debridement of the fibrotic nodule, either by arthroscopy or arthrotomy. If the clunk involves a malpositioned patella or inappropriately sized femoral component, revision is recommended. In one series, arthroscopic debridement yielded reliable improvement in patient-reported knee pain and crepitus as well as Knee Society score [29]. A similar entity, synovial entrapment, is described in which hypertrophic synovium causes pain during extension from 90° of flexion. Patients typically had pain when arising from a chair or climbing stairs but had no symptoms with level walking. Treatment with synovectomy resulted in relief of symptoms in all patients studied [30].

A number of entities may cause anterior knee pain in patients with total knee replacements. A systematic approach and inclusive differential diagnosis can yield the appropriate diagnosis and guide treatment.

Osteolysis

Polyethylene wear in total knee arthroplasty continues to affect the longevity of modern total knee replacements. Wear and aseptic loosening have been shown to be the second most common modes of failure requiring revision surgery in the United States, accounting for up to 16.1% of revision operations [31]. From a basic science standpoint, osteolysis is the granulomatous response to polyethylene, polymethyl methacrylate, and metal debris, which are formed by both the articulating and nonarticulating (undersurface) surfaces of

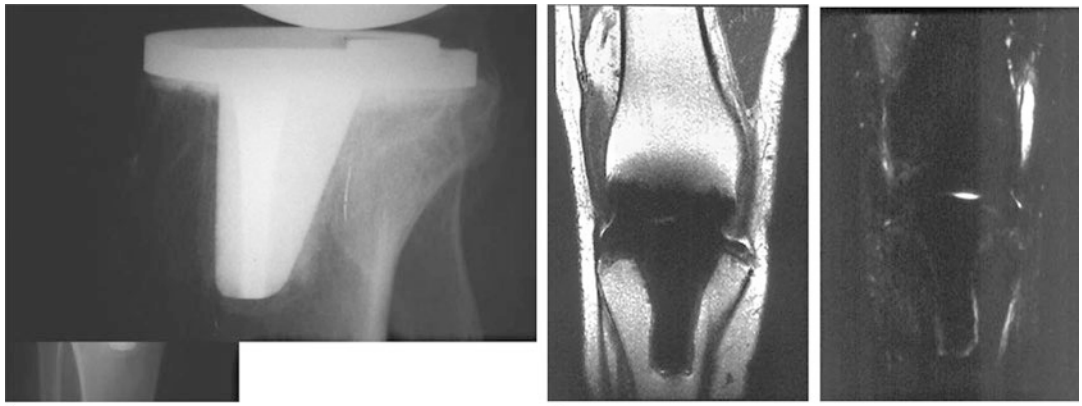


Fig. 3.5 Loose component. (**a**) Identification of a lytic osseous defect, absence of bone trabeculae, and geographic demarcation make the diagnosis radiographically. (**b**) Additional tests such as magnetic resonance imaging and bone scans may also facilitate the diagnosis of loose components

the prosthetic knee. Delamination, adhesion, and abrasion cause the liberation of loose particles that contribute to osteolysis. Osteolysis was implicated in 2% of early and 9% of late failures of total knee arthroplasties requiring revision surgery [32]. Risk factors include incongruent articulations, poor tibial locking mechanisms, thin polyethylene, sterilization of polyethylene with gamma irradiation in air, fixation screws in the tibial base plate, and an extended shelf life of the polyethylene implants. Most patients remain asymptomatic. However, some patients have a boggy synovitis and mild to moderate pain with activity. A triad of effusion, pain, and change in coronal alignment, usually into varus, is strongly suggestive of accelerated polyethylene wear. Identification of a lytic osseous defect, absence of bone trabeculae, and geographic demarcation makes the diagnosis radiographically (Fig. 3.5). The presence of the components may obscure the lesions on radiography, particularly as they are most commonly found within 2 mm of the tibial component and in the posterior femoral condyles. If osteolysis is suspected, computed tomography is a useful tool to evaluate the size of the osteolytic lesion [33]. Nuclear medicine studies may also demonstrate increased uptake around loose components. Osteolysis must be distinguished from radiolucent lines that are a common finding in radiographic surveillance of total knees. Lysis requires a complete radiolucent line of greater than 2 mm in length. Smaller lines are of unknown significance and may be followed clinically. Ranawat et al. noted radiolucent lines in 72% of the tibiae, 54% of the femurs, and 33% of patellae [3]. Not all of these represented osteolysis. Treatment of these lesions primarily depends on whether the osteolysis is associated with loose prosthetic components. It is essential to review serial radiographs to determine if radiolucent lines are progressive. Well-fixed components with lytic lesions may be treated with exchange of the polyethylene insert and bone grafting of the lesions. However, isolated tibial insert exchange resulted in a 63.5% cumulative survival rate at 5.5 years [34]. They recommended that limited revision of the polyethylene should be avoided if severe delamination is present, if there is significant undersurface wear of the polyethylene suggesting an inadequate locking mechanism, and if there is early failure within 10 years of the index operation. Revision of loose components with bone graft is indicated for lysis associated with loose components. It is important to have a full complement of revision instruments available with stems, wedges, and allograft when performing these revisions, as radiographs not only underestimate lesion size but do not take into account bone loss with explanation of the loose components (Fig. 3.6).

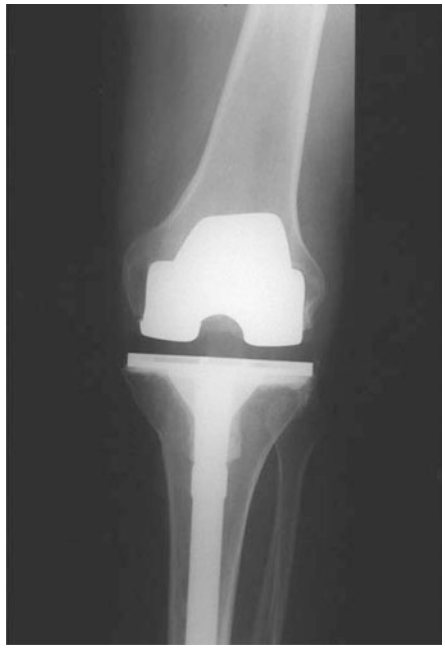


Fig. 3.6 Revision for loose components. Radiographs often underestimate lesion size and do not take into account bone loss with explanation of the loose components

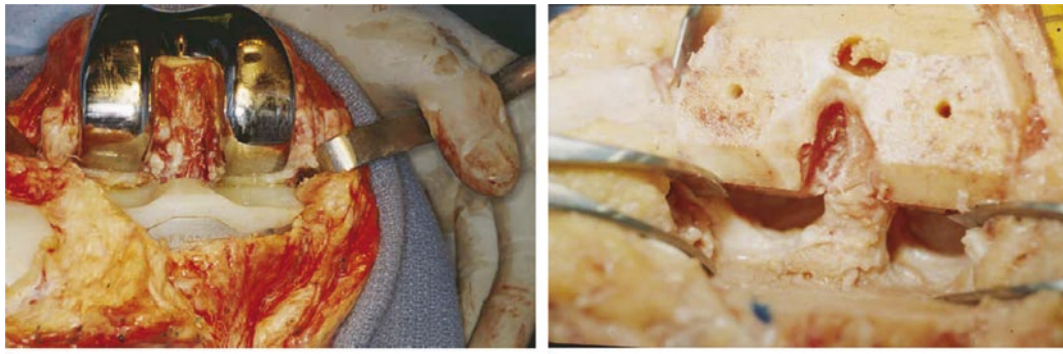
Instability

Symptomatic axial instability of a total knee arthroplasty, including valgus-varus and flexion-extension instability, is a potential cause for pain and disability following total knee replacement. It occurs in 1–2% of patients and may be present in either posterior stabilized or cruciate-retaining knees. Overall, instability accounts for 10–20% of all total knee revisions, following only infection and aseptic loosening in prevalence [35]. Instability may be caused by trauma, ligamentous stretch, inadequate balance at the time of surgery, or a systemic disorder such as Ehlers-Danlos disease.

Patients with mediolateral, valgus-varus instability often present with pain, buckling, giving way, and progressive weight-bearing deformity. This instability may be the result of traumatic injury but is often the result of failure to achieve appropriate soft tissue balance at the time of surgery. The diagnosis can usually be made by history and physical examination and may be confirmed by stress radiographs or video fluoroscopy. Using a systematic approach and meticulous technique, good results may be achieved in knees with severe varus or valgus alignment. Prevention is the best treatment. Revision to correct soft tissue imbalance or revision to a higher degree of prosthetic constraint with stems and wedges may be necessary. Kim and Kim reported reproducible results of revision surgery for patients with valgus-varus constrained implants, with a 96% 10-year survival rate [36].

Failure to balance the flexion and extension gaps properly may lead to symptomatic instability in the sagittal plane. This entity was first recognized and reported with the obvious acute dislocation of a posterior stabilized prosthesis. Subsequently this has been reported to occur in 1–2% of posterior stabilized knees [37]. Cam-post design, large lateral soft tissue release in valgus knees, and above average range of motion have all been implicated as risk factors for the dislocation of a posterior stabilized knee. The diagnosis is usually obvious, and treatment involves reduction and revision to balance the flexion-extension gaps or increase constraint if necessary.

Flexion instability in posterior cruciate-retaining knees is also evident. However, this entity is much more subtle than its counterpart in posterior stabilized knees (Fig. 3.7a). Patients typically present with anterior knee pain, a sense of instability, recurrent effusions, soft tissue tenderness of the pes tendons, and posterior instability, evidenced by a positive posterior drawer sign or sag. Symptoms may occur early in the postoperative period if there is inadequate flexion-extension or posterior cruciate ligament (PCL) balance. Late PCL rupture or attenuation may give a delayed presentation of symptoms. The diagnosis may be made by careful history and physical examination. Medial and lateral translocation of the polyethylene eminence under the medial or lateral femoral condyle performed passively with the knee flexed is a hallmark of flexion instability. Performing a posterior drawer test and examining for flexion instability should be routine in evaluating every painful total knee. A common cause for this pattern of imbalance



A B

Fig. 3.7 (**a**) Flexion instability in posterior cruciate-retaining knees. (**b**) The revision operation balances the flexion-extension gaps in conjunction with revision to a posterior stabilized knee

occurs when treating patients with residual flexion contractures. Proper balance in flexion but excess tightness in extension may entice the placement of a thinner polyethylene liner or further tibial resection. Although this may correct the flexion contracture, it is a setup for symptomatic flexion instability. A better remedy is to perform a posterior capsular release or resect more distal femur. The treatment of flexion instability may be difficult because it often involves considering revision of well-aligned, well-fixed components with the resultant bone loss and potential elevation of the joint line. There have been several reports on the results of treatment by isolated revision to a thicker polyethylene insert. Overall the results have been marginal. Seventy-one percent success with polyethylene liner exchange alone has been reported, with this technique being favored if the etiology was primarily soft tissue imbalance. If incompetent ligaments were identified, revision to more highly constrained components was recommended [38]. Eighty-six percent success is reported when revising to a more constrained component. A revision operation that focuses on balancing the flexion-extension gaps in conjunction with revision to a posterior stabilized knee is the most reliable treatment for symptomatic flexion instability after cruciate-retaining prosthesis (Fig. 3.7b) [39]. It is essential to always include valgus-varus and flexion-extension instability in the differential diagnosis of the painful total knee.

Arthrofibrosis

Most patients achieve a satisfactory range of motion after total knee replacement and are able to perform their activities of daily living without limitation. Typically, 63° is needed for the swing phase of gait, 83° for stair ascent, 84° for stair descent, at least 93° to rise from a chair, and 106° to fasten a shoelace [40]. However, postoperative stiffness occurs, and patients may not achieve these degrees of motion. This expectedly causes significant functional limitation and patient dissatisfaction. Stiffness occurs in both posterior stabilized and posterior cruciate-retaining implant designs. The etiology is largely unknown but may be biologic, related to an underlying collagen disorder characterized by rapid fibrous metaplasia of scar tissue, or mechanical, related to technical errors in operative technique, such as failure to properly balance the flexion and extension gaps or release the posterior capsule and remove posterior osteophytes when present. Actin and myosin fibrils have been identified histologically in arthrofibrotic tissue and may also be implicated. Risk factors for limited postoperative range of motion include limited preoperative range of motion, contractures, obesity in which posterior soft tissue impingement limits flexion, excessive intra-articular scar from previous operations, and poor patient compliance with postoperative rehabilitation protocols (Fig. 3.8). Excessive tension or laxity in the PCL may also

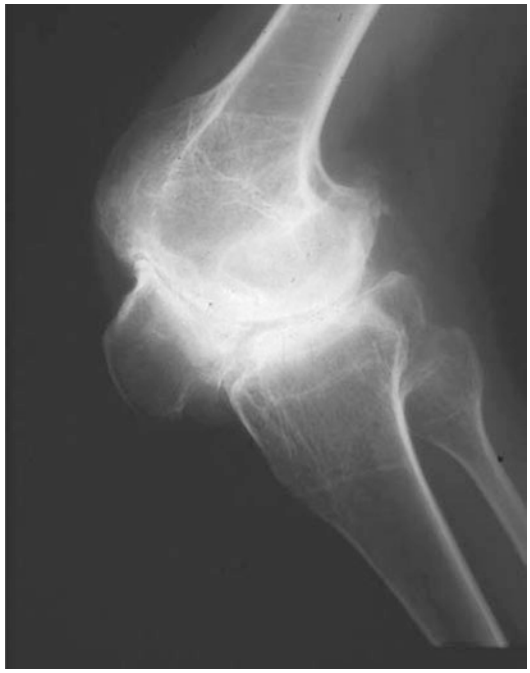


Fig. 3.8 Arthrofibrosis and patella infera limit range of motion postoperatively

result in limited motion. A lax PCL allows paradoxical anterior femoral translation with increased knee flexion, resulting in loss of flexion. It is important to recognize that arthrofibrosis may be the hallmark of other knee pathology such as infection, component loosening, periprosthetic fracture, complex regional pain syndrome, or heterotopic ossification. Thus, these must be considered in the evaluation of a stiff knee. Furthermore, it is particularly important to accurately document with a goniometer preoperative and intraoperative range of motion so that the patient, surgeon, and physical therapist appreciate realistic motion goals before embarking on an aggressive campaign to restore motion. Moreover, as shorter hospital stays mandate the majority of physical therapy as outpatient, the surgeon must convey to the therapist the patient's preoperative, intraoperative, and expected goals for postoperative motion.

Treatment of a stiff knee initially involves aggressive physiotherapy and closed manipulation under anesthesia. This is particularly advantageous in the first 3–6 weeks postoperatively when the scar tissue has not matured. After 8 weeks, the scar tends to mature, and the risk of supracondylar femoral fracture increases. Although continuous passive motion (CPM) is controversial, particularly when range of motion at 1 year postoperatively is considered, it is recommended after manipulation. Barring success with this, surgical intervention with arthroscopic or open arthrolysis is considered. Arthroscopy has been shown to provide gains in range of motion in 43% of patients treated for arthrofibrosis following total knee replacement [41]. Open procedures have the benefit of allowing radical scar excision, ligament rebalancing, and exchange of the polyethylene insert if necessary. Should these fail, revision arthroplasty with definitive reestablishment of flexion-extension gaps, ligament balance, and possibly a higher degree of prosthetic constraint may be necessary. Revision has shown satisfactory results in terms of pain and range of motion in several small studies [42, 43].

Recurrent Hemarthrosis

Recurrent hemarthrosis is an uncommon but significantly disabling cause of pain following total knee arthroplasty. Kindsfater and Scott reviewed 30 cases of patients who experienced painful recurrent hemarthrosis after total knee replacement [44]. The patients developed their first hemarthrosis an average of 2 years after their replacements. Most experienced multiple episodes of bleeding. Approximately one-third of the patients had resolution of symptoms with aspiration, rest, ice, and elevation followed by gradual return to activities. Of the patients who underwent surgical exploration, only 43% had an identifiable etiology for their bleeding. Proliferative synovium entrapped between the prosthetic articulations and a vascular leash was both implicated and treated. Usually an associated soft tissue laxity necessitates use of a more conforming or a thicker polyethylene insert. With synovectomy, 14 of 15 no longer bled. Thus, hemarthrosis must be considered in the differential diagnosis of the painful total knee.

Most resolve with aspiration, but some require open synovectomy that provides reliable relief of symptoms.

Popliteus Impingement

The popliteus tendon may subluxate anteriorly or posteriorly over a lateral femoral condylar osteophyte or an overhanging edge of the posterior femoral condylar prosthesis, causing a painful snap or even audible *popping* sensation in the posterolateral corner of the knee after total knee arthroplasty. Such symptomatic snapping is reported in 0.2% of total knee replacements [45]. Patients with valgus deformity and female patients, who require relatively larger components in the mediolateral dimension to compensate for their larger AP dimension, appear to be at increased risk for this. The diagnosis can only be made by placing the knee through a range of motion with the capsule closed. Treatment includes releasing the popliteus or removing the offending osteophytes at the time of the total knee replacement. Barnes and Scott diagnosed and intraoperatively addressed this in 2.7% of 300 consecutive knees [46]. Successful treatment with arthroscopic release has been reported for those symptomatic cases, which present after surgery.

Miscellaneous

Other significant intra-articular causes of a painful total knee replacement include the presence of loose bodies, loose polymethyl methacrylate cement, overhanging components, or incomplete seating of modular inserts. Persistent synovitis and gout or calcium pyrophosphate deposition disease (CPPD) may also present as a painful total knee replacement. Loose bodies and cement particles may be avoided by meticulous inspection and irrigation of the joint after implantation. It is particularly important to examine the posterior aspects of the knee for the presence of loose bodies and cement particles after polymerization of the bone cement. Many loose particles in the knee are asymptomatic because the knee is self-cleansing. Most particles tend to migrate away from the prosthetic articulations. Nevertheless, some cause persistent effusion, pain, and synovitis. Patients may even report a sensation of something moving in their knees. The diagnosis is made by history and physical examination, although some loose bodies may be apparent on high-quality plain radiographs. Treatment involves their removal, either arthroscopically or by arthrotomy. Overhanging components, particularly those overhanging anteriorly or impinging the popliteus, may also be painful. Such cases present with pain, synovitis, and recurrent effusion. History, physical examination, and radiographs revealing component overhang make the diagnosis. A localized anesthetic injection may be diagnostic and therapeutic. Treatment in the most severe cases involves removal of osteophytes or revision of the component.

Periarticular Causes of Pain

Neuroma

Extensive anatomical mapping of the cutaneous innervation of the skin and soft tissues around the knee has provided significant insight into the presence of symptomatic neuromas as an etiology of pain about the knee. While the infrapatellar branch of the saphenous nerve has a distribution across the tibial tuberosity, and the medial cutaneous nerve of the thigh has a distribution across the patella, the inferior cutaneous nerve of the thigh, the proximal tibiofibular nerve, the medial retinacular nerve, the common peroneal nerve, and the lateral reticular nerve all also have specific, known cutaneous distributions about the knee [47]. This knowledge, combined with detailed mapping of the patient's pain, may provide a diagnosis for previously enigmatic complaints. When suspected, neuromas should initially be treated with physical modalities such as moist heat, massage, topical steroid-containing creams, iontophoresis, and neuropathic pain medications. Diagnosis can be confirmed by positive Tinel's sign and by selective anesthetic

injections. Dellon et al. studied the results of 70 patients treated with selective surgical denervation of persistent neuroma pain about the knee. Having excluded other causes for knee pain, such as infection, they considered this procedure for patients who had persistent pain for at least 6 months and had no effusion or obvious mechanical cause for pain. Eighty-six percent of the patients were satisfied and demonstrated relief of their pain as well as significant improvement in their Knee Society scores, which increased from a mean of 51 to mean of 82 [48]. Pathological confirmation of nerve resection correlated with good results.

Heterotopic Ossification

Heterotopic ossification (HO) is the formation of mature lamellar bone in the soft tissues (Fig. 3.9). Reports suggest that the incidence of heterotopic ossification after total knee arthroplasty ranges from 15 [49] to 39% [50]. Although most cases are asymptomatic, pain and limited range of motion have been reported. Barrack et al. also demonstrated lower functional and Knee Society scores in patients with heterotopic ossification [51]. HO in the knee usually occurs in the quadriceps expansion. Predisposing factors include a previous history of heterotopic ossification, trauma, prior operations, postoperative manipulation, osteoarthritis, and immobilization, as well as intraoperative risks including excessive trauma to the muscles, periosteal exposure of the femur, notching of the femur, and hematoma formation. Infection is also a significant risk factor for HO. Prophylaxis against HO may be considered in primary or revision total knee arthroplasty if there are considerable risk factors. Treatment with a single fraction of 7-Gy radiation to the knee is effective prophylaxis with minimal documented morbidity [52].

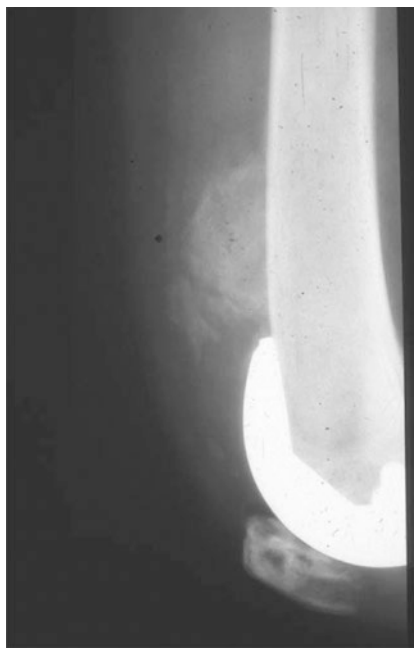


Fig. 3.9 The formation of mature lamellar bone in the soft tissues is shown in heterotopic ossification

Bursitis

Pes anserine bursitis and patellar tendinitis may also be responsible for a painful total knee arthroplasty. Periarticular pain located approximately 5 cm below the knee joint on the anterior and medial portion of the tibia may indicate pes bursitis. The diagnosis is usually made by history and physical examination. Selective anesthetic injection including corticosteroids may also prove diagnostic and therapeutic. Patellar tendinitis presents as localized pain along the patellar tendon and tibial tubercle. Scrutiny of patella tracking and the patellofemoral articulation is necessary. Stress fractures must be excluded. Isolated patellar tendinitis responds to physical therapy, stressing hamstring stretching, bracing, and vastus medialis strengthening.

Extra-Articular Pain

Complex Regional Pain Syndromes

Complex regional pain syndrome (CRPS) has been reported following total knee arthroplasty with a prevalence of 0.8% [53]. Although this syndrome is well described for the upper extremity, knowledge of its presentation in the knee and,

in particular, total knee arthroplasty is evolving. Intense, prolonged pain out of proportion to physical findings, vasomotor disturbance, delayed functional recovery, and various trophic changes should raise suspicion of CRPS. Typically, arthroplasty patients have an uncomplicated postoperative course but rapidly plateau and do not achieve their expected recovery. The presence of infection or other pathological process in the knee must be excluded. The prognosis of CRPS in the knee depends on early diagnosis and treatment. Institution of treatment within 6 months is the most favorable prognostic indicator in the treatment of CRPS [54]. Initially, mobilization and physical therapy should be stressed, followed closely by a lumbar sympathetic block if rapid improvement does not ensue. A good response to the block, characterized by 75% relief of symptoms, is the sine qua non of the diagnosis. Unfortunately, only 64% of the patients achieved some relief with sympathetic blockade. None achieved complete relief of symptoms, and most patients considered their knee replacements a failure. Patients who have had multiple operations on their knees and experience significant debilitating pain before their arthroplasties are at increased risk. Given the severity of this pathologically exaggerated physiological response, total knee arthroplasty should be approached cautiously in patients who may be at risk, and when the diagnosis is questioned, early, aggressive intervention should ensue.

Referred Pain

Pain may be referred to the knee from a number of sources including ipsilateral hip, lumbar spine, or vascular pathology. These sources of referred pain may be readily identified by complete and thoughtful history and physical examination. Ipsilateral hip pathology presents as knee pain by irritation of the continuation of the branch of the obturator nerve to the adductor magnus (Fig. 3.10). Thus, the presence of arthrosis or fracture of the ipsilateral hip must be explored. Selective intra-articular injections may help distinguish the primary source of pain if both joints

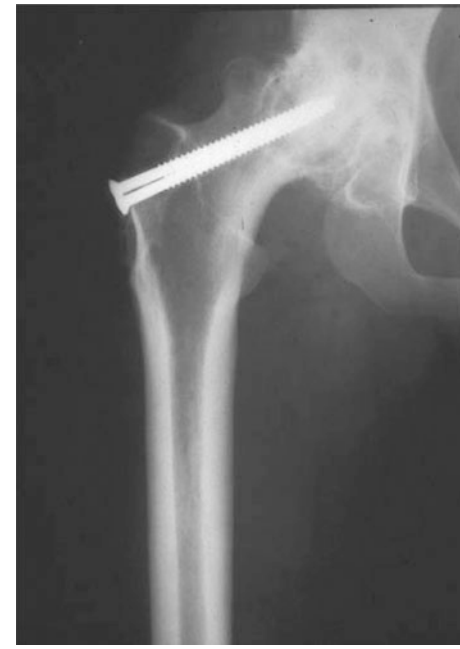


Fig. 3.10 Ipsilateral hip pathology presents as knee pain by irritation of the continuation of the branch of the obturator nerve to the adductor magnus

are arthritic. It is essential to exclude the possibility of such referred pain before performing a total knee replacement. Degeneration or spinal stenosis of the lumbar spine may also present as pain in the knee, particularly when affecting the L3/4 level. Careful history and neurological examination provide the diagnosis. CT myelography or MRI may confirm the clinical diagnosis and guide treatment accordingly. Vascular insufficiency and claudication and deep vein thrombosis may also present as pain in the knee. Once again, a careful history and physical examination make the diagnosis and permit appropriate referral. Moreover, depression, anxiety, and anger may all detrimentally affect a patient's expectations and results from a total knee replacement. Limited objective knee pathology before arthroplasty may also correlate with unsatisfactory results. Good communication between the patient and the surgeon helps clarify expectations and provides realistic goals for the patient. It is essential to take into account the patient's overall psychological and physical condition and to determine the role that the prosthetic knee plays

in the patient's life. Often, counseling and pharmacological management provide important adjunctive treatment for the patient's knee pain.

Summary

Although total knee arthroplasty predictably provides relief of pain and good functional results, a number of potential etiologies exist for a painful total knee replacement. It is paramount to exclude infection whenever evaluating a painful total knee. Results of treatment will not be satisfactory if the mechanism of pain or knee failure is not understood. There is no role for exploratory revision surgery. A complete history, physical examination, and thoughtful differential diagnosis help make the diagnosis and develop an effective treatment paradigm.

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Imaging of Total Knee Arthroplasty

4

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Total knee arthroplasty (TKA) is a commonly employed treatment for knee osteoarthritis that cannot be managed successfully with conservative measures. Good and excellent outcomes in greater than 90% of patients have been reported from many independent centers at long-term follow-up, and long-term prosthesis survival rates are greater than 90% [1]. Although surgical techniques and implant designs continue to improve, the potential for complications will remain. While traditionally implanted in an elderly population, TKAs are now increasingly used in younger patients, many under 60 years of age [2, 3]. The number of patients requiring imaging evaluation of their TKAs will likely increase. Moreover, the placement of TKAs in younger individuals and longer life expectancies have resulted in an increase in the incidence of revision TKA [4].

Diagnostic imaging is vitally important in the diagnosis and management of TKA complications. Infection and instability are the most common early complications (occurring within the first 2 years of transplant life). In a recently published study from Germany, slightly greater than two thirds of revisions were performed for aseptic causes with the remainder due to infection [5]. Loosening and infection are the most common complications of TKA. Other conditions such as component malposition, polyethylene wear, particle disease/osteolysis, periprosthetic fractures, bursitis, and tendon pathology may also result in hardware failure and/or pain. Conventional radiography can detect many potential complications [6]. Although metal hardware presents special challenges for advanced imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI), techniques have been developed in recent years to reduce artifacts and allow both modalities to make important contributions in the evaluation of TKA. Nuclear medicine studies may also provide valuable information. Differentiating between loosening and infection can be a diagnostic challenge. Dual and triple isotope scintigraphy can help reconcile this dilemma [7]. FDG PET imaging has shown promise in the evaluation of patients with orthopaedic hardware [8, 9]. The following discussion of total knee arthroplasty imaging reviews available imaging techniques and then describes imaging findings for each TKA complications.

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Techniques and Modalities

Many imaging techniques have been employed for the evaluation of the symptomatic TKA, including conventional radiography, fluoroscopy with or without arthrography, and several types of nuclear medicine studies, ultrasound, CT, and MRI. Given the broad spectrum of possible complications, there is no ideal advanced imaging modality for the evaluation of a symptomatic TKA. Each modality has significant limitations. Thus, several modalities are often used together to increase overall sensitivity and specificity.

Radiography

Conventional radiography is the first-line imaging study in the evaluation of the symptomatic TKA. The American College of Radiology Appropriateness Criteria for the Evaluation of the Patient with Painful Hip or Knee Arthroplasty gives conventional radiographs (with comparison to prior studies) the highest possible appropriateness rating [10]. Radiographs offer an informative, quick, and relatively inexpensive method of evaluation of both the prosthetic components and the native bone. Radiographs are limited, however, by their two-dimensional nature and their inability to depict most soft tissue pathologies.

A portable anteroposterior (AP) radiograph of the knee may be obtained in the recovery room immediately after surgery. AP supine and/or standing, lateral, and tangential patellar views are obtained routinely before the patient is discharged or within 3 months of the surgery. This series serves as a baseline for future comparison. Weight-bearing/standing views are necessary to assess true osseous alignment. Some authors stress the importance of using long films that include the femoral head and ankle to accurately measure the lower extremity's axial alignment. Others have found the differences in measurements between long and short films to be insignificant. The use of long films is probably most important in patients who have bowed tibias or femurs [11]. Some investigators advocate the use of paired oblique radiographs in the follow-up of TKA [12].

The ability to accurately measure TKA alignment is compromised due to variability in limb positioning. Limb rotation and knee flexion have a significant effect on measured values of TKA anatomic alignment. External rotation simulates decreased tibiofemoral valgus, while internal rotation simulates increased tibiofemoral valgus. Knee flexion significantly increases apparent anatomic valgus with progressive internal rotation, but does not have an effect when the knee is externally rotated. The apparent tibial axis also varies significantly with internal and external rotation, but is not affected by flexion [11].

Fluoroscopy

Fluoroscopic assessment is a relatively quick and inexpensive means for TKA. Fluoroscopy allows real-time dynamic assessment of the TKA, helps guide aspiration, and allows conventional arthrography to be performed. Since very small degrees of obliquity can obscure radiolucent lines adjacent to prostheses, fluoroscopy may guide positioning for radiographs so each interface of the TKA is well visualized [6]. As with conventional radiography, fluoroscopy is limited in its ability to depict soft tissue pathology.

Knee Aspiration and Arthrography

Joint aspiration is an important step in the evaluation of a painful TKA. At our institution, over the past decade, we have observed a decrease in referrals for arthrography to be performed at the time of aspiration. This, in part, is likely due to the increased use of CT in the evaluation of the painful TKA. The procedure for aspiration and arthrography of the TKA is relatively straightforward. We prefer a medial parapatellar approach due to the relatively vertical orientation and shorter length of the medial patellar facet. The anterior aspect of the knee is prepped and draped in the standard sterile fashion. The skin and subcutaneous tissues over the medial aspect of the patellofemoral joint are anesthetized with a few milliliters of an 80:20 mixture of 1% lidocaine and 8.4% sodium bicarbonate. A 1.5-in. needle (typically 20 or 21 gauge) is advanced into the

superomedial aspect of the patellofemoral joint space. A superolateral approach is preferred by some, though the lateral facet is longer than the medial and is oriented more parallel to the femur. In all cases, fluid is aspirated and is sent to the laboratory for aerobic and anaerobic cultures and sensitivities and Gram stain. If the sample volume is sufficient, fluid is also submitted for cell count with differential protein and glucose content and, occasionally, crystal analysis.

Knees with joint prostheses generally contain enough fluid that aspiration is not difficult. However, if fluid cannot be readily aspirated, contrast material may be injected into the joint and reaspirated. To avoid false-negative culture results, it is important that contrast without bacteriostatic properties be used. Some authors advocate using a wash with non-bacteriostatic sterile saline in the case of a dry tap [13].

If desired, arthrography may be performed at the time of aspiration. A small test injection of 1–2 mL of iodinated contrast material is performed under fluoroscopy to confirm intra-articular positioning. (The contrast should flow freely away from the needle, rather than pooling at the tip.) As the knee joint is voluminous compared with other joints, at least 20 mL of contrast should be injected. The knee should then be moved passively through a range of motion to ensure contrast material spreads throughout all joint recesses. During this manipulation, the operator should watch for abnormal motion of the prosthetic components within the native bone. An AP image of the knee should be obtained with the tibial tray in tangent, and a lateral image should be obtained with the prosthesis in profile. The patient is then asked to walk for several minutes to increase the likelihood of contrast extending around the prosthetic components into areas of potential loosening. AP, lateral, and patellar conventional radiographs are then performed.

Nuclear Medicine

Scintigraphic evaluation of orthopaedic implants is commonly performed to investigate suspected postoperative complications, especially loosening and infection. Nuclear medicine studies reflect physiologic changes rather than anatomic changes. They are generally more sensitive than conventional radiographs. The presence of orthopaedic hardware is not a limitation as the prosthesis will appear as a photopenic region without artifact to degrade neighboring structures as in CT and MRI.

Bone scans are performed with intravenous injection of technetium (Tc) 99 m–labeled diphosphonate. In the setting of orthopaedic hardware such as a TKA, triple-phase bone scans yield higher specificity than single-phase exams. In phase 1, known as the *blood-flow* phase, images are acquired every 2–5 s for the first 60 s after bolus injection of the radiotracer. This phase displays the vascular delivery of radiotracer to the area of the TKA. In phase 2, called the *blood-pool* phase, an image is obtained over a 5-min period (or for a certain number of counts, usually 200,000 to 300,000 counts), starting 1 min after the injection. This phase depicts a combination of vascular flow and tissue extraction and distribution. In both the blood-flow and blood-pool phases, both knees should always be imaged, so that the symptomatic and asymptomatic sides can be compared. In the third (delayed) phase, images are acquired 2–4 h after injection. This phase depicts the retention of radiotracer in bone due to chemisorption, reflecting osteoblastic activity. Osteoblasts assemble labeled diphosphonates into the hydration shell of hydroxyapatite crystals as they are formed and modified [14]. Thus, any cause of accelerated new bone formation may result in increased periprosthetic uptake in the delayed phase.

The white blood cell (WBC) scan theoretically increases specificity for infection in that white blood cells should only accumulate at sites of inflammation caused by infection. Thus, WBC scans are often performed after a positive triple-phase bone scan to rule out infection as the cause of the abnormal uptake around the TKA on bone scan. WBC scans are difficult to perform, however, as they involve a tedious, expensive radiopharmaceutical preparation process, a long delay time before imaging if In-111 is used (18–24 h), and poor count rates that result in low-resolution images. To counteract the low resolution of planar imaging on WBC scintigraphy, some institu-

tions add single-photon emission computed tomography (SPECT) with fusion CT imaging to their WBC scanning protocol to increase sensitivity and specificity [15]. Conceptually analogous to radiography and CT imaging, SPECT imaging rotates multiple gamma cameras around the patient in order to gather a cross-sectional image similar to a CT. This data can be reformatted in three planes. This is often used in conjunction with a fusion CT image for localization, similar to a PET/CT. White blood cells can be labeled with either In-111 or Tc-99 m HMPAO. Tc-99 m HMPAO is advantageous as it is less expensive and allows more rapid imaging (2 h following injection).

Interpretation of WBC scans is complicated by the fact that WBCs also accumulate in reticuloendothelial cells of normal hematopoietic marrow. In adults, hematopoietic marrow is usually not present to any significant degree around the knees. However, trauma and joint replacement surgery can prompt conversion of fatty marrow to hematopoietic marrow, which results in increased "abnormal" uptake on WBC scans. In order to deal with this problem, a Tc-99 m sulfur colloid marrow study may be performed immediately following the WBC scan. The Tc-99 m sulfur colloid is taken up in normal hematopoietic marrow. Thus, uptake of labeled WBCs around the TKA due to infection can be distinguished from uptake in normal hematopoietic marrow. The Tc-99 m sulfur colloid study adds little expense or time, with images obtained only 10 min after injection. The American College of Radiology Appropriateness Criteria for evaluation of the painful TKA gives combined WBC and sulfur colloid scanning the highest appropriateness rating in the setting of suspected TKA infection and negative or inconclusive cultures from joint aspirate [10].

Researchers have found the combination of SPECT and CT is useful for diagnosis because both mechanical and metabolic aspects of the painful TKA are evaluated in concert. One institution demonstrated that SPECT CT proved to be a useful tool for evaluating the painful knee prosthesis in 85.5% of cases, especially in differentiating mechanical loosening from other causes of pain such as infection. Infection demonstrated uptake more diffusely in the joint space, whereas loosening displayed uptake predominantly at the bone/metal interface [15].

Recent data show that positron emission tomography (PET) with fluorine 18 is useful for detecting musculoskeletal infections. A recent study shows equivalent sensitivity and specificity of FDG PET compared with WBC/sulfur colloid imaging in the detection of prosthetic hip and knee infection. Moreover, FDG PET can be performed more rapidly than WBC/sulfur colloid scanning due to more efficient handling of the pharmaceutical [16].

Ultrasound

Ultrasound (US) has the advantage over radiographs, fluoroscopy, and scintigraphy of being able to directly evaluate soft tissue structures. Additionally, artifacts caused by metallic hardware are less pronounced than on CT and MRI images and are generally limited to the area deep to the hardware producing the artifact. US is also advantageous in that it allows real-time dynamic evaluation of moving structures such as muscles, tendons, and joints. Color and power Doppler sonography allows evaluation of tissue vascularity, particularly in the setting of joint inflammation [17].

The development of high-frequency transducers allows for detailed evaluation of tendons, ligaments, and muscles. Selecting the proper transducer is important to optimize resolution while enabling sufficient tissue depth penetration. Lower-frequency transducers have poorer resolution but allow for scanning of deeper tissues. Higher-frequency transducers have better resolution but poorer penetration and thus are limited to evaluation of more superficial tissues. To illustrate this point, in the setting of a TKA, a high-frequency transducer (12 MHz or greater) should be used to evaluate the patellar or quadriceps tendons, while a lower-frequency transducer (9 MHz or lower) may be required to search for fluid collections deep in the calf or thigh, especially in a large patient [18].

It is possible to evaluate the intra-articular structures of a TKA with US. Bone, metal, polyethylene, and joint fluid each have characteristic ultrasound appearances [19]. Displaced intra-

articular structures, such as a detached patellar resurfacing component, can be detected by a skilled sonographer and thorough evaluation of the joint space [20]. The modality particularly excels in the evaluation of periarticular soft tissues. US is also excellent for detecting effusions and extra-articular fluid collections such as abscesses and bursitis. As it allows real-time, dynamic imaging, US guidance is ideal for pathology localization and needle placement during fluid collection aspirations and biopsies of synovium and/or soft tissue masses. Also, symptomatic popliteal cysts in patients with TKAs may be aspirated under US guidance. Extended-field-of-view imaging allows imaging over a large anatomic region, which is advantageous in the evaluation of a total joint replacement [19].

Computed Tomography

Although computed tomography (CT) shares with conventional radiography and fluoroscopy the same basic physics of detection of x-rays transmitted through a patient, CT is much more sensitive to small differences in densities of tissues. CT produces images with much higher contrast resolution, however at the cost of spatial resolution when compared with conventional radiography. Thus, it depicts soft tissues as well as bone much more effectively. CT also allows for evaluation of structures in three dimensions through acquisition of numerous thin contiguous slices. Through reformatting, which has been hugely improved by the advent of first helical CT then multidetector CT, it is possible to produce images in any plane desired that are of a quality equal or nearly equal to the images in the plane of original acquisition.

In the past, CT was of limited utility in the setting of metallic orthopaedic hardware due to the *beam-hardening* star artifacts. These artifacts are the result of the metal severely attenuating the x-ray beam, resulting in incomplete projection data and a distorted image. As CT hardware has improved (primarily in the form of multidetector CT) and as reformatting software has also been refined, these artifacts have been substantially minimized.

Multidetector CT (MDCT) allows for the use of very high photon techniques, which helps to overcome the severe attenuation of the x-ray beam by the metal. Also, very thin overlapping slices can be obtained and reconstructed into thicker slices. The process of reformatting (typically producing sagittal or coronal images from the original axial data), which is greatly facilitated by MDCT, also results in reduction in the metal artifact. The "soft tissue" or smooth reconstruction filter (rather than the typical "bone" or edge-enhancing filter) and wide windows (3000–4000 Hounsfield units) when viewing images also serve to diminish metal artifacts. The increasing use of titanium in orthopaedic implants has also been helpful because titanium has a relatively low X-ray attenuation coefficient, resulting in less beam-hardening artifact [21]. Unicondylar prostheses are particularly amenable to evaluation by CT, as the lesser volume of metal results in less artifact.

One important drawback of CT is the relatively high radiation dose. Doses are generally increased with the MDCT techniques designed to reduce metal artifacts. This is offset by the fact that the extremities are relatively insensitive to radiation. "Scatter" radiation during an extremity CT is quite small, rendering minimal exposure to more radiation-sensitive organs of the neck, thorax, and abdomen. CT examinations can probably be ordered more liberally in older patients, coincidentally the more common demographic with TKA, as older patients are at lower long-term risk for deleterious effects of radiation. Nevertheless, caution is warranted in using these techniques on younger patients and on anatomy near more radiosensitive structures (i.e., a scan of the hips, in which the gonads and axial skeleton could receive significant radiation).

Berger and Rubash have described a CT protocol for evaluation of component malrotation prior to revision surgery [22]. The patient is positioned supine, with the knee in full extension. The scan plane is perpendicular to the mechanical axis of the knee, as determined by an AP scout view. Then, a lateral scout view is obtained, and scanning is performed perpendicular to the long axis of the femur, then perpendicular to the long axis of the tibia (achieved by tilting the gantry). Next, 1.5-mm-thick slices are obtained at 4

locations: through the epicondylar axis of the femur, through the tibial tubercle, through the top of the tibial plateau, and through the tibial component itself. The rotation of the femoral component is determined by measuring the posterior condylar angle (the angle subtended by the surgical epicondylar axis and the posterior condylar line). The rotation of the tibial component is measured by comparing the AP axis of the tibial plateau with the position of the tibial tubercle.

CT may be performed following joint aspiration with arthrography. Metal artifact reduction techniques and multiplanar reformatting are used. This technique has not been well studied, but it seems possible that CT arthrography may offer added benefit in the detection of component loosening (Fig. 4.1).

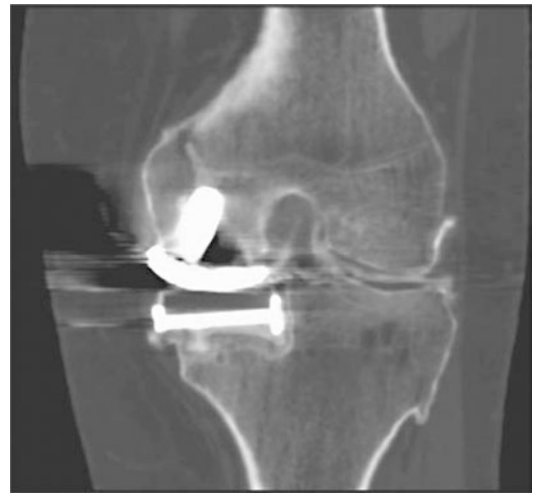


Fig. 4.1 CT arthrogram of a knee with a medial unicondylar prosthesis. Note the minimal artifact produced by the metallic hardware on this reformatted image in the coronal plane. This technique affords excellent visualization of the bone beneath the metal components, as well as the native lateral compartment. Note the clearly defined intact body of the lateral meniscus. A small region of osteolysis is evident in the medial femoral condyle. The vague linear lucency beneath the tibial tray is nonspecific, as no contrast tracks into it

Magnetic Resonance Imaging

In the past, MRI was limited in TKA patients due to the severe artifacts generated by the metal implants. The intrinsic ferromagnetic properties of metal distort the magnetic field, rendering image distortion and signal voids. This was particularly the case with older implants which were composed of more heavily ferromagnetic metals. Recent implants are composed of less ferromagnetic alloys, which mitigate artifact to some extent. Knees with unicondylar prostheses are particularly amenable to evaluation by MRI, as the smaller volume of metal results in less artifact, and the structures of the native compartments of the joint are readily evaluated.

MRI shares with CT the advantage of being able to depict structures in three dimensions via acquisition of thin contiguous slices. In contrast to CT, MRI can produce images of the same quality in virtually any plane. Perhaps the greatest advantage of MRI is the excellent contrast between different types of soft tissues, which is much greater than CT. As a result, MRI is generally much better than CT at depicting musculoskeletal soft tissue structures and is generally more sensitive to soft tissue pathologies. One caveat is that cortical bone and soft tissue calcifications are better evaluated with CT because they contain essentially no hydrogen atoms that can be magnetized. Also, CT can achieve better spatial resolution than MRI, which is advantageous in the evaluation of small calcifications and fine osseous detail.

Several technical strategies have been developed to minimize artifacts from metallic implants, resulting in improved depiction of the periprosthetic anatomy. These include relatively minor changes to imaging sequences on commercially available MR software such as orienting the frequency-encoding gradient along the long axis of the prosthesis, using fast spin-echo sequences, using three-dimensional acquisitions and thin sections, using high image matrix size (e.g., 512 × 512), increasing receiver bandwidth, and reducing interecho spacing. The use of inversion recovery fat suppression (STIR) results in less artifact than frequency-selective fat suppression [21, 23, 24].

These improvements allow the routine visualization of both intracapsular and extracapsular components of joint arthroplasty [23]. Sofka, Potter, and Figge have shown the usefulness of MRI in influencing clinical management of patients with painful TKA by revealing tendon

tears, polyethylene granulomatosis, ligament tears, and unexpected inflammatory synovitis in patients with normal radiographs [25]. Olsen et al. have developed a metal artifact reduction sequence (MARS) that uses some of the previously described techniques as well as *view-angle tilting* to significantly improve visualization of periprosthetic bone and soft tissue structures in TKA patients. This is achieved without an increase in imaging time [26]. More recent developments include the application of specific pulse sequences which further improve soft tissue and bone definition including MAVRIC (multiaquisition variable resonance imaging combination) technique and SEMAC (slice encoding for metal artifact correction) [27, 28]. Most of these MR parameter changes have been implemented on 1.5 T systems. Metallic artifact is exacerbated on higher field magnets such as 3.0 T MRI commonly seen in clinical practice [26]. These advantages do not imply that MRI should replace radiographs as the first-line modality for imaging of the symptomatic TKA. Rather, MRI is now a much more helpful second-line modality to be used when radiographs are negative or have findings of uncertain significance.

Radiological Findings of TKA Complications

Instability (Joint)

Instability, the displacement of the articular components, is one of the most common causes of early prosthetic failure after total knee arthroplasty. Instability prompts revision arthroplasty on average 4 years after primary arthroplasty [15]. Asymmetric widening of the prosthetic joint space suggests ligamentous imbalance and varus–valgus instability [29]. Yercan et al. describe three categories of instability seen in total knee arthroplasty including flexion, extension, and global instability [30]. Extension instability can be symmetric or asymmetric with respect to the joint space. Symmetric instability is often the sequela of improper surgical technique such as excessive resection of the distal femur or proximal tibia. Failure to correct valgus or varus deformities or overcorrection of angular deformities results in asymmetric instability. Asymmetric instability is far more common than symmetric. Flexion instability results in an excessive joint space gap and is usually created by undersizing of the femoral component or an excessive tibial slope. Global instability results from a combination of both loose flexion and extension gaps. Causes are multiple, including implant migration, extension mechanism failure, and polyethylene wear that give way to loss of surrounding soft tissue integrity. Most patients with global instability require constrained total knee arthroplasty revisions [30]. Flexion instability in the anterior–posterior plane can result in acute posterior dislocation, which is more common in posterior-stabilized prostheses. Prevalence of dislocations ranges from 1 to 2% in the early posterior cruciate ligament-stabilized designs, though recent design improvements have decreased this rate to 0.15–0.5% [15]. While signs of instability can be seen at a higher rate on radiographs, instability occurs in less than 1–2% of patients after primary TKA [30].

Component Malposition/ Malalignment

Evaluation of TKA alignment is important because of the direct relationship between malalignment, loosening, and instability. Both implant alignment and bony alignment must be evaluated to distinguish ligamentous instability from implant malpositioning. This is generally done with weight-bearing radiographs. Anteroposterior unilateral weight-bearing radiographs are useful for determining polyethylene liner wear. Valgus and varus stress AP radiographs can help evaluate the integrity of the collateral ligaments and determine if any deformity can be manipulated and reduced. Lateral extension and flexion radiographs are useful in detecting tibial slope and posterior subluxation [15].

The mechanical axis should pass through the center or just medial to the center of the prosthetic knee with both components perpendicular

to it. The femoral component should be within 4–11° of valgus, with 7° generally optimal [1, 14, 18, 31]. On the lateral view, the posterior flange of the femoral component should be parallel or nearly parallel to the long axis of the femur and the femoral component outline should match the outline of the original bone [10, 29]. Notching of the anterior femoral cortex can be seen when the femoral component is undersized, which predisposes to fracture. The posterior aspect of the anterior flange should be parallel to and flush with the anterior femoral cortex [29].

The tibial prosthesis should be aligned perpendicular to the tibial shaft on the AP view. Varus malalignment of the tibial component has been identified as a risk factor for prosthesis loosening [1]. On the lateral view, the position of the tibial component should be either central or posterior relative to the center of the tibial shaft. The plateau should be parallel to the ground or slope downward no more than 10° on the lateral view [10, 29]. Overhang of the tibial component can result in bursitis, especially anteriorly [29].

It has been reported that optimal TKA results are achieved when the joint line is altered 8 mm or less and the patellar height (as measured from the distal point on the femoral articular surface to the inferior pole) is 10–30 mm [10, 32]. The AP thickness of the patellar implant should not exceed the thickness of the original patella, as increased retinacular pressure may lead to pain and maltracking. Patellar tracking can be grossly assessed on tangential patellar views with the knee in 30–40° of flexion [29]. On this view, patellar tilt is assessed as the angle between a line along the anterior aspect of the femoral condyles and a line along the patellar component cement–bone interface.

Component malrotation can lead to rotational instability [22]. Berger and Rubash describe a method of evaluating component malrotation prior to revision surgery using CT. The rotation of the femoral component is evaluated using the posterior condylar angle, defined as the angle subtended by the posterior condylar line and the surgical epicondylar axis. The normal posterior condylar angle for men is 0.3° (+/− 1.2°) and 3.5° (+/− 1.2°) for women. The rotation of the tibial component is determined using the tibial tubercle orientation. This is defined as the angle between two lines: 1. a line drawn perpendicular to the horizontal posterior margin of the tibial tray that runs through the geometric center of the tibial tray and 2. a line drawn through the middle of the tibial tubercle that runs parallel to its axis. This is most easily calculated by creating a superimposed image of the tibial tray and tibial tubercle. The normal rotation value for the tibial component is 18° (+/− 2.6°) of internal rotation from the tip of the tibial tubercle. When femoral and tibial rotations were combined, patients without patellofemoral symptoms all had TKAs with mild degrees of combined external rotation (0–10°), while patients with patellofemoral problems all had TKAs with combined internal rotation. The degree of internal rotation correlated directly with the severity of patellofemoral complication [22].

One drawback in using CT for the assessment of component malrotation is the potential risk for inter and intraobserver variability [33, 34]. In a recent study be Servien et al. CT was used to assess for tibial component rotation in unicompartmental knee arthroplasty [35].

Extensor Mechanism Complications

While some authors find patellofemoral problems the most common postoperative complications associated with TKA and the most common reason for revision arthroplasty, others suggest patellofemoral problems closely follow infection and aseptic loosening as cause for revision surgery [15]. Patellofemoral complications range from patellar fractures, extensor mechanism rupture, patellar component failure, instability/maltracking, and soft tissue impingement syndromes. Patellar tilt and patellar subluxation are commonly seen on tangential (*sunrise*) views. These findings are often due to a tight lateral retinaculum, though a search should still be made for radiographic clues indicating component malrotation, valgus alignment, or oversizing of either the femoral or tibial component in the AP dimension—all of which can also lead to patellar tilt,

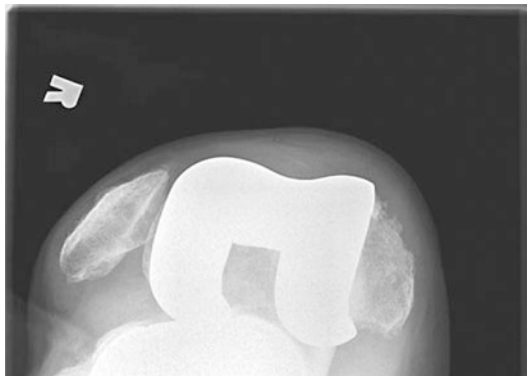


Fig. 4.2 Patellar dislocation. *Sunrise view* radiograph shows lateral dislocation of a nonresurfaced patella

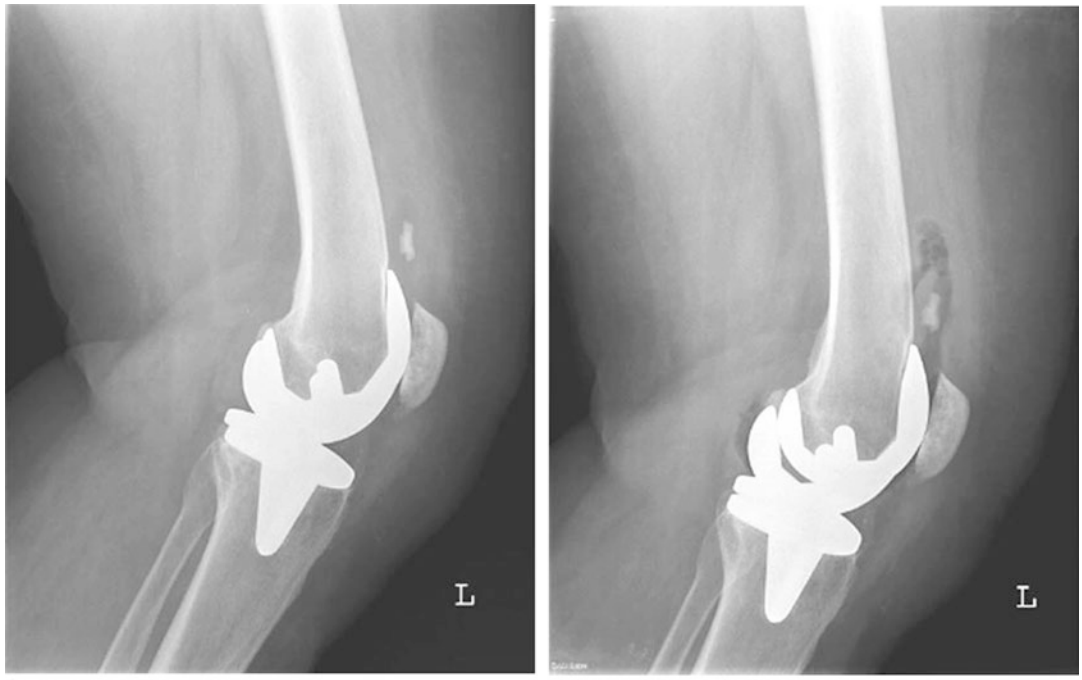
subluxation, and even dislocation (Fig. 4.2). As Berger and Rubash studied, excessive internal rotation can result from incorrect positioning of either the femoral or tibial component or both. Incidence of patellar instability after TKA can be up to 12%, ranging from 1 to 12% in one study [22]. Patellar tilt and subluxation also tend to result in more rapid polyethylene wear, which can lead to particle disease and even metallosis if the components are metal backed [29].

The polyethylene portion of the patellar component has been reported to come loose from its metal backing. The dense synovial linear opacities of metallosis may be apparent if this occurs [36]. The radiolucent polyethylene component often is displaced inferiorly into the region of Hoffa's fat pad but may be difficult to identify on routine radiographs due to its similar density to soft tissue. While metal-backed patellar prostheses were first used in the 1980s, more recent designs are entirely made of polyethylene with several peripheral pegs for cement or uncemented fixation. These components have a relatively low incidence for loosening of less than 2%. If the patellar resurfacing component is displaced for a substantial amount of time, biological remodeling, also called stress contouring, of the retropatellar surface will occur in the form of eroding and morphological changes of the subchondral bone plate as it adapts to the trochlear shape [37]. Adequate visualization may require soft tissue radiographic techniques, CT, or arthrography [36] (see Fig. 4.3). Displacement of the metal backing and polyethylene together, which results from fracture of fixation pegs [10, 29], is easily identified. A displaced patellar component may result in abrasion and rupture of the quadriceps or patellar tendons [10].

Patellar stress fractures occur with some frequency [10], as patellar resurfacing results in a thinned, possibly devascularized patella combined with stress risers via the peg holes [36] (Fig. 4.4). Fractures can be vertical or transverse, but most are vertical without compromise of the extensor mechanism [15]. Patellar component fractures may also be seen. These occur almost exclusively in metal-backed prostheses [10]. Patellar fractures are ideally treated conservatively as surgical intervention can result in high complication rate and marginal outcomes. Fractures in conjunction with extensor mechanism ruptures or resurfacing component loosening usually require repair and surgical fixation [15].

Rupture of the quadriceps or patellar tendon results in abnormal position of the patella (low and high, respectively) and localized soft tissue swelling with obscuration of fat planes. A wavy or buckled appearance of the soft tissues in the region of the tendon is sometimes seen on radiographs. An abnormally low patella (patella baja or infera) can also occur with an intact quadriceps tendon after TKA, due to fibrosis and scar contracture in Hoffa's fat pad. An abnormally high patella (patella alta) with an intact patellar tendon is much less likely [29].

Cross-sectional imaging with MRI or ultrasound is much more sensitive and specific for the detection of extensor mechanism tears and ruptures [15]. Dynamic evaluation with ultrasound is used at our institution in the detection of quadriceps tears in patients with TKA. The knee can be examined in full extension as well as in varying degrees of flexion. When there is suspicion for an extensor mechanism rupture on physical exam with an abnormal appearing patellar location on radiographs, discontinuity of the quadriceps or patella tendon is readily visible on ultrasound as there is minimal artifact to overcome from the metal prosthesis. MRI with metal artifact reduction techniques has also proved a



A B

Fig. 4.3 Patellar component dislocation. (**a**) Lateral radiograph (−) lucent polyethylene component with its dense metallic backing displaced into the suprapatellar pouch. (**b**) Lateral view from air arthrogram better displays the dislocated component and confirms its intra-articular position. Air was used as a contrast agent due to the patient's history of severe allergic reaction to iodinated contrast

reliable diagnostic modality for extensor mechanism ruptures.

Another potential complication of the patellofemoral extensor includes a soft tissue impingement syndrome called "patellar clunk" syndrome. In this scenario, a soft tissue fibrous nodule develops at the junction the posterior aspect of the quadriceps tendon and the proximal pole of the patella [20]. As the knee is extended from a fully flexed position, this nodule becomes entrapped within the intercondylar notch. Near the end of full extension, tension is placed on the fibrous nodule which causes it to "clunk out" of the intercondylar notch resulting in pain and sometimes a sense of instability. Some authors have found success in using MRI to demonstrate the soft tissue nodule at the junction of the patella and quadriceps tendon confirming the diagnosis. While possible causes for patellar clunk syndrome include surgical technique, patellar maltracking and prosthesis design and technical enhancements, such as deepening the femoral trochlea at the time of TKA, have dramatically reduced the incidence of this complication.

Stress Shielding

Ideally, a prosthetic joint component would carry stress and distribute it to the underlying bone in a manner identical to the original bone. However, the mechanical properties of the prosthetic components are different than the original bone, resulting in altered distribution of forces to underlying bone. Bone is formed and maintained along the lines of stress. Thus, bone resorption occurs in areas that no longer receive as much stress after joint replacement. This is called *stress shielding*. On radiographs, this is evident as rarefaction of trabeculae, or localized osteopenia. This must be differentiated from osteolysis, which causes focal complete destruction of bone.

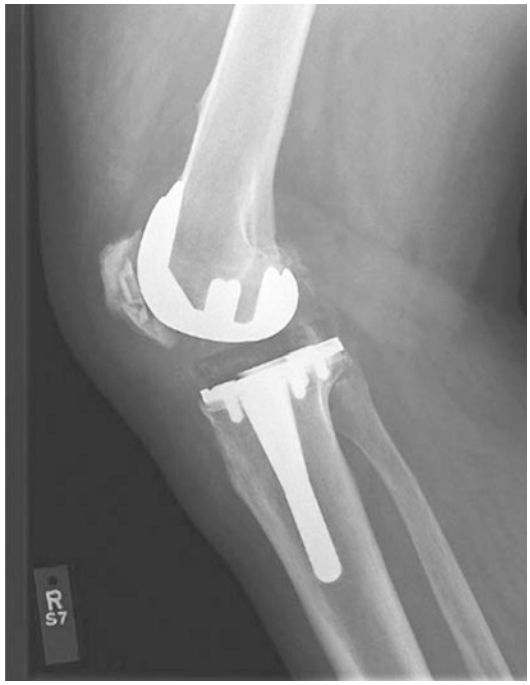


Fig. 4.4 Patellar fracture. (**a**) Lateral radiograph shows slightly displaced transverse fracture through the midpatella. (**b**) Sagittal CT image demonstrating transversely oriented fracture through the inferior pole of the patella

Progressive bone loss due to stress shielding is one of the primary causes of loosening and one of the limiting factors in the life span of a joint prosthesis. Stress shielding occurs in all knees in which the femoral component has an anterior femoral flange [37]. Stress shielding can also occur around the tibial tray, especially when there is a long-stem distal fixation as forces are diverted distally, away from the tibial plateau. It usually occurs within the first 2 years of the life of the prosthesis. Upon follow-up imaging, it is imperative to comparison with early postoperative radiographs to detect subtle progression of osteolysis and component loosening [20].

Polyethylene Wear

Polyethylene wear and particle-induced osteolysis remain a common cause for revision arthroplasty. Contributing factors to polyethylene wear are multitudinous, including increased patient's weight and/or activity level, specific type of polyethylene composing the liner, configuration and alignment of the femoral condylar component, and irregularities in the surface of the femoral condylar component articulating with the polyethylene [39]. Delamination of the polyethylene generates intra-articular particulate debris, which may subsequently engender osteolysis. Wear can occur from both the articular side (topside wear) and between the metal tibial tray and polyethylene liner (backside wear) [20]. Wear should be suspected when radiographs show narrowing of prosthetic joint spaces on weight-bearing views. When wear is asymmetric, varus or valgus deformity or patellar tilt results. Polyethylene fragments may be shed into the joint. It is important to look for loose intra-articular, porous-coating beads on radiographs, because they can lead to an accelerated type of wear, called *third-body wear*. Annual weight-bearing films are recommended to detect subclinical wear in TKAs, especially for prostheses with metal backing [29]. Early detection may allow simple exchange of the polyethylene liner before irreversible damage to the metal tray occurs [40]. Mild liner wear often can be subtle and can be confounded by differences in patient positioning. Therefore careful evaluation with prior studies is very useful in detecting subclinical polyethylene liner wear.

Using ultrasound, it is possible to detect polyethylene wear directly by measuring the thickness of the polyethylene tibial tray [41]. The joint effusion and synovitis that can result from polyethylene wear are also detectable with ultrasound. The effusion appears completely black (hypoechoic), while synovitis is manifested as fronds or nodules of intermediate echogenicity projecting into the joint fluid. This is most readily visualized in the suprapatellar pouch [19]. It is also possible to directly evaluate the tibial tray with ultrasound, enabling detection of polyethylene wear and tray fractures [19].

Particle Disease/Osteolysis

Osteolysis is a general term that simply means destruction of bone. In the setting of joint

replacement, the term is used specifically to denote bone destruction due to particulate debris, thus designated *particle disease*. Particles may be polyethylene, cement, or metal [38]. Debris of a critical size triggers an inflammatory reaction with macrophages and foreign body giant cells, which results in osteolysis. When severe, the bone loss from osteolysis can result in component loosening. Osteolysis is one of the leading causes of revision arthroplasty [15, 39].

Osteolysis is manifested on radiographs and CT as focal periprosthetic areas of lucency due to loss of trabeculae (Fig. 4.5). Common anatomic regions include the femoral condyles near the collateral ligament attachments and about the periphery of components. The reduction in metal artifacts and the improved ability to reformat high-quality multiplanar images made possible by multidetector CT have resulted in CT becoming a valuable tool for the detection and quantification of osteolysis. Puri et al. showed helical CT with metal artifact minimization to be more sensitive than radiographs for identifying and quantifying osteolysis after total hip arthroplasty [42].

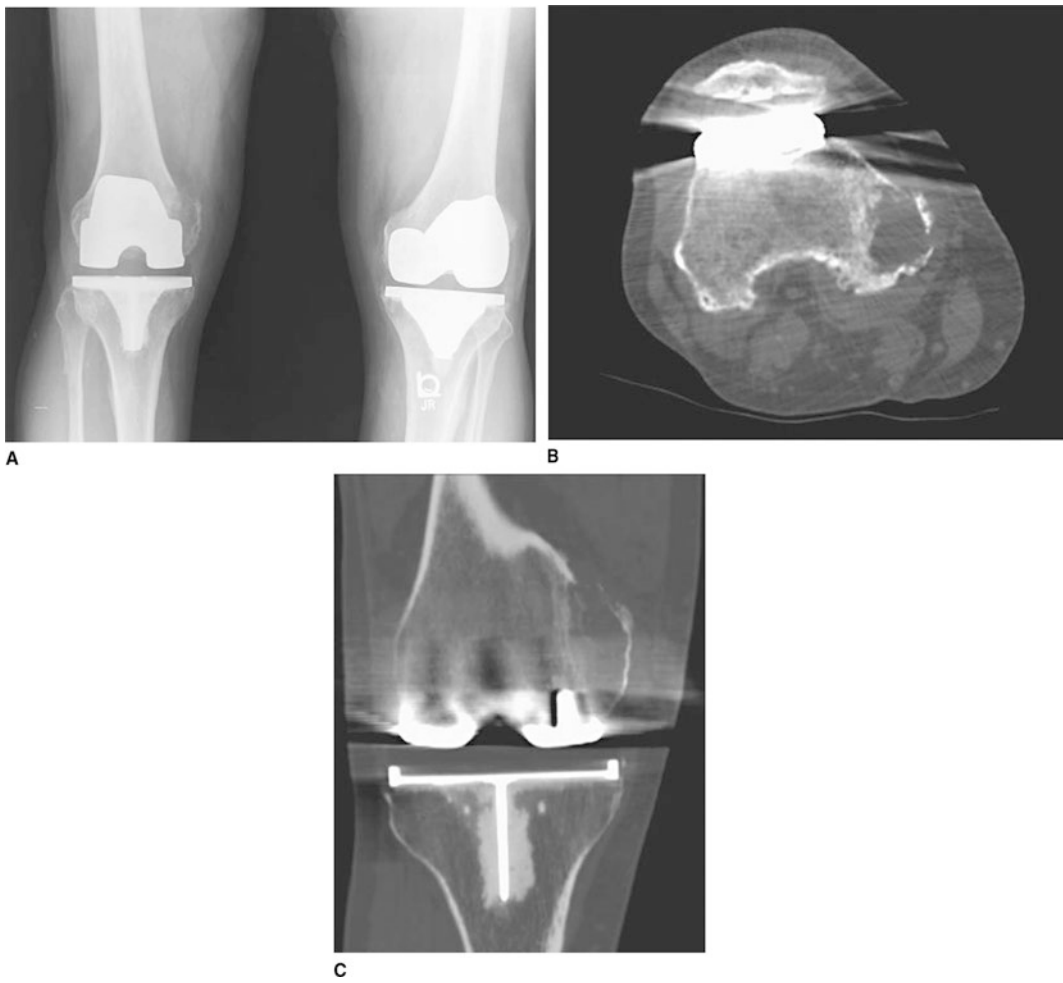


Fig. 4.5 Osteolysis. (**a**) AP standing radiograph of both knees shows a focal, well-defined region of lucency/bone destruction in the medial femoral condyle, with an apparent break in the overlying cortex suggesting a pathologic fracture. (**b** and **c**) Axial and coronal reformatted CT images allow determination of the volume of osteolysis and confirm the presence of a pathologic fracture. Note the minimal artifact produced by the metallic hardware on this multidetector study using artifact reduction techniques

Work by Seitz et al. indicates that CT is similarly advantageous in the evaluation of osteolysis at the knee [8, 43]. On sonographic images, osteolysis can be appreciated as focal loss of the normal bright, hyperechoic line of cortical bone, with an underlying hypoechoic, cystlike erosion [19]. The MRI appearance of osteolysis has been described as focal periprosthetic intraosseous masses with low T1 signal and heterogeneous, predominantly low to intermediate T2 signal. With IV contrast, these masses show peripheral enhancement and some irregular internal enhancement [24]. Vessely and colleagues found that the extent of osteolysis was greater on MRI than on radiographs in nine of 11 patients. MRI demonstrated radiographically occult lesions in five of 11 [44]. Similar findings of radiographically occult lesions visible on MRI were also described by Mosher et al. [45].

Metal Synovitis/Metallosis

Metallosis reflects the deposition of metallic debris in the soft tissues. This complication was observed with metal backed patellar components, which are no longer in frequent use [46]. Morevoer, liner failure allows for metal scrapings and debris to be released into the joint space and incite a granulomatous foreign body reaction [15]. Metallosis can also occur when polyethylene wear is so severe that there is metal-on-metal contact. A dense synovial *metal line* seen on radiographs is pathognomonic. A dense joint effusion and/or synovitis are always present in the setting of metal synovitis (Fig. 4.6) [29].

Quale et al. described five patients with titanium-induced arthropathy associated with polyethylene-metal separation after total joint replacement (three hips, two knees). Radiographs revealed abnormal position of the metal components in all patients and opaque curvilinear periarticular deposits in four of them. These periarticular opacities were pathologically proven to correspond to arthropathy induced by the shedding and deposition of small titanium particles from metal friction (in the absence of interposed polyethylene) [36].

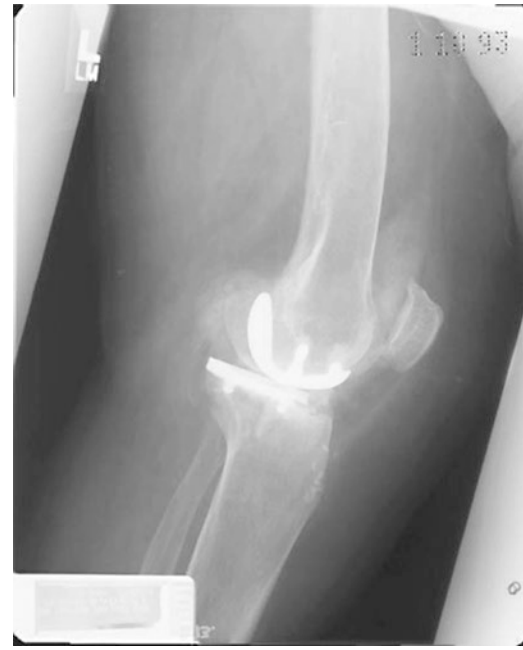


Fig. 4.6 Metallosis. Lateral radiograph shows a very dense joint effusion, evident both in the suprapatellar pouch and posteriorly, in this knee with a unicondylar prosthesis. Note the markedly narrowed joint space and the jagged anterior edge of the tibial component, indicating severe polyethylene wear, component fracture, and metal-to-metal contact

Infection

Prosthetic/periprosthetic infection is one of the most serious complications of TKA [47, 48]. The most common culprits include *Staphylococcus aureus* and coagulase negative *Staphylococcus.* Being able to differentiate loosening from infection is vitally important, since a noninfected prosthesis can be removed and replaced in a single procedure. A patient with an infected prosthesis typically undergoes a multistage protocol involving infected arthroplasty explantation; several months of antibiotic therapy, possibly both IV antibiotics; and placement of an articulating antibiotic spacer and revision arthroplasty.

Radiographs may be normal in the setting of infection. Alternatively, serial radiographs may demonstrate progressive periprosthetic radiolucency. Lucencies may occur in the absence of infection and are often absent in the early stages of infection [47, 49]. Extensive periosteal new

bone formation and osteolysis suggest (but are not diagnostic of) infection [29] (see Fig. 4.7a).

Joint aspiration is the most useful confirmatory procedure and is advocated by some prior to all revision arthroplasties [48]. Sensitivity and specificity have been reported to be 67 and 95.6%, respectively, and even as high as 100% in a series of 43 knees reported by Duff et al. [50]. Levitsky et al. concluded in 1991 that preoperative joint aspiration is the most useful single test in the workup of a painful total joint arthroplasty [49]. It is notable that the data from which this conclusion was drawn did not compare with the WBC scan–sulfur colloid marrow scan combination, which shows the best accuracy of all radionuclide scans.

Arthrographic features that suggest infection include extension of contrast between the cement/bone or prosthetic/bone interface, filling of periarticular cavities or sinus tracts, and lymphatic opacification [51] (Figs. 4.7 and 4.8). Tracking of contrast underneath the tibial tray can be seen as a *normal variant* or in aseptic loosening and does not necessarily indicate loosening or infection. However, tracking of contrast around the tibial pegs is always abnormal. Lymphatic opacification is not specific for loosening or infection, as it can occur in the setting of a small joint capacity. Synovitis may also predispose to lymphatic opacification [51].

Bone scan uptake patterns around knee prostheses are more variable than those around hip prostheses. Many asymptomatic patients show persistent periprosthetic uptake for several years after TKA. The natural course of a TKA is to show mildly to moderately increased uptake for years, and scans without uptake are unusual [31]. Bone graft material may result in increased blastic activity and, thus, prolonged uptake on bone scans. When infection is present, there is no diagnostic pattern of uptake [52]. If a bone scan is negative, infection can be confidently ruled out. For this reason, some believe that the bone scan is useful as an initial screening test, because of its high negative predictive value.

Three-phase bone scans should theoretically be more accurate than single-phase scans, as the hyperemia that produces increased uptake during the first two phases (blood-flow and blood-pool) should theoretically not be present in loosening (see Fig. 4.7b–d). Levitsky et al. found the three-phase bone scan to be limited in its ability to discern between infection and aseptic loosening due to unacceptably high rates of false-negative results [49]. Accuracies for three-phase bone scans are 50% to 70% [52]. Increased uptake in all three phases can also be seen in the setting of acute heterotopic bone formation, acute stress fractures, noninfectious inflammatory arthropathies, neuropathic arthropathy, and the reparative phase of avascular necrosis. Tonakie et al. state that three-phase bone scans do little to improve the accuracy of routine bone scanning for diagnosing infected joint replacements [31]. Some investigators have suggested the utility of three-phase bone scanning as a screening test, but sensitivities are higher at the hip than at the knee [52, 53].

The radionuclide studies with the best-reported accuracies (75% to 95%) are WBC (labeled leukocyte) scans paired with either three-phase bone scans or Tc-99 m sulfur colloid marrow scans [29]. Love et al. stated in 2001 that "combined leukocyte–marrow scintigraphy remains the procedure of choice for diagnosis of the infected joint replacement" [52]. They based this opinion on accuracies of 90% or greater as reported by Palestro et al. for In-111 WBC scans combined with Tc-99 m sulfur colloid marrow imaging [54]. When uptake on both studies is of similar intensity and spatially congruent, the study is considered negative for infection. If there is uptake on the WBC scan, but not on the sulfur colloid marrow scan, the study is considered positive for infection [52].

FDG PET appears to be a promising technique for the evaluation of musculoskeletal infections. De Winter et al. in 2001 showed FDG PET to have sensitivity, specificity, and accuracy of 100%, 86%, and 93% for patients with suspected chronic infection of the peripheral skeleton [8]. In a series of 22 patients with 29 metallic orthopaedic implants for trauma (not joint replacements), Schiesser et al. demonstrated sensitivity, specificity, and accuracy of 100%, 93.3%, and 97%, respectively [9]. In the study by De Winter, FDG PET performed well in identifying infection in the small subgroup of patients with joint prosthe-

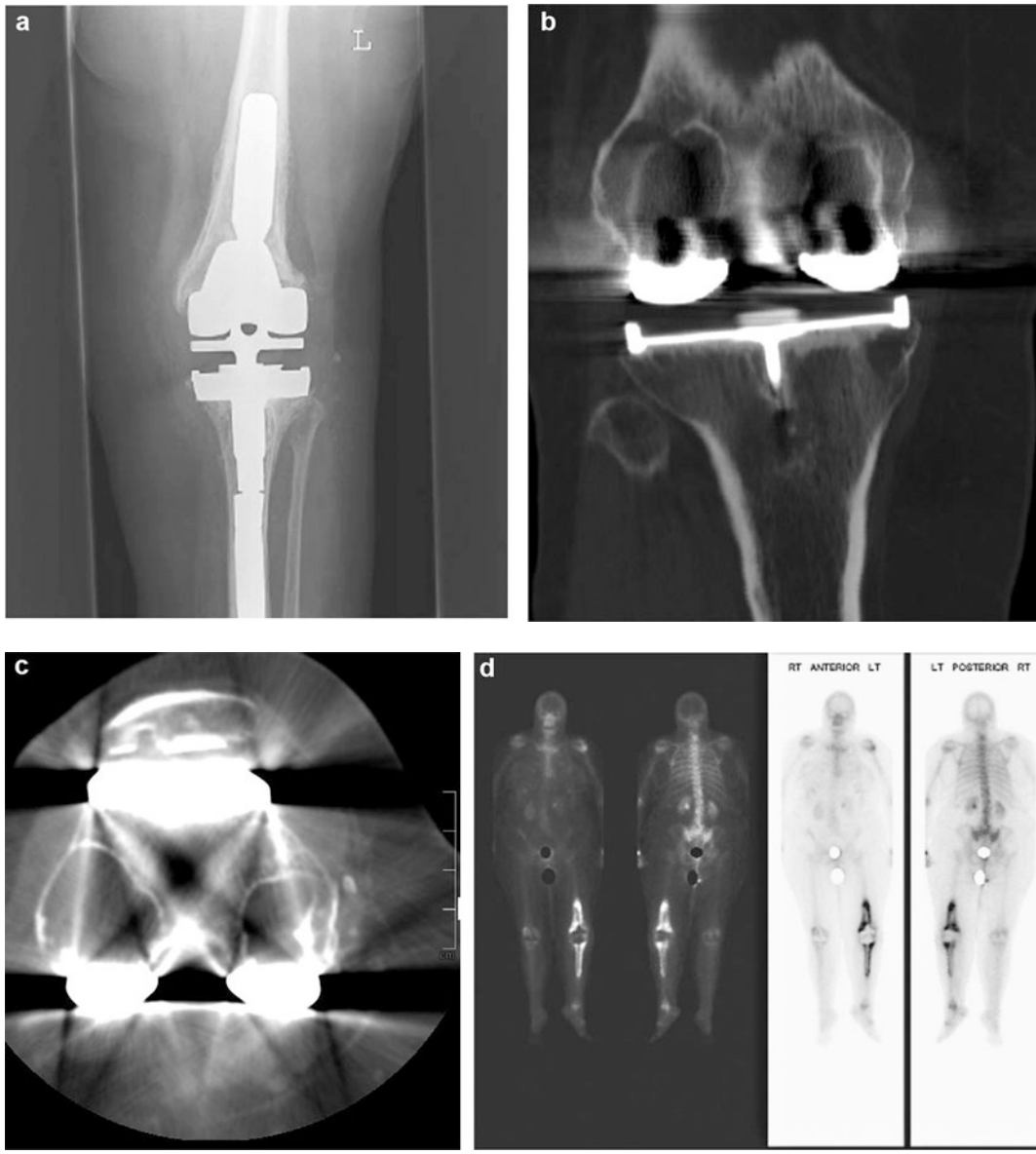


Fig. 4.7 Osteomyelitis. (**a**) AP radiograph of a revision TKA complicated by chronic osteomyelitis (culture-proven coagulase negative *Staphylococcus* infection). Note the wide lucencies at bone–metal interfaces about both the tibial and femoral components and also periostitis, which is most evident at the medial femoral metaphysis. (**b**–**d**) Three-phase bone scan of a different patient than patient in **a**. (**b**) Anterior and posterior images of both knees from the first (blood-flow) phase show diffusely increased activity about the right knee. (**c**) Anterior, posterior, and oblique images of both knees from the second (blood-pool) phase show increased activity better localized to the bone of the tibia and femur about the prosthetic components. (**d**) Anterior oblique images from the third (delayed) phase show well-defined intense activity in the same distribution as in the second phase

ses—eight true-positive, eight true-negative, and a single false-positive result. Of these 17 patients, seven had TKAs. The one false-positive result was in a TKA with aseptic loosening [8]. Other authors have found FDG PET to be disappointing in its ability to distinguish between aseptic loosening and infection [52]. While further studies are necessary, it is conceivable that FDG PET will play a significant role in the workup of the painful TKA in the future.

Ultrasound is useful when periarticular fluid collections are suspected to accompany an infected prosthesis. Collections of simple fluid are homogenously black (anechoic), while complex fluid collections are heterogeneously echogenic. Complex fluid collections can be differentiated from normal soft tissues by fluidlike motion of echoes when compression is applied and released with the transducer and by mass effect on adjacent normal structures. It should be emphasized that although infected fluid collections tend to be complex, complex fluid collections are not necessarily infected. Ultrasound is very useful in guiding percutaneous needle aspiration of fluid collections for decompression and subsequent microbiological evaluation.

MRI is also capable of depicting periprosthetic fluid collections, especially with metal artifact reduction techniques. Fluid collections that show a peripherally enhancing rim following intravenous contrast and communicate with the joint replacement suggest infection. The advent of improved metal artifact reduction techniques has resulted in the increased application of MRI in the setting of suspected infection. In a recent publication, Plodkowski et al. described the appearance of multilayered, "lamellated" synovium in the setting of synovitis due to infected TKA. This pattern was described to have high sensitivity and specificity for infection as well as high inter- and intraobserver reliability [55].

Loosening

TKA component loosening can occur as a consequence of bone loss from stress shielding. It can also occur due to infection or osteolysis from particulate debris. Some authors state that loosening in TKAs is most common in the femoral component [56], while others [10, 38] believe that it is more common on the tibial side. This discrepancy seems to be based on whether one considers subsidence to be a type of loosening. The tibial component often subsides, typically on the medial side, which results in a shift of the tibial component into varus angulation [1, 38]. This is especially prevalent in uncemented tibial components [29]. The fibular head can be used as a bony landmark to aid in detection of tibial component subsidence.

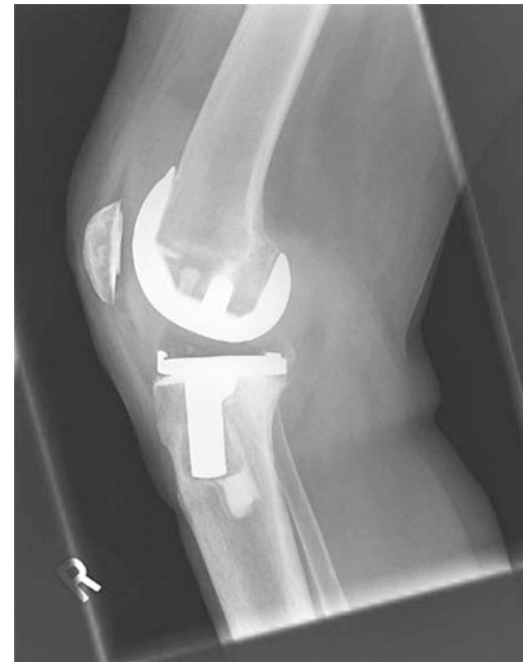


Fig. 4.8 Loosening. Lateral radiograph shows a wide lucency surrounding the stem of the tibial component and border-line-width lucencies under the tibial tray. Note also the large joint effusion evident in the suprapatellar pouch and posteriorly. Cultures of aspirated joint fluid were negative

Radiographic criteria for loosening include a wide (greater than 2 mm) or progressively enlarging cement–bone or metal–cement lucent line, component migration, collapse of underlying trabecular bone with subsidence of the component, cement fractures, and changes in the degree of knee angulation on weight-bearing views [10, 29] (Figs. 4.8 through 4.10). A lucent zone of 1 to 2 mm between cement and bone is considered normal and likely due to cement contraction [10, 56]. When a lucent line progressively widens on sequential radiographs, loosening can be diagnosed [56]. With uncemented prostheses, the finding of displaced porous-coating beads (bead shedding) also indicates loosening [29]. Component subsidence has also been described as a relatively consistent indicator of component loosening. The tibial tray is most commonly involved as it affects the tibial plateau. Femoral

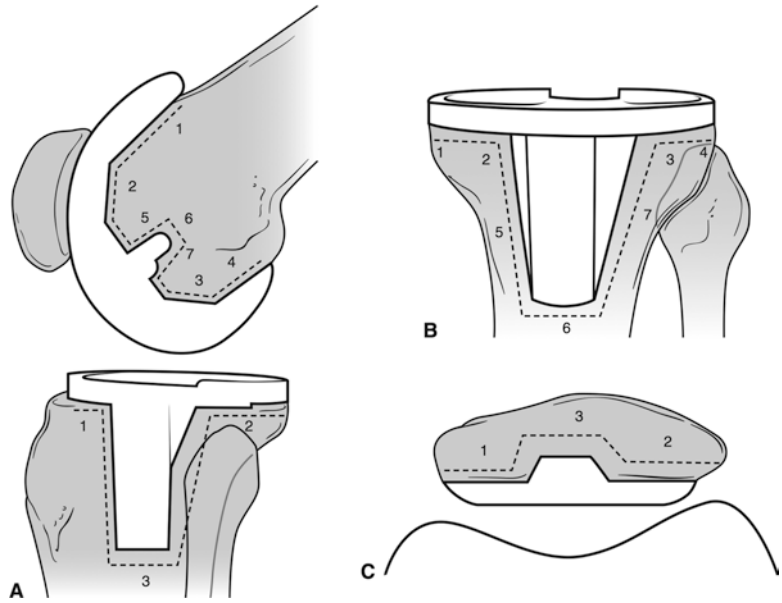


Fig. 4.9 Periprosthetic lucency evaluation after total knee arthroplasty. (**a**) Lateral view of femoral and tibial components. For femoral component, zones 1 and 2 are for anterior flange, 3 and 4 for posterior area, and 5 through 7 for either stem or central portion if there is no stem. (**b**) Anteroposterior view of representative tibial component. Zones 1 and 2 are for medial plateau, 3 and 4 for lateral plateau, and 5 through 7 for stem fixation. If there are no stems, central part of tibial plateau should be assigned zones 5 through 7. (**c**) Patellar tangential axial view with zone 1 representing medial side and zone 2 the lateral side. Zones 3 through 5 are reserved for fixation pegs of the central part of the patellar component

component subsidence is far less common. When it does occur, it results in a more flexed position on the lateral view [15]. Loosening is more difficult to detect in the femoral component, because the component obscures the prosthetic–bone interfaces on the AP view. The x-ray beam must be perpendicular to the cement–bone interface for the thin radiolucent lines to be detectable. Positioning is therefore crucial, and some investigators have recommended the use of fluoroscopically guided radiographs [6]. In both cemented and uncemented prostheses, the radiolucent zones are often bordered by a thin layer of lamellar bone resulting from stress remodeling. When this *neocortex* is absent, failure of the prosthesis is more likely [29]. The Knee Society Evaluation/Scoring Zone System may be used to describe, document, and follow periprosthetic radiolucent lines [57]. Specific zones about the femoral, tibial, and patellar components have been designated in attempts to standardize reporting of findings related to loosening (Fig. 4.9).

Fluoroscopic push-pull maneuvers can be used to document gross loosening. In equivocal cases, arthrographic evaluation can be helpful. Aspiration of joint fluid for cultures should be performed first, and then contrast is injected. Tracking of contrast into and along periprosthetic lucencies indicates loosening.

Bone scans are less helpful in evaluating for loosening in TKAs than in total hip arthroplasties. This is because the natural course of the TKA is to show mildly to moderately increased uptake for many years [7]. Intense focal uptake after more than 6 months postoperatively suggests loosening or infection [29], but false-positive rates are high (up to 72%) [58]. Sequential bone scans showing increasing radiotracer uptake are also suggestive of loosening, but are not diagnostic, as wide variability in

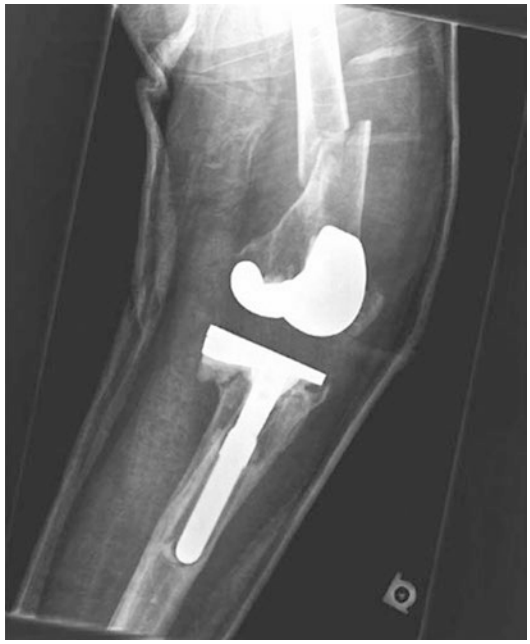


Fig. 4.10 Periprosthetic fracture and loosening. AP radiograph shows an angulated, displaced fracture through the femoral metaphysis just proximal to the femoral component. Note also the wide lucencies about the stem and underneath the tray of the tibial component, indicative of loosening

uptake has been shown in asymptomatic patients followed with sequential scans [58].

Periprosthetic Stress/Insufficiency Fracture

Periprosthetic fractures are uncommon and have been observed most frequently in patients with rheumatoid arthritis [38]. They are most frequent in the distal femur. Notching of the anterior femoral cortex during resurfacing and osteoporosis risk factors. Stress fractures can occur anywhere in the lower extremity or pelvis after TKA, due to increased activity [29] (see Fig. 4.10).

Periprosthetic fractures may occur intraoperatively or postoperatively, with femoral condylar fractures more common than tibial fractures. Supracondylar fractures of the femur can result in significant morbidity. Often only minor trauma is reported in the presentation of supracondylar femur fractures. Incidence ranges from 0.3 to 2.5%. Lewis and Rorabeck have developed a classification which describe characteristics of displacement and prosthetic loosening or failure [20].

Nondisplaced periprosthetic fractures that may be occult on radiographs (and even on CT) can be identified with MRI, especially with the aid of recently developed metal artifact reduction techniques. Such fractures appear as linear low T1, high T2 signal abnormalities, with variable amounts of surrounding high T2 signal marrow edema. Prosthetic tibial fractures are far less common. They should be described according to location and stability related to the tibial component.

Bursitis and Tendon Pathology

Pain from soft tissue pathologies such as tendinosis, tendon tear, bursitis, or distended popliteal cysts can mimic a loosened or infected joint. The patellar and quadriceps tendons are well suited to evaluation by ultrasound. Normal tendons appear hyperechoic and show a fibrillar echotexture when imaged perpendicular to the ultrasound beam. Tendinosis is manifest as thickening and heterogeneous hypoechogenicity, with loss of the normal fibrillar appearance. Tendon tears are also readily identified with ultrasound. Complete tears manifest as fluid-filled gaps extending all the way through the substance of the tendon, often with retraction of the torn ends of the tendon. Partial tears present either as fluid-filled gaps that do not extend through the entire substance of the tendon or as longitudinal clefts along the long axis of the tendon [16].

Tendinosis and tendon tears may also be detected with MRI, especially when metal artifact reduction sequences are used. Tendinosis and partial tears can be difficult to differentiate, as both can appear as tendon thickening with increased proton density and/or T2 signal. In chronic partial tendon tears, the tendon is often thinned but of normal low proton density and/or T2 signal. Complete tendon tears often show retraction of the torn ends with a gap filled by high T2 signal fluid or heterogeneous signal blood products [59].

Popliteal (Baker's) cysts and other extra-articular fluid collections such as bursitis, hematoma, and soft tissue abscess are readily detected

by ultrasound or MRI. Such collections may be aspirated under ultrasound guidance for symptomatic relief and microbiological analysis. Following aspiration, corticosteroids and anesthetic may be injected into the cyst or bursa under ultrasound guidance.

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II

General Principles of Revision Surgery

Skin Exposure Issues

5

Jason M. Jennings and Douglas A. Dennis

Patient Risk Factors

Malnutrition increases the incidence of postoperative wound complications [1–3] by impairment of wound healing and prolonging inflammation through multiple mechanisms including reduction of fibroblast proliferation and collagen synthesis [4]. It is wise to consider obtaining a preoperative assessment of serum albumin level, total lymphocyte count, and transferrin levels in patients prior to surgical intervention. Ideal supplementation should aim to achieve a total lymphocyte count >1500 cells/μL, albumin level >3.5 g/dL, and transferrin levels >200 mg/dL [1, 2, 5]. In addition, low preoperative zinc levels have been associated with impaired wound healing in patients who underwent a hemiarthroplasty for a hip fracture [6]. To our knowledge, this has not been studied in TKA but may be a critical factor for efficient wound healing in the at-risk patient. If a patient is malnourished preoperatively, a thorough discussion with the patient and their primary care physician and delaying surgery until the abnormalities have been corrected are recommended.

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Morbid obesity can create exposure difficulties in TKA, necessitating more vigorous retraction of skin flaps and the subsequent risk of soft tissue devascularization [7–12]. Additionally, in heavier patients with a thick adipose layer, the skin is less adherent to its underlying vascular supply, which increases the risk of separation of the dermis from the subcutaneous layer during skin retraction [13]. The importance of morbid obesity is debated as an independent risk factor for complications after TKA since it is rarely seen as an isolated diagnosis although a recent study demonstrated it to be an independent risk factor for wound dehiscence [14]. For the aforementioned reasons, patients with obesity should be encouraged to lose weight prior to surgical intervention. These patients often benefit from nutritional consultation to design a safe weight loss program. In addition, despite being overweight many patients are often malnourished and benefit from correction of their nutritional deficiencies preoperatively. Bariatric surgery may be considered in this patient population and has been shown to decrease the rate of wound healing complications [15].

Medications used to manage patients with inflammatory arthritis have been associated with wound healing difficulties [9–12]. Corticosteroids have been shown to decrease fibroblast proliferation, which is necessary for wound healing [16]. Chronic corticosteroid use also reduces collagenase clearance from the healing wound,

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which results in diminished collagen accumulation at the wound healing site and a subsequent decrease in wound tensile strength [17, 18]. These medications are typically continued perioperatively secondary to the suppression of the adrenal axis related to their chronic use. Stress dose steroids may be required to prevent adrenal insufficiency in these patients [19]. Continued use of methotrexate and hydroxychloroquine in the perioperative period has been shown to be safe in most reports [9, 11, 12]. The emergence of biologic agents (i.e., anti-TNF agents) has significantly reduced the joint destruction associated with inflammatory arthritis but at the expense of significant immunosuppression and potential wound healing complications. There is conflicting evidence about the discontinuation of these medications in the perioperative period [10, 20]. Currently the American College of Rheumatology recommends discontinuing these agents at least 1 week prior to surgery, with the possibility of an earlier preoperative cessation as determined by the pharmacokinetic half-life of the medication in question. These medications may be restarted 2 weeks following TKA when the wound is healed [21]. We typically discuss the risk-benefit ratio of discontinuing these medications with the patient and their rheumatologist preoperatively since reduction of the immunosuppression and potential wound healing issues are at the expense of increasing inflammatory arthralgias in patients with long-standing disease.

The deleterious effects of cigarette smoking on wound healing have been well documented and are related to systemic vasoconstriction resulting from nicotine [22–27]. One proposed mechanism is that nicotine changes skin homeostasis by directly affecting dermal fibroblasts through a specific nicotinergic pathway [22]. Fortunately, perioperative smoking cessation appears to be an effective tool in reducing this complication [28–30]. The benefits of smoking cessation seem to be maximized when started at least 4–8 weeks preoperatively [28–30].

The method of thromboembolism prophylaxis has an effect on wound healing [31]. Excessive bleeding from anticoagulant use increases wound tension, risks prolonged wound drainage and subsequent risk of infection, and can limit TKA flexion. Additionally, an intra-articular hemarthrosis can serve as an excellent growth medium for bacterial proliferation. Mechanical prophylaxis in combination with a less potent chemoprophylaxis has been advocated in the at-risk patient.

Other factors associated with wound healing complications postoperatively include but are not limited to diabetes (mean postoperative blood glucose >200 mg/dL or a preoperative hemoglobin A1C level of >6.7%) [32] perioperative chemotherapy, previously irradiated wounds, and burns over the anterior peri-incisional region. Additionally, use of continuous passive motion (CPM) beyond 40° has been shown to reduce transcutaneous oxygen tension measured in the healing wound edges, especially during the first 3 days following TKA. CPM should therefore be limited to less than 40° during the early postoperative period if the risk of skin necrosis is substantial [33, 34].

The management of modifiable risk factors prior to surgery and in the perioperative period is critical to prevent wound complications after TKA. While the risk factors have been discussed separately, many patients present with multiple medical comorbidities and modifiable risk factors in combination. Identification and management of these risk factors is imperative to decrease wound complications.

Vascular Anatomy

The blood supply to the anterior aspect of the knee is random, receiving contributions from multiple vessels. This blood supply arises predominately from the terminal branches of the peripatellar anastomotic arterial ring. This anastomotic ring has numerous contributing arterial branches, including the medial and lateral superior geniculate arteries, the supreme geniculate artery, the anterior tibial recurrent artery, and a branch of the profunda femoris artery (Fig. 5.1) [35–37]. In contrast to the circulation of the thigh proximal to the knee, there is no underlying muscle or intermuscular septa directly anterior to the knee to provide a direct pathway for arterial

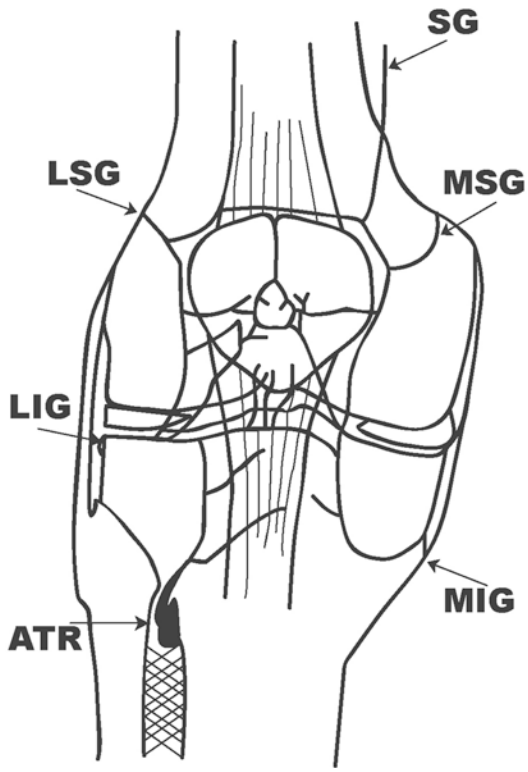

Fig. 5.1 Diagram demonstrating the extraosseous peripatellar anastomotic ring. *ATR* anterior tibial recurrent, *LIG* lateral inferior genicular, *LSG* lateral superior genicular, *MIG* medial inferior genicular, *MSG* medial superior genicular, *SG* supreme genicular

perforators. Skin circulation in this area is dependent on the dermal plexus, which originates directly from arterioles traveling within the subcutaneous fascia (Fig. 5.2a, b). Surgical dissection performed superficial to this subcutaneous fascia disrupts the arterial supply to the skin and increases the possibility of skin necrosis. Elevation of skin flaps requires dissection deep to the subcutaneous fascia to preserve the perforating arteriolar network between the subcutaneous fascia and dermal plexus.

Skin Incision

Analysis of vascular anatomy about the knee suggests that the choice of a midline skin incision is less disruptive to the arterial network. Medial peripatellar skin incisions are undesirable because they create a large, laterally based skin flap, which has been associated with higher wound complication rates secondary to lower oxygen tension to the lateral skin region [38, 39]. Placement of the skin incision slightly lateral to the midline may assist in eversion or lateral subluxation of the patella, particularly in obese patients in whom a large and bulky lateral skin flap resists patellar subluxation or eversion.

When previous skin incisions are encountered, selection of the most appropriate incision may diminish the risk-associated skin healing complications. It is usually safe to ignore previous short medial or lateral peripatellar incisions. One should be wary of wide scars with thin or absent subcutaneous tissues, as damage to the underlying dermal plexus is likely, increasing the risk of wound necrosis. Problems with placement of a longitudinal incision crossing a transverse incision previously used for high tibial osteotomy or patellectomy are uncommon [40].

If long parallel skin incisions exist, choice of the lateral most skin incision is favorable to avoid a large lateral skin flap that has previously been compromised. In complex situations, such as knees with multiple incisions or previously burned or irradiated skin, plastic surgical consultation is wise, both for the configuration of the preferred skin incision and for consideration of preoperative muscle flap procedures if the risk of skin necrosis is substantial. In selected complex situations, using a staged technique can reduce wound complications. A *pre-revision* skin incision to the depth of the subcutaneous fascial layer is made and then closed. If this incision heals without difficulty, one can later proceed with TKA with much greater confidence. This does not take into account the substantial dissection that occurs with a TKA, and caution is still warranted, with careful intraoperative and postoperative management of the soft tissues.

Soft tissue expansion techniques have been used successfully in cases of contracted soft tissues from previous skin incisions, burns, or irradiation [41–46]. Success has also been described for tissue expansion before primary TKA, conversion of arthrodesis, reimplantation following infection, and revision TKA [41–50]. These tech-

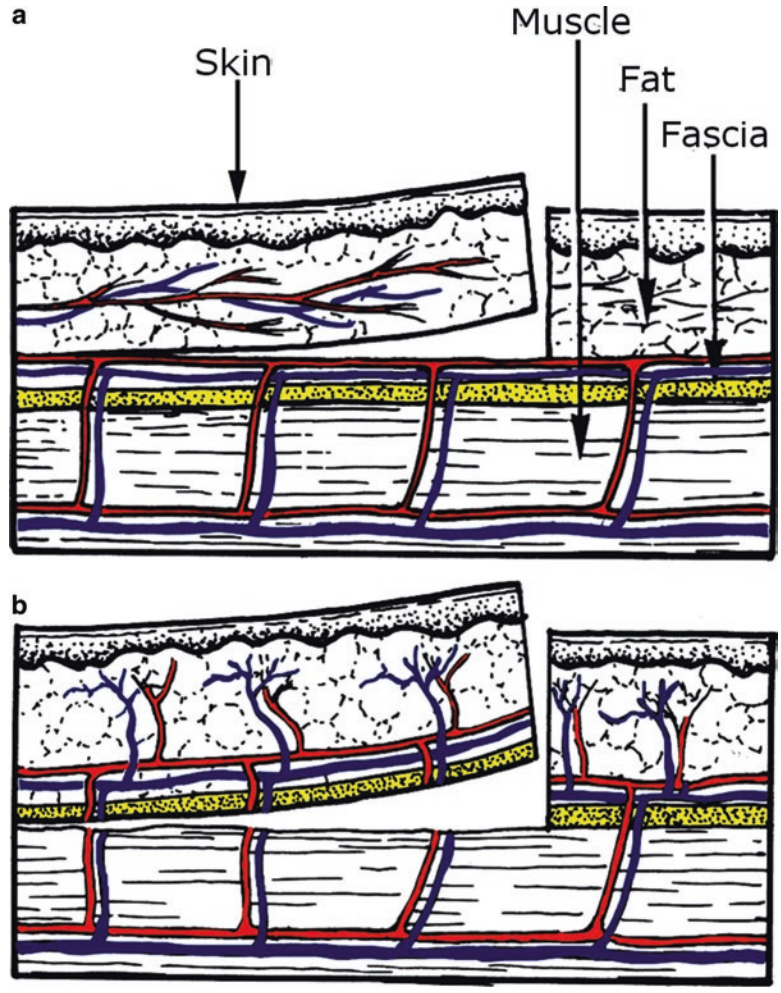

Fig. 5.2 (**a** and **b**) Diagrams demonstrating the cutaneous blood supply to the skin exhibiting extra-fascial dissection (**a**; not recommended) versus the desired method of subfascial dissection (**b**)

niques involve implantation, usually subcutaneously, of an expandable reservoir, into which saline can be intermittently injected to expand the surface area of the skin. Studies have shown that while epidermal thickness is maintained, dermal thinning occurs, and overall dermal collagen synthesis is increased. Complications with soft tissue expansion have been minimal and include hematoma formation, reservoir deflation, infection, and skin necrosis from vigorous tissue expansion [50]. Disadvantages of soft tissue expansion include the requirement for additional surgical procedures and the time required for expansion.

Another complicating factor in choosing a skin incision follows previous muscle flap procedures. Knowledge of the prior surgical procedures is imperative before proceeding with surgical intervention. Care must be exercised not to disrupt the vascular pedicle of the flap or portions of the muscular flap itself. Again, consultation with a plastic surgeon is recommended.

Additional Technical Factors

A thorough preoperative vascular examination of the limb is necessary to minimize the risk of wound healing complications. The skin incision for TKA should be of adequate length to avoid excessive tension on the wound edges, particularly when the knee is positioned in extremes of flexion. Meticulous handling of the soft tissues is

essential, and gentle retraction of the skin edges is necessary to avoid disruption of perforating arterioles originating in the subcutaneous fascial layer. It is best not to undermine large areas of the skin. If undermining skin flaps is required, it must be done in the subfascial plane to preserve the blood supply to the skin, which originates in the dermal plexus. Numerous studies have demonstrated that a lateral retinacular release decreases lateral skin oxygenation and increases the subsequent risk of wound complications [51–54]. If a lateral retinacular release is required, attempts should be made to preserve the lateral superior geniculate artery. Meticulous wound hemostasis is paramount to avoid postoperative hematoma formation. In the authors' experience, performance of TKA without use of a tourniquet (except for cementation) is beneficial to reduce the incidence of hematoma formation as hemostasis is continuously obtained during the operative procedure in contrast to cases in which delayed vasodilation occurs after tourniquet deflation and wound closure has been completed. We favor routine use of suction drainage to reduce pain, postoperative hematoma formation, and facilitate early knee flexion. Wound closure without tension is imperative in minimizing the risk of skin necrosis. Additionally, recent studies evaluating the clinical and scientific efficacy of negative pressure wound therapy (NPWT) suggest it may be helpful over closed surgical incisions [55–58]. Potential benefits include decreasing postoperative edema, regaining wound breaking strength more rapidly, and hematoma and seroma reduction [55–57].

Wound Complication Management

Various types of wound complications can occur, including prolonged postoperative drainage, superficial soft tissue necrosis, and full-thickness soft tissue necrosis, in which the prosthetic components are usually exposed. All three types of wound problems require immediate attention, as delay in treatment risks deep infection and subsequent failure of the TKA.

Prolonged Drainage

Substantial drainage from the incision in the first 3 days is managed with lower limb immobilization in extension and application of a compressive dressing. Use of NPWT can also be entertained. In the authors' experience, if drainage persists beyond 5–7 days despite immobilization, elevation, and local wound care, spontaneous cessation of drainage is unlikely, and surgical debridement is indicated. Subcutaneous hematomas or large intra-articular hemarthrosis is commonly encountered in cases of persistent wound drainage. Hematomas threaten the wound integrity by increasing soft tissue tension, releasing toxic breakdown products of hemoglobin, and serving as a healthy medium for bacterial growth.

The incidence of prolonged drainage in patients who eventually develop culture-proven infected TKA ranges from 17 to 50% [59, 60]. Weiss and Krackow [60], in a retrospective review of 597 TKAs, identified eight patients (1.3%) with persistent wound drainage. All were treated with surgical irrigation, debridement, and parenteral antibiotics. All cases healed without infection despite the fact that two patients (25%) had positive cultures at the time of irrigation and debridement. The authors suggest that prompt surgical management in these cases may prevent chronic drainage problems from becoming established infections.

Scientific data are lacking to clearly support surgical drainage rather than observation of the non-draining hematoma. We recommend treating the non-draining hematoma through close observation as long as no signs of infection or impending skin necrosis from excessive soft tissue tension are present. An additional consideration for possible surgical drainage is a large hematoma that substantially limits knee range of motion. Evacuation procedures should be per-

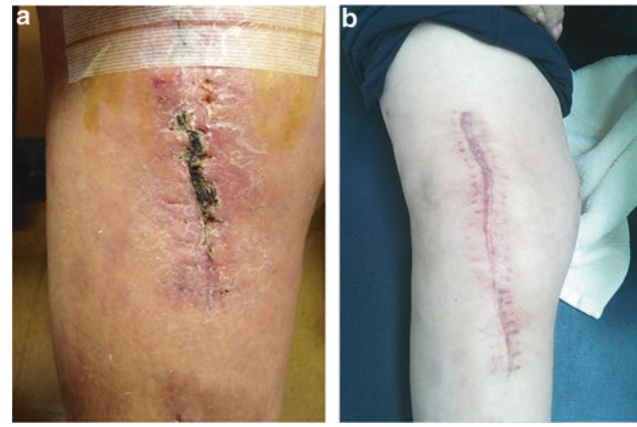

Fig. 5.3 (**a** and **b**) Postoperative photographs demonstrating superficial, marginal wound necrosis (**a**) treated with local wound care and subsequent healing (**b**)

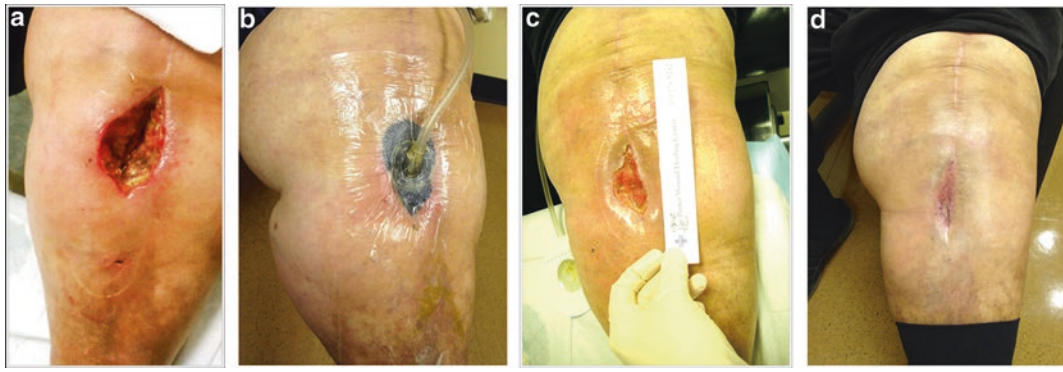

Fig. 5.4 (**a**–**d**) Three-week postoperative photograph following TKA in an obese subject (BMI 43) with incomplete wound healing despite two failed wound debridements with delayed primary closure (**a**) eventually treated with NPWT (**b**). Photographs 2 (**c**) and 4 (**d**) weeks following NPWT demonstrating successful healing

formed in the operative theater with perioperative antibiotic therapy.

Superficial Soft Tissue Necrosis

Necrotic tissue generally requires surgical debridement. Small necrotic areas less than 3 cm in diameter may heal with local wound care or delayed secondary closure (Fig. 5.3a, b). Larger areas of superficial necrosis should be debrided and covered with split-thickness skin grafting or fasciocutaneous flaps [61–63]. NPWT may be used following debridement to reduce the size of the initial wound, allowing for later skin grafting while suppressing bacterial overgrowth [58] (Fig. 5.4a–d). NPWT promotes a reduction in wound depth and facilitates reparative granulation tissue instead of fibrosis when compared with saline dressing changes [64]. Use of this technology is an adjunct to wound debridement and not a substitute. Wounds that do not show clinical improvement within several days require additional operative intervention.

Full-Thickness Soft Tissue Necrosis

Full-thickness soft tissue necrosis is usually associated with exposed prosthetic components and requires immediate, aggressive debridement (Fig. 5.5). Simple secondary closure procedures

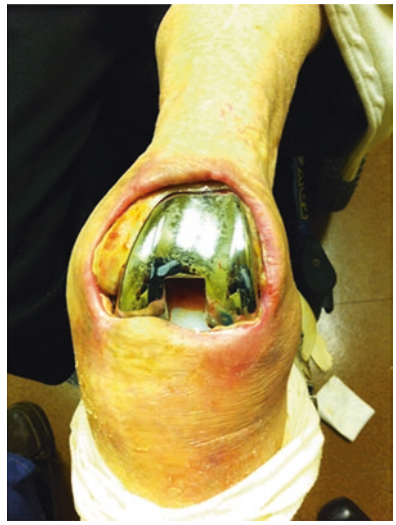

Fig. 5.5 Photograph of a patient afflicted with severe rheumatoid arthritis after revision TKA complicated with full-thickness skin necrosis and exposed components

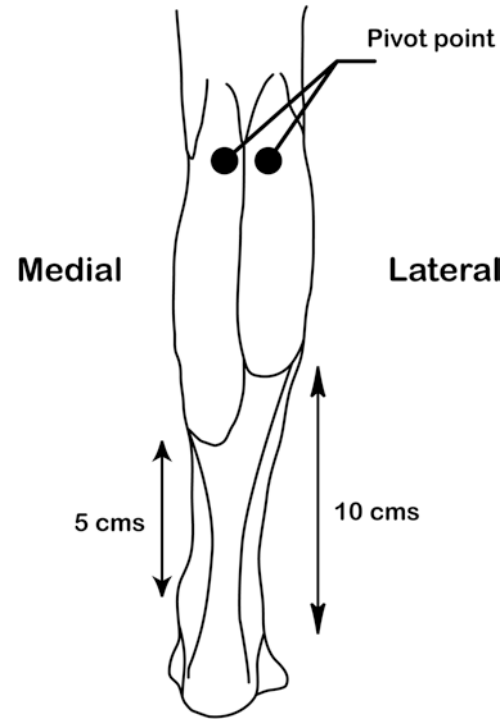

Fig. 5.6 Diagram demonstrating the pivot points for a medial and lateral gastrocnemius flaps for soft tissue reconstruction

are often unsuccessful, and some type of flap reconstruction is usually required. Various types of flaps have been used, including cutaneous [65], fasciocutaneous, [61, 62] myocutaneous [65–71], and myotendinous [72]. Bengston and associates [66] reported on the treatment of 10 TKAs with full-thickness skin loss and exposed prosthetic components. Delayed closure failed in six of six cases in which it was attempted. Split-thickness skin grafting failed in both cases in which it was utilized. In contrast, coverage with gastrocnemius myocutaneous flaps proved successful and was recommended as the treatment of choice in these cases. Gerwin et al. [73] reviewed 12 patients with full-thickness skin necrosis and exposed prostheses, 6 of which had positive deep cultures. All patients were treated with aggressive debridement and closure with medial gastrocnemius myocutaneous flaps. Eleven of 12 patients (92%) obtained excellent results, with 10 (82%) retaining their components or having a successful reimplantation. Nahabedian et al. [74] reported an 83% success rate in salvaging TKAs with wound breakdown with medial gastrocnemius flaps. Adam et al. [75] presented a 76% success rate in preserving TKAs with exposed components due to wound breakdown with myocutaneous flaps, but the functional results were not as good as compared with knees that healed with primary wound healing, stressing once again the importance of preoperative assessment and intraoperative techniques to minimize wound complications from occurring.

The medial head of the gastrocnemius muscle is often the preferred flap for reconstruction [74]. It is both larger and 2–3 cm longer than the lateral gastrocnemius muscle (Fig. 5.6). Furthermore, because it does not have to traverse the fibula, it has a larger arc of motion. It provides excellent soft tissue coverage in the region of the patella and tibial tubercle, the area where the incidence of skin necrosis is the highest (Fig. 5.7a, b). Free myocutaneous flaps may be used, but they are reserved for cases with full-thickness necrosis that cannot be covered with other local flap reconstructions. In cases in which tendinous structures are compromised by infection or debridement, myotendinous gastrocnemius flaps

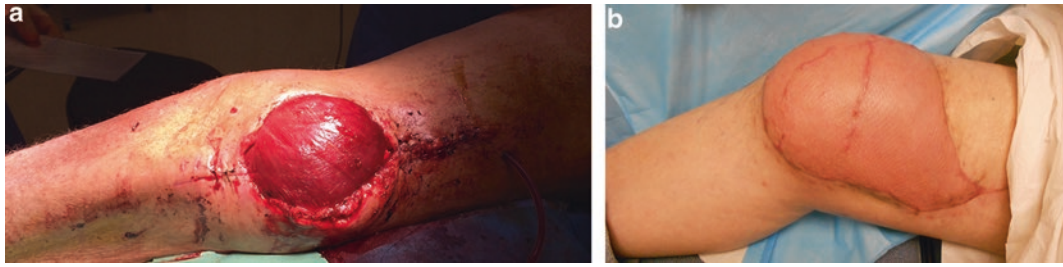

Fig. 5.7 (**a**, **b**). Intraoperative photograph of a medial head of the gastrocnemius muscle flap for reconstruction of an anterior soft tissue defect after total knee arthroplasty (**a**) (Courtesy of Conrad Tierre, MD). Postoperative image of a healed medial gastrocnemius muscle flap in a patient with wound complications following total knee arthroplasty (**b**) (Courtesy of Conrad Tierre, MD)

can be used [72]. This flap uses the superficial layer of the Achilles tendon with the deep aponeurotic layer of the gastrocnemius to reconstruct quadriceps or patellar tendon defects.

Antibiotic use

Parenteral antibiotics are often required in cases with persistent drainage and wound necrosis but should not be used indiscriminately. Unnecessary use of antibiotics risks alteration of bacterial flora and sensitivities, should deep infection occur. Joint aspiration for culture is suggested before initiation of antibiotic therapy to maximize culture results. The thresholds in the acute postoperative period (within 6 weeks of surgery) are higher with synovial white blood cell and polymorphonuclear cutoffs being as high as 27,800 and 89%, respectively [76]. Cultures of superficial drainage are often spurious, with little correlation with deep infecting organisms [77, 78].

Summary

Wound problems are a dreaded complication following TKA, and all measures should be taken to avoid them. Preventative measures include modification of patient risk factors, proper choice of the skin incision, gentle handling of the soft tissues, meticulous hemostasis, and wound closure without excessive tension. Should persistent wound drainage or soft tissue necrosis occur, early intervention is imperative, because delay risks deep infection and ultimate failure of the TKA. Cases associated with full-thickness soft tissue necrosis often require transfer of well-vascularized tissue, such as a medial gastrocnemius myocutaneous flap reconstruction.

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Extensile Exposures for Total Knee Arthroplasty

6

Richard L. Purcell, Nitin Goyal, and Gerard A. Engh

A well-planned surgical approach allowing for adequate exposure is one of the more common difficulties encountered in revision total knee arthroplasty. Careful attention must be paid to patients who have undergone previous knee operations as the skin may have become densely scarred into the deep fascial layers or even to the underlying bone. As a result, the surgical approach is particularly difficult secondary to a loss of tissue elasticity, which can place the patient at risk for wound breakdown.

Patients who are at increased risk for wound healing and deep infection include immunocompromised individuals such as those with diabetes, rheumatoid arthritis, systemic lupus erythematous, acquired immunodeficiency syndrome, as well as patients on immunosuppressive medications or corticosteroids. These patients are not only susceptible to infection due to their reduced ability to fight infection but also related to the friable nature of their skin which can make them especially prone to skin sloughs from manual pressure or excessive skin retraction.

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Vascular Anatomy

A thorough understanding of the bony, ligamentous, and vascular anatomy of the knee is paramount in allowing for a safe and sufficient surgical exposure while preserving the biomechanics of the knee and minimizing the chance for skin necrosis and deep infection.

The blood supply to the skin of the knee is well understood due to the work of Haertsch et al. [1] The vascular supply to the overlying skin of the knee is asymmetrical with the majority of perforators originating off the saphenous artery and the descending geniculate artery. There is an anastomosis of vessels just deep to the fascia of the knee with small perforators penetrating and supplying the overlying skin. Therefore, wide dissection superficial to the fascia may violate the blood supply, where dissection deep to the fascia will preserve these skin perforators and avoid vascular compromise. If multiple previous longitudinal incisions are present, using the lateral-most incision that will still allow for adequate exposure is recommended while preserving the medially based vascular supply.

In some instances it may be necessary to incorporate a prior incision or to cross an old transverse skin incision. As a rule, any new incision should intersect an old incision at a right angle as much as possible. A new incision should not engage an old incision at an acute angle, as the thin peninsula of skin isolated between the two incisions is susceptible to skin necrosis (Fig. 6.1).

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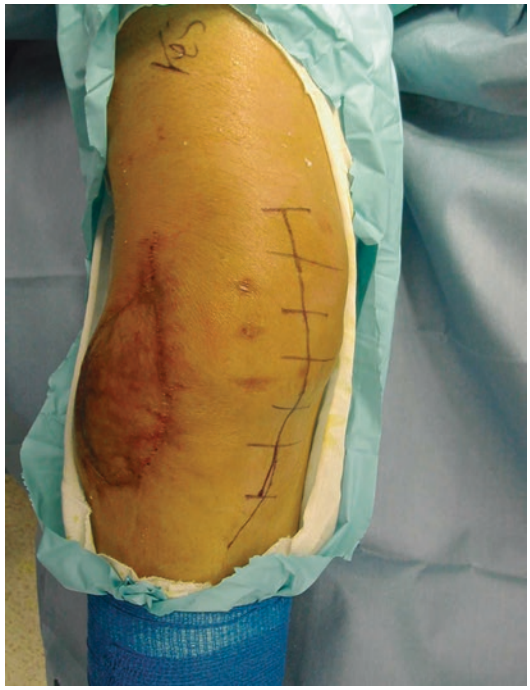

Fig. 6.1 After revision arthroplasty for infection and placement of a lateral gastrocnemius pedicle flap, this incision is displaced to the medial side of the midline in order to preserve a skin bridge at least two times the length of the planned longitudinal incision

Two areas of skin that are particularly vulnerable to breakdown are over the anteromedial proximal tibia and over the patella due to the marginal soft tissue beneath the skin. During the early postoperative period, special attention should be paid to these areas, and early intervention in the form of advanced wound care techniques should be employed to mitigate the risk for further breakdown as skin grafting alone is generally not possible due to the limited muscle bulk available.

The blood supply to the patella is formed from an anastomosis of arteries arising from the descending genicular, superior, and inferior medial and lateral genicular arteries as well as the anterior tibial recurrent artery [2]. The majority of blood supply to the patella is from the superior lateral genicular artery. An increased incidence of patellar fracture, fragmentation, and avascular necrosis has been documented with lateral release and subsequent compromise of this artery [3]. When a lateral release is required, care must be taken to preserve this artery. It is generally recommended to perform the release via an inside-out technique to avoid undermining the lateral skin edge and subsequent risk for skin edge necrosis.

Preoperative Assessment

A detailed medical history should be obtained to elucidate any details of previous surgeries on the knee with special attention paid to any wound healing problems, wound drainage, or extended use of postoperative antibiotics. The surgeon should document the location of the most recently used incision and any history of wound healing problems with use of that incision. Discoloration of previous wound edges with hemosiderin may shed light on previous wound healing complications. A history of knee stiffness or loss of knee motion is important to determine as well as inquiring when the stiffness began and what methods of management, if any, were employed to restore motion.

Knee range of motion, flexion contractures, and extensor lag should all be measured and documented carefully. A knee with extensor lag may suggest extensor mechanism dysfunction and is associated with poor long-term results. A stiff knee is at risk for patellar tendon rupture at the time of surgery. Patellar mobility should be examined with special regard to limited motion in the coronal plane as this may indicate scarring of the extensor mechanism. Location of the patella is also important, as the finding of patella baja will make subluxation or dislocation of the patella more difficult at the time of surgery and may necessitate further exposure options discussed in detail later.

If there is concern about the pliability of the soft tissue envelope that may result in a tenuous wound closure at the conclusion of the case, a preoperative plastic surgery consultation should be considered. Although tissue expansion or use of a sham incision are generally carried out by plastic surgeons, many orthopaedic surgeons prefer to do these procedures themselves as they

have the best understanding of their requirements relative to the skin and soft tissues for wound closure. In order to avoid last minute decision making in the operating room, details of the planned surgical approach should be documented in the preoperative notes so the surgeon can implement this plan on the day of surgery.

Preoperative radiographs are useful in determining if there is a bony restriction to knee flexion. In most instances, standard anterior-posterior (AP) and lateral radiographs provide satisfactory visualization of the knee components. The lateral radiograph is particularly helpful in identifying posterior osteophytes or heterotopic bone that may block flexion and in determining the location of the patella. An Insall-Salvati ratio of less than one indicates a shortened patellar tendon that will make patellar displacement difficult. The AP radiograph is useful in identifying capsular ossification, periosteal new bone formation, and component subsidence. Full-limb standing radiographs of the extremity may be required to evaluate the quality of fixation and the location of the femoral and tibial stems. The surgeon should pay particular attention to the fixation of the tibial stem. In some circumstances, a tibial tubercle osteotomy is necessary to access a well-fixed tibial stem. Given a well-fixed femoral stem, it may be necessary to breach the anterior femoral cortex to access the stem-cement interface.

Addressing the Stiff Knee

If during the preoperative evaluation the patient is noted to have flexion limited to 90° or less, a modification to the routine surgical approach is warranted. This is carried out in a logical, systematic way to enhance visualization while doing so in a safe and reasonable manner.

Skin and Capsular Incision

The skin incision used should be performed according to the principles previously discussed and identified during the preoperative examination. It is generally easier to incise the skin with the knee held in flexion as this allows for tension/counter-tension on the skin. The incision should be at least 8–10 in. in length, as limiting surgical exposure through a smaller incision is not recommended as this can place undue stress on the already compromised soft tissue envelope. Extending the incision past any previous surgical incision may aid in the identification of normal anatomic tissue planes free of any scar tissue that will help with deeper tissue dissection (Fig. 6.2).

The traditional medial parapatellar capsular incision is the workhorse for revision total knee arthroplasty as other capsular incisions such as the midvastus or subvastus are avoided as they can compromise exposure and result in excessive tension on the patellar tendon insertion. The middle and distal extent of the capsulotomy are fairly well standardized; however there are various techniques in carrying out the proximal extent of the capsulotomy. The most common practice is to extend the incision proximally just lateral to the medial border of the quadriceps tendon, ensuring a cuff of tissue to repair to. Alternatively, detaching the part of the quadriceps tendon in an oblique fashion (directed away from the vastus medialis) from its insertion on the patella can allow for patellar displacement in cases of mild knee stiffness. This technique has been dubbed "the wandering residents" approach (Fig. 6.3).

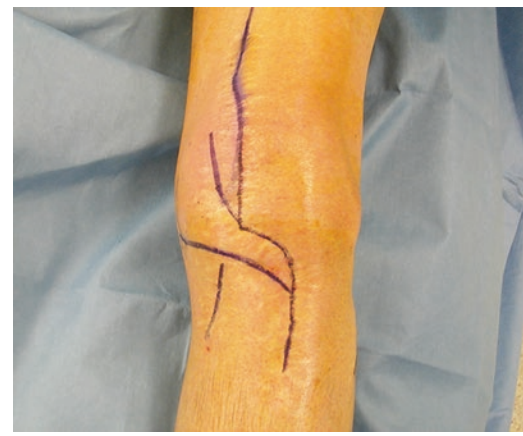

Fig. 6.2 Multiple previous scars are outlined with a marking pencil. The skin and subcutaneous tissues adhere at the apex of the interconnecting scars. A decision was made to use tissue expanders preoperatively because of the multiple scars and loss of skin elasticity

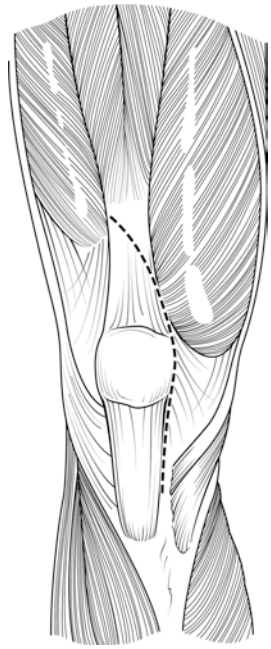

Fig. 6.3 The wandering resident approach

Hendel et al. reported on its use in a retrospective cohort of 18 patients with a preoperative flexion arc of 50° that improved to 86° postoperatively [4]. An alternative incision is the direct midline capsular incision as described by Insall in which the extensor retinaculum is peeled from the medial side of the patella [5]. The surgeon should use whichever technique he/she is most comfortable with that allows for full exposure while avoiding iatrogenic rupture of the patellar tendon during patellar dislocation or subluxation.

Restoring Synovial Recesses and Dealing with Intracapsular Scar Formation

After a capsulotomy has been performed, the surgeon will likely encounter some degree of intracapsular adhesion formation that will need to be addressed prior to displacing the patella and obtaining full exposure of the knee joint. Within the suprapatellar region, there will typically be adhesion formation beneath the quadriceps tendon as well as between capsular layers over both

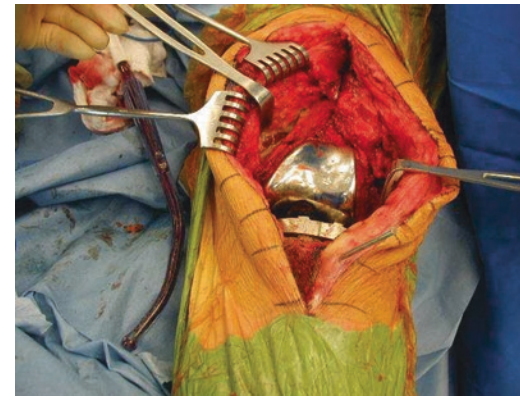

Fig. 6.4 The synovial recesses are opened elevating the vastus medialis from adhesions to the medial femoral condyle

femoral condyles. This scar formation will limit full exposure of the femur, as the tissue will not fall away during knee flexion (Fig. 6.4). These adhesions should be divided with either sharp dissection or cautery. The dissection should continue both medially and laterally over the condyles and down into the medial and lateral gutters, taking care to stay superficial to the collateral ligaments. It may help to bring the knee into full extension in order to fully free the lateral gutter of adhesions and to ultimately allow for lateral displacement or dislocation of the patella over the lateral femoral condyle.

The capsular incision is extended distally, opening the joint capsule medial to the patella and patellar tendon and ending at the inferior margin of the tibial flare, just proximal to the pes anserine insertion. The incision should leave a small border of capsular tissue on the medial side of the patellar tendon to permit capsular closure without placing sutures directly into the patellar tendon. The medial joint capsule then is elevated from the medial tibial flare at least to the midline of the tibia. The sleeve of tissue must remain intact as it contains fibers of the deep medial collateral ligament and can be avulsed easily from the tibial flare creating gross medial laxity of the knee.

Detaching the medial capsule from the anterior one-half of the metaphyseal flare will allow the tibia to sublux forward from under the medial femoral condyle in primary knee arthroplasty

cases. With the more extensive scarring present with revision cases, the capsule may need to be released around to the posterior corner of the medial tibial plateau. This step is necessary if a stemmed tibial component is being revised.

In the setting of revision total knee arthroplasty, a dense layer of scar may be seen deep to the extensor mechanism. The tissue that develops around the patella is a distinct layer of fibrous tissue that engulfs the margins of the patellar implant. A similar dense layer of scar forms along the entire course of the patellar and quadriceps tendon. This layer limits the elasticity of the extensor mechanism. This scar should be excised to restore the pliability of the patellar and quadriceps tendons. Often, a layer of fat is still present beneath this layer of scar, making it relatively easy to remove and identify the shiny, organized fibers of the tendons without violating their integrity.

Patellar Dislocation

All intracapsular scar formation should be thoroughly released prior to any attempt to flex the knee and displace the patella. In order to fully expose the tibiofemoral joint, the patella can be dislocated in one of two ways. Traditionally, while scrutinizing the patellar tendon insertion, the patella is everted and dislocated as the knee is brought into flexion. The knee should be flexed slowly as the tibia is externally rotated to reduce stress on the patellar tendon. If flexion is blocked or the patellar tendon insertion is in jeopardy, then alternative steps should be taken to relax the extensor mechanism.

An alternative method for dislocating the patella described by Fehring et al. uses inversion rather than the traditional complete eversion of the patella [6]. In essence, the patella is slid laterally over the side of the lateral femoral condyle using a bent Homan retractor to hold the patella lateral to the distal femur. With this technique, exposure of the proximal tibia can be slightly compromised. The authors advocate making an anteromedial to posterolateral tibial cut with an extramedullary guide or, if the incision does not provide adequate exposure for the tibial cut, using an intramedullary guide as is used traditionally with revision total knee arthroplasty instrumentation. This method of exposure was used in 95% of the revision cases in Fehring's study without a single case of patellar tendon avulsion. If the knee can be flexed to 110° with the patella displaced laterally either by eversion or inversion, the case can likely continue without any additional extensile exposures.

Extensile Exposures

Whenever the knee lacks 90° of flexion, the extensor mechanism is at risk of avulsion or rupture when vigorous efforts are made to retract the patella to achieve exposure. If the extensor mechanism is not relaxed, avulsion of the patellar tendon at its insertion to the tibial tubercle may occur. This is the weakest point of the structure, as the surgical approach alone devascularizes a majority of the tendon [7]. Avulsion or rupture of the patellar tendon that occurs intraoperatively is a difficult complication to manage. Direct suture or staple repair has a high rate of failure and has resulted in high rates of deep infection, tendon re-rupture, and extensor lag [8, 9]. In the setting of poor tissue quality, augmented repair with a hamstring autograft requires prolonged postoperative knee immobilization [10]. Although the extensor mechanism can be stabilized, immobilization of an already stiff knee is likely to result in less than satisfactory postoperative knee motion.

Relaxing tension from the extensor mechanism should not be an afterthought performed only after struggling with a difficult surgical exposure. Methods of relaxing tension include quadriceps snip, quadriceps (patellar) turn down, and a tibial tubercle osteotomy. Each of the three options has indications based upon patellar location and where along the extensor mechanism the primary location of immobility is. Thus, the decision of which adjunct procedure to use should be thoroughly considered in the preoperative planning and carried out strategically during the surgical exposure. When patella baja is present, a distal release with a tibial tubercle osteotomy should be considered. In severe patella baja,

no amount of proximal release may be sufficient to translate the patella laterally. In addition, the osteotomized tubercle can be translated as much as 2 cm proximally, which will improve both range of motion and patellar impingement against the tibial component. When the patella is in a normal or elevated position, the scarring that limits knee motion is most severe in the quadriceps tendon. A proximal release provides direct access to the scarred area and is more likely to aid in the recovery of knee motion. In a study by Barrack et al., patients who underwent a full quadriceps turndown were compared with a group of patients managed with tibial tubercle osteotomies [11]. The group of patients who had quadriceps turndown had a significantly greater increase in the arc of motion.

Quadriceps Snip

The quadriceps snip, originally described by Insall, is the most widely used method for relaxing and protecting the extensor mechanism with revision total knee arthroplasty when the standard medial parapatellar approach fails to give adequate exposure and a small amount of additional exposure is needed to safely dislocate the patella (Fig. 6.5) [12]. This exposure is technically straightforward and has the advantage of causing minimal risk to the extensor mechanism with no postoperative immobilization needed.

The most important consideration with a quadriceps snip is to divide the tendon at its proximal end, near the musculotendinous junction. This is to avoid devascularization of the patella and, more importantly, to allow direct repair of the vastus medialis into the quadriceps tendon and the quadriceps expansion distal to the location of the snip.

Technique

At the apical end of the standard medial parapatellar incision, the junction of the rectus femoris with the quadriceps tendon is identified, and the tendon is divided obliquely at a 45° angle in an inferomedial to superolateral direction, parallel to the direction of the vastus lateralis muscle fibers. Insall originally performed the quadriceps snip with a transverse incision across the quadriceps tendon. An advantage to a 45° oblique incision through the tendon is to maintain the entirety of the vastus lateralis insertion to the quadriceps tendon. The intact vastus lateralis bridge, as this is called, preserves blood supply to the quadriceps tendon and the patella.

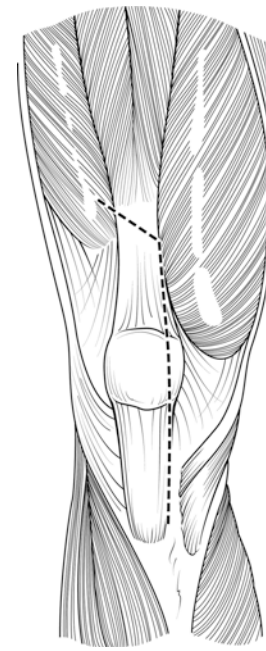

Fig. 6.5 The quadriceps snip

Results of this exposure have shown no adverse effects with regard to the overall outcome of these patients postoperatively. Garvin et al. reported on 16 patients who underwent this procedure, and all patients had good or excellent ratings based on the Hospital for Special Surgery (HSS) knee score [12]. The authors compared peak torque and work of the operated knee compared to the contralateral previously operated knee that only underwent a standard medial parapatellar approach and did not find any statistically significant differences.

More recently, Meek et al. reported on 107 patients, 57 who underwent a standard approach and 50 who required a rectus snip [13]. They found no differences in Western Ontario and MacMaster Universities Arthritis Index (WOMAC) scores

and also concluded that this exposure has no effect on clinical outcome.

V-Y Quadricepsplasty or Quadriceps Turndown

A quadriceps turndown is a feasible option but should be reserved only for the most severely ankylosed knees. In such knees, scarring can be so extensive in the lateral gutter, capsule, and vastus lateralis as to prohibit knee flexion even with a full quadriceps release. Prior to converting a quadriceps snip to a full quadriceps turndown, a full lateral retinacular release should be performed. The lateral retinacular release may be enough to allow knee flexion. However, if knee flexion remains limited following a lateral retinacular release, a decision must be made either to proceed with a full turndown or to combine a tibial tubercle osteotomy with a quadriceps snip. The determining factor is whether the pathology prohibiting flexion is mostly adhesions in the lateral gutter or adhesions distal and posterior to the patellar tendon.

In 1943, Coonse and Adams originally described a quadriceps turndown as an inverted V-incision with the capsule and quadriceps tendon turned distally on a broad-based flap to preserve vascularity [14]. The drawback from this approach was that it could not be converted from a standard medial parapatellar incision. Therefore, Insall modified the technique from a standard medial parapatellar incision to allow extensile exposure of the knee similar to the Coonse-Adams, however with the theoretical advantage of preserving the inferior lateral geniculate artery (Fig. 6.6) [5]. This approach was further modified by Scott and Siliski by dividing the quadriceps tendon obliquely but downward and distally and detaching the vastus lateralis muscle through its tendinous insertion but maintaining the integrity of the lateral retinaculum and therefore preserving the superior lateral geniculate artery (Fig. 6.7) [15]. Trousdale et al. reported on a series of patients who underwent total knee arthroplasty with use of the V-Y quadricepsplasty [16]. They found no differences in isokinetic knee strength between the knee that underwent the V-Y quadricepsplasty and either the contralateral TKA without an extensile approach or a

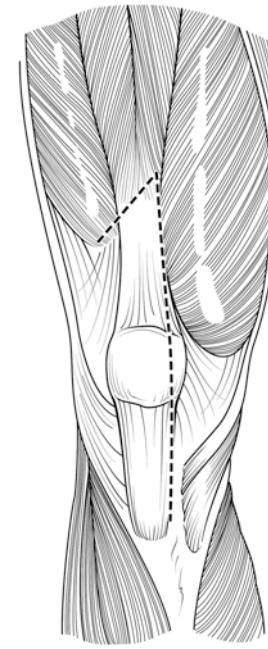

Fig. 6.6 The quadriceps turndown

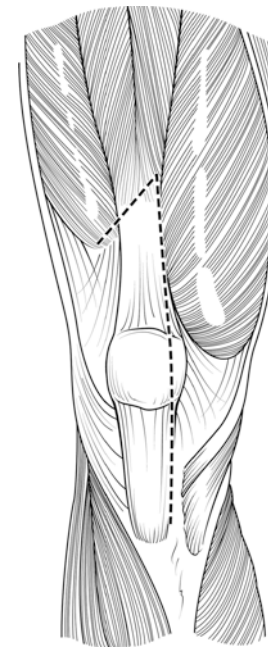

Fig. 6.7 The V-Y quadricepsplasty

group of aged matched controls with an implanted standard medial parapatellar TKA.

Technique

A standard medial parapatellar approach is made. A second incision made at a 45° acute angle from the apex of the quadriceps tendon is extended distally through the vastus lateralis tendinous insertion. The base of the capsular incision should be broad with the apex at the proximal end of the quadriceps tendon. To avoid devascularization of the patella, the inferior lateral genicular artery should be preserved along with the vessels within the remaining fat pad attached to the inferior pole of the patella.

The apex of the quadriceps tendon must be repaired along with the entire medial arthrotomy. If necessary to achieve correct patellar tracking, the lateral retinaculum can be left open as a lateral retinacular release. The patient should be immobilized in extension for at least 2 weeks and then limited to flexion beyond 60° for the next 6 weeks. Most patients will have an extension lag that, as a rule, resolves within 6 months.

Tibial Tubercle Osteotomy

In 1983, Dolin originally introduced the use of a tibial tubercle osteotomy (TTO) in total knee arthroplasty (Fig. 6.8) [17]. A longitudinal osteotomy 4.5 cm in length was made along the medial border of the tibial tubercle. The tibial tubercle and attached tendon were then flipped laterally, leaving the lateral soft tissues and a small bone bridge to act as an osteoperiosteal flap. To repair the osteotomy, a 36-mm cortical screw was passed through a drill hole (approximately 4.5 mm) in the tibial tubercle and anchored into a threaded hole in the underlying bone cement. Dolin reported no complications with this technique used in the knees of 30 patients, including 4 knees with advancement or relocation to optimize extensor mechanism balance. However, Wolff et al. reported a high incidence of fixation failure with TTO in knees in which the tubercle fragment was short and fixed with screws [18].

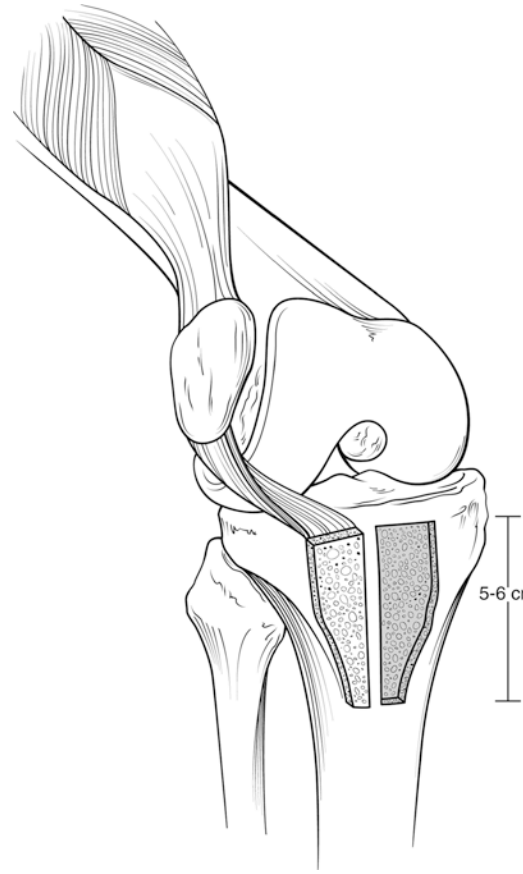

Fig. 6.8 The tibial tubercle osteotomy

Whiteside subsequently modified and popularized Dolin's technique recognizing the advantages of an TTO with fixation with wires instead of screws [19]. He also noted that a tibial tubercle osteotomy provided excellent exposure by laterally displacing the tibial tubercle along with the patellar tendon and patella. An extended tibial tubercle osteotomy was used in a series of 136 total knee arthroplasties that included 76 revision procedures. The postoperative rehabilitation was not modified. With the use of wire, the potential for loss of fixation was reduced. Only two proximal tubercle avulsion fractures occurred, but these fractures did not widely separate or result in quadriceps dysfunction.

A recent article by Young et al. describes their use of a TTO in 97 revision TKAs with an average follow-up of 30 months [20]. They reported excellent or good patient satisfaction in 87%

of patients with a mean flexion arc of 107°. Satisfactory healing of the osteotomy without nonunion, extensor lag, or metaphyseal stress fracture occurred in 93% of patients. The most common complication was proximal migration of the osteotomized fragment; however none of these patients had extensor lag or weakness with knee extension.

Technique

The tibial tubercle osteotomy, as described by Whiteside, should be 6–8 cm in length. The corners of the osteotomy are marked and drilled with a 1/8-in. drill. The tibial metaphyseal cortex is then opened with an oscillating saw along the length of the osteotomy. The width of the osteotomy should be at least the full width but preferably 1½ times the width of the tibial tubercle. The proximal transverse cut is made in an oblique upward manner to provide a ledge on the fragment of bone to prevent proximal migration of the osteotomized tubercle after reduction of the osteotomy. The distal transverse bone cut is made at a 45° angle from the longitudinal cut. The lateral metaphyseal cortex is then perforated with a 1-in. wide curved osteotome along the length of the planned osteotomy. The osteotomized fragment is hinged laterally, maintaining all of the soft tissue attachments, in order to prevent proximal migration of the fragment. To allow full eversion of the tibial tubercle, the more proximal capsular and soft tissue attachments located just lateral of the tibial plateau and more proximally along the lateral border of the patellar tendon must be released.

Rigid fixation of the tibial tubercle to the tibia is essential to restore knee flexion in the early postoperative interval. The use of three wires (16-gauge or stronger) passed through drill holes in the tubercle and medial tibial cortex is the preferred method of fixation. The drill holes are placed at an obliquely downward angle to minimize the risk of proximal migration of the tibial tubercle. Range of motion in the knee should be passively tested to be sure the fixation is rigid. To further enhance fixation, cortical or cancellous screws can be placed, or a cerclage wire can be passed through both cortices. The long stem of a revision tibial component may have to be negotiated to accommodate supplemental screw fixation.

Exposure for revision surgery is optimal with a tibial tubercle osteotomy. The extensor muscles including the rectus femoris are not compromised, allowing for a quicker and more complete recovery of extensor mechanism function as compared with a quadriceps snip. However with a tubercle osteotomy, bone bleeding is increased, and the soft tissue coverage over the tibial tubercle is often only skin with no substantial subcutaneous tissue. Postoperative wound drainage from this area can lead to sinus tract formation and the potential for deep infection. An additional risk associated with a tibial tubercle osteotomy is that fixation can be lost and/or fracture of either the tubercle fragment or the tibia can occur. As previously mentioned, Whiteside reported 3 tibial shaft fractures from a group of 136 total knee arthroplasties managed with an extended tibial tubercle osteotomy. Ritter et al. reported two tibial shaft fractures from nine revision total knee arthroplasties managed with a 10-cm long extended tibial tubercle osteotomy [21].

Alternative Techniques for Achieving Surgical Exposure

Situations that require more radical maneuvers to achieve adequate exposure in the most difficult of revision cases may present. Three techniques should be considered when scarring and ankylosis are extensive and of long-standing duration. These are the femoral peel, epicondylar osteotomy, and quadriceps myocutaneous flap.

Femoral Peel

In 1988, Windsor and Insall described a technique called a femoral peel [22]. As its name implies, a femoral peel releases all of the soft tissues subperiosteally from the distal end of the femur, effectively skeletonizing the distal femur. A femoral peel is necessary when the extent of posterior knee scar tissue formation is so robust

that even after removing the block to knee flexion from the extensor mechanism the knee still cannot be adequately flexed in order to proceed with revision knee arthroplasty.

In knees that have lost flexibility, the synovial pouch and capsular recesses in the posterior fossa are often obliterated on both the medial and lateral sides. In addition, osteophytes and foreign bodies from implant delamination and wear may interfere with knee flexion. From an anterior approach to the knee, it is surgically impossible to remove this block to flexion. Often, the surgeon has released the soft tissue attachments around the medial side of the knee completely and still cannot achieve enough knee flexion to proceed with revision surgery. Thus, the decision to perform a femoral peel usually is not planned but becomes necessary in the course of a revision total knee arthroplasty.

In knees without extensive scarring, stripping the collateral ligaments and all capsular structures from the femur would undoubtedly result in marked knee instability. However, when the capsular envelope is extensively scarred and thickened, stability is restored at the end of the operation by simply re-approximating the medial parapatellar incision. The inelastic quality of the soft tissue envelope provides satisfactory stability to the knee even though the bony attachments of the collateral and capsular ligaments have been sacrificed.

The only clinical study to date looking at outcomes of patients following revision TKA with use of the femoral peel was by Lavernia and Contreras in 2011 [23]. The authors retrospectively reviewed 132 revision TKAs and found a statistically significant improvement in HSS knee scores postoperatively with and average increase in knee flexion arc of 10°. They reported a 12% orthopaedic-related complication rate with three patients sustaining tibiofemoral dislocation of the arthroplasty. Of the patients requiring a reoperation, they observed complete collateral ligament adhesion to bone and conclude that the complete tissue sleeve (including the ligaments) heals and adheres to bone as long as the ligaments are not transected.

Technique

In most instances, the femoral peel involves only detaching the collaterals and capsular structures from the medial femoral condyle. This can be accomplished either with sharp dissection or with a cautery. Once the capsule is dissected free from the medial femoral condyle, the knee loses stability in flexion, and the scarred capsular structures blocking flexion can be excised from the medial side.

In the most severe cases, the distal femur is fully skeletonized on both the medial and lateral sides delivering the femur through its soft tissue investment. The femoral peel is relatively safe as long as the tissue dissection is close to the bone. Often after completing a femoral peel, the hypertrophic scar will need to be excised from the posterior fossa to allow knee flexion. After the hypertrophic capsule and scar are removed, a relatively thin and pliable layer of posterior capsule is still present and can be identified by placing the knee in full extension and distracting the tibia away from the femur.

No attempt is made to reattach the collateral ligaments to the femoral condyles. With the knee in full extension, stability of the knee is usually excellent even before capsular repair. When the patella is reduced and the repairs of the extensor retinaculum and wound closure are complete, the knee is stable in flexion. The extensive soft tissue dissection may devascularize the distal end of the femur along with potential for inadvertent injury to the neurovascular structures posterior to the knee. Thus, caution is recommended with this procedure.

Medial Epicondylar Osteotomy

Epicondylar osteotomy is another valuable method of enhancing exposure in both total knee arthroplasty and revision knee arthroplasty [24]. Much like a femoral peel, an epicondylar osteotomy provides exposure of the posterior compartments of the knee by destabilizing the knee in flexion. Instead of sharply releasing all the soft tissues including the collateral ligaments from the condyles, an epicondylar osteotomy detaches

the epicondyle with a large fragment of the bone that can be reattached to restore stability after the revision components have been implanted. In this regard, an epicondylar osteotomy is somewhat similar to a tibial tubercle osteotomy; one end of a stabilizing structure is released temporarily to allow access for revision surgery, and the structure is then repaired to reestablish stability. In most instances, the osteotomy involves only the medial epicondyle. With the medial epicondyle detached, the knee is unstable medially in flexion, and the knee hinges open laterally with the extensor mechanism and tibia externally rotated. An osteotomy of both femoral epicondyles is indicated in two scenarios. The first is in the conversion of a knee fusion to a total knee arthroplasty, and the second is when a full distal femoral allograft is used in the composite reconstruction of a failed total knee arthroplasty. In both instances, the reattached epicondyles restore stability in flexion so effectively that even varus-valgus or constrained condylar components have not been necessary.

The epicondylar osteotomy does not rely upon a densely scarred soft tissue envelope to provide stability. Therefore, an epicondylar osteotomy is indicated when knee flexion is blocked, yet the collateral ligaments and capsular tissues are not a thickened sleeve of hypertrophic fascial tissue. The decision between an epicondylar osteotomy and a femoral peel is dictated by the character of tissue encountered during the revision surgical exposure.

Technique

The epicondylar osteotomy is performed with the knee at 90° of knee flexion. Osteophytes are removed from the margins of the medial femoral condyle. A 1½-in. osteotome is placed in the long axis of the femur just lateral to the origin of the medial collateral ligament (Fig. 6.9). By palpating the epicondyle proximally, the adductor magnus tendon is located. The osteotome is advanced so as to exit above the adductor tendon. This will assure that the adductor tendon, as well as the collateral ligament, is fully released with the osteotomized bone fragment. A fragment of bone approximately 4 cm in diameter and 1-cm thick is detached from the epicondyle. A cortical bridge of bone should remain at the junction of the osteotomized epicondyle and the anterior femoral resection for the revision knee implant. This bridge is used for anchoring repair sutures to reattach the epicondyle at the end of the procedure.

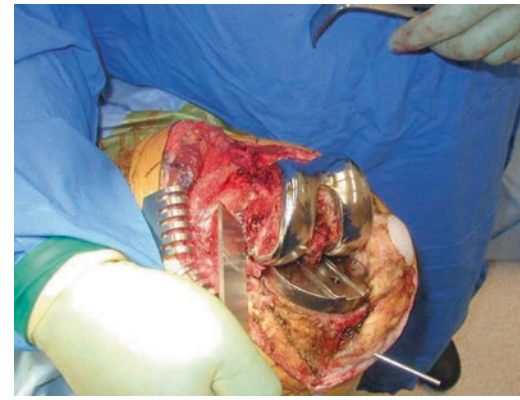

Fig. 6.9 A medial epicondylar osteotomy is performed with a 1½ in. osteotome

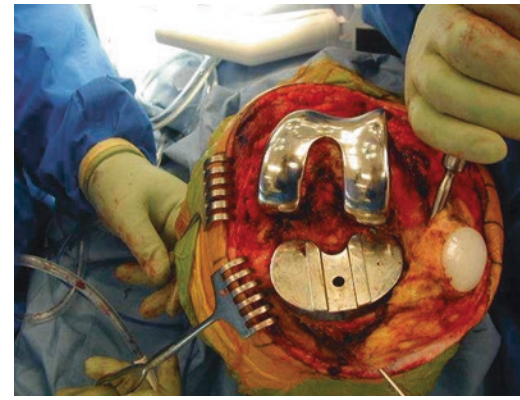

Fig. 6.10 Following the epicondylar osteotomy, the tibia is easily rotated away from the medial femoral condyle, and the posterior fossa is exposed

The wafer of bone is detached and hinged posteriorly with the large osteotome. This provides direct visualization of the posterior capsule (Fig. 6.10). The posterior capsule is released directly from the back of the femur with a cautery while the knee is in flexion and hinged open laterally. Hypertrophic capsule osteophytes and foreign bodies are easily visualized and removed to further enhance exposure. The tissue can be dissected across the entire posterior compartment of

the knee. The tibia will fall back underneath the femur only when exuberant soft tissue has been removed restoring a semblance of posterior recesses to the knee.

Detaching the medial epicondyle in continuity with the adductor tendon does not create knee instability in extension. In fact, with the knee in extension, the knee often is still unbalanced. If the knee failed in a varus manner, the medial side will remain too tight. A similar situation can be encountered with a femoral peel. In such a situation, further release of the medial soft tissue sleeve is indicated to restore a balanced extension gap. This can be accomplished either by conventional stripping of the collaterals from the tibial metaphysis or by selectively detaching contracted portions of the medial collateral ligament from the inferior aspect of the medial epicondyle.

After the revision is complete, the epicondylar fragment of bone is repaired with heavy nonabsorbable or slowly absorbable (#2 or heavier) sutures placed through the epicondyle and adjacent medial femoral condyle. The cortical bridge at the anteromedial border of the knee is used to anchor these sutures. A heavy gauge needle is passed through the epicondyle and then under the cortical bridge in a figure of eight or mattress fashion. A minimum of three sutures is necessary for the repair. Like the osteotomy, the repair is performed with the knee at 90° flexion, recognizing that stability in flexion is being restored with the final components in place. The epicondyle may be positioned posteriorly because of scar tissue. If this occurs, a release of this tissue from the posterior border of the epicondyle is necessary to allow the epicondyle to reposition to a satisfactory location. Some of the epicondylar wafer may overhang the condyle. In this case, the overhanging bone may need to be trimmed back to avoid impinging with the prosthesis.

Osteotomy of the lateral femoral epicondyle also is performed with the knee in 90° flexion. The fragment of bone is usually 3 cm in diameter. There is no tendon that inserts into the lateral epicondyle from the proximal end; therefore, stability can be lost in both flexion and extension, even though the iliotibial band provides some stability in extension. The lateral epicondyle can be reattached with heavy non-absorbable or slowly absorbable sutures. Cancellous lag screws also may be used if the revision prosthesis does not preclude the placement and stability of the screws. If screws are used, the drill hole in the epicondylar fragment should be slightly oversized to avoid fragmentation of the epicondyle when the screw is inserted.

Quadriceps Myocutaneous Flap

Kerry et al. described a technique for tumor resection and insertion of a prosthesis in which a U-shaped myocutaneous flap based on the quadriceps muscle is used in the surgical approach [25]. Medial and lateral longitudinal incisions are made along the line of the femoral shaft and joined by a transverse anterior incision. Next, the extensor mechanism is divided, either by a turndown through the quadriceps tendon or a turnup through the tibial tubercle. The quadriceps muscle remains attached to both the deep fascia and skin, thereby preserving the blood supply to the soft tissues while exposing the entire distal end of the femur. The entire quadriceps muscle is raised from the lateral intermuscular septum and from the medial side along the adductor tendons. This approach, as reported by the authors, is used for tumor resections as well as in the insertion of a revision, tumor, or custom total knee prosthesis. Wound healing was not a problem in the report of 13 cases with follow-up of 1–13 years.

Revision total knee arthroplasty surgery in knees with severe ankylosis is the most challenging of surgical procedures for the arthroplasty surgeon. A thorough understanding of the anatomic nuances is paramount in achieving a successful exposure while limiting the risk for wound complications and infection. Wide exposure can be accomplished by careful selection of the approach and conversion to an extensile approach early in the operation. Although we have tried to cover principles and describe techniques, no amount of preparation can substitute for experience with these difficult cases. The surgeon needs to gain experience with cases of mild

to moderate complexity before undertaking the most difficult procedures.

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Removal of the Femoral and Tibial Components for Revision Total Knee Arthroplasty

7

Daniel J. Berry

The importance of implant removal in revision knee arthroplasty frequently is overlooked as the surgeon concentrates on the planned reconstructive phase of the operation [1]. However, safe and effective implant removal is important for several reasons. First, implant removal can be a time-consuming process, particularly if the surgeon is not familiar with optimal techniques or if the surgeon does not have optimal tools available for the purpose. Second, severe bone loss or bone fracture can occur during implant removal. Marked unnecessary bone loss has a substantial negative impact on the type and quality of the reconstruction that subsequently can be performed. Third, struggles with exposure and implant removal can lead to soft tissue injury that compromises collateral ligament attachments or the extensor mechanism. Methods of safe implant removal have advanced dramatically over the last decade, and in most cases today, implants can be removed efficiently and with relatively little bone loss [2, 3].

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Tools for Implant Removal

Tools available for implant removal include hand instruments, power instruments, and ultrasonic instruments. In addition, implant-specific instruments are helpful to disassemble or extract specific implant designs.

Hand Instruments

Osteotomes

Osteotomes can be used to divide implant-cement interfaces and implant-bone interfaces. Stacked osteotomes can be used to lever implants away from the underlying bone or cement. When bone beneath the implant is soft, it is important to be careful that osteotomes do not crush the underlying bone. When an osteotome is used to remove cemented implants, keeping the osteotome at the implant-cement interface rather than the cement-bone interface is preferable.

Gigli Saws

Gigli saws can be used to cut beneath implants in areas that are inaccessible to power saws [4]. However, Gigli saws can migrate, and their path can be difficult to control, and most surgeons have found that they tend to remove more bone than power hand saws for applications such as removal of the femoral component.

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Punches

Punches are useful to disimpact well-fixed implants from the bone.

Cement Removal Instruments

Dedicated cement removal instruments, initially developed for revision THA, are useful to remove intramedullary cement, when present.

Power Instruments

Power Saws

Power saws can very effectively divide the implant-bone interfaces of uncemented implants. Thin saw blades remove less bone but can also wander into the healthy bone. Oscillating saws are used most commonly but reciprocating saws also may be used. Reciprocating saws that have one smooth edge can be useful to reduce risk of damage to nearby surrounding structures, such as when dividing the interfaces of the posterior aspect of a well-fixed tibial component.

Power Burs

Thin-profile cutting burs can divide interfaces that are not easily accessible to power saws. Furthermore, power burs are very useful to remove well-fixed cement from the underlying bone under direct vision. This method can prevent crushing or bone loss sometimes associated with cement removal with hand instruments.

Metal Cutting Instruments

Metal cutting instruments can cut away portions of well-fixed metal implants, thereby allowing access to otherwise inaccessible interfaces. For example, a metal cutting instrument can be used to remove a portion of a femoral or tibial component to allow access to a well-fixed underlying stem.

Ultrasonic Instruments

Ultrasonic instruments can be used to divide metal-cement and cement-bone interfaces. Special ultrasonic cutting tips are available that allow the metal-cement interface to be divided effectively [5–7]. Ultrasonic instruments also may be used to remove well-fixed cement from medullary canals. Instruments designed for this purpose for revision hip surgery are particularly useful when revising stemmed femoral or tibial components.

Strategies for Implant Removal

Exposure

Adequate exposure is essential for safe implant removal. A safe path to disrupt implant interfaces must be gained, and soft tissues, especially the extensor mechanism, popliteal vascular structures, and collateral ligaments, must be protected. A safe trajectory for implant extraction, particularly for the tibial component, also must be gained, while protecting the remaining bone from damage.

Loose Implants

Loose implants typically can be removed with little difficulty, once adequate exposure has been achieved. As implants are removed, care should be taken so that surrounding soft tissue and bony structures are not damaged. Loose, uncemented implants may have fibrous fixation that allows micromotion but does not allow easy extraction. The fibrous tissue usually can be disrupted with an osteotome or saw, following which the loose implant is easier to remove.

Well-Fixed Cemented Implants

For well-fixed cemented implants, it is desirable to remove the metal implant from the cement mantle and leave the cement mantle behind (Fig. 7.1). Subsequently, the cement can be removed under direct vision with hand or power instruments, thereby minimizing bone loss. Implants with a smooth surface typically can be debonded from the underlying cement without difficulty. For implants that are well bonded to the cement, more aggressive means of cutting the implant free of the cement with saws, osteotomes, or ultrasonic instruments often are necessary.

Fig. 7.1 Disrupting the cement-metal interface of a femoral component with an osteotome. The goal is to debond the implant from the cement first and then to remove remaining cement after the metal implant has been removed (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

Well-Fixed Uncemented Implants

For well-fixed uncemented implants, the implant-bone interface should be divided before extraction is attempted; otherwise substantial bone loss can result if the bone is pulled away with the implant. The bone-implant interface is best divided sharply with a power saw, Gigli saw, osteotomes, or thin high-speed cutting tools.

Order of Implant Removal

An orderly process of implant removal reduces the likelihood of associated complications. In most cases the preferred sequence of implant removal, after gaining knee exposure, is (A) removal of the tibial polyethylene insert, (B) removal of the femoral component, (C) removal of the tibial component, and (D) removal of the patellar component. This order of implant removal provides successively better exposure for removal of each subsequent implant. Removal of the tibial insert facilitates exposure of the femoral component because knee flexion is easier, and removal of the femoral component provides better access to the posterior aspect of the tibial component, facilitating its safe removal. Some surgeons prefer to perform implant removal in a different order: (A) tibial insert removal, (B) tibial component removal, and (C) femoral component removal. This method allows use of a retractor that levers the tibia anteriorly while using the femoral component as a fulcrum, thereby preventing crushing of the underlying femoral bone. This order of implant removal only works if the flexion gap after polyethylene insert removal is large enough to allow delivery of the tibia from beneath the femur without undue force.

Methods to Remove Each Implant

Removal of the Tibial Polyethylene Insert

The tibial polyethylene insert, whether modular or nonmodular, usually can be disengaged from the underlying metal tibial tray. Removal of the tibial polyethylene insert creates a space that allows easier exposure of the remaining implants and sometimes can reduce the amount of dissection required to gain access to the tibial and femoral components. Removal of the polyethylene insert of most modular knees (and even nonmodular knees) can be achieved by levering the tibial insert out of the tray with an osteotome. Many manufacturers also have implant-specific tools to remove the modular polyethylene from the tibial tray. The surgeon should be aware that special screws or pins may secure the tibial insert to the tray; having manufacturer-specific screwdrivers or pin-grasping instruments available is helpful. When difficulty is encountered removing the tibial polyethylene from the tray, an osteotome or saw can be used to divide the tibial polyethylene, after which it can be removed from the metal tray.

Studying the specific locking mechanism of the implant that will be removed ahead of surgery, understanding optimal methods of disassembly, and having specific required tools available can save time and simplify implant removal.

Removal of the Femoral Component

Removal of the femoral component begins by dividing the implant-cement interface (for cemented implants) or the implant-bone interface

(for uncemented implants). For cemented implants, the best instruments are osteotomes or ultrasonic instruments, and for uncemented implants the best instruments are power saws, thin osteotomes, or thin high-speed cutting instruments. The anterior flange interface, distal interface, and chamfer interfaces usually all can be accessed without difficulty. Fixation pegs at the distal interface may impede access to a small central part of that interface. Narrow osteotomes or saws can be used to work along the chamfer interfaces or in the narrow spaces between fixation pegs of the distal interface. It is best to work from both the medial and lateral sides of the implant separately; this reduces the distance that the sharp instruments travel while out of sight beneath the implant and thus reduces the likelihood of the instrument wandering away from the implant and creating excessive bone loss. The posterior condylar interfaces are hardest to access, but often there is osteolysis or little fixation at this interface. Dividing this interface is best done with narrow, thin osteotomes, special angled osteotomes, or a thin saw. Once the implant interfaces are divided, the femoral component may be removed with a company-specific or generic extractor that grasps the femoral implant and allows extraction with a slap hammer. Alternatively the implant can be tapped off of the femur gently using a metal punch against the anterior flange of the implant.

Posterior stabilized implants with a closed posterior cam box present interfaces that are difficult to access. Special care needs to be taken to remove these implants gently to avoid fracturing a condyle away from the femur.

Removal of the Tibial Component

Most tibial components can be removed by passing a saw or osteotome beneath the tibial tray, then levering the tibial component away from the underlying bone. As is the case for femoral components, cemented implants usually can be removed by passing an osteotome between the implant and the cement. When the metal implant is roughened, porous coated or precoated, the cement may not readily separate from the metal. In this circumstance the cement can be divided with a saw or ultrasonic instruments to facilitate implant removal. Uncemented implants usually can be removed by dividing the bone-implant interface with a saw. When pegs, central stems, or keels prevent the surgeon from passing instruments from anterior to posterior, to divide posterior interfaces of the tibial implant, good medial exposure with external tibial rotation often allows instruments to be passed in a medial to lateral direction posterior to the pegs or keel. Care should be taken to protect soft tissues in the popliteal fossa area. A reciprocating saw, with the smooth side of the saw directed posteriorly, may help protect posterior soft tissue structures.

Once the proximal tibial interface is divided, the tibial implant usually can be removed by using stacked osteotomes (Fig. 7.2) to lever the tibial implant out of the tibia or by using a manufacturer specific or generic tibial implant extractor to pull the implant out of the tibia. During this process, the knee needs to be hyperflexed and the tibia translated anteriorly to avoid impingement of the tibial tray against the femoral condyle during extraction. The surgeon needs to be careful to avoid avulsion of the patellar tendon insertion at the tibial tubercle during this exposure. When extraction is difficult, a punch can be inserted beneath the tibial tray to drive it out of the tibia with a hammer. To gain purchase on the tray with a punch, a small medial or lateral hole in the tibial metaphyseal bone may be made that allows the punch to be directed perpendicularly against the tibial tray (Fig. 7.3).

The surgeon should be cautious not to exert excessive force when trying to remove a tibial tray with a well-fixed keel or stem. At times the interface between the stem and the tibia needs to be accessed directly and divided before the tray is removed. This technique is discussed in the following section.

Well-fixed, all-polyethylene implants can be removed easily by using a saw to cut through the inferior aspect of the tray at the bone-cement interface, thereby providing the surgeon with direct access to remaining cement and the keel.

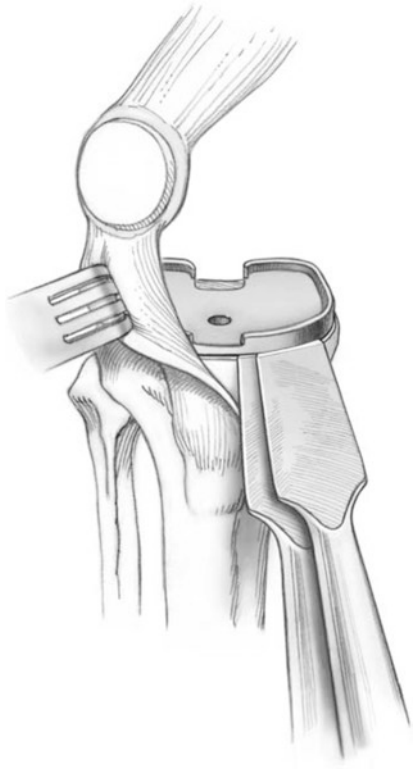

Fig. 7.2 Stacked osteotomes are used to lever a tibial component away from the bone. Care must be taken to avoid crushing the underlying bone. The broadest osteotome is placed nearest the bone (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

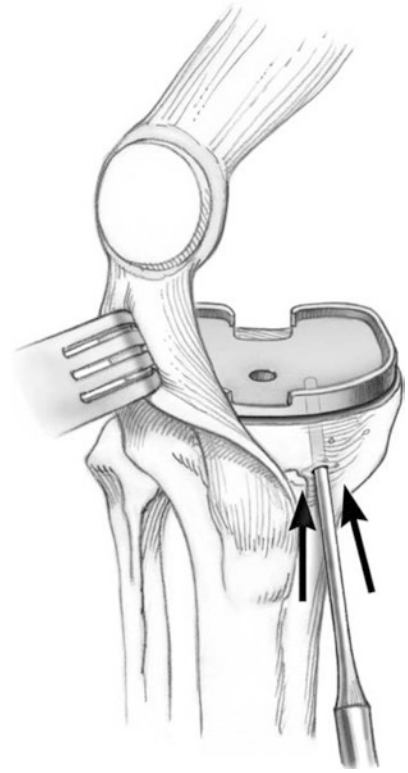

Fig. 7.3 A punch used to disimpact a tibial component through a small hole drilled in the metaphysis (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

The keel can be removed by using a thin bur to cut the cement-implant interface.

Well-fixed highly porous metal tibial components with lug pegs made of trabecular metal represent a special case scenario. The porous pegs of these devices, when well-fixed, may be divided with an osteotome (which avoids creating a lot of metal debris) or with a saw. Once the pegs are divided, a saw can be used to free the flat tibial tray from the underlying bone.

Removal of Implants with Stems

Uncemented Stems

Most implants with uncemented stems can be extracted using the same methods discussed previously for condylar implants. Most long uncemented knee implant stems are smooth or fluted with smooth surfaces and are not biologically fixed in the metaphysis or diaphysis. Therefore, once the condylar interfaces are divided, the implant with the stem attached can be driven out of the bone. Well-fixed roughened or porous stems are more difficult to remove. Thin high-speed cutting tools can be used to divide the metal-bone interface, or trephines designed to remove well-fixed total hip arthroplasty stems can be used to cut the stem free of bone. Initial removal of the condylar portion of the implant, discussed below, may be required to access the stem.

Cemented Stems

Well-fixed implants with cemented stems can be very difficult to remove [8] and require an individualized approach that depends on the specific

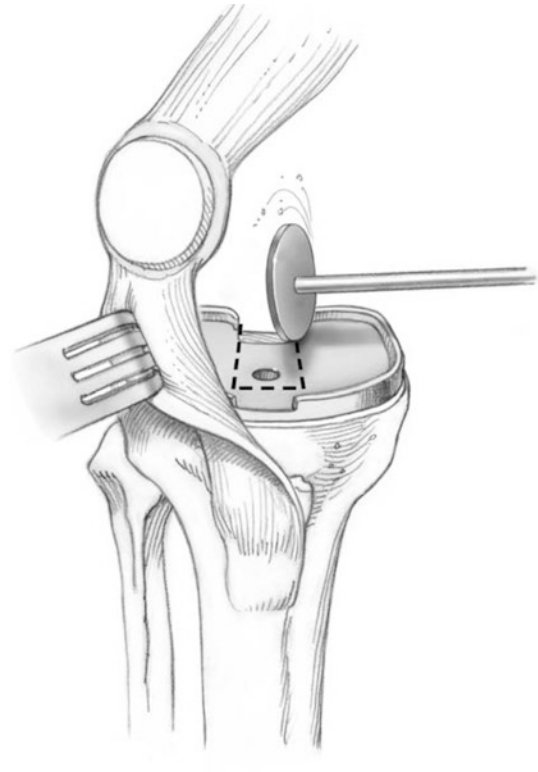

Fig. 7.4 Gaining access to a well-fixed tibial stem by cutting the metal tray of the tibial component. After the tray is removed, the interface along the stem can be divided (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

design and patient anatomy. Usually the interfaces of the condylar portion of the tibial or femoral implant are divided, and then the implant—with stem attached—is driven out of the remaining cement. When this is not possible, sometimes the condylar portion of the implant can be disassembled from the stem, allowing the stem to be accessed separately. Alternatively, metal cutting instruments can be used to cut the stem, or a portion of the femoral or tibial implant, thereby allowing direct access to the stem (Fig. 7.4). Once direct access to the stem has been gained, thin high-speed cutting tools or ultrasonic instruments can be used to divide the stem-cement interface, allowing stem extraction. Some stems have manufacturer-specific threaded holes in the accessible end of the stem that help the surgeon gain purchase for extraction.

Surgeons should be aware that some stems are not designed for straightforward removal when used with cement. Such stems that have kinks (offset stems) or stems with transverse notches that fill with cement often cannot be driven directly out of the cement mantle. On rare occasions, an osteotomy of the femur or extended tibial tubercle osteotomy may be needed to remove a very well-fixed stemmed implant.

Massin et al. described six cases of well-fixed infected stemmed hinged implants that were removed successfully with the aid of tibia and/or femoral osteotomies as part of a two-stage procedure. Five knees had extended tibial tubercle osteotomies and four had anterior cortical flap osteotomies of the distal femur [9]. One postoperative diaphyseal tibial fracture occurred in association with an extended tibial tubercle osteotomy, and one extended tibial tubercle osteotomy broke in two pieces intraoperatively. In the uncommon instances in which osteotomies of the distal femur or proximal tibia are needed for implant removal, emphasis should be placed on maintaining soft tissue attachments, and hence vascularity of the osteotomy fragment, and being careful to avoid fragmentation of the osteotomy fragment during the osteotomy. The methods of tibial tubercle osteotomy are described in numerous sources, but the

methods of distal femoral cortical osteotomy are less well known. Merz and Farid described and illustrated the method nicely in a recent publication [10]. The key elements include a longitudinal anterior medial femoral osteotomy limb, a transverse osteotomy limb, and completion of the lateral longitudinal osteotomy limb while preserving attachments of the vastus intermedius to the lateral aspect of the anterior cortical osteotomy fragment.

Patellar Component Removal

When a previously placed patellar component is well fixed and well positioned and has a surface geometry roughly compatible with the planned femoral component, in most cases, surgeons will choose to retain the patellar component rather than removal.

However, when infection is present or the patellar component is loose, severely worn, or malpositioned, removal typically is indicated.

All-polyethylene patellar components may be cut away from the bone with an oscillating saw. Underlying cement and fixation pegs may be removed with a fine-tipped high-speed bur. Well-fixed metal-backed patellar components may be removed by dividing the metal fixation pegs (and prosthesis-cement or prosthesis-bone interface) with a metal cutting wheel and then removing the fixation pegs with a fine-tipped high-speed bur.

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Allograft in Revision Total Knee Arthroplasty

8

Erick G. Torres, Donald T. Reilly, and J. Craig Morrison

Some degree of bone loss is present in every failed total knee arthroplasty. In most instances, bone loss is minor and adequate bone stock is available to support primary components. However, certain failure modes lead to more severe bone loss that may affect the structural integrity of revision components. Management of this type of bone loss and the accompanying soft tissue asymmetry is the most challenging aspect of revision total knee arthroplasty. Augmentation with cement, bone graft, and modular or custom components may be needed. Cement is adequate in smaller defects and has been used in larger defects with screws [1, 2]. Cement has poor biomechanical properties; therefore, as defects increase in size or complexity, other solutions are necessary. Graft offers intraoperative flexibility and relatively low cost when compared with customs. Autograft is preferred; however, it is usually in short supply in the revision setting. Therefore, allograft is relied on commonly in these situations. Despite its widespread use, good clinical studies are sparse. In this chapter, we delineate the indications and results of allograft in revision total knee arthroplasty.

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Preoperative Planning

Modes of Failure

Although cliché, it is true that successful revision surgery begins with careful preoperative planning. It is essential in predicting the severity and location of bone loss. Quality imaging to include standing AP, lateral, and sunrise views can aid in evaluating anticipated bone loss. However, it is not unusual for radiographs to minimize the amount of intraoperative bone loss encountered. This is due to the fact that some bone loss is expected after removal of failed implants and fibrous debris. Additionally, excessive additional resection during revision arthroplasty or overzealous debridement for infection can lead to significant bone loss [3]. Static cement spacers in the staged treatment of infection can also lead to more erosion and destruction of the bone than articulating spacers increasing the likelihood of required augmentation during second-stage implantation [4].

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Planning should begin with an understanding of the mode of failure if the factors leading to the primary failure are to be corrected at revision surgery. The most common reasons for knee revision are aseptic loosening, infection, instability, and osteolysis [5, 6]. With improvements in implant manufacturing and polyethylene quality, failure from polyethylene wear is no longer a leading cause of failure. Early failures are alarmingly common. Lombardi et al. saw over 30% of their revisions performed within 2 years of the index procedure and approximately 60% within the first 5 years [6]. Revision surgeons are doomed to repeat history if the technical reason for failure is not recognized and addressed. Aseptic loosening alone is unlikely to result in massive bone loss unless grossly loose components are neglected. However, loosening secondary to malalignment from ligament imbalance or component malposition can lead to characteristic deficiencies. This is most commonly seen in a residual varus malalignment that results from a varus tibial cut, an inadequately released medial side, or a combination of both. The tibial plateau collapses on the compression (medial) side, and the tibial component lifts off on the tension (lateral) side (Fig. 8.1). Femoral condyles can collapse in the same way (Fig. 8.2).

Although less commonly reported than in total hip arthroplasty, osteolysis from polyethylene debris does occur in cemented and cementless total knee arthroplasties [7]. High contact stresses secondary to poor design or technique can result in large volumes of debris. Regardless of particle size, large particle volume can cause early failure and catastrophic bone loss that is almost always underestimated by plain radiographs. As implant design, technique, and polyethylene quality have improved longevity, there is speculation that osteolysis may become a more common cause of late failure as well [8]. The surgeon should be prepared for major bone loss in a patient with a loose, painful total knee and any hint of cystic changes on X-ray.

Poor implant removal technique at the time of revision surgery is a further cause of bone loss. Patience is the key to removing any implant, well fixed or otherwise. It is imperative for the surgeon to expose the implant-bone interface. In cemented implants, disruption must occur at the implant-cement interface, not the cement-bone interface. Thin osteotomes are useful in this regard; however, one must fight the temptation to lever the implant out, as this may crush the underlying soft cancellous bone. Well-fixed cementless implants are difficult to

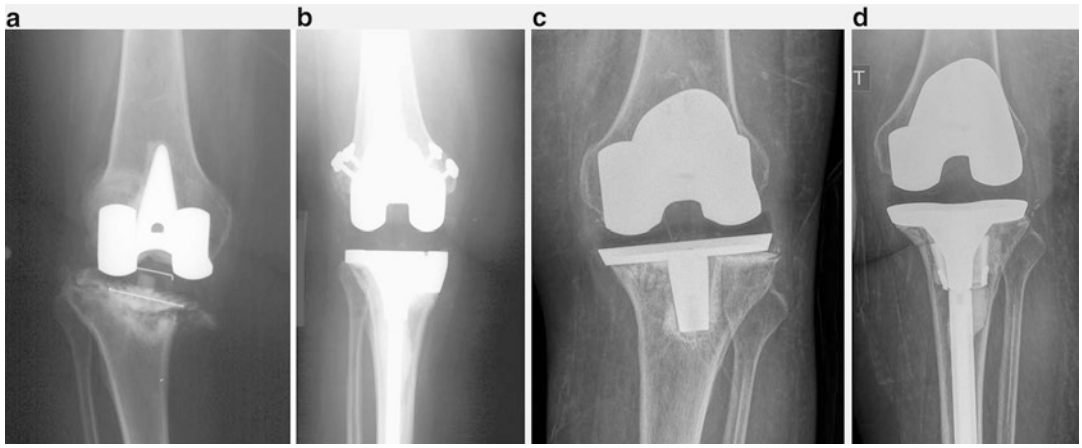

Fig. 8.1 (**a**) Radiograph of a failed total knee arthroplasty, demonstrating medial tibial collapse with component liftoff on the lateral side. (**b**) This knee was reconstructed using a custom tibial component. (**c**) Radiograph of a failed total knee arthroplasty with similar failure mechanism. (**d**) Tibia was able to be reconstructed with use of a metaphyseal sleeve and long uncemented stem

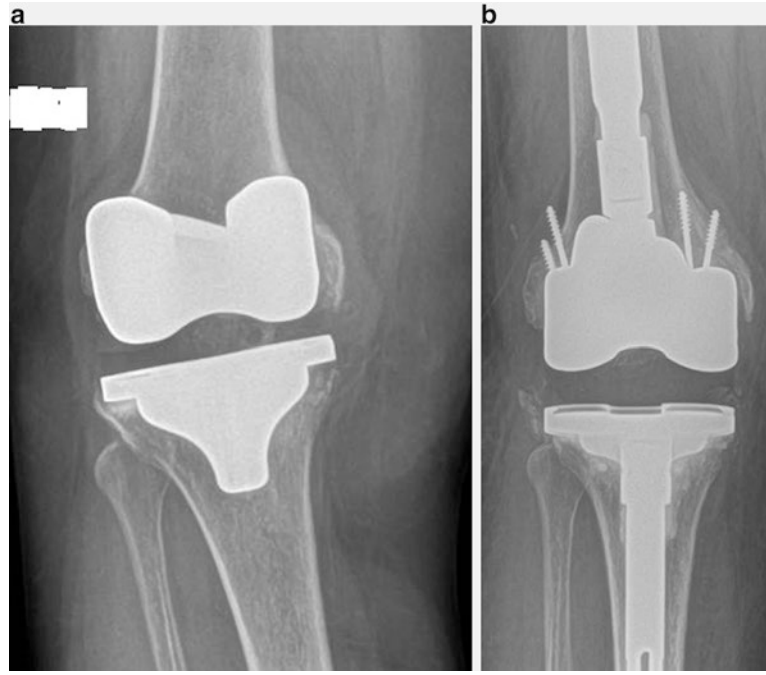

Fig. 8.2 (**a**) Radiograph of a failed total knee arthroplasty, demonstrating femoral subsidence worse on the medial side. (**b**) Femoral head allografts were used to reconstruct the extensive bone loss and reestablish the joint line in this 2-year postoperative radiograph

remove. The use of a Gigli saw beneath the anterior flange and along the posterior condyles coupled with thin curved osteotomes in the notch is recommended. The use of slap hammers should be avoided until complete implant loosening is confirmed. Ill-advised use of these devices can easily lead to femoral or tibial fractures. In some instances, a condyle or entire distal femur may be removed with the well-fixed implant [9].

Defect Classification

Assessment of bone deficiency is best done after implant removal and preliminary cuts; however, the surgeon must have a reasonable expectation of the type of bone loss from preoperative X-rays. Several classification systems have been developed in the hip to assist revision surgeons. There has been less emphasis on defect classification in the knee. As in the hip, defects are generally divided into contained or segmental. Contained defects are surrounded by intact bone, whereas segmental defects have no remaining cortex [10]. Segmental defects can be further broken down into circumferential or non-circumferential [9]. Engh and Rubash have both devised classification schemes that attempt to correlate type and severity of defect with a recommended surgical management strategy (Tables 8.1 and 8.2) [5, 9]. Placement into one of these classification systems preoperatively allows the surgeon to have appropriate instruments, hardware, and graft on hand to limit intraoperative surprises.

Several options for each category of deficiency are available to the revision surgeon. Cement with or without screws, modular or custom augments, and particulate or bulk graft have all been advocated for certain bone deficiencies [7, 8, 11]. For any strategy, implant stability on the host bone is vital to long-term success. A second goal of revision surgery, namely, bone stock restoration, may be accomplished through the use of bone graft. An understanding of the basic science involved in the use of allograft is exceedingly important for the revision surgeon to comprehend. Therefore, a brief review of the biology and biomechanical aspects of allograft is in order.

Basic Science of Allograft

Biology

The bone was one of the first tissue transplants performed and remains one of, if not the most, abundant tissues transplanted. Originally, autograft was used to unite fractures and fuse joints. Allograft use increased in prevalence in orthopaedic oncology as limb-salvage techniques improved. In revision hip and knee surgery, allograft bone is used when conventional methods of reconstruction are inadequate and because autograft is in short supply. As a tissue, bone has unique properties that are critical for success. *Osteogenesis* is the ability to produce a new bone and is accomplished by osteoblasts. Bone proteins, such as bone morphogenic protein that are a part of the bone matrix, stimulate new bone formation through the recruitment and differentiation of pluripotent mesenchymal stem cells into osteoblasts. This characteristic is known as *osteoinduction*. Lastly, *osteoconduction* is the graft's ability to act as scaffolding for the ingrowth of blood vessels and cells from the host bed. The process known as *creeping substitution* is the gradual resorption and replacement of this scaffolding with the host bone. Autograft and fresh allograft possess all of these properties. Fresh allografts, however, are rejected by the host immune system, resulting in complete graft resorption or marked delay in incorporation. Therefore, allograft used in revision joint surgery is processed and possesses the property of osteoconduction only. The success of allograft depends largely on its ability to heal to and incorporate with the host bone. Histologically, these events are similar to fracture healing. Inflammation predominates early on. Unlike autograft, in which surviving surface osteoblasts contribute bone, allograft incorporation depends on osteoblasts differentiated from pluripotent cells brought in by vasculature from the host bed. Thus, the process is similar to autograft incorporation but slower. This early phase is similar for the cancellous as well as cortical bone. Creeping substitution characterizes the incorporation of cancellous bone. That is, bone formation and resorption occur concomitantly. Eventually the entire graft may be replaced by the host bone. In the cortical bone, formation only occurs after resorption. Consequently, the graft is weaker than the normal bone for a long period of time and must be protected from excessive loading. In theory, this remodeling process eventually involves the entire

Table 8.1 Anderson Orthopaedic Research Institute bone defect classification guidelines

	Preoperative radiographs	Surgical management
Type 1 defect (intact metaphyseal bone)	A full metaphyseal segment	No augments, structural bone grafts or cement fill >1 cm
Femur	Metaphyseal bone intact distal to the epicondyles	
	No component subsidence or osteolysis	
Tibia	Metaphyseal bone intact above tibial tubercle	
	No component subsidence or osteolysis	
Type 2 defect (damaged metaphyseal bone)	A shortened metaphyseal flare	Joint-line restoration with augments (>4 mm), particulate or chunk bone graft, or >1 cm cement fill; joint-line elevation with a primary component as the revision implant
Femur	Component subsidence or joint-line elevation of the failed component	
Tibia	Small osteolytic defects in bone distal to the epicondyles	
	Component subsidence or position up to or below the tip of the fibular head; a shortened tibial metaphyseal flare	

(continued)

Table 8.1 (continued)

	Preoperative radiographs	Surgical management
Type 3 defect (deficient metaphyseal bone)	A deficient metaphyseal segment	A reconstructed condyle or plateau with structural graft or cement or a custom or hinged component
Femur	Bone damage to or above the level of the epicondyles	
	Component subsidence to the epicondyles	
Tibia	Bone damage or component subsidence to the tibial tubercle	

From Engh GA. Bone defect classification. In: Engh GA, Rorabeck CH, editors. Revision total knee arthroplasty. Baltimore, MD: Williams & Wilkins; 1997, p. 63–120, with permission

Table 8.2 Massachusetts General Hospital femoral defect classification system for total knee arthroplasty and treatment algorithm

Classification		
Minor	Below the level of the epicondyles Volume <1 cm^3 Contained: no cortical bone loss, cancellous defects only Uncontained: cortical loss resulting in an unsupported portion of the implant	
Major	Defects are at or above the level of the epicondyles Volume >1 cm^3 Contained: no cortical bone loss, cancellous defects only Uncontained: cortical loss resulting in an unsupported portion of the implant or condylar fracture	
Treatment algorithm		
Defect type	*Minor*	*Major*
Contained	Particulate graft Cement Implants: CR or PS +/− stem	Bulk allograft Femoral head allograft Implants: PS with stem, possible constrained condylar
Uncontained	Augments Structural graft Cement or particulate graft if <5 mm fill and varus/valgus stable	Condylar allograft Bicondylar allograft
	Implants: PS with stem	Distal femoral allograft Implants: constrained condylar with long stem or hinged device

From Hoeffel DP, Rubash HE. Revision total knee arthroplasty: current rationale and techniques for femoral component revision. Clin Orthop. 2000;380:116–32, with permission

structural graft. In reality, these grafts have little biologic activity outside of the graft-host junction [12].

Although animal studies have supplied most of our knowledge of the basic science of allograft, human retrievals have given the most insight into the biologic behavior of processed allografts in humans. Enneking et al. studied 16 retrieved massive human allografts that had been in situ for 4–65 months [13]. They demonstrated that union between allograft and host took place slowly at cortical-cortical junctions and more rapidly at cancellous-cancellous junctions. Internal repair was confined to the superficial surfaces and ends of the grafts and had involved only 20% of the graft by 5 years. The deep portions of the graft retained their architecture. Parks and Engh's study of allografts in revision knee arthroplasty retrievals had similar findings with no evidence of revascularization, resorption, or remodeling beyond the graft-host union [14] (Figs. 8.3 and 8.4).

Ultimately, the biology depends greatly on the clinical situation and the type of graft used. As discussed, bone loss in revision surgery can be cavitary or segmental. A cavitary lesion with a well-vascularized bed is ideal for the cancellous bone, and complete incorporation is to be expected. With increasing bone loss and decreasing vascularity, a more inconsistent incorporation is to be expected. In contrast, segmental loss requiring large structural allograft relies on cortical-to-cortical contact between host and graft. The majority of the graft is surrounded by soft tissue that is usually avascular scar. Here the allograft can unite

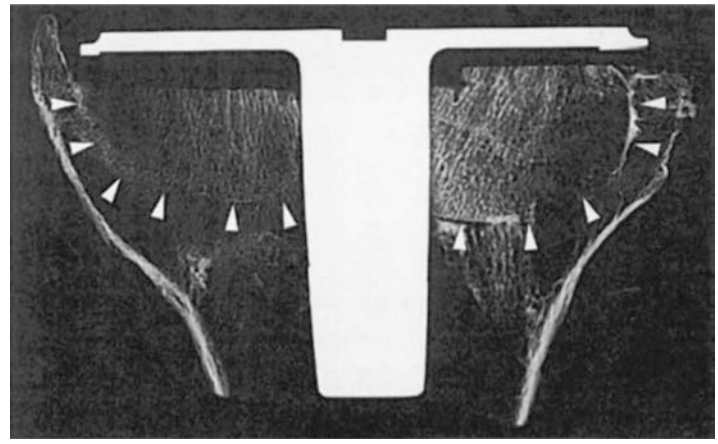

Fig. 8.3 Slab radiograph showing location and intact structure of two femoral head allografts in the proximal tibia. Note host to graft junction (*arrows*) (from Parks NL, Engh GA. The Ranawat Award. Histology of nine structural bone grafts used in total knee arthroplasty. Clin Orthop. 1997;345:17–23, with permission)

to the host bone, but there will be little if any internal remodeling of the graft [13].

Biomechanics

In reviewing the biology of allografts, we see that union with the host bone is the first step toward success. Unfortunately, failure can and does still follow all too often. Fracture of structural allograft is reported to be as high as 16.5% [15]. It goes without saying that the biomechanical behavior of the graft is of critical importance in determining success or failure. The individual factors that influence the physical properties of transplantable bone are analyzed in this section.

The ability of a graft to withstand loads is largely determined by the original properties of the bone at the time of donation. Although supply often limits surgeons' options when choosing donor material, the factors that influence these properties should be known. For instance, bone tissue is strongest in the 20- to 39-year-old age groups and typically weakens thereafter. However, even in the 70- to 79-year-old age group, 70% to 85% of the maximum strength is maintained [16]. The surgeon can more closely control other factors, such as the method of preservation and sterilization.

The more common methods of preserving and storing specimens until they are required for implantation are freezing and freeze-drying. Both alter the immunogenicity of the graft, but freeze-drying has a more substantial effect on the physical properties [16, 17]. Freeze-drying causes little change or a slight increase in compressive strength but lowers the bending and torsional strength substantially [15, 18, 19]. Cracks have been observed in rehydrated freeze-dried specimens, which might explain the observed reduction in strength [18]. Freezing alone has little if any effect on the physical properties of the bone [18, 20]. These observations suggest that fresh frozen bone would be best when large torsional and bending loads can be expected. Clinically, this would be seen at the host-graft junction when a whole distal femur was used. Conversely, in a situation in which the graft will see primarily compressive loads, freeze-dried graft should be biomechanically sound. Most cavitary or isolated metaphyseal lesions fall into this category.

Sterilization of a graft prior to implantation can be done either of two ways. The grafts can be sterilely harvested and stored, or nonsterile grafts can be secondarily sterilized with high-dose radiation. Radiation below 3 megarads appears to cause little change in bone strength; however, above this level, significant alterations in the physical properties occur, resulting in a decrease in the compressive, bending, and torsional strength of the graft. These effects are magnified when combined with freeze-drying [19, 20].

Once retrieved, preserved, stored, sterilized, and implanted, a bone graft is subjected to load.

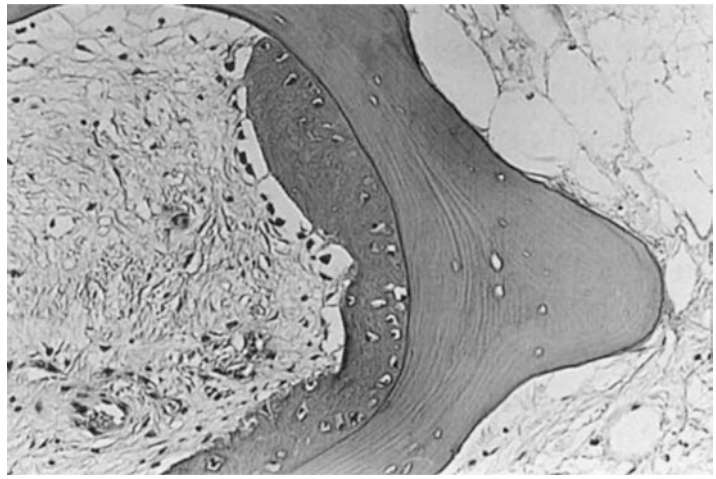

Fig. 8.4 Left to right: live marrow elements, live host bone, dead graft bone, avascular grafted region. The live bone is growing onto the dead graft as if it were a scaffold at the host to graft junction (Stain, hematoxylin and eosin; magnification light microscopy, ×200) (from Parks NL, Engh GA. The Ranawat Award. Histology of nine structural bone grafts used in total knee arthroplasty. Clin Orthop. 1997;345:17–23, with permission)

The bone can fail under the single application of a large load if a fall or some other trauma ensues. However, fatigue failure secondary to repetitive smaller loads is more common with large allografts. Live bone is capable of remodeling when subjected to these loads. Until transplanted bone becomes vascularized, it does not have this capability. Because retrieval studies have shown that outside of the host-graft junction little remodeling occurs, it is imperative that large allografts be protected with adequate internal fixation to prevent fatigue failure. Intramedullary fixation with stemmed components is preferred over plates and screws because the stress risers made by screw holes weaken the graft, thus increasing the fracture risk.

Disease Transmission

Although extremely rare, transmission of an infectious agent through allograft bone transplantation remains a relevant concern. Most of this has centered on transmission of human immunodeficiency virus (HIV). The risk estimate for HIV transmission in 1990 was 1 in 1.6 million [21, 22]. With improved screening tools and sterilization methods and stricter donor criteria, this risk may be even less today. In the early 2000s, disease transmission from allograft bone received significant attention after a Minnesota man died from a *Clostridium* infection 4 days after an osteochondral transplant, and the Centers for Disease Control (CDC) uncovered 26 cases of infection from orthopaedic allograft transplants related to poor techniques in procurement, processing, and storage. Utilizing a tissue bank that is a member of the American Association of Tissue Banks reduces this risk of bacterial contamination, but these risks should be considered when counseling patients on surgical options.

Indications and Techniques

As stated before, preoperative planning combined with intraoperative findings can help the surgeon formulate the appropriate treatment strategy for dealing with bone loss. Determining the quantity, location, and extent of the bone loss is critical to a successful revision. Once the existing components have been meticulously removed using bone preservation techniques, the surgeon can evaluate whether the bony defects are contained or segmental. Contained defects are

defined as defects that are surrounded by an intact cortical sleeve or rim. Uncontained defects, also known as segmental defects, are those which are not surrounded by cortical rim but rather in continuity with surrounding soft tissues.

Contained Defects

Bone deficiency in many revisions is minor and contained. After component removal, bone loss is limited to punctate cancellous defects. Minor defects have been defined differently in terms of size. In general, it is assumed that cancellous metaphyseal bone is in sufficient supply and quality to support primary implants. In these cases, defects can be filled with cement, particulate autograft from bone cuts, or particulate allograft if autograft supply is insufficient. Outcome will be similar regardless of management.

For smaller defects under 5 mm in depth that remain contained, the use of cement can be utilized to successfully fill the void [23]. This has the advantage of being readily available, given the fact that majority of revision implants are cemented. Additionally, the use of cement to fill bony contained defects can be supplemented by the use of cortical screws to enhance the strength of the construct. However, in a young patient, filling the bony defect with morselized allograft can restore bone stock facilitating any future revision that might take place.

Larger contained defects are commonly seen in failures resulting from polyethylene wear with associated osteolysis and component loosening. In these cases, cancellous metaphyseal bone is insufficient to support a primary component. On the femoral side, an intact rim of metaphyseal cortical bone is invariably present because this bone is stressed by collateral ligament attachments. When the tibial base plate subsides, the resultant defect may depend on the size and position of the base plate in relation to the proximal tibia. Commonly the base plate's perimeter sits just inside the cortical rim of the plateau. When the base plate subsides, an intact cortical rim is left, and a large central, cavitary defect remains after component removal. Although some authors advocate cement fill in these situations, allograft is preferable, because of its potential for incorporation in this setting [1, 2].

Some authors advocate the use of femoral head allografts for these defects [5, 24, 25]. Attention to detail is critical to success. The surgeon must first prepare the host bone. A clean, vascularized bed is ideal. All cement and fibrous debris should be removed. Sclerotic bone should be removed sufficiently to provide a bleeding bed without compromising structural integrity. Next the graft must be debrided of any cartilage or remaining soft tissue and fashioned to match the host defect as intimately as possible. The use of male and female hemispherical reamers has been described to facilitate this process [25] (Fig. 8.5). Alternatively, saws or high-speed burs can be used. The fashioned graft is then placed into the defect. A gentle press-fit is desirable if possible for additional stability (Fig. 8.6). Any gaps between the graft-host junction should be packed with particulate graft (autograft if available). After placement, rigid fixation to the host bone should be achieved with K-wires or small fragment screws. Because the majority of tibial baseplates are composed of titanium, titanium self-tapping screws are preferred to avoid galvanic corrosion [26]. Galvanic corrosion occurs when dissimilar metals come in contact leading to electrochemical destruction. Even with the use of titanium screws, it is recommended to countersink them below the level of the anticipated components to prevent direct contact. Rigid fixation is important for junctional healing, but the minimum amount of fixation necessary should be used to avoid unnecessary stress risers. Next, any protruding graft should be resected to the level of the previously resected distal femur or proximal tibia. Because these grafts lend structural support to the implant, they must be protected with a load-sharing intramedullary stem. If the previously placed graft encroaches on the stem path it can be fashioned to allow the stem to pass. Often a high-speed burr is preferable to power reamers to allow more control and prevent graft fracture or fixation compromise. Finally, the components are placed. The undersurfaces of the femoral and tibial components should be cemented, as the

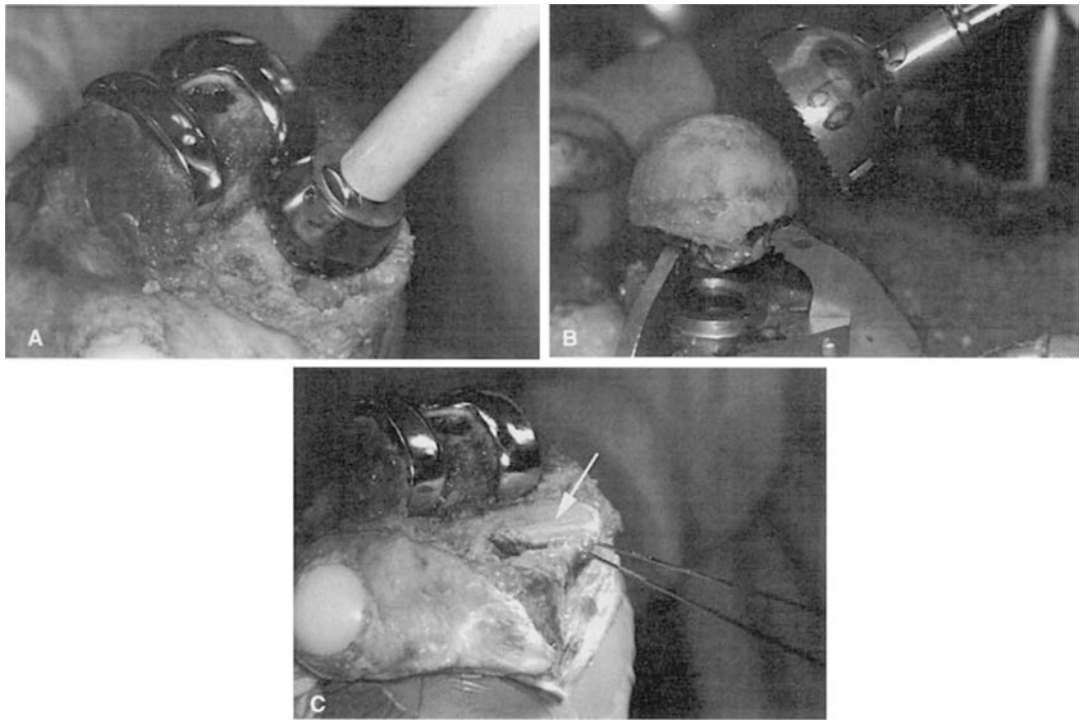

Fig. 8.5 (**a**) Reaming a tibial defect with an acetabular reamer to prepare it for a femoral head allograft. (**b**) Reaming the femoral head allograft with female hemispheric reamers (Allogrip, DePuy, Warsaw, IN) to remove the cartilage and subchondral bone. (**c**) The *arrow* indicates the femoral head allograft, which was placed into the proximal tibial defect and cut flush with the proximal tibia (from Parks NL, Engh GA. The Ranawat Award. Histology of nine structural bone grafts used in total knee arthroplasty. Clin Orthop. 1997;345:17–23, with permission)

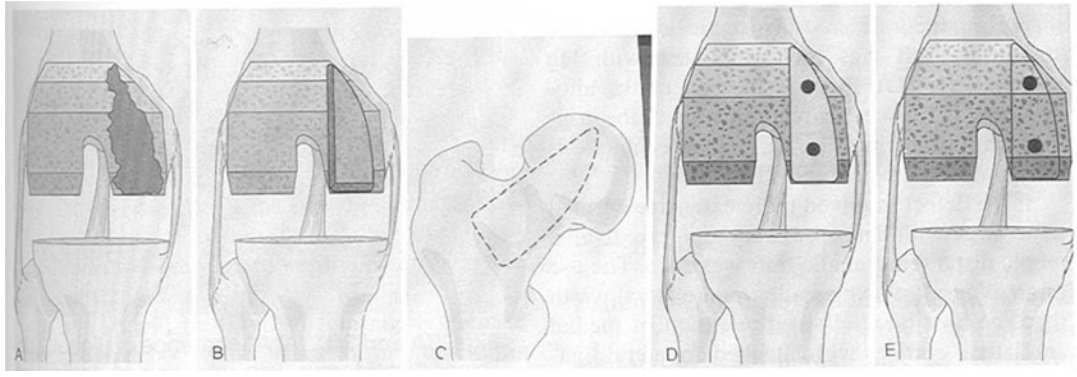

Fig. 8.6 (**a**) Typical complex distal femoral condylar deficiency. (**b**) Appearance of the same deficiency after contouring into geometric configuration. (**c**) Outline of a femoral head allograft to fit the defect. (**d**) The deficiency after the placement of the allograft, in which intimate allograft to host bone junction apposition and screw stabilization are shown. (**e**) The deficiency after bony resection before prosthetic implantation (from Tsahakis PJ, Beaver WB, Brick GW. Technique and results of allograft reconstruction in revision total knee arthroplasty. Clin Orthop. 1994;303:86–94, with permission)

cancellous allograft surface is excellent for cement interdigitation but has no potential for biologic fixation. The use of a cemented or cementless stem is the surgeon's preference. A cementless stem must be sufficiently long to engage the diaphysis.

Results

Several prior studies have revealed satisfactory results with the use of cement and screws for smaller contained defects. Berend et al. reported long-term follow-up of 609 knees who underwent the use of screws and cement and primary and revision specific prosthesis for revision knee arthroplasty. At 17 years follow-up, the Kaplan-Meier survivorship was 0.9859 for revision specific prosthesis with screws and cement compared to 0.9848 for revision prosthesis with no screws. They recommend the use of revision prosthesis along with screws and cement to correct largely defects in revision total knee arthroplasties [27]. In addition, Ritter et al. published a series of 57 total knee arthroplasties in whom tibial defects were filled with cement and screws. At 3 years follow-up, there were no loose tibial components [2]. In a subsequent publication by the same author, they investigated the placement of screws beneath the medial tibial plateau to fill large defects and prevent collapse. Of 536 implanted AGC all-polyethylene tibial components, 20 had screws inserted beneath the medial tibial plateau. None of their knees that were supplemented with screws failed because of aseptic loosening or collapse. This was compared to a previous study which found that the AGC all-polyethylene tibial component had a 14% rate of collapse in the first postoperative year [28]. They conclude that placement of screws beneath the medial tibial plateau to fill large defects is an appropriate precaution to avoid against collapse [28].

Good results have also been published with the use of particulate allograft in these large contained defects [29]. In a prospective study performed by Lotke et al., the midterm results were promising for the use of impaction bone allograft in both contained and segmental defects in revision total knee arthroplasty. Of 48 consecutive revision TKAs with substantial bone loss treated with impaction grafting, there were no mechanical failures, and all radiographs showed incorporation and remodeling with an average follow-up of 3.8 years [30]. Furthermore, biopsies have confirmed incorporation and revascularization. The downside to particulate graft is its poor load-sharing capability. The surgeon must be confident that the revision component is stable on the intact cortical rim of the host bone to avoid asymmetric stress on the implant that may lead to subsidence or component fracture. As with structural grafts, an intramedullary stem must be used.

Whiteside and Bicalho reviewed their experience with morselized graft in revision knee arthroplasty [29]. Sixty-two knees required major grafting of the tibia and/or the femur. Major defects were defined as necessitating at least 30 mL of bone graft. Over one-half of the defects required greater than 60 mL of graft. The graft was a combination of fresh frozen cancellous morsels measuring 0.5–1.0 cm plus powdered demineralized cancellous bone. The authors emphasized rim fit of the components over at least 25% of the intact cortical rim and press-fit diaphyseal-filling stems. All components were cementless. Fourteen knees (22%) underwent revision for various reasons. Two were revised for loosening. All of those revisions had biopsies of the graft between 3 weeks and 37 months. After 1 year, all radiographically visible allografts were said to show healing with a trabecular pattern. Biopsy specimens showed vascular ingrowth and new bone formation. At 37 months, allograft bone was still present but encased by a viable lamellar bone.

Segmental (Uncontained) Defects

Unlike cavitary or contained defects, segmental bone loss involves a cortical bone that is needed to support implants when the joint line is properly restored. For large defects greater than 1.5 cm in depth, the use of bulk allograft can provide mechanical support and have the advantage of reconstituting bone stock [26]. This is especially advantageous in younger patients who have a

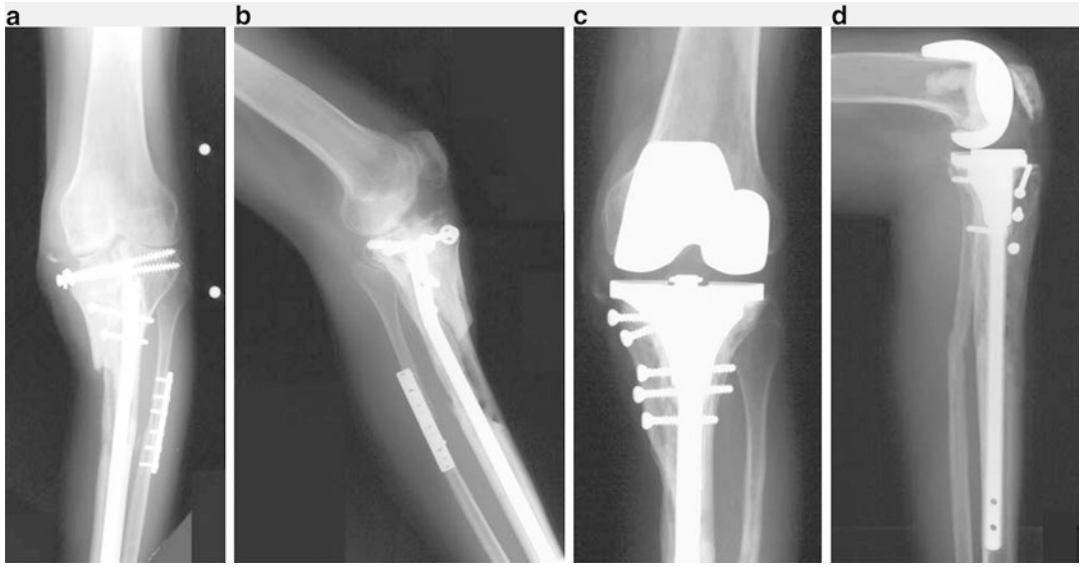

Fig. 8.7 (**a** and **b**) Preoperative and postoperative radiographs demonstrating severe proximal tibial bone loss status open reduction internal fixation. (**c** and **d**) Five-year postoperative radiographs showing a custom long stem tibial component (Techmedica, Camarillo, CA) and with structural allograft medially

higher likelihood of need for a future revision procedure. Unfortunately, there are some cons to the use of bulk allograft; graft resorption, collapse, and graft-host nonunion have been reported [26]. Prior studies have shown the incidence of nonunion of large frozen allografts with the host bone to be as high as 11% and graft fracture to be as high as 16.5% [31].

Modular revision implants are well suited to manage these defects if they are not too large [11, 32, 33]. On the tibial side, wedges or block augments along with intramedullary stems are ideal for defects involving one plateau. In this manner, the implant can be stabilized circumferentially on the viable host bone. Fortunately, tibial augments are now contoured to match the relatively acute flare of the tibial metaphysis in most systems. In defects greater than 1 cm, there used to be significant overhang resulting in medial collateral *tenting* or soft tissue irritation. Now for reconstruction of defects larger than 1 cm, the surgeon could use metallic augments or consider use of a femoral head allograft or partial proximal tibial allograft (Figs. 8.1a, b and 8.7a–d).

If both sides of the plateau are involved, bilateral block augments up to 15 cm are acceptable in helping reestablish the joint line. If larger augments are needed, the surgeon may elect to downsize the tibial base plate up to one size smaller than the femoral component if this will result in stable contact between the smaller augments and host bone. Obviously, this will require a thicker insert, and the revision system must accommodate this. Alternatively, a custom base plate or complete proximal tibial allograft can be used. The real advantage of an allograft is its intraoperative adaptability. In theory, bone stock is reconstituted. This assumption is controversial and not supported by retrieval studies of large structural graft in the hip and knee [13, 14, 34]. The best one can hope for in this situation is sufficient load-sharing by an intramedullary stem to prevent fatigue failure and ultimately collapse of the allograft. It is essentially an inert implant but with less predictable in vitro mechanical characteristics than metal.

The technique for a proximal tibial allograft involves a *back-table* arthroplasty. First, the combined thickness of the base plate and allograft must be determined. This composite must restore the joint line when combined with a reasonable range of insert thicknesses. The proximal tibial

surface is then resected perpendicular to the host tibial mechanical axis with the proper slope. The graft-host junction is prepared to optimize contact surface area preferably parallel to the proximal surface to decrease shear forces. Internal step cuts further increase contact and enhance rotational stability. Finally, the assembled tibial component is cemented to the allograft and the composite is stabilized to the host with a press-fit stem that engages the tibial diaphysis (Fig. 8.8).

Segmental femoral defects should be handled with a similar philosophy. Unlike the tibia, however, in which only one surface must be addressed, the surgeon must adequately reconstruct the distal and posterior surfaces of the femur to obtain symmetric flexion and extension gaps. Modular augments in many revision systems come in sizes up to 15 mm. As long as bone loss is distal to the collateral attachments, augments are sufficient and can even be stacked and cemented together if necessary. Distally, the augments must contact enough host bone to be deemed stable by the operative surgeon. As the trial augment contacts the distal cortical rim during trial femoral insertion, the surgeon must make note of any residual deficiency behind the augment that is now essentially a contained defect. If this residual defect does not jeopardize stability, then cement or morselized graft can be used. However, if stability may be jeopardized or the surgeon finds that stem position and femoral component size do not allow the augment to contact the intact cortical rim, then the use of a structural graft as described previously for large contained defects should be added to the construct (Fig. 8.9). Furthermore, if this residual deficiency is bicondylar, as is seen in the cone-shaped femur, then use of a metaphyseal sleeve or cone augment should be considered. These implants are described in greater detail in other chapters.

For bone loss that extends proximally to involve the collateral insertions on the femoral epicondyles, modular augmentation is insufficient. Comminuted supracondylar fractures, neglected femoral subsidence, and revisions for infection account for the majority of these catastrophic scenarios. In these instances, ligamentous stability, as well as component stability must be considered. Options available to the

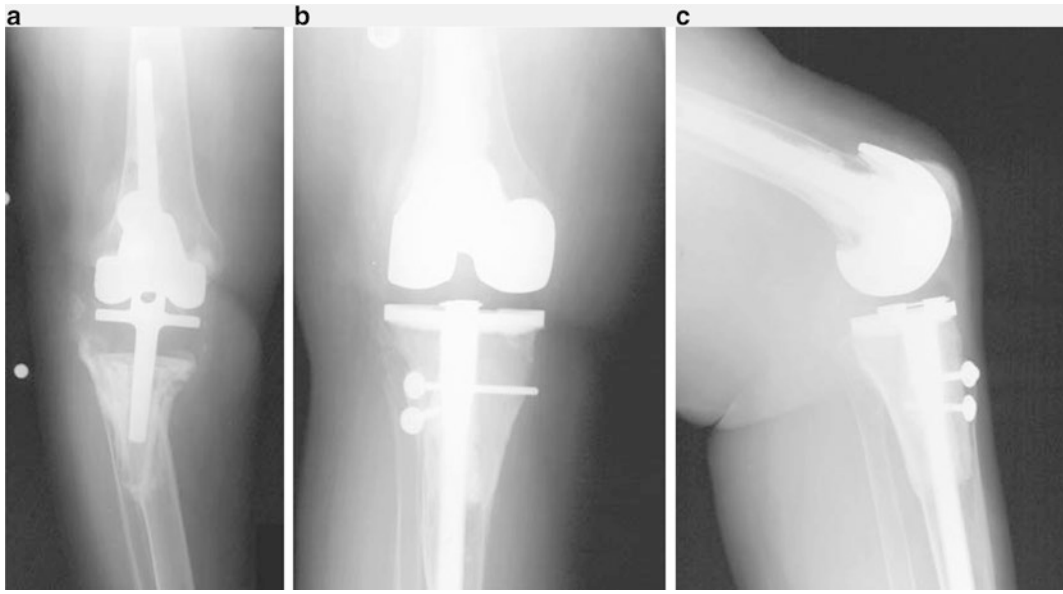

Fig. 8.8 (**a**) Failed, infected total knee arthroplasty demonstrating severe tibial and femoral bone loss. (**b** and **c**) Postoperative radiographs taken 3 years after revision using a custom femoral component, custom tibial stem, custom tibial insert, and structural allograft cemented to the tibial and femoral components (Techmedica, Camarillo, CA)

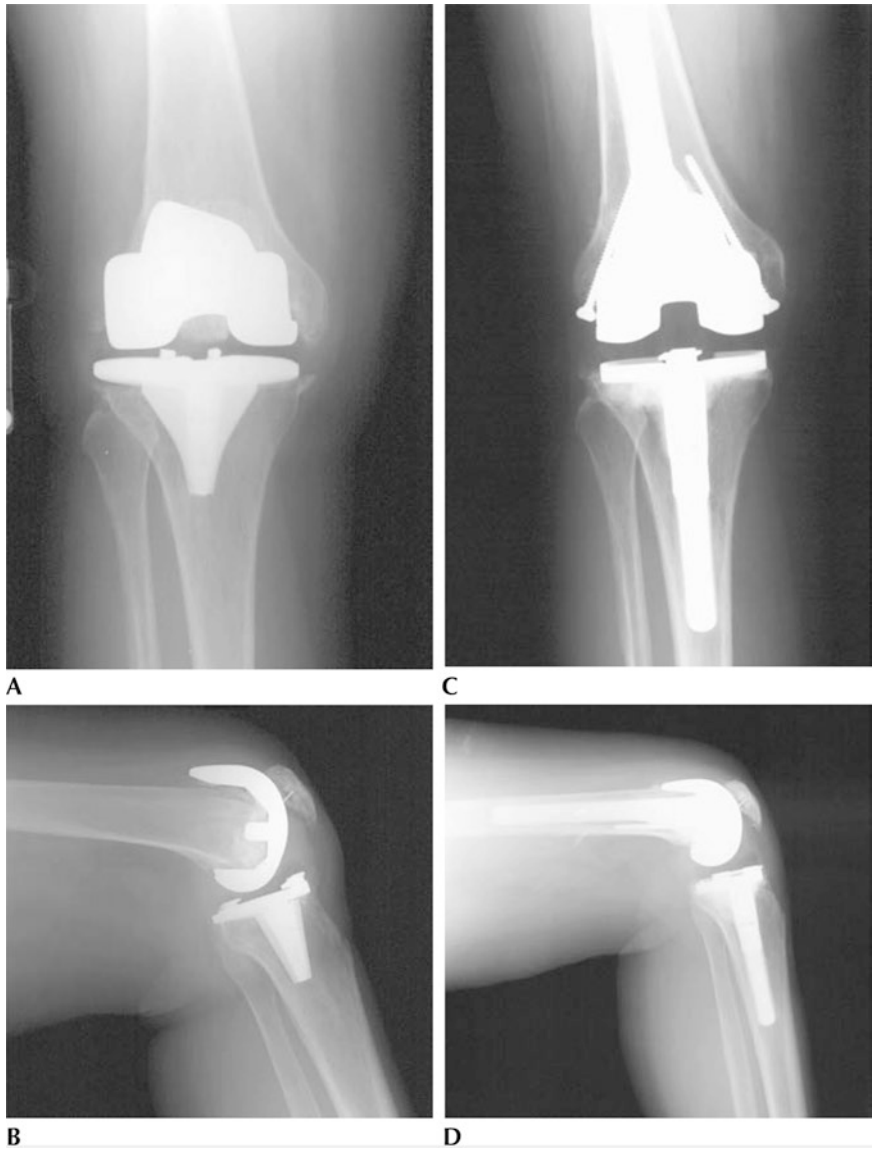

Fig. 8.9 (**a** and **b**) Preoperative radiographs of a failed total knee, demonstrating a loose femoral component and posterior cruciate ligament insufficiency. Although the epicondyles are intact, there is significant cone-shaped bone loss centrally. (**c** and **d**) At 4 years postoperatively, the allograft appears to have incorporated nicely

surgeon include segmental replacement with a tumor or custom prosthesis, or reconstruction with a distal femoral allograft. The allograft can be partial or a femoral head if only one condyle is involved or complete if bicondylar (Fig. 8.10a–d). Some authors advocate the use of a highly constrained implant if remaining epicondylar bone is sufficient to allow rigid attachment of the collaterals to the allograft, but the use of a rotating hinge may be desirable (Fig. 8.11). As in all revisions with significant defects, tightly fitting, long, diaphyseal-filling stems must be used.

Clatworthy et al. have elegantly illustrated and described the technique for distal femoral allograft composite reconstruction [35] (Fig. 8.12). To ensure proper size, the radiograph of the allograft should be compared

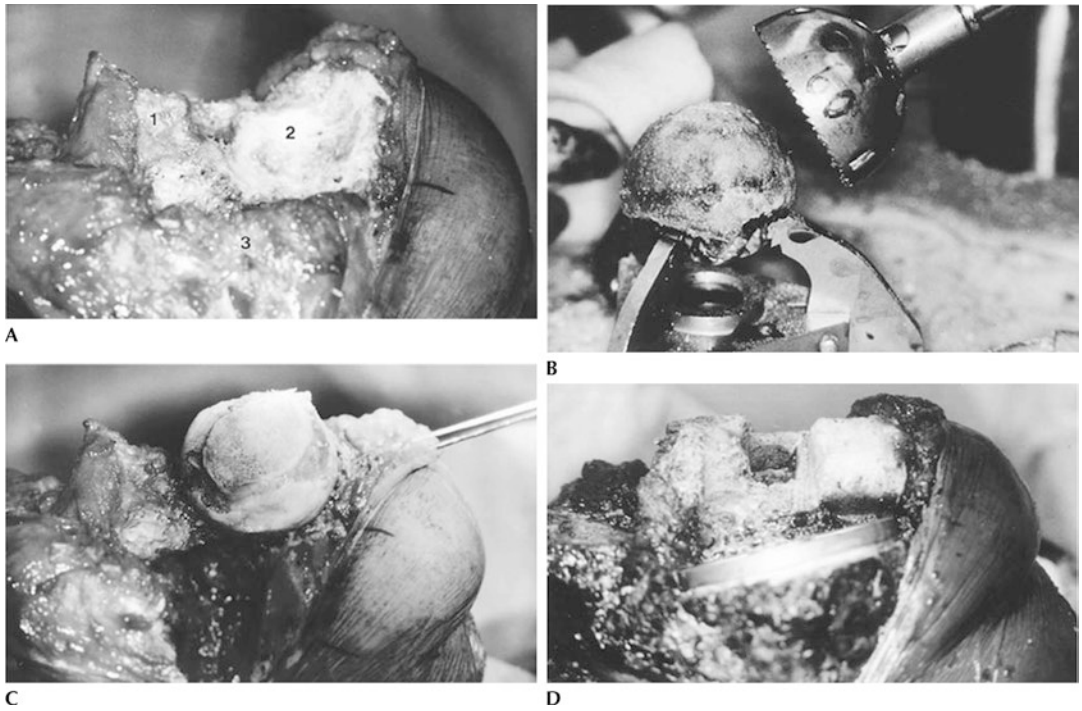

Fig. 8.10 (**a**) Preparation of the host bed of the lateral femoral condyle [2] with use of an acetabular reamer. *1 = damaged medial femoral condyle* and *3 = tibia.* (**b**) The femoral head allograft is prepared with use of a female-type reamer. (**c**) The femoral head allograft is placed in the prepared host bed and is secured by an interference fit and temporary stabilization with Kirschner wires. (**d**) The allograft and the bone in the distal part of the femur are resected to allow the revision femoral component with a canal-filling stem to be inserted with cement (from Engh GA, Herzwurm PJ, Parks NL. Treatment of major defects of bone with bulk allografts and stemmed components during total knee arthroplasty. J Bone Joint Surg Am. 1997;79:1030–39, with permission)

with the radiograph of the contralateral knee. They recommend using an allograft smaller than the host bone so that it may be placed within any remaining host cortical shell. As for a proximal tibial allograft, a *back-table* arthroplasty is performed after assurance that the graft is the appropriate length to establish the proper joint line. A step-cut junction with the host bone is recommended, and cerclage wires with strut grafts are preferred over plates and screws to prevent stress risers in the graft (Fig. 8.13).

Results

Structural bone grafting for segmental, large cavitary, and combined defects has seen promising short- and midterm results. Engh and Parks reviewed the histology and radiographs from seven bulk allografts retrieved from three knees [14]. Five grafts in two knees were postmortem, and two grafts in one knee were biopsied at re-revision. Grafts had been in situ for an average of 41 months. All grafts were used to treat T3/F3 lesions according to the Anderson Orthopaedic Research Institute (AORI) classification system. No components were loose, and all grafts had healed at the graft-host junction. No grafts had revascularized, resorbed, or remodeled.

Engh et al. also reviewed their midterm clinical results with structural allografts for type 3 defects [25]. Twenty-nine femoral heads, five composite distal femurs, and one composite proximal tibia were used in these reconstructions. At a mean of 50 months, 26 of 30 patients had good or excellent results. Radiographically, all grafts not obscured by the femoral component had healed at an average of 7 months. Three of

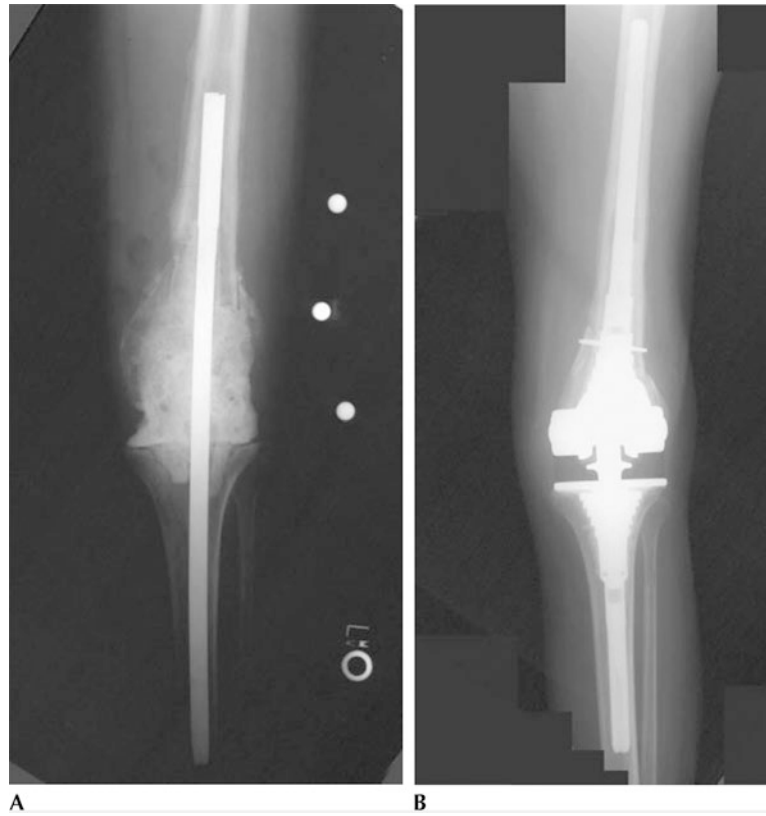

Fig. 8.11 (**a**) Preoperative radiograph of a failed total knee status post-resection, demonstrating significant femoral and tibial bone loss. (**b**) This knee was reconstructed using the S-ROM Noiles rotating hinge total knee system (DePuy Orthopaedics, Warsaw, IN)

four uncemented components subsided significantly. No cemented components subsided. All stems were uncemented. No revisions were performed for loosening.

Ghazavi et al. followed 30 knees with whole or partial distal femoral or proximal tibia allografts for an average of 50 months [36]. All components were cemented, with uncemented long stems. There were seven failures. Two of four knees revised for septic loosening failed for recurrent infection. One additional failure for infection occurred. Two components loosened, one graft fractured, and one graft-host nonunion occurred. Mow and Wiedel reviewed their results in 13 patients with 15 distal femoral or proximal tibial grafts at an average 47 months [37]. All components were uncemented except for three distal femoral and four proximal tibias, in which the component was cemented to the allograft only. All grafts healed radiographically. No components loosened or subsided.

Clatworthy et al. reported a series of structural allografts in revision total knee arthroplasty [35]. All defects were large segmental defects defined as loss of supporting cortical rim bone. Defects were further classified as non-circumferential or circumferential. Non-circumferential defects were treated with femoral heads, partial distal femurs, or partial proximal tibias rigidly fixed to the host bone. Circumferential deficiencies were managed with allograft composites. The average follow-up of 96 months is the longest in the literature. Fifty-two knees requiring 66 grafts made up the study. Forty-eight of the grafts were whole allograft composites. All components were cemented to allograft, with 39 procedures utilizing press-fit stems. Thirteen knees were considered failures. Five were revised for resorption and loosening. Four knees failed for infection, including one of six revised for septic failure. Two knees went on to nonunion with one of these requiring revision. Finally, two knees in one patient failed

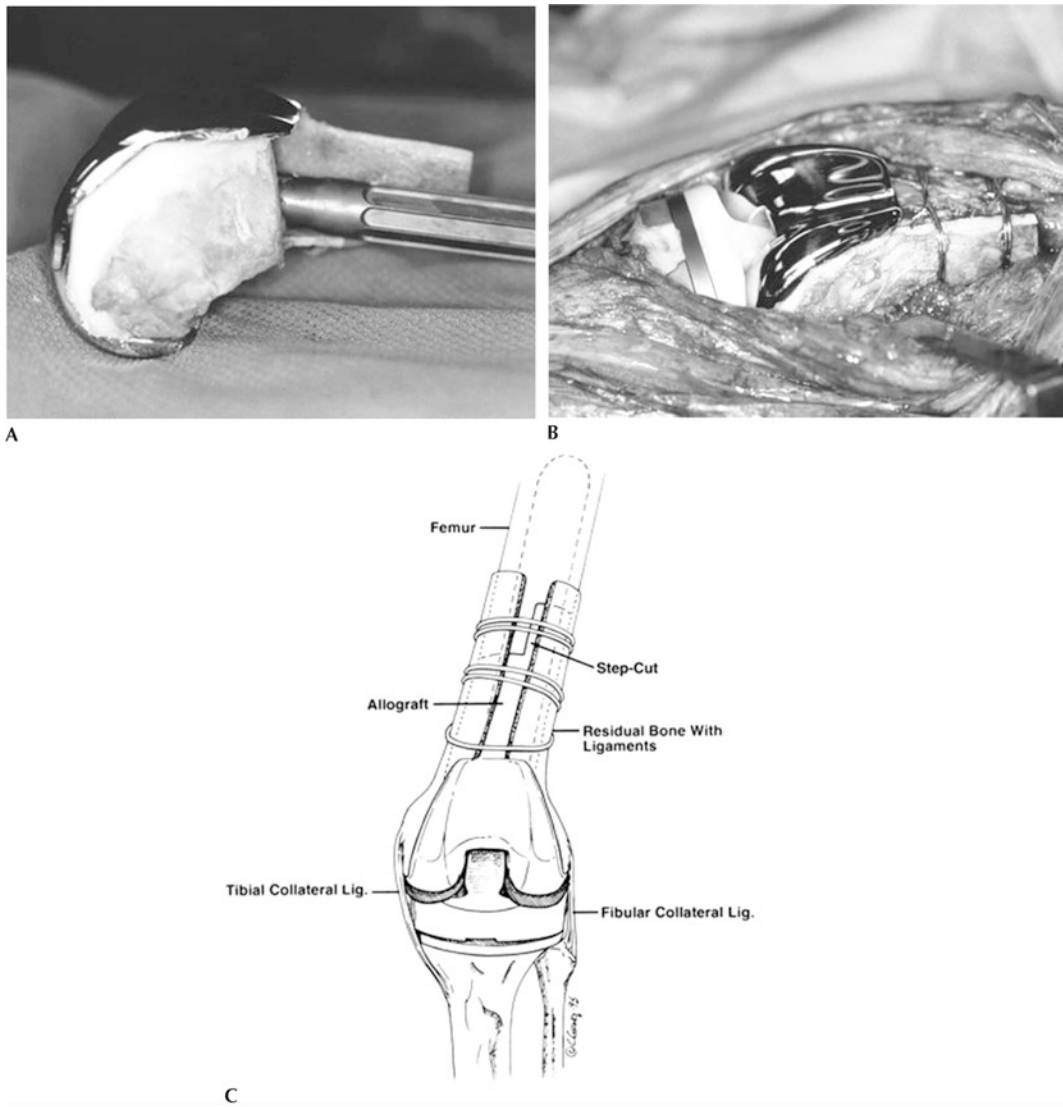

Fig. 8.12 (**a**) The component is cemented onto the allograft, and cement is inserted up to the level of the step-cut. (**b**) The distal femoral allograft construct after implantation. (**c**) The distal femoral allograft construct (from Clatworthy MG, Ballance J, Brick GW, Chandler HP, Gross AE. The use of structural allograft for uncontained defects in revision total knee arthroplasty. a minimum five-year review. J Bone Joint Surg Am. 2001;83-A:404–11, with permissions)

clinically. Overall success was 75%. Graft survival was 92% at 5 years and 79% at 10 years.

In a retrospective study by Chun et al., they assessed the mid- to long-term clinical and radiographic results of revision TKA using a fresh frozen femoral head allograft for large bony defect. Of 27 patients with a mean follow-up period of 107 months, there were no cases of collapse, disease transmission, or stress fracture. Furthermore, all but one knee demonstrated bony union at an average of 7 months postoperatively [38]. Their results demonstrate that femoral head allografts in the treatment of severe bone defects are reliable and durable in the setting of revision total knee arthroplasty [38].

Sandiford et al. recently published encouraging clinical results comparing femoral head structural allografts with trabecular metal cones at a mean 9-year follow-up. Of 45 TKA revisions performed using augmentation of the host bone,

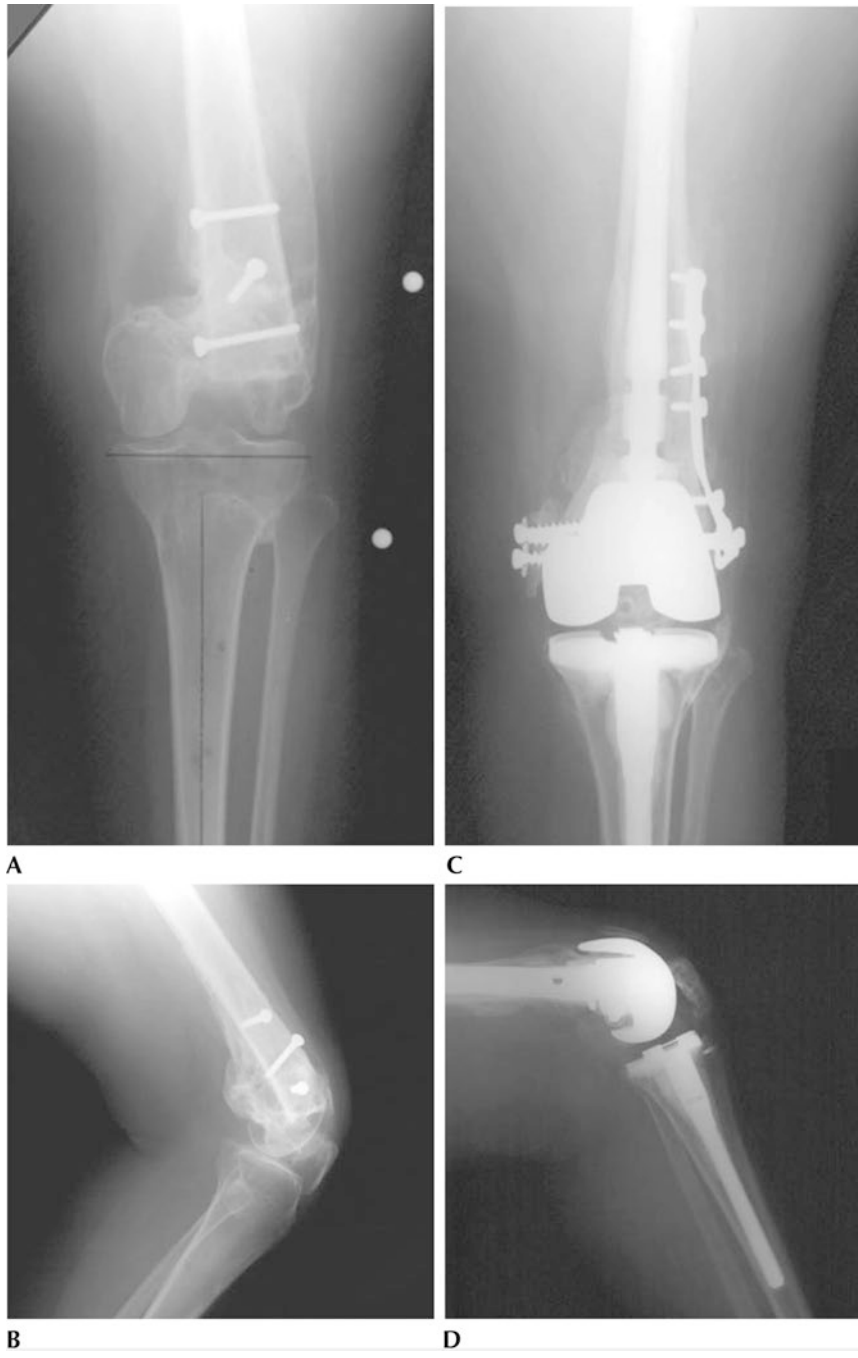

Fig. 8.13 (**a** and **b**) Preoperative radiograph of a patient with posttraumatic arthritis with malunion of the distal femur. (**c** and **d**) Radiographs at 10 years postoperatively. The knee was reconstructed using structural allograft fixed with a lateral T-buttress plate and screws and custom femoral component (Techmedica, Camarillo, CA). Note the fibrous union of the medial epicondyle. Current technique includes a step-cut with cerclage cables rather than overplating

30 were supplemented with femoral head allograft and 15 with trabecular metal cones. The mean Oxford Knee Score in the allograft and trabecular metal cone groups was 91 (SD 10) and 91 (SD 14), respectively. The mean UCLA activity scores were 6 (SD 1.2) and 6 (SD 1.5), respectively. The mean WOMAC scores were 94 (SD 10) and 92 (SD 14), respectively. Five- and 10-year survivorship of the allografts was 93% (95% CI, 77–98) and 93% (95% CI, 77–99), respectively. Survivorship at a mean of 5 years in the trabecular metal cones group was 91% (95% CI, 56–98). There were no differences between the groups in terms of the frequency of surgical complications [39].

Postoperative Management

Most of the literature on the use of allograft in revision total knee arthroplasty has focused on radiographic and functional outcomes. Attention to operative technique is stressed and often detailed. Postoperative management, however, is mentioned only in passing. Most surgeons recommend protected weight-bearing for a minimum of 6–8 weeks. It is probably advisable to extend this until radiographic signs of union at the graft-host interface are present. This could take several months. Although not advocated in the literature, the use of antibiotics for a prolonged time is a common part of postoperative management. Allograft is a nidus for the growth of organisms. Indeed, the infection rate for revisions with allograft is roughly twice that of comparable revision series without allograft [10, 35, 37, 40, 41]. Despite this fact, previous infection is not viewed as an absolute contraindication to the use of allograft.

Conclusion

Most defects encountered at the time of revision surgery can be reconstructed with augments and stems available in modern revision systems. Larger defects, however, may require replacement with custom implants or allograft bone. Morselized allograft is ideal for smaller contained defects and has even been successful in larger defects as long as the component achieves stability on host rim bone [29]. Structural allograft should be considered in large contained, segmental, and combined defects. When circumferential, deficiencies can be reconstructed with whole allograft composites. Medium-term survival is encouraging [35].

Technique is critical. Rigid fixation between graft and host is essential. Components should be cemented to cut surfaces, as allograft has no biologic potential for ingrowth. Press-fit diaphyseal stems share load to protect grafts but may allow enough compressive force to promote union. Although radiographic resorption is reported in most series, it is unlikely that grafts revascularize and collapse. Retrieval studies in the knee and hip do not show revascularization or resorption [13, 14, 34]. Graft collapse is probably due to trabecular fracture and the inability of the graft to repair and remodel. Many acetabular grafts failed early because they were not off-loaded. With the use of cages, survival has improved. Likewise, in the knee, stems reduce stress on grafts and protect against early fatigue failure.

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Modular Augments in Revision Total Knee Arthroplasty

9

Lucas Anderson and J. Bohannon Mason

Bone loss and subsequent defects are often encountered in revision total knee arthroplasty and occasionally in primary total knee arthroplasty. The variability in size and location of these defects has led to the development of multiple techniques for restoring the support for a stable and functional prosthesis. Techniques frequently reviewed in the literature include filling minor defects with cement; augmentation of cement with screws, wires, or mesh; bone grafting; metal augmentation with blocks and wedges and more recently sleeves and cones; and, finally, custom components (Figs. 9.1, 9.2 and 9.3).

Modularity in total knee systems has earned its acceptance by providing utility in the management of a wide spectrum of bony defects. Consequently, custom implants are now rarely needed as the array of modular options have evolved to include offset stems, stem extensions, variable femoral and tibial prosthetic body options, and modular augmentations. The clinical acceptance of modular metal augments is due in large part to their off the shelf availability and flexibility in effectively managing the variety of clinical situations that face the knee arthroplasty surgeon.

Bone defects that remain contained by the cortical rim can often be successfully managed with morcellized bone grafting techniques [1]. For very large contained defects, a combination of bulk and morcellized graft may be most appropriate, usually offloaded with extended prosthetic stems. However, in many surgeons' hands, newer sleeve and cone options are replacing these grafting techniques.

When the cortical rim of either the distal femur or proximal tibia is breached, the reconstructive options are more challenging. In younger patients, structural allograft may be an option for consideration, yet this is tempered by reported problems including host-graft nonunion, disease transmission, and possible late collapse or resorption of the allograft [2]. Indeed, most revision centers rarely use bulk, structural allograft in revision arthroplasty.

Surgical techniques other than the use of modular or custom implants include shifting of the prosthesis to a region of more supportive host bone stock and/or possibly downsizing the prosthesis. These intraoperative choices represent compromises that may be accompanied by potentially undesirable consequences including component subsidence, loosening, and failure [3]. Downsizing

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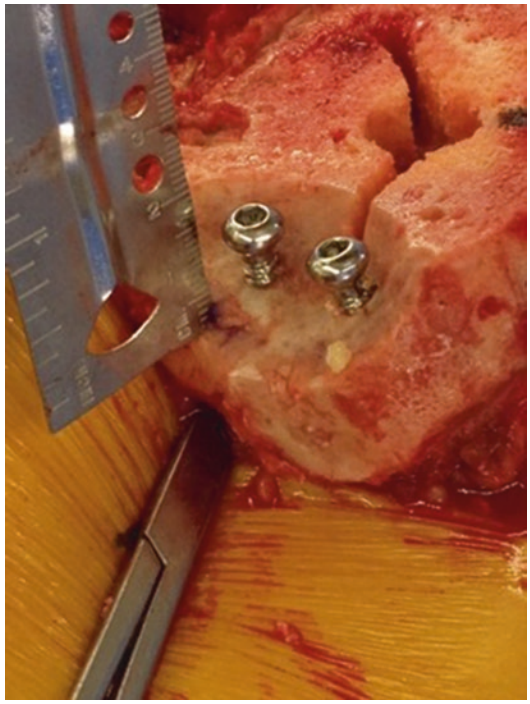

Fig. 9.1 Intraoperative image of 4.5 screws being placed in medial tibial bone defect as "rebar" for cement

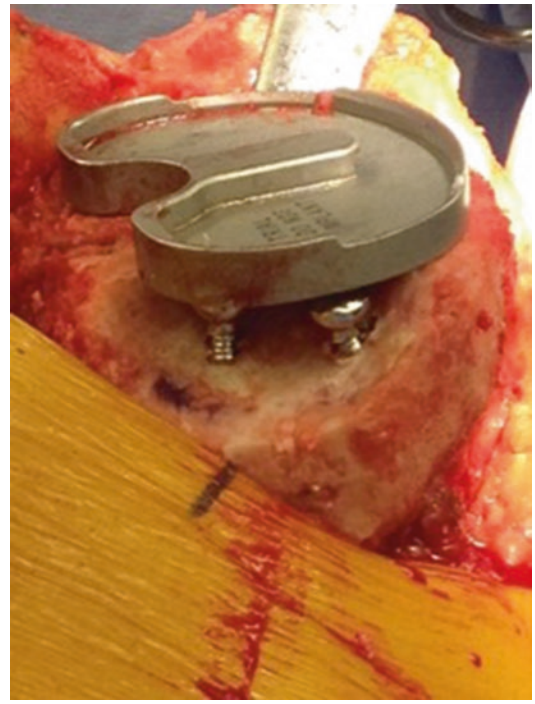

Fig. 9.2 Intraoperative image of screws being placed level with tray in medial tibial bone defect

of a femoral component to accommodate bone loss may inadvertently lead to flexion space instability.

Recognition of the above limitations led to the development of modular metal augments. Brand et al. reported the first clinical series of modular metal wedges for the management of bone deficiency in 1989 [3]. Modular metal augmentations are now readily incorporated in modern knee reconstruction systems and include augments of the individual condyles, cones, sleeves, and wedges [4]. In this chapter, we discuss the indications, limitations, and techniques for the use of femoral or tibial modular augmentations in total knee arthroplasty.

Bone Loss: General Considerations

Bone deficiencies and bone loss are encountered in both primary and revision settings. In a primary knee extreme varus, valgus, or flexion deformities may preoperatively herald the presence of bone defects, which, if ignored, may threaten the component reconstruction. Extreme defects related to severe disease, progressive or rapid bone loss associated with avascular necrosis, neglect, or trauma may result in bone defects that require augmentation even in primary knee arthroplasty. Inflammatory arthropathies, such as rheumatoid arthritis, may result in severe cyst formation and bone loss.

The bone defects seen in revision knee arthroplasty generally occur with component loosening, component removal, or from osteolysis. Several authors have described classification schemes for bone loss about the knee [4]. Engh's classification system is similar for both femoral (F) and tibial (T) sides; Grade 1 is a minimal metaphyseal defect, Grade 2A is a loss of medial or lateral condyle, Grade 2B is the loss of both condyles, and Grade 3 is a severe condylar bone loss with absent MCL/LCL. An algorithmic approach to preoperative grading of deficiencies can help in strategically planning for the appropriate combination of components, stems, and augments. The most common patterns of bone

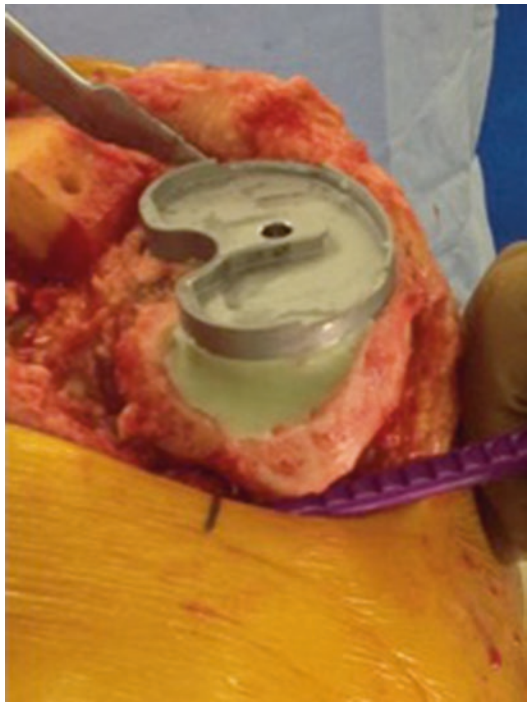

Fig. 9.3 Intraoperative image of cemented tray over screws to fill medial tibial bone defect

loss that require modular augmentation include the medial or lateral tibia in association with varus and valgus collapse, respectively, and a combination of distal and posterior femoral augmentation with femoral component failure.

Preoperative radiographs can help identify patients who may require tibial or femoral augmentation. Brand et al. have proposed a method for estimating tibial defect size based off of preoperative anterior-posterior radiographs [3]. A line is drawn down the central axis of the tibia. A perpendicular line is then drawn at the top of the intact tibial plateau. A tibial defect exceeding 15 mm from the horizontal line may require augmentation and should be considered in preoperative planning of the reconstruction.

Estimation of the need for augmentation on the femoral side can be more difficult (Figs. 9.1, 9.2 and 9.3). The metallic bulk of the femoral implant makes visualization of the distal femur difficult even with multiple oblique views. Knowledge of the prosthetic design and history may be of benefit in preoperatively determining the need for femoral augmentation if defects are not obviously apparent. Preoperative estimation of bone stock after component removal can be helpful in planning augmentation options that should be available.

Modular Metal Augmentation

Modular augmentation represents an attractive option in reconstructive surgery, allowing a surgeon to provide an implant construct customized to the defects encountered, reestablish correct component levels with respect to the joint line, maintain or reestablish limb alignment, and adjust soft tissue balance (Figs. 9.4 and 9.5).

The mechanical strength of augmentation wedges and blocks has been investigated. In vitro studies have focused on two areas of interest [5]. The first is the fixation of the augment to the prosthesis. Most modern designs rely on a screw or snap-lock mechanism, occasionally augmented with cement. Older designs relied exclusively on cement fixation of the augment to the prosthesis. All mechanisms of augment fixation have been used successfully in the short term with clinical experience up to 5 years reported. The long-term concerns include loosening, dissociation of the augments, and possible fretting leading to third-body wear.

Brand et al. reported a revision of a nonmodular tibial tray for polyethylene failure in which they had previously applied a 5 mm wedge with cement for a medial tibial defect [3]. After 5 years in vivo, the medial wedge maintained 77% of the sheer strength of control and showed no evidence of corrosion, fretting, or impending failure. Fehring et al. found that tensile strain within the cement-bone interface was less with block augments compared with wedges [5]. However, the maximal strain differential between blocks and wedges was only slight, arguing that the augment that best fills the defect should be used.

Patel et al. reported on 102 primary knees revised with type-2 defects treated with modular augments and stems with mean follow-up 7 ± 2 years (5–11). There were 18 tibial augments and 176 femoral augments implanted, all of

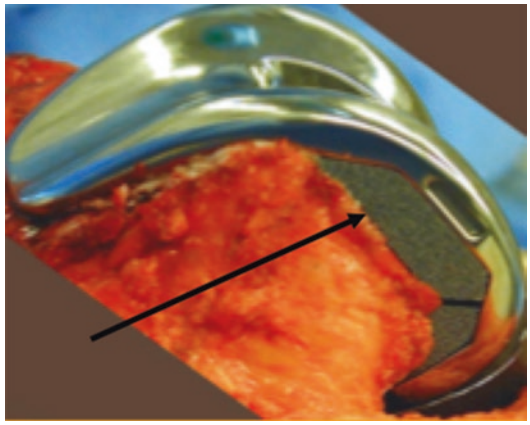

Fig. 9.4 Modern revision knee systems allow for the use of augments of varying thickness, as here on the posterior and distal femur

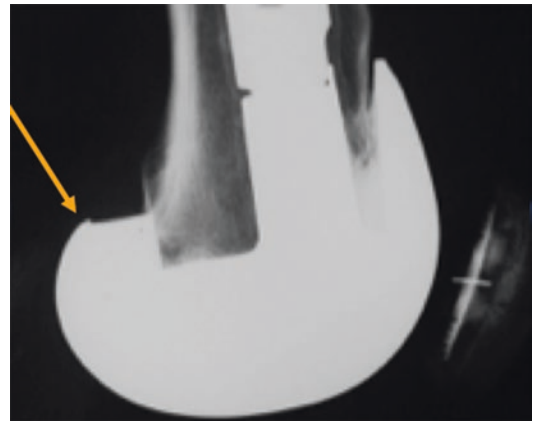

Fig. 9.5 Radiograph of a posterior augment the femoral component

which were fixed to the component by cement. There was a 92% survivorship at 11 years and a 14% rate of nonprogressive lucent lines that was not associated with outcomes or survivorship or implant utilized [6].

The first clinical series reporting the use of metal wedges for tibial bone deficiencies was reported by Brand et al. [3]. In this series, 22 knees in 20 patients were included. Modular metal wedges used to customize the tibial implant. Three of the 22 knees were revision cases. In each case a small, cemented tibial stem extension was employed. Six knees, at average 37 months' follow-up, revealed radiolucent lines beneath the tibial wedge; however, no tibial tray was judged to be loose.

Rand reported a series of 28 primary knees with defects up to 18 mm, majority medial, at a mean follow-up of 27 months. Clinical scores for all patients were rated as good to excellent despite nonprogressive radiolucent lines beneath 13 of the 28 tibial wedges. In a follow-on study of the same patient cohort, no significant degradation in the radiographic follow-up of the wedges was noted [7].

Tibial Component Augmentation

Modular augments used beneath the tibial tray are typically either wedge-shaped, which fit above an oblique bone resection, or are more commonly blocks. Hemi-wedges can be used to fill small peripheral defects, whereas full-wedge augments can be used to correct axial alignment beneath the tibial tray or to substitute for more extensive proximal cortical bone loss. Block augments, sometimes referred to as *step wedges*, are employed when bone loss at the cortical rim includes a unicondylar defect (medial or lateral) and supporting anterior or posterior cortical bone at the level of the tray-bone resection.

Indications

Tibial augmentation with modular metal wedges or blocks is usually applied to defects of 5–20 mm in depth, particularly when these defects fail to support more that 25% of the tibial base plate (Fig. 9.6). Several factors guide the decision to use modular augments. Since the tibial diaphysis tapers distal to the joint line, resection to the supportive tibial host bone requires the use of a smaller base plate or risks overhanging metal, which can be particularly problematic to the patient postoperatively. Tibial defects rectified by downsizing the tibial base plate, with greater resection of bone to the depth of the defect, may limit the opposing femoral component sizing choices. The depth of modular augmentation, too, is limited by several practical considerations. First, most commercially available augments do not taper as the host bone metaphysis does.

Larger tibial augments may likewise expose a sharp prosthetic edge at the base of the augment. This modular *overhang* may cause pain and should be avoided if other options for reconstruction are suitable. The depth of a modular augmentation is additionally limited by the extensor mechanism. Resection levels greater than 20 mm below the native joint line place the tibial tubercle and extensor mechanism in jeopardy, particularly if on the lateral side.

Extensive proximal tibial bone loss over both medial and lateral surfaces of the proximal tibia may be handled with thicker polyethylene inserts. Tibial bone loss may exceed the height of the modular polyethylene inserts available for a given knee system. Additionally, as the polyethylene insert's thickness increases, the stresses at the insert locking mechanism increase, potentially leading to increased micromotion. Elevating the tibial base plate and reducing the thickness of the polyethylene insert required can offset this negative biomechanical consequence. Full tibial base plate augments or bilateral matched medial and lateral augments can be used to raise the tibial tray closer to the native joint line (Fig. 9.7). As the tibial base plate is elevated with augments from below, the stem is effectively shortened, suggesting consideration of a longer stem (Figs. 9.8 and 9.9).

Surgical Technique

In reconstructing the deficient proximal tibia with modular augments, the objectives remain restoration of alignment, soft tissue balancing, and a near-anatomic replication of the joint line to restore knee kinematics. In primary and revision knee arthroplasty, the initial resection level is selected with optimal preservation of host bone stock. The residual peripheral defects are then assessed. It is important to determine the flexion-extension gap relationship between the femoral and tibial trial components. This is particularly true when trial distal femoral augments are considered, as the tibial resection level equally affects the flexion and extension space. With the trial femoral component in

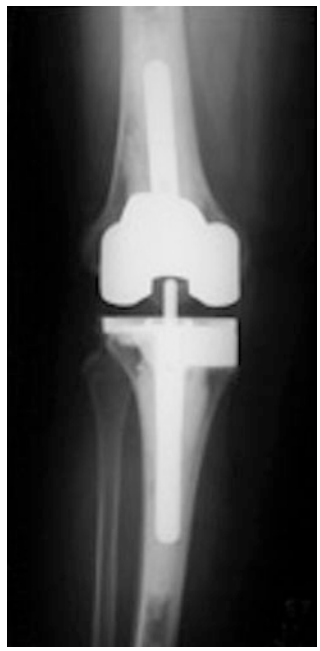

Fig. 9.6 Contained tibial defects are easily managed with a tibial augment, allowing cortical rim contact with the prosthesis

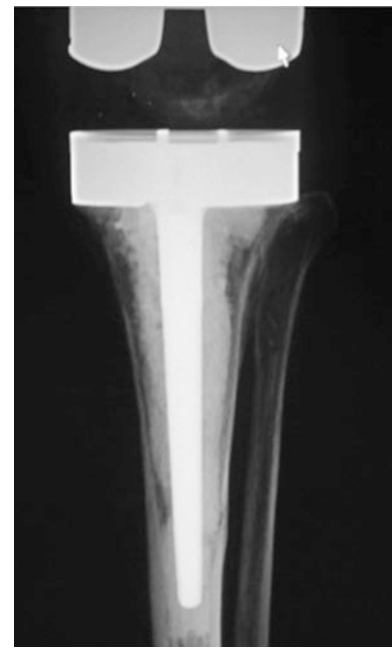

Fig. 9.7 A full tibial tray augment can raise the joint line of the tibial tray and decrease tibial polyethylene thickness

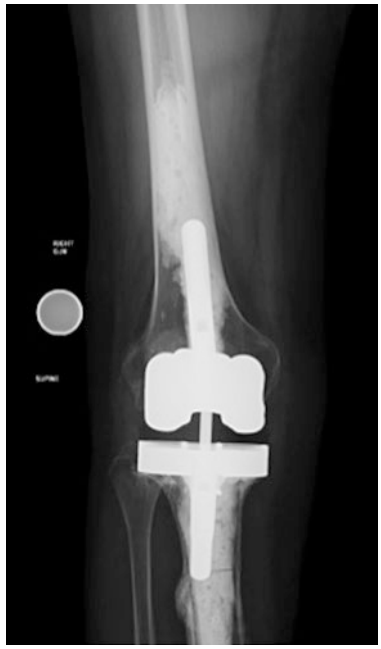

Fig. 9.8 A full modular wedge augment was used in this patient who had experienced valgus failure of his prior implant. A short stem extension was selected. Despite initial stability, implant loosening occurred at 3-year follow-up. When host bone is significantly compromised to require a tibial augment, a longer stem extension should be considered

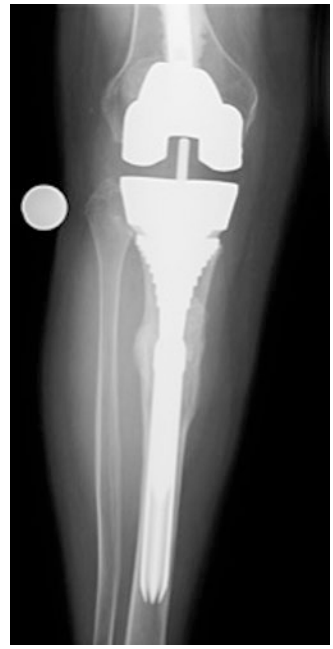

Fig. 9.9 Prior TKA was revised to a longer cementless stem that gained diaphyseal fixation below metaphyseal replacing augment

position, the knee is brought into full extension, and the rotational alignment of the tibial tray relative to the tibial host bone is determined and marked on the proximal tibia. This step is important before preparing the proximal tibia for an augment. The axial rotation of the tibial tray relative to the tibia determines the anterior to posterior (sagittal) orientation of the wedge or block resection. Failure to note this rotational alignment may result in difficulty matching the modular augment to the prepared resection, or inadvertent internal or external rotation of the tibial tray.

The size of the wedge or block is then determined by measuring the distance between the undersurface of the tibial tray and the depth of the cortical defect. Most revision systems provide resection guides for the various modular components. However, in obese patients who require deep resection levels or have lateral defects, these resection guides may be difficult to use and the resection may require free-hand adjustments. A narrow oscillating saw or high-speed bur can be particularly useful in these situations. The selection of a modular augment typically mandates the use of a stem. Consequently, intramedullary alignment systems are most helpful and can prevent errors including medial or lateral displacement of the augment, excessive or reversed slope of the tibial tray, and large errors in axial alignment in the AP plane. Offset stems can be useful in avoiding component overhang (Fig. 9.10).

Estimating the height of the joint line can be difficult in cases with extensive bone loss associated with ligament laxity. Although the kinematic relationship between the femoral and tibial components is most important, the surgeon should strive for accurate joint line restoration. Helpful techniques available to the surgeon include comparing the patella ligament height to the contralateral knee or to the knee prior to reconstruction, as well as radiographically examining the contralateral, uninvolved joint line, and

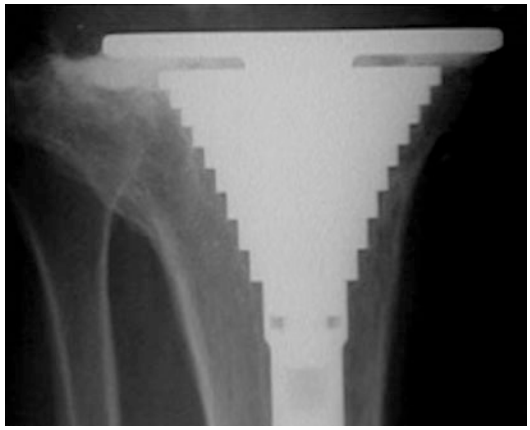

Fig. 9.10 Radiograph demonstrates how tibial stem drove the tibial tray medial due to a lack of offset options with this sleeve/tray construct

extrapolating the distance of the proximal fibula or epicondyles to the native joint line (Fig. 9.11).

Femoral Component Augmentation

The use of modular metal augmentations on the femoral side has received less attention in the literature. Current knee systems include augments of variable thicknesses for the medial and lateral condyles both distally and posteriorly, or in combination. A few systems provide anterior femoral augments though less often used or indicated. As surgeons become more conscious of soft tissue balance, the role of femoral joint line restoration and correct axial rotation is prioritized. Failure to restore the joint line or properly rotate the components relative to each other can compromise knee kinematics including knee flexion and patellar tracking.

Indications and Considerations

Modular femoral augments may help facilitate accurate restoration of component rotation. Lateral femoral condylar hypoplasia is often associated with valgus axial alignment. Lateral condylar hypoplasia is easily managed with posterolateral modular augmentation on the femoral component, whereas inattention may lead to internal rotation of the femoral component, particularly if a posterior condylar referencing system is used. Revision of an improperly internally rotated femoral component is a frequently encountered situation in revision arthroplasty. Restoration of proper rotational alignment is aided by posterior modular augments (Fig. 9.12).

When femoral component failure requires removal of the implant, there is often loss of distal femoral bone. Additionally, distal resection of bone to achieve a stable bone surface elevates the prosthetic-bone interface. Modular distal femoral augmentation can help reduce this artificial elevation of the joint line. References for femoral joint line mirror the discussions above on tibial joint line restoration. The epicondyle can be used as a relative bony reference point; however, the distance from the epicondyle to the joint line varies from patient to patient making contralateral and preoperative radiographs valuable [7, 8].

The modular femoral augments are particularly useful in restoring proper anterior-posterior dimension to the femoral component. The advantage of modular metal augmentations for the distal femur over solid, non-modular components is the ability to independently fit defects of each condyle and conserve host bone. The surgical technique for femoral preparation using modular augments is quite simple and familiar to most surgeons. An intramedullary guide is suggested. A stem is recommended when modular augments are employed. As the height of the distal femoral augment increases, the rotational constraint implied by host bone contact within the intracondylar notch region of the component is decreased (Fig. 9.9, 9.10, 9.11, 9.12 and 9.13). If augments are employed, the extra depth of the box resection of a constrained condylar designed knee provides additional rotational stability to the femoral implant. Additionally, if late ligament instability occurs, the femoral component need not be exchanged to allow use of the condylar constrained tibial insert. That said, many systems allow the use of a constrained condylar designed knee with cruciate substituting polyethylene inserts. As is frequently the case in revision surgery, the flexion space is capacious compared

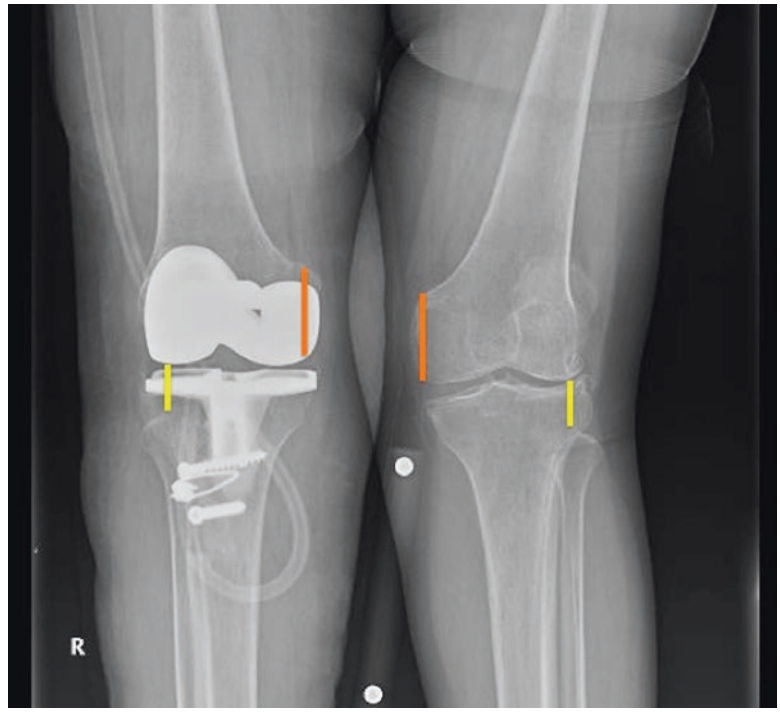

Fig. 9.11 Radiograph demonstrating technique of measuring distance from the lateral joint line to the fibular head and comparing to the contralateral side (*yellow lines*) versus comparing measurements from the medial femoral condyles to the medial joint line (*orange lines*)

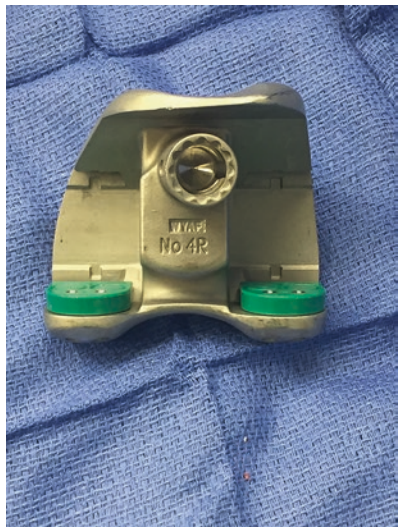

Fig. 9.12 Posterior condylar augments of the femur, as shown, fill bony defects as well as help control femoral rotation, improving flexion space balance and patellofemoral tracking

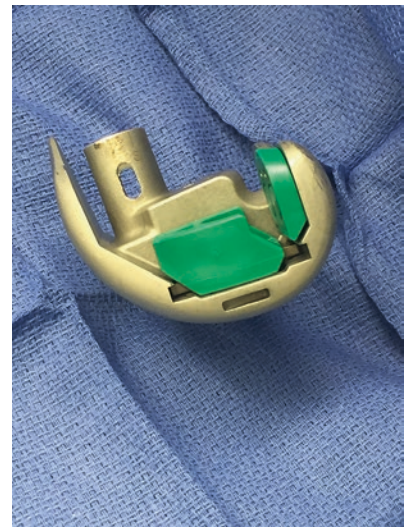

Fig. 9.13 Rotational control by a standard intra-condylar box is lessoned by distal femoral augments that minimize bony contact

with the extension space. Posterior augmentation of the femoral component allows proper sizing of the prosthesis, maximizing medial-lateral bone coverage and addressing the extension-flexion mismatch (Fig. 9.14). Establishing the extension space and then matching it on the flexion side by adjusting the femoral size and posterior augments will yield a balanced knee. Some systems provide flexion/extension spacer blocks that can both guide femoral rotation and help equalize the

Fig. 9.14 Posterior modular augments are used to "upsize" the femoral implant, assisting with flexion space management without affecting the extension space

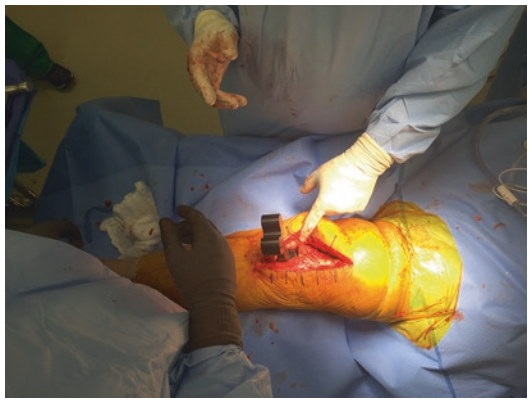

Fig. 9.15 After freshening up the tibial and distal femoral cuts, gap blocks can be used to establish first either the extension gap (as in this case) or the flexion gap. Thereafter, adjusting distal femoral augments or femoral size can lead to balanced flexion/extension gaps

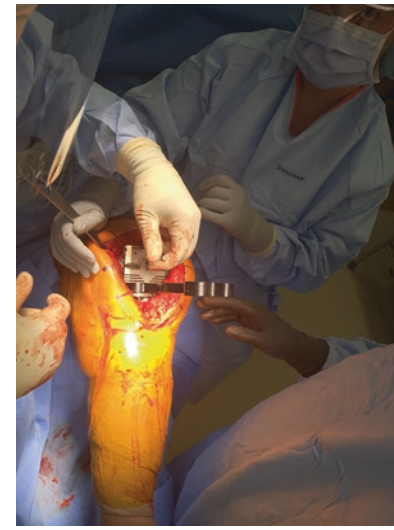

Fig. 9.16 Some systems allow the distal cutting block to slide over the inserted reamer, and then rotation and femoral size is chosen by the corresponding block placed in the flexion gap

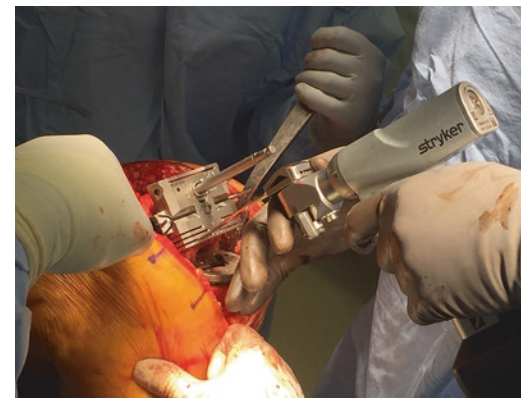

Fig. 9.17 Revision cutting blocks usually have variable posterior condylar cutting slots to determine posterior femoral augments required

flexion and extension gaps (Fig. 9.15, 9.16 and 9.17). Posterior femoral augments may additionally be of benefit if the prosthetic stem forces the femoral component anteriorly and thus causes a reduction in the posterior condylar offset. Chamfer resections should be assessed and made with the appropriate sized distal femoral augment trial in place. In many revision cases in which distal augments are required, the chamfer resection is minimized. Implanting a condylar constrained femoral housing can increase the rotational stability of the reconstruction. Anterior-posterior femoral stem offset is available now with most systems. Combined with the flexibility of cementing a smaller diameter femoral stem, it is uncommon that the femoral component cannot be placed flush to the anterior cortex of the femur.

Stand-Alone Augments: Tantalum Augments, Sleeves, and Cones

Components cemented into large defects are liable to rotational instability and subsidence over time. Metaphyseal sleeves and cones are

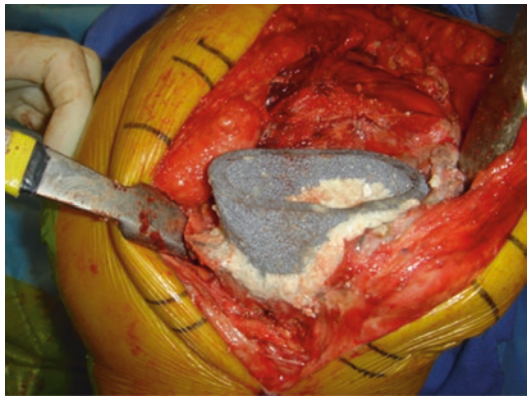

Fig. 9.18 The tibial highly porous metal cone creates a contained medial column for cementing a stemmed tibial component where there was a large medial deficiency. The large hollow center of the cone permits translation of the stem where there is offset between the metaphysis and diaphysis

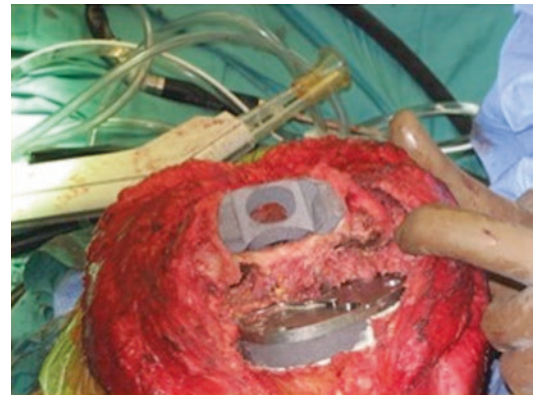

Fig. 9.19 Femoral highly porous cones provide rotational and axial stability in setting of large central cavitary lesion of the femur with medial and lateral shells of bone

modular augments designed to fill bone voids. Sleeves and cones provide biological fixation or alternatively enhanced cement fixation that can in turn provide improved rotational support as well as prevent subsidence. When press-fitting the augments into bone that has been prepared to accept the augment shape, demineralized bone graft putty can be used to seal the cone/bone interface to prevent cement from penetrating this interface.

Highly porous metaphyseal augments are made of the material tantalum that is both highly inert and corrosion resistant. Tantalum porous metal has high compressive strength and low modulus of elasticity, physical and mechanical properties similar to cancellous bone, making it an ideal augment to encourage ingrowth and prevent stress shielding. Tantalum augments were the first common metaphyseal metal augments used in arthroplasty [9, 10]. It has been described as "prosthetic bone graft" as it ingrows into surrounding bone. These tantalum augments come in a variety of premanufactured sizes and shapes; larger cones are used for metaphyseal defects, while smaller cones are used for metadiaphyseal defects. Tantalum cones are one of the better solutions for uncontained defects as it allows either the medial or lateral column to be reestablished and can be used in conjunction with traditional modular augments (Fig. 9.18). Different-sized augments can be stacked on one another for differing diameter defects in the metaphysis versus meta-diaphysis [11]. The cones have a hollow center and can be modified with a metal cutting bur or round saw to permit better fit to the surrounding bone or allow further stem/component translation to allow positioning freedom of the cone to the stemmed implant. These cones are then cemented to the stems/components to permit offset and height adjustment. Tantalum femoral cones are particularly helpful in "goalpost" femurs that have large central cavitary lesions but intact medial and lateral shells (Fig. 9.19). The negative of tantalum cones is that there is no bone preparation system, and so establishing a stable fit of the augment to the bone defect either requires modifying the metal cone or using a freehand bur or rasp to remove more bone in a stepwise manner which can be tedious and time consuming. That said, Lachiewicz reported in a meta-analysis on 196 patients with tantalum augments from 8 different studies, which demonstrated a good short-term (2–5 years follow-up) track record of ingrowth as well as providing a rotationally stable platform for revision implants [12].

Metaphyseal sleeves are aspherical augments that are placed into defects over stems and provide metaphyseal support in the revision setting [13, 14]. Sleeves are useful in both femoral and

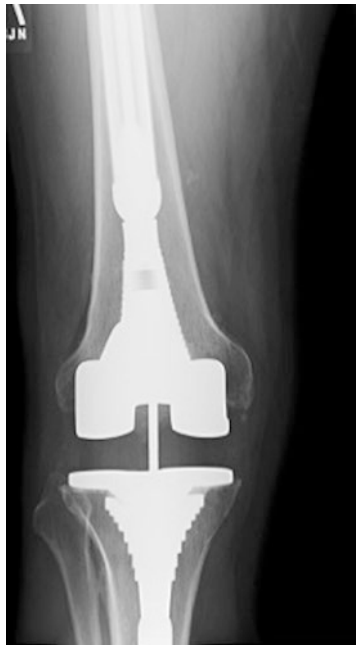

Fig. 9.20 Radiograph demonstrating revision TKA with tibial and femoral sleeves with stems

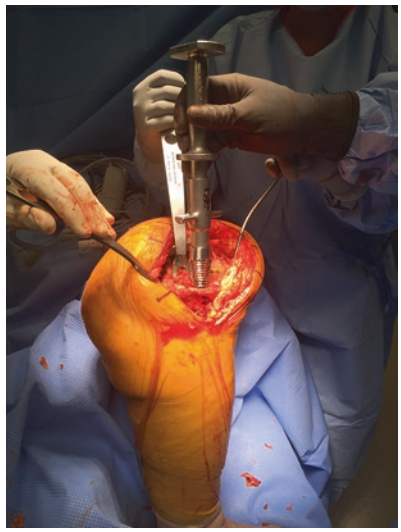

Fig. 9.21 Intraoperative picture demonstrating broach system for sleeves

tibial constructs (Figs. 9.20 and 9.21). They have porous coating for bone ingrowth but can be fully cemented as well, often with stems, providing a load sharing benefit. Sleeves have a modular taper

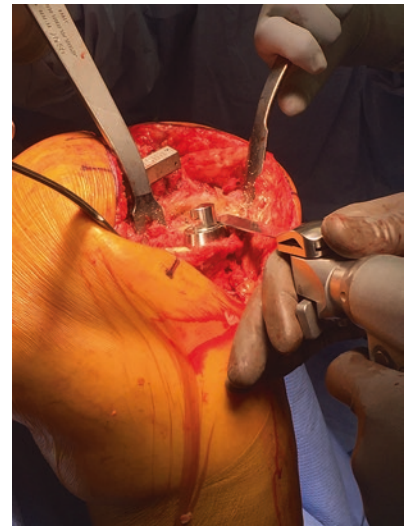

Fig. 9.22 Intraoperative picture demonstrating use of the tibial sleeve to provide a cutting surface for the new proximal tibial height

connection that links the sleeve to the stemmed implant and fixes the height. This can make it difficult to adjust height of the implant without further seating the sleeve, taking away additional bone. Fortunately, a range of sleeve sizes can allow adjustment of component height. A cautionary note regarding sleeves is that they constrain implant positioning by limiting component offset/translation (Fig. 9.10). Additionally, the broaches can translate forces to compromised bone and, if rotation is not matched, can lead to iatrogenic fractures. That said, sleeves have a simple, efficient broach instrumentation system that provides metaphyseal rotational and axial control (Figs. 9.21 and 9.22) and good early-term results with 43 months (30–65) mean follow-up [13].

Milled porous cones are conical augments that provide rotational control and subsidence prevention. The metaphyseal defects are machined by calibrated milling type instrumented reamers to provide an accepting contour that varies in size and depth including an SROM type reaming for the lobed aspects of the augments. This permits ease of cone sizing and insertion and reproducible height of the overall construct (Fig. 9.23, 9.24 and 9.25). These benefits provide the revision

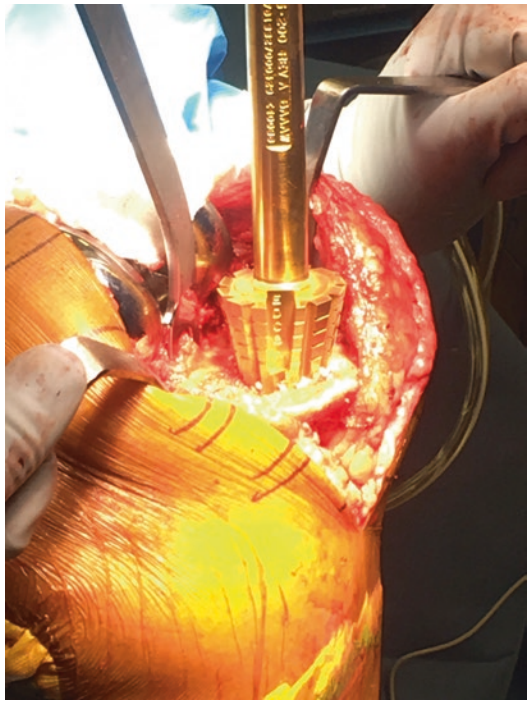

Fig. 9.23 Picture demonstrates intraoperative milling of central tibial defect with calibrated depth/size indicators on reamers that match cone size options

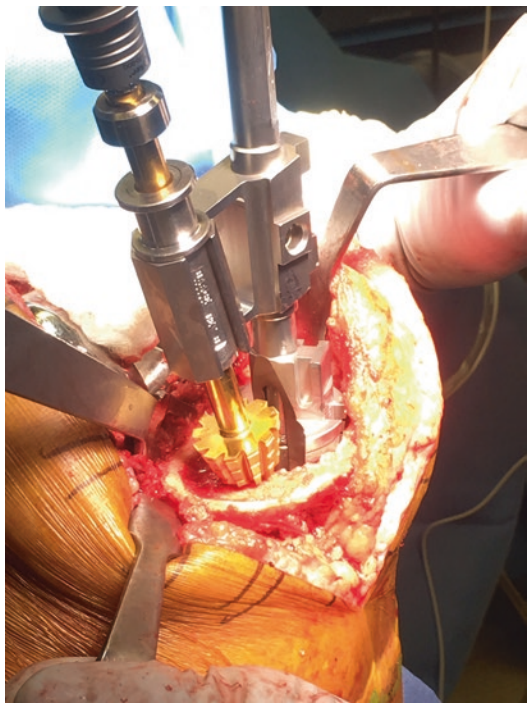

Fig. 9.24 Picture demonstrates intraoperative milling of medial defect

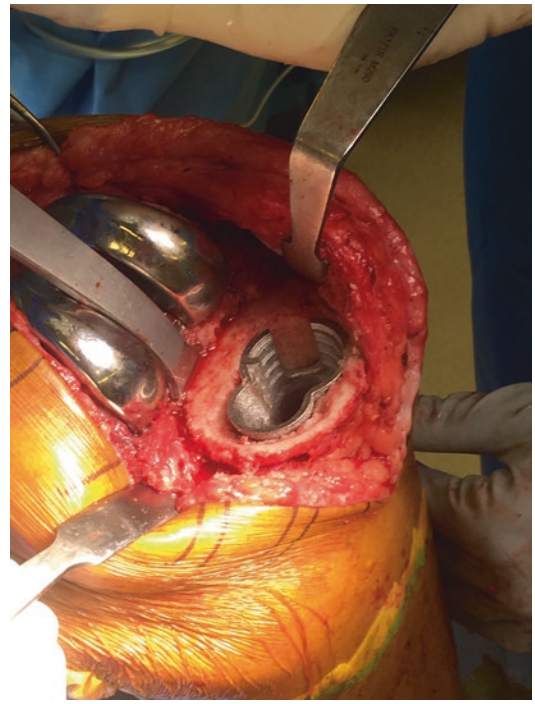

Fig. 9.25 Picture demonstrates intraoperative placement of cone in prepared defect

surgeon with reliable surgical flow and permits efficient insertion and cementing without significant risk of fracture. The cones come in a range of sizes to match defect depth and size and allow adjustment of component height. Cones, similar to sleeves have porous coating for option of ingrowth as a "prosthetic bone graft" though the augment bone interface can be cemented as well. Cones are particularly useful on the tibial side where bone loss is asymmetric. The femoral cones have special symmetric bilobed options. Stems are typically cemented into the cones providing extended fixation. Cones typically have a more capacious open canal into which stems are cemented allowing greater translation of the component/stem within the cone and placement of the stem in the canal independent of the cone (Fig. 9.26). These cones have a newly introduced ingrowth surface without a published track record at this time. Future outcome studies will establish its utility and performance among the options that include the proven cones and sleeves mentioned above.

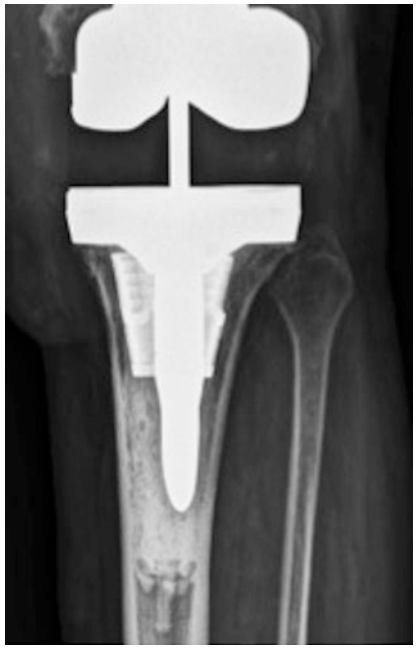

Fig. 9.26 Postoperative radiograph demonstrates translation of stem within cement mantle of cone placed in tibial metaphyseal defect

Discussion

Although modular metal augments do not restore host bone stock, properly applied, these augments allow immediate weight bearing and range of motion, transferring loads to intact host bone, while providing durable long-term implant stability [2]. Additionally, the multiple sizes available with modular revision knee systems allow expedient reconstruction at a cost saving compared with custom implants. In addition to modular trabecular metal augments, stems, cones, and sleeves have become widely used. These augments offer the same modular benefits of solid metal augments, which can be press fit or cemented, with the added potential for osteointegration and soft tissue interdigitation.

Current clinical data support the continued application of modular augmentations in revision knee arthroplasty. Modular augments are particularly applicable in revision cases with peripheral cortical defects, allowing tremendous intraoperative flexibility in the management of tibial and femoral deficiencies. Load transfer to bone is more evenly distributed by metal augmentation than by other reported techniques of reconstruction of bone defects. Additionally, modular augments do circumvent the potential complications associated with bone graft harvest, donor site morbidity, or allograft incorporation/resorption. Though long-term data regarding various modular augments is lacking, early to midterm results are promising, and the convenience and utility of these augments appear to be the present and future of revision knee arthroplasty.

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Metaphyseal Sleeves and Cones in Revision Total Knee Arthroplasty

10

Kelly L. Scott, Matthew P. Abdel, and Arlen D. Hanssen

The demand for primary total knee arthroplasty (TKA) is increasing in the United States, with an estimated 1,046,000 primary TKAs to be performed in 2016 [1]. This can be explained in part by the aging population, expanded indications for joint surgery including a younger patient population, and improved surgical techniques and implant designs [2–5]. Even with tremendous success rates in primary TKAs, revisions are inevitable and unfortunately necessary in a subset of patients. In 1990, approximately 12,000 revision TKAs were performed, whereas 15 years later, the numbers almost quadrupled (38,300). In 2030, the projection for revision knee surgeries is estimated to be 268,200, an increase of 600% from 2005 [1, 6].

The reasons for failed TKAs can be divided into two broad categories: septic and aseptic. The latter, namely, aseptic failures, includes instability, loosening, device fracture, osteolysis, wear, and periprosthetic fracture. Tremendous bone defects are often encountered either secondary to the reason for periprosthetic failure or due to prosthesis removal required at the revision procedure itself. While there is no uniformly accepted method for management, there are alternative means to establish a well-fixed, stable revision construct [7, 8].

In revision TKA cases where massive bone loss is present and revision is necessary, the concept of zonal fixation [9] allows the surgeon to address the bone loss in terms of three different areas of both the femur and tibia. Zone 1 refers to the epiphysis-metaphysis, or joint surface, and also includes the integrity of the proximal cortical bone. Zone 2 refers to the metaphysis, and zone 3 refers to the metaphysis-diaphysis. In revision cases, zone 1 of the bone is almost always compromised, leaving zones 2 and 3 as areas that must be structurally stable to support the revision prosthesis. The metaphysis, composed of abundant trabecular bone with rich vascularity, is the largest surface area that needs to be reconstructed both for initial and sustained structural stability. Due to the shapes of the proximal tibia and distal femur, intramedullary fixation can usually be achieved with stemmed components of various shapes and/or lengths. Screws and polymethyl methacrylate (PMMA) cement are utilized with defects less than 5–10 millimeters (mm) [10, 11]. Prosthetic wedges,

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similarly successful and useful in 5–15 mm unicondylar defects, are not sufficient to handle the larger bone deficiencies often seen in the metaphyseal area. Stainless steel, cobalt chromium alloys, and titanium metals were used in the past as implant materials to enhance fixation, but their unaided success was limited, prompting the emergence of a variety of coatings and porous materials to enhance their metaphyseal effectiveness [12–14]. The ability to allow or promote osseointegration, as well as to support and mimic native bone biomechanics, became a desirable feature for the long-term success of revision TKAs. Structural allografts and cancellous bone have been used, but the timing and extent of subsequent revascularization have not been ideal. Allograft can remain structurally stable but does not promote prosthesis osseointegration. In this chapter, we will focus our attention on the use of coated sleeves and porous metaphyseal cones to manage bone defects in revision TKA.

Preoperative Assessment and Planning

It is important to investigate the reason a TKA has failed. Patients are most likely to present complaining of pain, instability, and/or a decline in function [15]. Performing a history and physical examination is important, especially with regard to flexion instability [16]. Infection must always be considered as a potential cause of prosthetic failure [17]. The ultimate treatment of an infected TKA, whether in a primary or a secondary exchange, often requires the use of sleeves and cones, and thus, the surgical principles of reconstruction are similar for both aseptic and septic reconstructions. The results, however, will obviously vary due to the potential for reinfection.

Preoperative radiographs should include weight-bearing anteroposterior (AP) radiographs accompanied by 45° posteroanterior (PA), lateral, and patellofemoral views. For most revisions, full-length hip-to-ankle radiographs are also required to assess the bones and joints above and below the knee [18]. Computerized tomography (CT) scans overestimate bone loss and are usually not necessary [19]. Preoperative radiographs, on the other hand, are suggestive, but not diagnostic, of the amount of bone loss and commonly underestimate the defect that is present. This is due to the additional bone loss secondary to prosthetic removal. Thus, intraoperative evaluation is the ultimate evaluation, and surgeons must have the versatility to address the cortical and cancellous defects as presented.

Bone Loss Classification and Management

Historically, there have been many bone loss classification systems aimed at addressing bone defects and aiding in the question of what is considered significant bone loss. In 1991, Rand [20] proposed a system of intraoperative bone assessment looking at defects in terms of symmetry, location, and extent. Stockley et al. [21] defined bony defects as contained (intact cortical rim) or not contained (cortical rim not intact) and further showed the successful use of allograft bone in treating these defects.

Currently, the Anderson Orthopaedic Research Institute (AORI) classification, developed by Engh in 1997 [22], is the most practical and commonly used staging system to address different degrees of bone loss both pre- and intraoperatively. In addition, this classification is probably the most commonly used protocol for treatment options. Bone defects are divided into three different types [1–3], and each type is subdivided into A (involvement of one condyle or one side of the tibial plateau) or B (bicondylar or total plateau involvement). The AORI system allows for independent management of both tibial and femoral sides.

The location and extent of the osseous defects in the femur and tibia guide treatment options. In general, smaller defects (AORI Type 1; approximately 5 mm or less) can be managed with cement with or without screws, localized cancellous or rarely structural bone grafts, and occasionally metal augments (defects = 5 mm–15 mm) [23]. As the defects increase in size (AORI Type

2), treatment options include cement, metal augmentation (cones and sleeves), and structural allograft. The largest, most devastating type of defects (AORI Type 3) can be treated with metal augmentation (cones and sleeves), impaction grafting, structural allograft, and in some cases condylar-replacing prostheses.

Metaphyseal Sleeves Versus Porous Metaphyseal Cones

The decision to use a sleeve versus a cone is based not only on the AORI but also on the implant system used. Sleeves are system specific (Fig. 10.1), whereas cones are adaptable to any system. In general, sleeves are used for Type 1 and Type 2A deformities, whereas cones are used for Type 2B and Type 3 deformities. Both sleeves and cones tend to be used in the more difficult bone loss situations.

Recent Innovations

In 1999, Bobyn et al. [12] studied cylindrical porous tantalum implants in a transcortical canine model. Two pore sizes (430 and 650 μm) were used, and the shear strength of the bone-implant interface was assessed. At 4 weeks postoperatively, the authors found the extent of filling of both the smaller and larger pores with new bone ranged from 40 to 50%, and by 16 and 52 weeks, the filling grew to 63–80%. In addition, mechanical tests indicated a shear fixation strength of at least 18.5 MPa, which is substantially higher than other less porous materials [24–26]. The primary benefit of this material is that the modulus of elasticity approximates that of the bone, thereby promoting osseointegration and avoiding periprosthetic stress shielding. The results of this study were promising, prompting the 2008 landmark study assessing the use of porous tantalum in humans.

Meneghini et al. [27] studied porous tantalum metaphyseal cones (Trabecular Metal [TM]; Zimmer; Warsaw, Indiana) in 15 patients (eight females, seven males; mean age 68 years) undergoing revision TKA (Fig. 10.2). The patients had an average of 3.5 prior total knee replacement procedures, and classification of tibial bone loss, assessed intraoperatively, included Type 2B [7] and Type 3 [8]. At the final follow-up (mean 34 months), all 15 cones showed evidence of osseointegration, and there was no evidence of loosening or migration of any of the tibial reconstructions. Four patients required reoperation for the following reasons: recurrent deep infection [2], pain secondary to aseptic loosening of the femoral component [1], and acute periprosthetic tibial fracture sustained during a fall [1]. The overall average Knee Society clinical scores [28] improved by 33 points.

Fig. 10.1 Photograph depicting an implant specific tibial sleeve (DePuy; Warsaw, IN)

Based on the initial success of porous tantalum metaphyseal cones and acetabular components [29–34], there has been an explosion of investigation and development of alternative porous metal constructs, primarily using titanium

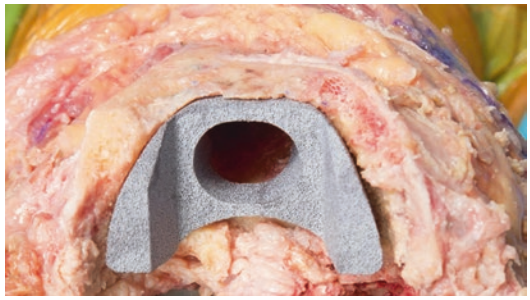

Fig. 10.2 Intraoperative photograph of a revision total knee arthroplasty and an Anderson Orthopaedic Research Institute (AORI) Type 2B defect treated with a tantalum femoral cone (Zimmer; Warsaw, IN)

rather than tantalum [35–38]. These approaches have included a variety of technologies to produce a porous metal construct. However, the most promising and cost-effective approach seems to be that of three-dimensional (3-D) printing of implants [39–41].

3-D Printed Titanium Cones

This newly released cone system is based on an intramedullary guided milling system that provides very precise bone preparation which increases implant stability and apposition of the cone to available host bone. These cones are unlinked to a specific prosthesis and, like the tantalum cones, are inserted independent of the prosthesis being used. The tibial shapes and sizes are designed so that the simple symmetric shapes can be used in cases that one would typically use sleeves rather than cones (i.e., Type 1 and 2A bone defects). The lobe-shaped cones are designed to be used in Type 2B and Type 3 bone defects (Fig. 10.3). These cones require less bone removal, and bone preparation time is significantly less than freehand high-speed burrs.

The femoral cones are based on a bilobed design that allows the lobes to bottom out at the junction of the metaphysis and diaphysis so that the diaphyseal portion of the cone cannot be inserted beyond the preparation area (Fig. 10.4). This design feature was incorporated to avoid longitudinal fractures of the distal femur that have been observed with the tantalum cone designs.

Fig. 10.3 The innovative 3-D printed titanium tibial cones come in asymmetric shapes with lobes to allow for bottoming out at the junction of the metaphysis and diaphysis (Stryker; Mahwah, NJ)

Surgical Technique

Metaphyseal Sleeves

Once the surgeon has classified the bone defect, a starter reamer is used to open the metaphyseal bone until the desired symmetry is achieved for subsequent sleeve placement [42]. Trial sizing of components is performed, and once the appropriate size is selected, the sleeve is placed. Usually a tapered junction that is system specific is used to connect the sleeve to the stem, rather than cement [8]. Both cemented and cementless stems are available for use. When using a cemented stem proximal to the femoral sleeve or distal to the tibial sleeve, the combination sleeve and stem is cemented by filling the femoral and tibial canals with cement prior to insertion of the components. In a cementless system, the stems are impacted into the metaphyseal-diaphyseal bone of the distal femur and/or proximal tibia in order to achieve adequate axial and rotational press fit. Bone graft is used to fill any voids that exist between the host bone and the sleeve.

The advantages of this approach include a straightforward surgical technique that can be effectively used in mild to moderate bone loss. The disadvantages of this approach are that the preparation broaches can be difficult to use in sclerotic bone, and these sleeves are intrinsically specific to one implant system.

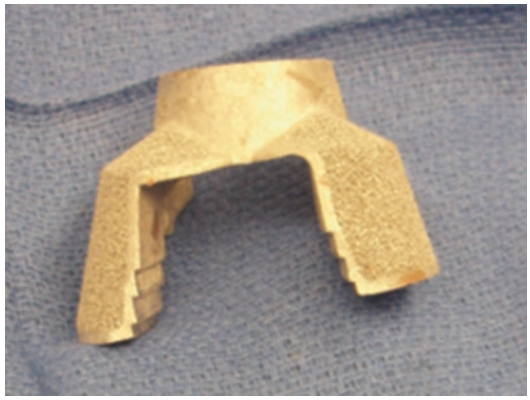

Fig. 10.4 The innovative 3-D printed titanium femoral cones come in bilobed shapes to allow for bottoming out at the junction of the metaphysis and diaphysis (Stryker; Mahwah, NJ)

Porous Tantalum Cones

The surgical technique for porous tantalum metaphyseal cones has previously been described [8, 27, 43, 44]. Once the surgeon has decided to use a metaphyseal cone, a trial intramedullary stem or reamer may be used to create the appropriate positioning of the cone. Trial sizing of the cone is done by inverting the cone to match the size most closely to the proximal part of the defect in the tibia or the distal part of the defect in the femur. Due to the variability of bone defects, cones can be contoured, usually to accommodate large defects. The bone is then contoured free hand with a high-speed burr to ensure optimal press fit. The cone is impacted into its final position, and trial components and stems are inserted. The final sized implant and stem are inserted through the cone into the correct rotational alignment. The interface between the cone and stemmed implant is reinforced with cement. It is our preference to only utilize cemented stems. When using a cemented stem proximal to the femoral cone or distal to the tibial cone, the stem is passed through the cone, placed in the cement, and held in place until the cement hardens. Bone graft is used to fill any voids that exist between the host bone and the cone.

The advantages of these metaphyseal cones are that there are multiple shapes and sizes to accommodate a large spectrum of bone defects in the moderate to severe range of bone loss. Additionally, the porous tantalum can be cut with a high-speed burr to alter the shape and size if needed. The primary disadvantage of these cones is that the bone preparation is done with high-speed burrs in a freehand manner, which results in a less than optimal bone preparation in many cases and is often quite time-consuming. Additionally, the size and shape of these implants often require considerable bone removal, and this is particularly true of the femoral cones.

3-D Porous Titanium Cones

Once the surgeon has decided to use a metaphyseal cone, the canal is reamed up to a diameter so that the reamer is stable within the canal. Based upon the intended size of the prosthesis, a target range of cone sizes can be anticipated to gauge the depth of the central symmetric cone reamer (Fig. 10.5). In the tibia, a determination can then be made as to whether or not it is desirable to proceed with additional bone preparation for the lobed-shaped cone. If so, a side reamer is used in the appropriate position to prepare the lobe portion of the bone preparation (Fig. 10.6). Symmetric and lobe-shaped trials are then used to judge final position of the cone in relation to the prosthesis. In the femur, the cones are bilobed. The femoral bone preparation is also medullary guided, initiated with a central reamer, and then finally with two-side lobe reamers (Fig. 10.7).

It is important to note that both the tibial and femoral cones are inserted with a stem trial to guide appropriate implant position. The final sized implant and stem are inserted through the cone into the correct rotational alignment. The interface between the cone and stemmed implant is reinforced with cement. It is our preference to only utilize cemented stems. When using a cemented stem proximal to the femoral cone or

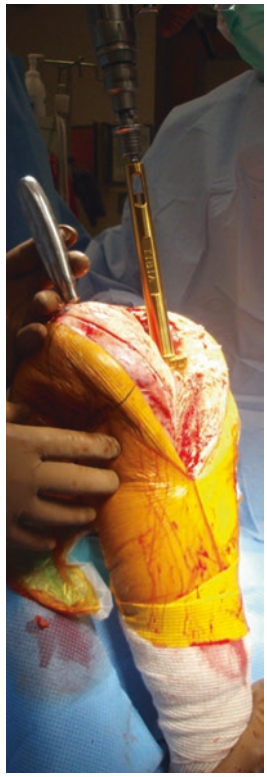

Fig. 10.5 For the 3-D printed titanium cones, a central symmetric cone reamer is used to gauge the depth of the cone, and a trial from a variety of sizes and shapes can be selected (Stryker; Mahwah, NJ)

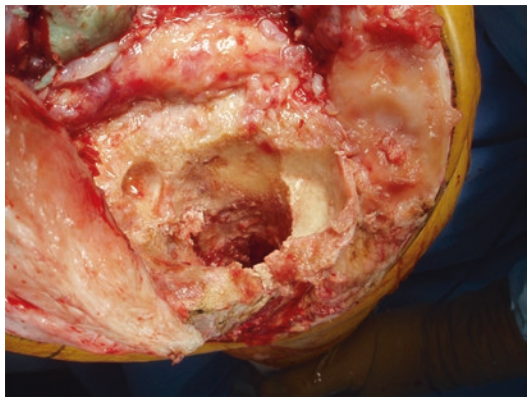

Fig. 10.6 If a lobed-shaped cone is selected, a side reamer is utilized in the appropriate position to prepare the lobe portion of the bone (Stryker; Mahwah, NJ)

distal to the tibial cone, the stem is passed through the cone, placed in the cement, and held in place until the cement hardens. Bone graft is generally not required to fill any voids that exist between the host bone and the cone because of the precise nature of the bone milling preparation (Figs. 10.8a, b).

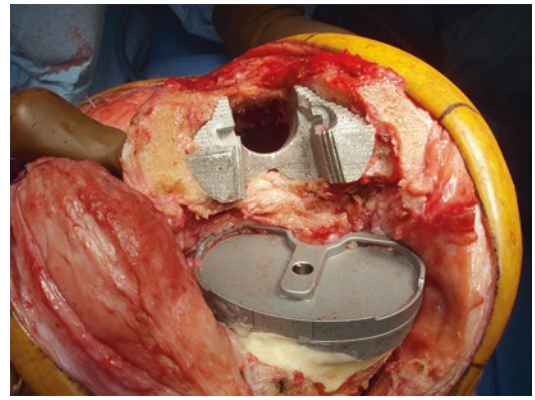

Fig. 10.7 As with the tibia, the femoral cone has a central reamer and lobes that are milled and is inserted with the intention of bottoming out and preserving the bone (Stryker; Mahwah, NJ)

The advantages of these 3-D printed porous titanium cones include more precise and rapid bone preparation, less bone removal, and better axial alignment due to the use of a medullary guided bone preparation system. The disadvantages of this system are yet unknown as there have been no clinical studies yet reported.

Key Technical Points

When bone defects are encountered in revision TKAs, there are five general steps that are critical:

1. Classify intraoperative bone defect using the AORI classification system.
2. Contour the metaphysis to get an optimal fit with a sleeve or cone.
3. Impact the sleeve or cone.
4. Fill defects between the sleeve or cone and host bone with bone graft to promote bone ingrowth.
5. Bypass prosthesis and cone with mid-length cemented stem to provide rigid initial fixation until cone has time to ingrow.

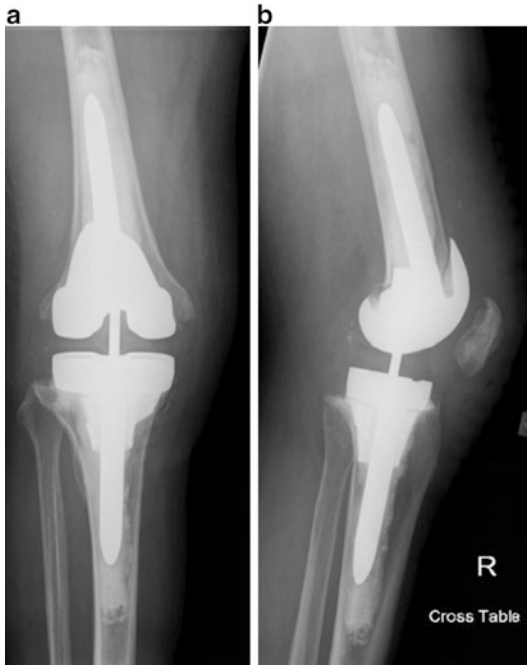

Fig. 10.8 Anteroposterior (**a**) and lateral (**b**) radiographs of a reimplanted total knee arthroplasty with 3-D printed titanium femoral and tibial cones

Clinical Outcomes

Metaphyseal sleeves and cones, in comparison to their alternative allografts, have several advantages: implementation through a simpler technique, shorter operative times, decreased risk of transmitting infection, and potentially more durable fixation [45–48]. Recent literature has further stressed these advantages.

Metaphyseal Sleeves

Metaphyseal sleeves have been available for revision TKAs for almost four decades, yet most data is relatively short term (Table 10.1). In 2014, Barnett et al. [48] retrospectively reviewed 34 revision TKAs using stepped porous titanium metaphyseal sleeves (DePuy) in 34 patients (13 females, 21 males; mean age 66 years). The patients had a mean of 0.22 (range, 0–2) prior knee revisions after the primary TKA, and classification of bone loss, performed intraoperatively, included Type 2A [14], Type 2B [15], and Type 3 [5]. At the final follow-up (mean 38 months), all 34 sleeves showed radiographic evidence of osseointegration, and there were no signs of implant migration or fracture. Three patients required reoperation for the following reasons: failure of femoral adaptor [1], supracondylar femoral fracture [1], and intractable end-of-stem pain [1]. The Knee Society functional scores improved by a mean of 34 points, and knee scores improved by a mean of 47 points.

Table 10.1 Comparison of results with metaphyseal sleeves for revision TKAs in the literature

	Barnett et al. [48]	Huang et al. [42]	Bugler et al. [49]
Year	2014	2014	2015
Mean age	66	64	72
No. of patients	34	79	35
No. of revision TKAs	34	83	35
AORI types included	2, 3	1, 2, 3	1, 2, 3
No. of tibial sleeves	34	83	10
No. of femoral sleeves	0	36	1
No. of both tibial and femoral sleeves	0	0	24
Mean follow-up (months)	38	29	39
Osseointegration rate (%)	100	100	100
Reoperation for any reason (%)[a]	8.8	16.9	0

[a]Defined as number of patients undergoing reoperations/number of revision TKAs

Also in 2014, Huang et al. [42] published a study that prospectively looked at 83 revision TKAs using 119 metaphyseal sleeves (36 femoral, 83 tibial) in 79 patients (50 females, 29 males; mean 64 years). The number of prior knee revisions was not specified, and classification of bone loss, performed only preoperatively, included femoral defects (Type 1 (4), Type 2B [25], Type 3 [7]) and tibial defects (Type 1 (9), Type 2A [1], Type 2B (68), Type 3 [5]). At the final follow-up (mean 29 months), all of the sleeves showed evidence of osseointegration. Two patients required reoperation due to aseptic loosening of their tibial components. An additional 12 patients required revision for reasons not involving the implanted component. Knee

Society functional scores improved by a mean of 18 points.

An international study published in 2015 by Bugler et al. [49] retrospectively reviewed 35 patients (57% male; mean age 72 years) undergoing revision TKA using a metaphyseal sleeve (DePuy) (10 tibial, 1 femoral, 24 both). Classification of bone loss, performed intraoperatively, included femoral defects (Type 1 (17), Type 2 [16]) and tibial defects (Type 1 (20), Type 2 [13], Type 3 [2]). At the final follow-up (mean 39 months), all radiographs showed evidence of osseointegration, and there was no evidence of osteolysis or loosening of either the femoral or tibial component. No reoperations were required; one sleeve-related complication was reported (femoral condylar fractures 3 years postoperatively; treated conservatively). At final follow-up, the mean Knee Society score was 81, while the mean Knee Society functional score was 58.

Porous Tantalum Metaphyseal Cones

Metaphyseal cones have been available for revision TKAs for approximately a decade, with many studies specifically investigating their outcomes (Table 10.2). In 2009, Long et al. [47] studied the use of porous tantalum cones for large metaphyseal tibial defects in revision TKAs. The authors retrospectively reviewed 16 revision procedures performed on 15 patients (8 females, 7 males; mean age 66 years), who each had tantalum tibial cones implanted during the revision procedure. Classification of bone loss, performed intraoperatively, included Type 2A [2], 2B [3], 3A [4], and 3B [7]. At the final follow-up (mean 31 months), all 16 cones showed evidence of osseointegration, and there were no cases of aseptic loosening. There were two patients who required reoperations due to recurrent infections. However, the authors noted that in these two cases, the porous cones were found to be well fixed, and postoperative radiographs demonstrated stable osseointegration into the cones as well as reestablishment of the anatomic joint line.

In 2012, Lachiewicz et al. [50] retrospectively reviewed 33 porous tantalum metaphyseal cones (TM; Zimmer) (9 femoral, 24 tibial) implanted during revision TKAs in 27 patients (14 females, 13 males). The number of prior revision surgeries ranged from 0 to 10, and classification of bone loss, performed preoperatively, included Type 2B (4; all tibias) and Type 3 (29; 20 tibias, 9 femurs). At the final follow-up (mean 40 months), 26 of the 27 knees demonstrated osseointegration. There were four patients who required reoperation for the following reasons: infection [1], aseptic loosening [1], periprosthetic distal femur fracture due to a fall [1], and superficial wound dehiscence [1]. Knee Society scores for pain improved by a mean of 39 points, and scores for function improved by a mean of 28 points.

In 2011, Howard et al. [43] retrospectively reviewed 24 revision TKAs using porous tantalum metaphyseal femoral cones (TM) in 24 patients (13 females, 11 males; mean age 64 years). Classification of bone loss, performed intraoperatively, included all Type 2B or greater defects. At follow-up (mean 33 months), there were 20 radiographs available for postoperative analysis, all of which demonstrated osseointegration. Five patients underwent reoperations, but the authors stated there were no complications related to the use of the cone. Knee Society scores improved by a mean of 26 points.

There has been one additional study assessing the use of metaphyseal cones in revision TKAs that have had lengthier follow-up. Published in 2015, Kamath et al. [51] looked at a 5- to 9-year follow-up for the use of 66 porous tantalum metaphyseal cones for tibial bone loss in 63 patients (36 females, 27 males; mean age 67 years) undergoing revision TKAs. The mean number of prior knee surgeries was 3.4, and classification of bone loss, performed intraoperatively, included Type 2A [17], Type 2B [25], and Type 3 [24]. At follow-up (mean 70 months), 64 cones (97%) demonstrated osseointegration on the postoperative films. Fifteen patients underwent 19 reoperations for the following reasons: extensor mechanism disruption [5], infection [4], explantation of the tibial cone [3], femoral fracture [2], manipulation under anesthesia [2], tibial fracture [1], granuloma and hematoma evacuation [1], and aseptic loosening [1].

Table 10.2 Comparison of results with porous tantalum metaphyseal cones for revision TKA in the literature

	Meneghini et al. [27]	Long et al. [47]	Howard et al. [43]	Lachiewicz et al. [50]	Kamath et al. [51]
Year	2008	2009	2011	2012	2015
Mean age	68	66	64	65	67
No. of patients	15	15	24	27	63
No. of revision TKAs	15	16	24	27	66
AORI types included	2B, 3	2A, 2B, 3	2B, 3	2B, 3	2A, 2B, 3
No. of tibial cones	15	16	0	24	66
No. of femoral cones	0	0	24	9	0
Mean follow-up (months)	34	31	33	40	70
Osseointegration (%)	100	100	100	97	97
Reoperation for any reason (%)[a]	26.7	12.5	20.8	14.8	22.7

[a]Defined as number of patients undergoing reoperations/number of revision TKAs

Knee Society scores improved significantly by a mean of 25 points.

In 2012, Jensen et al. [52] published the first study to assess bone mineral density (BMD) in patients who had undergone revision TKAs. The authors specifically compared the BMD between two groups of patients: those whose revision procedure included the use of a TM cone and those whose revision procedure did not include the use of a TM cone. The authors used a prospective randomized trial study design that included 36 patients (17 females, 19 males; mean age 67 years). Twenty-four patients had at least two prior TKAs, while the other 12 had only one prior TKA, and bone loss classification, assessed by pre- and postoperative radiographs, included Type 2B defects [31] and Type 3 defects [5]. Intraoperatively, patients were randomized to receive treatment reconstructing the tibial bone defects either using the TM cone [17] or not [19]. Results (minimum follow-up 24 months) showed no differences between the groups in terms of knee and function scores as well as BMD, measured by dual-energy X-ray absorptiometry (DEXA) scan. The authors concluded the bone remodeling pattern to be almost identical between the two groups after 2 years.

In unpublished data from our institution, two of the authors (MPA and ADH) assessed the mid-term results of porous tantalum femoral cones in revision TKAs. This retrospective study, a longer-term follow-up of the study published by Howard et al. [43], assessed 159 revision TKAs in 157 patients (75 females, 82 males; mean age 64 years), and classification of bone loss, performed intraoperatively, included Type 2B (127) and Type 3 [32]. At the final follow-up (mean 60 months), all unrevised cases showed evidence of osseointegration. At 5 years, 23 femoral cones had been revised, for reasons including infection [14], aseptic loosening of the cone [6], and ligamentous instability [3]. Knee Society scores improved by a mean of 18 points (47 points preoperatively to 65 points at the most recent follow-up). One of the most interesting findings in this analysis was that all cases of cone aseptic loosening were associated with hinged TKAs that had Type 3 bone defects. As such, we believe that such cases will need to be addressed with different shapes and sizes of cones and quite possibly may need to be addressed with more precise bone preparation techniques.

Conclusion

Metaphyseal sleeves and cones are now much more frequently used in revision TKAs to address bone defects and obtain metaphyseal fixation. The results thus far have been encouraging, yet more studies with longer follow-up are needed to evaluate the total scope of their capability, as well as to guide the direction to head in the future to maximize the effectiveness of this revision construct.

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Femoral Alignment and Femoral Rotation

11

Paul M. Lichstein, Amar S. Ranawat, and James I. Huddleston III

Total knee arthroplasty remains a remarkably successful operative intervention to address advanced osteoarthritis of the knee. The goals of total knee arthroplasty are to relieve discomfort while providing functional range of motion and stability. While TKA is arguably one of the most successful medical interventions, the need for revision surgery endures. Many revision cases present a formidable challenge for the orthopaedic surgeon. Accurate restoration of alignment, management of bony defects, attention to reestablishment of the joint line, and balancing of the flexion and extension gaps are acme to success, both in the setting of primary and revision surgery.

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In the revision setting, establishment of a neutral mechanical coronal alignment is usually achieved with use of an intramedullary cutting guide. In cases where femoral bone stock has not been compromised substantially, the medial and lateral epicondyles can be referenced to determine axial alignment. In cases where bone loss precludes use of the transepicondylar axis, femoral axial alignment can be achieved by establishing congruence with desired tibial rotation in full extension. Accurate assessment and restoration of appropriate coronal and axial femoral alignment is an essential component in determining the longevity of primary and revision knee replacement. The purpose of this chapter is to highlight techniques for maintaining and/or restoring femoral alignment during knee arthroplasty with a focus on the revision paradigm.

Our previous chapter sought to outline techniques and strategies to assist the adult reconstruction surgeon in establishing appropriate femoral component axial alignment both in the primary and revision settings. This update seeks to incorporate interim developments for addressing coronal and axial alignment of the lower extremity while reinforcing baseline tenants. We will not discuss sagittal alignment, as there is general agreement that the femoral implant should be placed in 0–3^0 of flexion with regard to the neutral sagittal plane. Slight flexion of the femoral implant may be desired to help minimize notching of the femoral bone. Achievement of proper coronal and axial femoral alignment

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should facilitate establishment of optimal patellofemoral mechanics as well as balancing of the flexion and extension gaps.

Anatomy

There is a great degree of variation in the anatomy and alignment of the native knee joint over *normal* ranges. When coupled with height and weight, such variations influence the static alignment of the knee, whereas arthritic or other deforming changes may influence kinematics as well. Several works have elucidated what is accepted as an anatomically *normal* distal femur and deviations in terms of morphology [1–3].

Distinct variations in anatomy combine to affect each of four main axes that are pertinent to femoral alignment: (1) anatomic axis, (2) mechanical axis, (3) vertical axis (perpendicular to the horizon), and (4) flexion axis. In the coronal plane, the *anatomic axis* is defined by lines drawn through the center of the femoral canal and through the center of the tibial canal (Fig. 11.1), creating, on average, an angle of 5–7^0 of valgus. The tibiofemoral angle results from a combination of the varus tilt of the tibial plateau (30) and the average 7^0 valgus tilt of the femoral condyles [4]. The *mechanical* axis (coronal plane) is defined by a line drawn from the center of the femoral head, passing through the center of the knee joint, and ending in the center of the ankle joint. In general, the mechanical axis deviates 3^0 from the *vertical* axis, which is a line perpendicular to the horizon. Finally, the *flexion* (or transepicondylar) axis of rotation for the knee transects the epicondylar axis (drawn between the medial and lateral epicondyles at the origins of the medial and lateral collateral ligaments, transverse to the long axis of the tibia) (Fig. 11.2). It should be appreciated that at 90^0 of flexion, the medial epicondyle lies 1–6 mm more posterior in relation to the lateral epicondyle and varies greatly dependent upon the morphology of the distal femur and proximal tibia [5]. Additionally, there is variation in the amount of each condyle that lies posterior to the epicondylar axis.

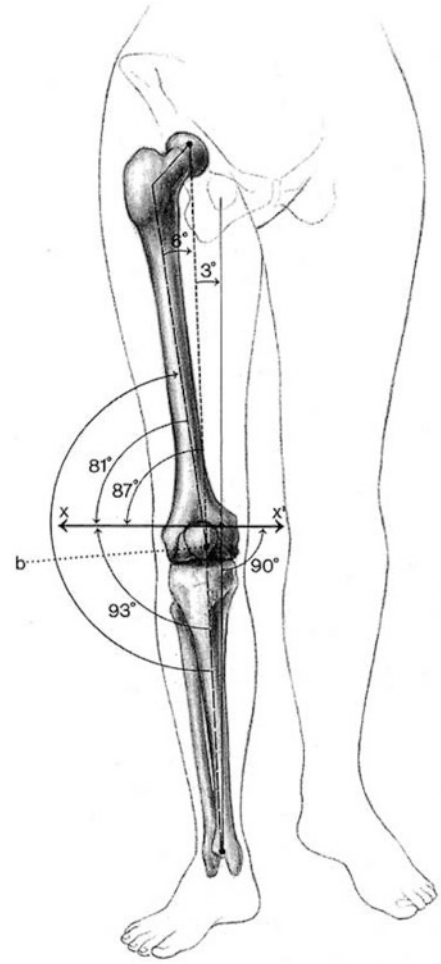

Fig. 11.1 The LE axes (from Pollice P, Lotke P, Lonner J. Principle of instrumentation and component alignment. In: The adult knee. Philadelphia: Lippincott, Williams & Wilkins; 2003. p. 1085–93, with permission)

Biomechanics

It is important to consider the gait cycle as it pertains to femoral alignment in total knee arthroplasty. Two discrete stages are encountered. The *stance* phase is defined by weight bearing, and the *swing* phase is defined by advancement of the limb. During stance phase, a period of double-limb support is transitioned to single-limb support as the gait cycle progresses. Further division of the single-limb segment encompasses the first heel strike and progresses from a flat foot through heel-off and finally to toe-off and the swing phase. Following

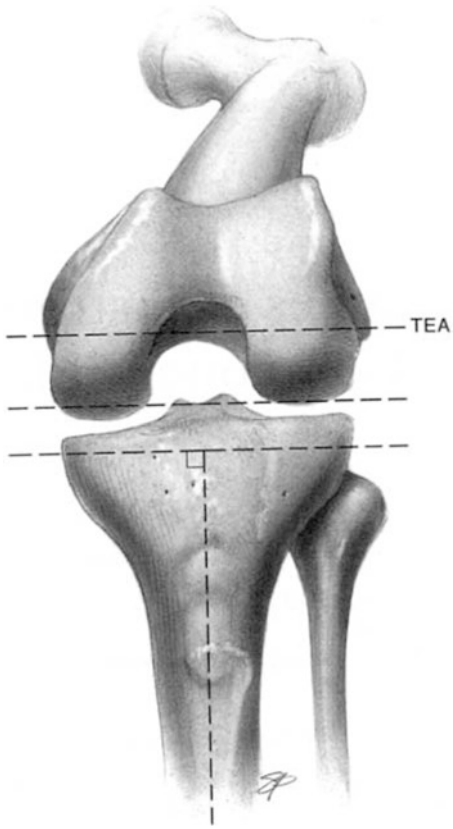

Fig. 11.2 Transepicondylar axis (from Pollice P, Lotke P, Lonner J. Principle of instrumentation and component alignment. In: The adult knee. Philadelphia: Lippincott, Williams & Wilkins; 2003. p. 1085–93, with permission)

the initial heel rise of the incident limb, the contralateral limb enters heel strike. Stance phase accounts for the majority of the gait cycle, on average 62%, whereas the swing phase is attributed 38% [6]. During stance phase, the medial compartment of the knee experiences a significantly disproportionate weight-bearing load of approximately 60–70% of the sum total. Therefore, any disruption in axial or rotational alignment may significantly alter force distribution and portend degenerative changes of the articular surfaces [7–10]. Therefore, reestablishing normal force distribution during total knee arthroplasty is essential to a long-standing and successful intervention in terms of clinical results and component survivorship, especially in patients with higher body mass index and subsequent increased forces through the knee [11]. Studies have shown that deviation in axial alignment by as little as 5^0 of tibial varus may alter the load-bearing mechanics of the knee by up to 40% and lead to early failure [12]. In particular, internal rotation of the tibia or femur may result in patellofemoral maltracking. Instances of internal rotation from 1 to 4^0 result in lateral tracking and increased patellar tilt, whereas 3–8^0 of internal rotation has been observed to result in patellar subluxation. In cases of exaggerated internal rotation from 7 to 17^0, dislocation and ultimate failure of the patellar component have been routinely documented [13]. Additionally, the altered force distribution caused by malalignment may place undue stress on the bone-cement interface and lead to bone loss and failure secondary to loosening.

During primary and revision surgery, it is important to factor in the patients' level of activity and the stresses that will be placed on the implant. In 2005, Colwell et al. began investigating in vivo knee forces utilizing an instrumented tibial component equipped with force transducers, affording a direct measure of intra-articular load distributions following total knee arthroplasty [14]. The initial assessment was limited to quantifying total axial load and localizing the center of pressure between the tibial and femoral components. In 2008, the same group utilized a more refined, second-generation implant capable of measuring all components of tibial force to analyze forces during activities of daily living and exercise. Measurements were obtained during walking, jogging, rowing, stair-climbing trainer use, elliptical trainer use, leg press/extension, stationary biking, tennis, and golfing. Stationary biking generated the least force. Interestingly, exercising on a so-called low impact elliptical trainer generated lower forces than jogging, but not lower forces than treadmill walking. Swinging a golf club generated relatively high forces, especially in the leading knee [15].

Coronal Alignment

Restoration of a neutral coronal mechanical axis is essential to successful primary and revision total knee arthroplasty. Any deviation may

ultimately result in failure and devastating consequence for the patient. Therefore, it is essential that the reconstruction surgeon places emphasis on accurate bony resections. A distal femoral resection in 5–7^0 of valgus is most commonly employed, effectively restoring the anatomic tibiofemoral angle to 6^0 (± 1–2^0) of valgus [16, 17]. Bearing in mind the average 3^0 varus alignment of the native tibia, a cut perpendicular to the long axis is generally performed. However, adjustments may be made depending upon such variables as preoperative alignment, integrity of the collateral ligaments, and patient phenotype. Proper bony resections of the distal femur and proximal tibia as well as appropriate soft tissue releases are needed to establish a rectangular extension gap.

The "kinematic approach" to alignment in primary total knee arthroplasty, as described by Stephen Howell, M.D., focuses on aligning the transverse axis of the femoral component with the primary axis of the femur in regards to tibial flexion and extension, removal of osteophytes to restore unimpeded native soft tissue tension, and placing a tibial component with longitudinal axis perpendicular to the transverse femoral axis of tibial flexion and extension [18]. This approach considers three axes between the femur, tibia, and patella. The primary transverse axis of the femur, in relation to tibial flexion-extension, is defined as a line that passes through the center of two best-fit circles drawn in the medial and lateral femoral condyles and equidistant from the articular surface of the femur from 10 to 160^0 of flexion. The patellar axis exists in the transverse plane parallel to the primary axis. The third axis is the perpendicular relationship between the longitudinal axis of the tibia and that of the femur and patella. Selection and placement of the femoral component are based upon aligning the transverse axis of the component with the primary transverse axis of the femur, thereby shape matching the component to the femurs prearthritic geometry. Although positioning of the femoral component is rather straightforward, tibial component coronal positioning requires several more steps. Additionally, the utilization of a kinematically aligned total knee arthroplasty requires a preoperative MRI. Although functional results of primary operations utilizing a kinematic construct are encouraging at short-term follow-up, the approach for establishing correct femoral rotation is currently not utilized in the revision setting [19].

While many experienced, high-volume surgeons often use a "freehand" technique for performing bony cuts for its speed and practicality, we do not recommend this technique for less-experienced surgeons, especially in the revision setting where extensive bone loss may be encountered and the usual anatomic landmarks are deformed or absent. Instead, both intramedullary and extramedullary cutting guides are available to assist in measured resections. Multiple investigative series have revealed the accuracy of intramedullary guides in establishing a distal femoral resection in the desired 5–7^0 of valgus. One series by Teter et al. reviewed radiographic analysis of 201 knee arthroplasties conducted with a standard intramedullary guide and revealed distal femoral cuts were accurate 92% of the time [20]. Errors in resection were encountered in scenarios of a capacious tibial canals and bowed femora. Additionally, intramedullary guides have been shown to be superior to extramedullary guides in establishing accurate alignment and joint line orientation. The same group, reviewing 352 total knees, found 94% of cuts performed with an intramedullary device were within ±4^0 from the ideal 90^0 cut (perpendicular to the mechanical axis) compared to 92% performed with a standard extramedullary guide [21].

Appropriate employment of an intramedullary alignment guide relies on correctly identifying a femoral canal entry point just anterior to the insertion of the posterior cruciate ligament and medial to the center of the intercondylar notch. This may be challenging in the revision arthroplasty setting, especially in situations where the native anatomy is altered such as with post-traumatic arthritis following femur fracture, extensive bone loss with osteolysis, or bone and soft tissue compromise associated with infection. Excessive varus or valgus cuts may result if the starting point errs medially or laterally. Preoperatively, obtaining weight-bearing

full-length anteroposterior and lateral plain radiographs of the limb allows for assessment of both the axial alignment of the limb and morphology of the intramedullary canal of the femur. One concern that arises from the use of an intramedullary guide is fat emboli syndrome [22]. Strategies such as overdrilling the starting point and utilizing fluted guide rods have been developed to reduce intramedullary pressures during insertion and the incidence of fat embolism [22]. New data suggest that the use of computer navigation, a technique where the intramedullary canal is not violated, reduces the embolic load compared to the use of traditional, intramedullary-based, mechanical cutting guides [23, 24].

Axial Alignment

Accurate restoration of femoral axial alignment is key to establishing not only a balanced flexion gap but also an acceptable Q-angle and patellofemoral kinematics. A large subset of complications following primary and revision total knee arthroplasty arise from malalignment of the patellofemoral joint [25, 26]. Problems such as poor patellar tracking, patellar subluxation, anterior knee pain, patellar clunk, and accelerated wear of the polyethylene patellar component may arise in a construct with improper axial alignment [27–30]. Slight external rotation may assist in producing a favorable relationship between the patellar and femoral components in terms of functional outcomes, but patella-associated problems leading to revision remain of serious concern [30–34].

Gap balancing and measured resection are the two primary strategies for producing proper femoral axial alignment. There may be wide variation in anatomy, bone stock, and soft tissue integrity encountered in each revision scenario, and thus certain strategies may offer more or less utility depending on the specific case. Careful physical examination, preoperative planning and templating, and intraoperative assessment are essential in choosing an appropriate strategy.

The gap balancing technique was originally described by Insall [5, 35, 32]. When surgeons use this method, an accurate femoral cut is dependent upon an initial tibial cut that is perpendicular to its long axis. Prior to distal femoral resection, osteophytes that may adversely influence alignment should be removed, and the soft tissues should be balanced in extension. Following the tibial cut, the limb is placed under extension, and tensioning instruments are inserted. Utilizing the cut tibial surface as a guide, resection of the distal femur is performed in parallel, establishing a rectangular extension space. The knee is then flexed to 90^0, and the tensioning instruments (Figs. 11.3 and 11.4) are again inserted for cutting the posterior femur, again in parallel to the tibial cut, thus establishing a rectangular flexion space (Fig. 11.5). This technique may be challenging when performing revision arthroplasty, as distorted morphology secondary to bone and soft tissue compromise is encountered.

The measured resection technique may be employed, whereby defects created by degenerative changes in the distal femur and proximal tibia are supplemented by prosthetic components. With femoral resections, the chosen prosthesis must mimic the amount of condylar bone removed (Fig. 11.6). Measured resection relies on the use of bony landmarks to guide appropriate cuts. Femoral axial alignment is generally determined with reference to the posterior condylar line, the anteroposterior axis, and/or the transepicondylar axis. Tibial resection is similar in both the measured resection and gap balancing techniques, as the goal is to achieve a cut surface that is perpendicular to the mechanical axis of the tibia.

In our previous chapter, we highlighted the unique features of both the *clinical* and *surgical* epicondylar axes. For review, the clinical epicondylar axis, as defined by Yoshioka et al. in 1987, is a virtual line connecting the lateral epicondylar prominence and the most prominent part of the medial epicondyle [36]. The group employed this orientation to additionally describe the condylar twist, or the angle subtended by the posterior condylar line and the clinical epicondylar axis (Fig. 11.7). The prominent part of the medial and lateral epicondyles may usually be palpated below the skin and subcutaneous tissues except perhaps in the morbidly obese patient. The

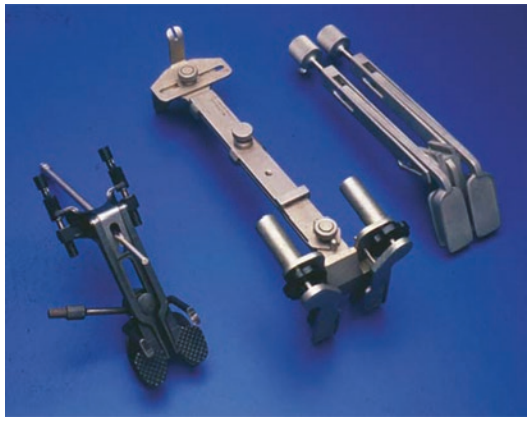

Fig. 11.3 Tensioners in laboratory

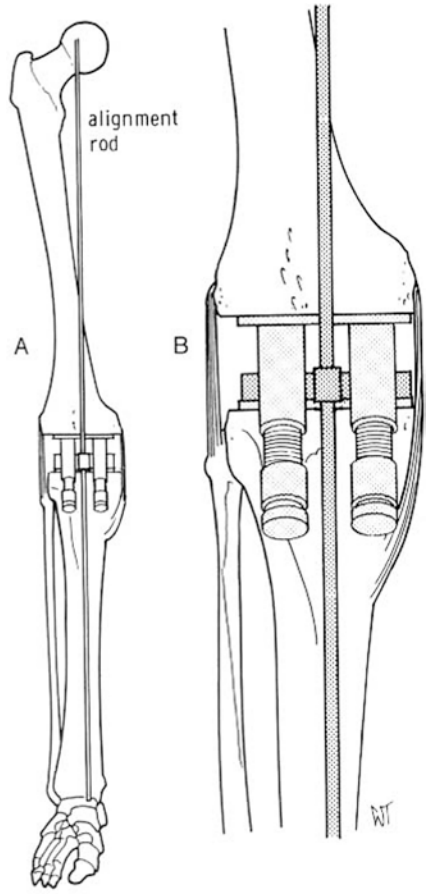

Fig. 11.4 (**a**, **b**) Tensioners (from Insall JN, Scott W. Surgery of the Knee. 3rd ed. Philadelphia: Churchill Livingstone; 2001, with permission)

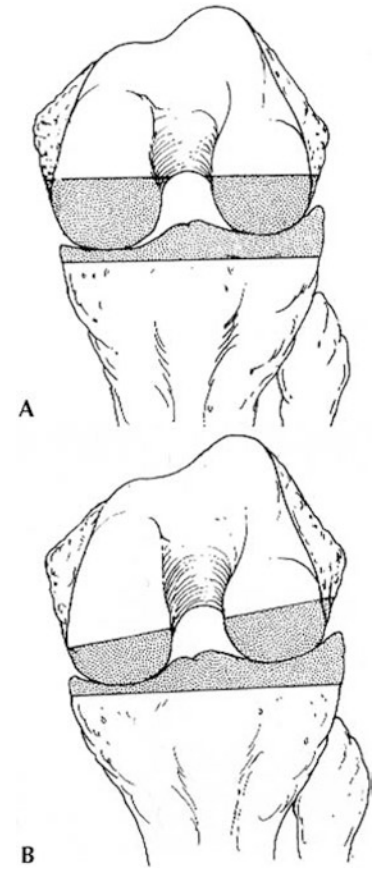

Fig. 11.5 (**a**, **b**) Posterior condyle, equal resections and appropriate resections (from Krackow KA. The technique of total knee arthroplasty. St. Louis: Mosby; 1990. p. 131, with permission)

medial prominence lies on the crescent ridge and serves as the femoral attachment site for the superficial fibers of the medial collateral ligament. The lateral collateral ligament originates on the lateral prominence posterior and superior to the insertion of the popliteus. The posterior condylar line is another anatomical reference created by a line tangent to the most posterior aspects of the medial and lateral femoral condyles. Yoshioka et al. utilized the virtual angle created by the intersection of the posterior condylar line and the clinical epicondylar axis as the condylar twist angle. The posterior condylar line is frequently used by total knee arthroplasty systems to determine axial alignment for distal femoral cutting guides. Typically, the cutting guides

reference to posterior condylar line to establish a prefixed cut in 3–5^0 of external rotation (Fig. 11.8). The use of such posterior referencing systems may be limited by not only the deformities and/or defects in the articular surface encountered during primary surgery but by the potential absence of anatomic reference points during revision surgery [37].

The *surgical* epicondylar axis, as defined by Berger et al., is a virtual line drawn between the lateral epicondylar prominence and the medial sulcus of the medial epicondyle [27] (Figs. 11.9 and 11.10). The medial sulcus serves as the origin of the deep fibers of the medial collateral ligament, with the superficial fibers inserting superficially in a fanlike projection (Fig. 11.11). This reference is useful both for primary knee replacement surgery and for referencing femoral rotation during revision total knee arthroplasty when the posterior femoral condyles may be deformed. The medial sulcus may be readily palpated during primary surgical endeavors or obscured by scar or overlying soft tissues during revision procedures. In order to define the relevant anatomy, superficial soft tissues may be dissected and removed and the medial epicondylar prominence circumscribed with a surgical marking pen. The sulcus is then palpated as a depression in the center of the demarcated area. Once the axis is defined, the anterior and posterior distal femoral resections are performed in parallel.

Whiteside's line (anteroposterior femoral axis), as described by Whiteside and Arima in 1995, is a virtual line that runs in the deepest part of the femoral trochlear groove to the center of intercondylar notch, parallel to the epicondylar axis [38] (Fig. 11.12). It serves as bony landmark that may be referenced for determining femoral rotation and is commonly used intraoperatively to properly orient the distal femoral cutting block. However, the reliability of this reference is dubious in cases of advanced patellofemoral arthritis or during revision surgery where cuts from the index surgery may obscure accurate interpretation of the axis.

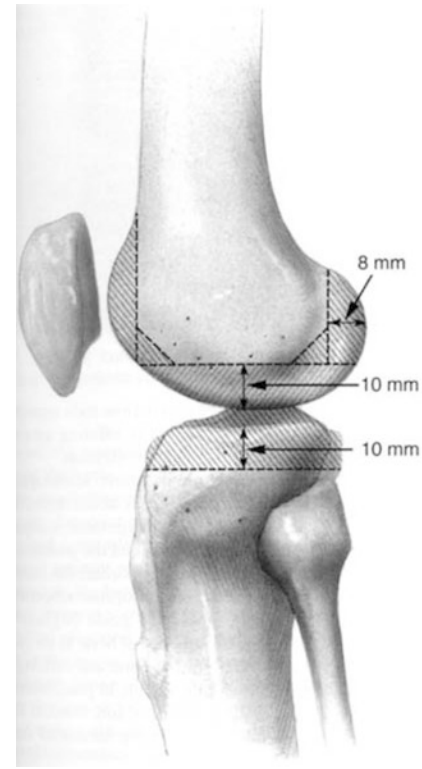

Fig. 11.6 Measured resection technique (from Pollice P, Lotke P, Lonner J. Principle of instrumentation and component alignment. In: The adult knee. Philadelphia: Lippincott, Williams & Wilkins; 2003. p. 1085–93, with permission)

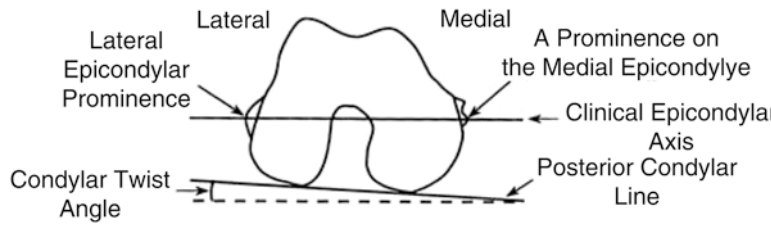

Fig. 11.7 Condylar twist angle (from Berger RA, Rubash HE, Seel MJ, Thompson WH, Crossett LS. Determining the rotational alignment of the femoral component in total knee arthroplasty using the epicondylar axis. Clin Orthop. 1993;(286):40–47, with permission)

The anterior trochlear groove may serve as an additional resource for intraoperatively determining femoral rotation. Generally, the lateral aspect of the femur is more prominent than the medial; thus, more of the lateral side than the medial side is resected when performing the anterior femoral cut. The preferential resection, if performed correctly, creates a profile in the underlying cancellous bone with a larger proportion observed on the lateral aspect. This characteristic pattern has been termed the *Insall boot* (Fig. 11.13). A resection made in neutral or with an internally rotated bias is conducted; equal amounts of cancellous bone may be viewed and indicate inappropriate rotation of the distal femoral cuts. If this scenario is encountered, it is advisable to reassess rotation utilizing other anatomical references (such as the surgical epicondylar axis) and revise the resection [39].

In 1999, Olcott and Scott compared the efficacy of these reference axes, evaluating 100 consecutive primary total knee arthroplasty surgeries [40]. The femoral alignment required for a balanced flexion gap was determined and compared to Whiteside's line, the transepicondylar axis, and a line in 3^0 of external rotation relative to the posterior condylar line. The transepicondylar line was found to most consistently allow for recreation of a balanced flexion space, and the posterior condylar line was found to be the least consistent, especially in the instance of valgus knees. The lack of reliability in referencing the posterior condylar line for establishing appropriate femoral rotation has been supported by numerous subsequent investigations [40], and even more so when the tibiofemoral angle exceeded 90^0 [41].

The tensioning technique has been found to be the most reliable in determining correct femoral rotation [42]. Additionally, there is significant variation in both the clinical and surgical transepicondylar axes. Furthermore, the medial to lateral placement of the femoral component plays a significant role in establishing proper patellar tracking. Excessive medial placement of the final

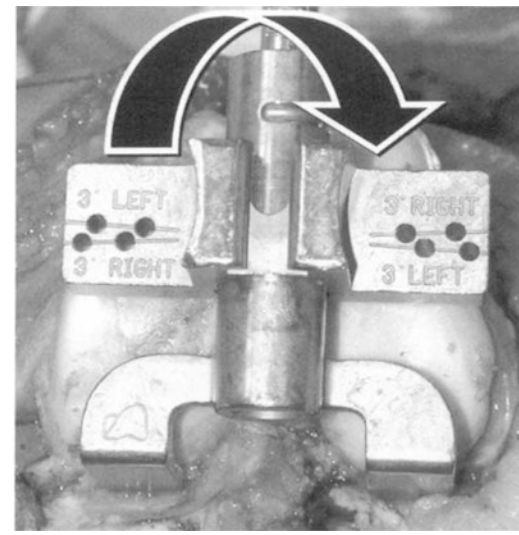

Fig. 11.8 ER off posterior condylar line (from Callaghan J, Rosenberg A, Rubash H, Simonian P, Wickiewicz T, editors. In: The adult knee. Philadelphia: Lippincott Williams & Wilkins, 2003, with permission)

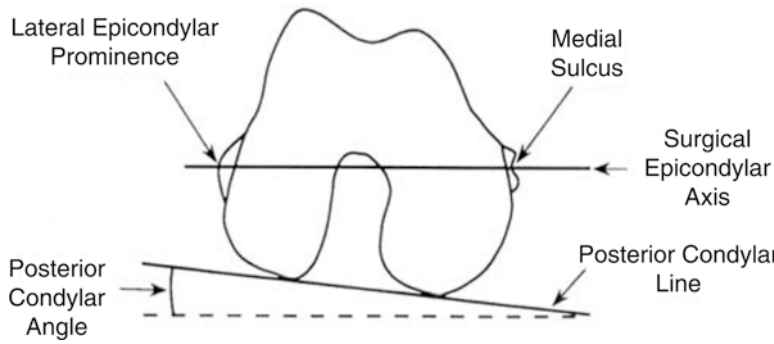

Fig. 11.9 Line drawing of the surgical epicondylar axis (from Berger RA, Rubash HE, Seel MJ, Thompson WH, Crossett LS. Determining the rotational alignment of the femoral component in total knee arthroplasty using the epicondylar axis. Clin Orthop. 1993;(286):40–47, with permission)

femoral implant may lead to an excessive Q-angle and the inherent problems associated (Figs. 11.14 and 11.15) [26]. During trialing, if cancellous bone remains visible, it is advisable to err laterally to the extent that the lateral edge of the prosthesis bisects the cut lateral surface of the femur.

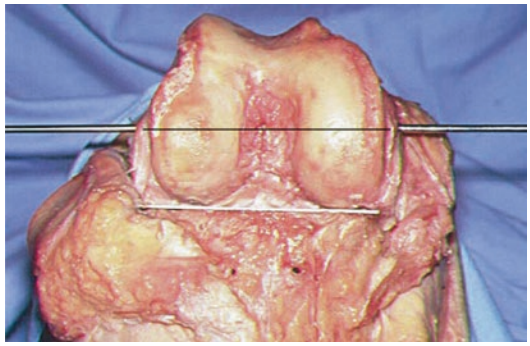

Fig. 11.10 Photograph of the surgical epicondylar axis (from Callaghan J, Rosenberg A, Rubash H, Simonian P, Wickiewicz T, editors. In: The adult knee. Philadelphia: Lippincott Williams & Wilkins, 2003, with permission)

The trochlear groove is therefore lateralized, reducing any untold strain on the patellar component during flexion and extension cycling. If the femoral component is placed medially, the patella is necessarily lateralized by soft tissue constraints and may impinge on the apex of the lateral trochlear groove, incurring possible complication.

Advanced imaging paradigms such as computed tomography and magnetic resonance imaging have been utilized, with success, to guide restoration of proper femoral rotation and coronal limb alignment during total knee arthroplasty. These modalities have been incorporated into preoperative assessment of ligamentous and bony deficiencies for the production of patient-specific cutting guides and intraoperative protocols for guided resections. However, there has been no proven superiority between the two methodologies in terms of clinical outcomes when compared to the previously described techniques [43]. The benefits

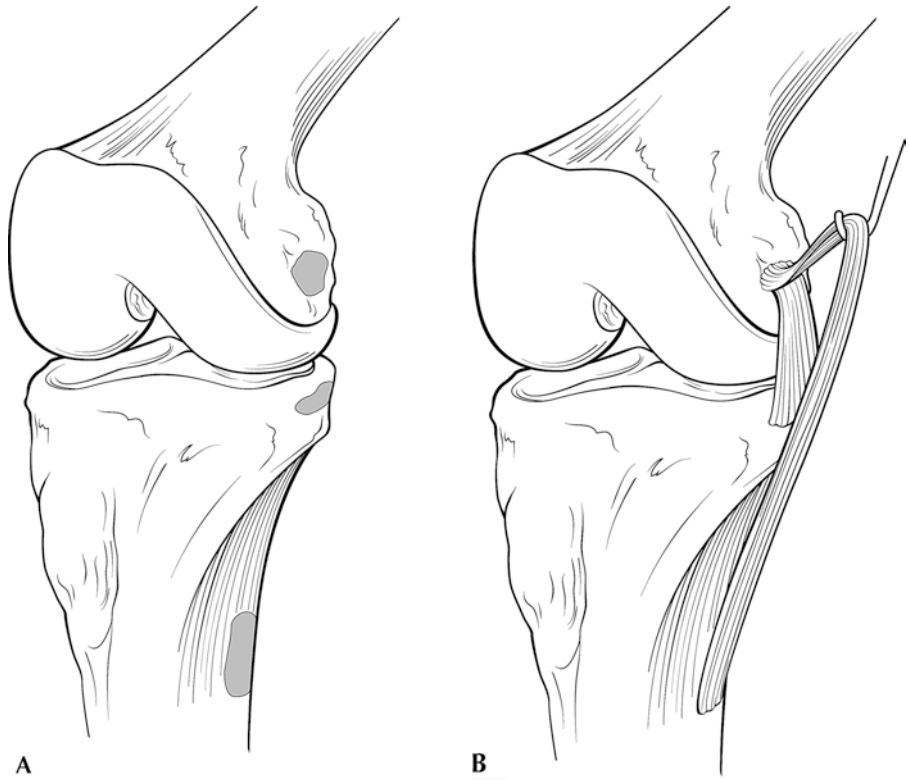

Fig. 11.11 (**a**, **b**) MCL origin (adapted from Berger, Rubash, Seel, et al. [24] by permission of Clin Orthop)

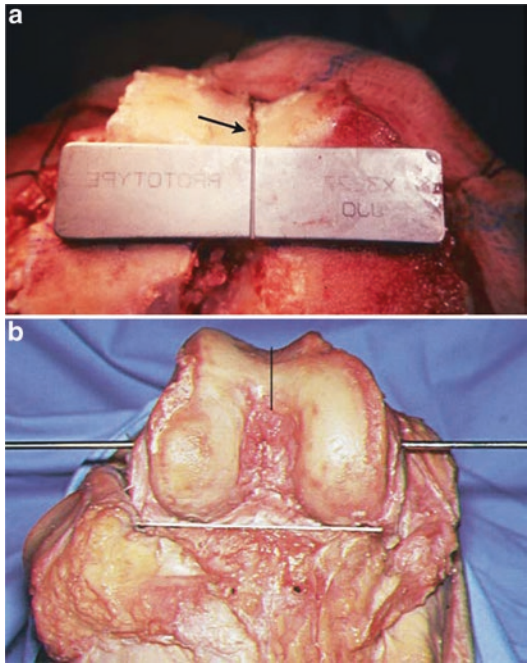

Fig. 11.12 (**a**, **b**) Whiteside's line (from Callaghan J, Rosenberg A, Rubash H, Simonian P, Wickiewicz T, editors. In: The adult knee. Philadelphia: Lippincott Williams & Wilkins, 2003, with permission)

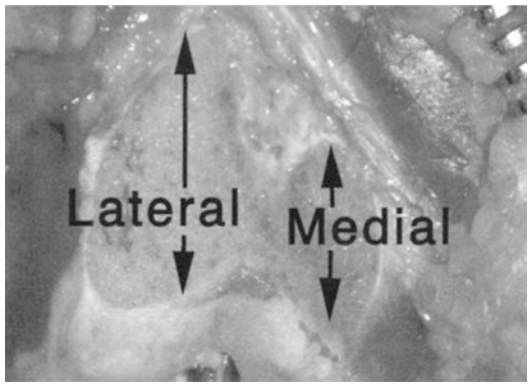

Fig. 11.13 Insall boot (from Callaghan J, Rosenberg A, Rubash H, Simonian P, Wickiewicz T, editors In: The adult knee. Philadelphia: Lippincott Williams & Wilkins, 2003, with permission)

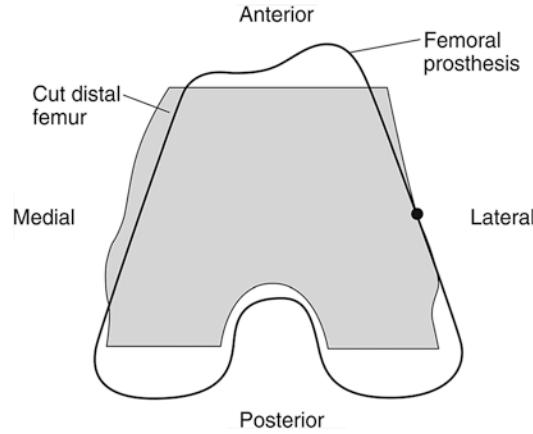

Fig. 11.14 Mediolateral placement of the femoral component. The femoral component should be adjusted until the lateral edge of the prosthesis bisects the cut lateral surface of the femur

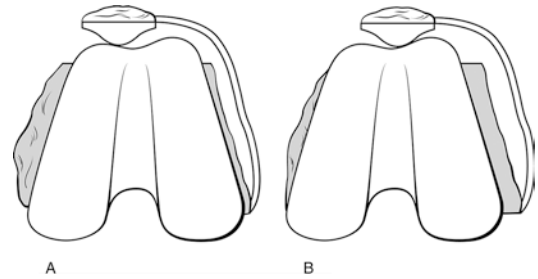

Fig. 11.15 (**a**, **b**) Mediolateral placement of the femoral component. Medialization of the prosthesis causes lateralization of the patella relative to the trochlear groove, which should be avoided (adapted from Callaghan J, Rosenberg A, Rubash H, Simonian P, Wickiewicz T, editors. In: The adult knee. Philadelphia: Lippincott Williams & Wilkins, 2003, with permission)

seen with utilization of such advanced imaging protocols must be taken in context with increased time (both pre- and intraoperative), expense, and patient exposure to potentially harmful radiation. In 2005, Perlick et al. prospectively investigated postoperative limb alignment following revision total knee arthroplasty conducted with a computer-assisted versus conventional technique [44]. Two groups of 25 patients underwent revision surgery employing either a CT-free or classical "surgeon-controlled" technique. Restoration of 3^0 of varus/valgus deviation between femur and tibia was superior with statistical significance in the image-guided group (92% vs 76%). In 2012, a meta-analysis by Cheng et al. of 41 randomized controlled trials revealed favorable results in terms of postoperative mechanical axis and component alignment when employing a computer-assisted technique compared to

conventional methods [45]. Additionally, in 2014, Pfitzner et al. sought to elucidate any advantages in terms of restoration of mechanical axis between patient-specific implants generated with the use of MRI or CT compared to conventional methods [46]. Although MRI-based patient-specific implants were shown to more accurately restore the mechanical axis in the coronal plane compared to CT and conventional imageless methods, differences were small and of questionable clinical significance. In general, concerns regarding the accuracy of custom cutting guides as well as their costs have precluded widespread adoption [47, 48].

Summary

Despite advancements in techniques for revision total knee arthroplasty, maintaining proper coronal and axial alignment of the femoral component remains imperative to ensure a successful, durable surgical intervention. Any deviation from normal alignment may incur consequences such as dissatisfaction, discomfort, and ultimately failure. Although developments incorporating advanced imaging and fabrication techniques hold promise, currently, the most effective method for restoring appropriate alignment employs the utilization of an intramedullary alignment guide. This allows for the distal femur to be resected in a consistent 5–7^0 of valgus. Particularly in the revision setting, proper axial alignment may be achieved with resections of the distal femur made parallel to the surgical epicondylar axis, thereby reestablishing the native axial alignment of the femur and maximizing the chances of a successful and durable revision total knee arthroplasty.

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Tibial Alignment

12

James V. Bono, Maxwell K. Langfitt, and Richard D. Scott

Precise component alignment in both the anteroposterior and lateral planes is essential for proper implant function and longevity in total knee arthroplasty (TKA). Inability to achieve proper alignment can generate eccentric implant loading resulting in early aseptic loosening and failure (Fig. 12.1). In addition, correction of the mechanical axis of the lower extremity (Fig. 12.2) to within 5–7° of valgus has been shown to improve TKA implant longevity both biomechanically and clinically [1–15].

To correct deformity in TKA, the angle of the distal femoral and tibial cuts can be achieved through the use of intramedullary or extramedullary alignment systems, computer-assisted surgery (CAS), or patient-specific instrumentation (PSI). Intramedullary and extramedullary systems are dependent on the degree to which each guide rod approximates the anatomic axes of the femur and tibia. Intramedullary alignment of the femur in TKA has been generally accepted as superior to extramedullary alignment, as the femoral shaft is difficult to locate through a large, surrounding soft tissue envelope. Additionally, femoral extramedullary alignment systems require estimation of the center of the femoral head. Radiographic skin markers or intraoperative fluoroscopy often can be used; however, bulky surgical drapes and obesity may present problems. A long-term follow-up study by Meding et al. found overall alignment was not as precise using the extramedullary system, but found no significant statistical difference in postoperative Knee Society scores, pain, or stair-climbing abilities of patients between intramedullary or extramedullary alignment guide use [16].

On the tibial side, there is considerable debate as to whether intramedullary or extramedullary alignment is superior. Tibial intramedullary alignment devices are based on the assumption

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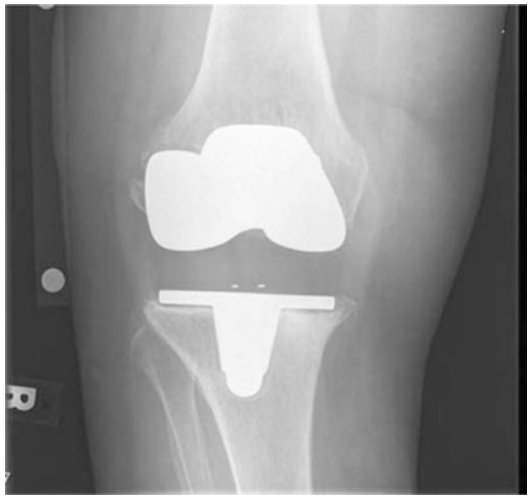


Fig. 12.1 Massively obese 70-year-old woman with early mechanical failure following TKA. Varus alignment of the tibial component contributed to mechanical overloading of the medial compartment

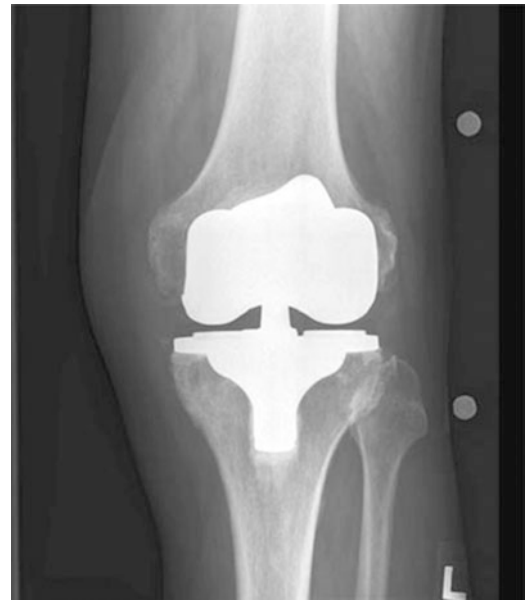


Fig. 12.2 Proper alignment of the femoral and tibial component allows even distribution of stress over the medial and lateral compartment

that the angle between the anatomical and the mechanical axis is not significantly different from zero in either the coronal or sagittal planes [17–21]. This chapter seeks to define the indications and emphasize the contraindications for intramedullary alignment of the tibia in revision total knee arthroplasty. Furthermore, specific case examples are reviewed that illustrate the pitfalls of and alternatives to intramedullary alignment of the tibia in total knee arthroplasty.

In our previous report, 44 adult cadaveric tibiae without obvious clinical deformity were harvested [22]. Using a stepped drill bit, the proximal medullary canal was entered anterior to the tibial attachment of the anterior cruciate ligament. The starting hole was oversized with a rasp, and a long 8-mm diameter solid intramedullary fluted guide rod was passed down the medullary canal until it was firmly engaged distally. The bone cut was made referencing off the intramedullary cutting jig. Anteroposterior and lateral radiographs were taken, and the anatomical, mechanical, and guide rod axes were assessed on each radiograph. The accuracy of the guide rod was assessed by measuring how closely the guide rod axis approximated the anatomic and mechanical axis in both the anteroposterior and lateral planes. The difference between the anatomic axis and the guide rod axis was measured and defined as the axis angle.

Observations obtained from this cadaveric study revealed that certain deformities and clinical situations would preclude the use of intramedullary alignment of the tibia in total knee arthroplasty. The clinician needs to be aware of the contraindications and alternatives to intramedullary alignment of the tibia in total knee arthroplasty.

Alternatives to intramedullary and extramedullary alignment systems include CAS and PSI. These newer technologies aim to improve limb alignment and component position, with the goal of decreasing overall operative time and instrument trays required and avoiding intramedullary instrumentation. Studies assessing CAS have been mixed, with some meta-analyses finding an improvement in mechanical axis and component orientation, while others have found no significant difference in alignment or functional outcomes [23–27]. Drawbacks of CAS may be increased cost, difficulty with intraoperative landmark registration, increased setup and intraoperative time, and pin site loosening or even

fracture. PSI, which utilizes a preoperative CT or MRI to create personalized cutting blocks based on a patient's anatomy, has failed to show any significant clinical or radiographic benefit over standard intramedullary alignment in several studies and may be associated with an increased cost [28–30]. However, both computer-assisted surgery and PSI may reduce the number of outliers in regard to mechanical axis and may be useful in cases with severe deformity or when intramedullary instrumentation is not possible. In addition, Nam et al. studied a handheld, accelerometer-based navigation device and compared this to extramedullary alignment guides. They found that, compared to extramedullary guides, use of the handheld device decreased outliers in tibial component alignment in TKA [31].

Results of Anatomic Studies

Anatomic requirements for successful intramedullary alignment require a patent intramedullary canal for complete seating of the guide rod. In the cadaveric tibiae examined, analysis of the anteroposterior radiographs of all 44 specimens revealed the guide rod to be on average in 0.56° of valgus (range 1.4° varus to 2.8° extension) compared with the mechanical axis. Analysis of the lateral radiographs of all 44 specimens revealed the guide rod to be in 0.2° of extension (range 3.3° flexion to 2.5° extension) compared with the mechanical axis.

The anteroposterior guide rod-mechanical axis angle was examined in 10% increments of guide rod insertion. There was a tendency for this angle to increase as the insertion amount decreased, from 0.75° at 90–100% insertion to 1.90° at 40–50% insertion. Maximum accuracy of the tibial intramedullary alignment guide rod required complete seating of the device to the level of the distal physeal scar ($p < 0.05$). The valgus tibiae, i.e., the tibia with a valgus bow, demonstrated an increased anteroposterior guide rod-mechanical axis angle as compared with the neutral or varus tibiae. Furthermore, the intramedullary guide was more accurate in reproducing the mechanical axis in the non-valgus tibiae ($p < 0.05$). This finding suggests that the valgus tibia may be a relative contraindication to relying exclusively on intramedullary alignment.

In addition to the findings described previously, other clinical situations can prohibit the use of intramedullary alignment in total knee arthroplasty. Any situation that blocks the passage of a straight guide rod would disallow the use of intramedullary alignment. Both anatomic abnormalities and retained implants can result in mechanical obstruction of the intramedullary canal and may necessitate extramedullary devices, CAS, or PSI (Figs. 12.3a, b and 12.4a, b).

Observations in Revision Total Knee ARTHROPLASTY

The incidence of revision TKA is increasing, largely due to the increased number of primary procedures performed annually. Estimates believe that by 2030, the demand for TKA is projected to grow by 673% to 3.48 million procedures, while the demand for knee revisions is projected to grow by 601%, due to an aging, increasing, and more active population [32]. The leading indications for revision TKA include reimplantation after infection and aseptic loosening. Bone stock loss is invariably encountered at revision resulting from mechanical collapse of bone, osteolysis, or a result of aggressive debridement in the setting of post-septic reimplantation. The use of intramedullary stems in this setting is advisable due to the compromised bony platform of the tibial plateau, as well as to offset the stresses transmitted to the bone, which accompany the use of constrained and semi-constrained revision components.

Intramedullary extension stems may be used both with and without cement and are discussed further in the following chapter. Cementless fixation is typically achieved by intimate contact of an uncoated, fluted extension stem within the intramedullary canal of the tibia and femur. The intramedullary canal is prepared with rigid axial reamers to match the diameter of the selected intramedullary extension stem. The intramedullary extension stem is assumed to replicate the

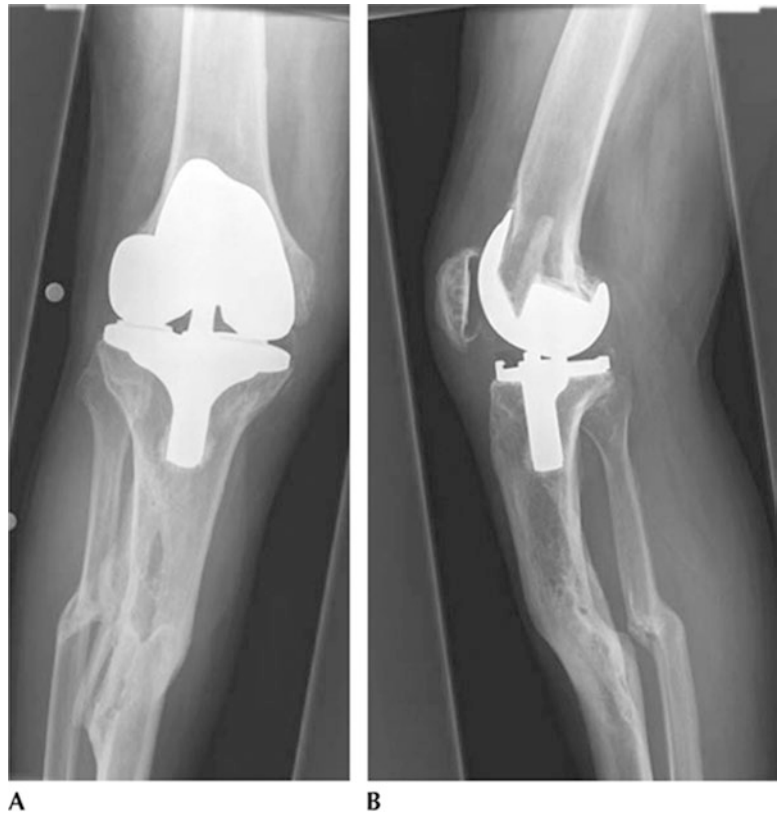


Fig. 12.3 (**a**, **b**) AP and lateral views of the tibia depict a well-healed fracture of the tibial diaphysis, which would block the passage of an intramedullary guide rod into the tibia

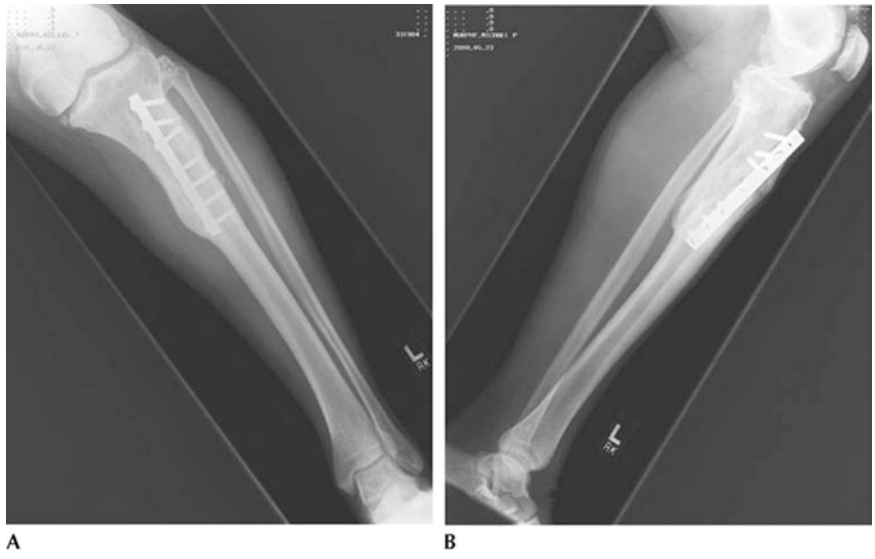


Fig. 12.4 (**a**, **b**) Nonanatomic alignment of the tibial diaphysis precludes the use of intramedullary alignment

intramedullary axis of the femur or tibia. As a result, component position is dictated by the use of an intramedullary extension stem. If a cementless extension stem is selected, greater stability of the intramedullary extension stem occurs with circumferential filling of the stem within the intramedullary canal.

Intramedullary extension stems may be used in two distinct manners, based on surgeon preference. First, if the surgeon elects to emphasize stability of the stem within the canal based on a line to line fit, the component position will by necessity be dictated by the intramedullary stem and may not result in symmetric coverage by the underlying bone (Fig. 12.5). If, however, the surgeon prefers symmetric positioning of the component, the diameter of the intramedullary extension stem may have to be compromised, to shift the component from the intramedullary axis of the tibia or femur (Fig. 12.6a, b). If this is done, the stability of the cementless stem within the canal will suffer. Stability may be recovered by cementing the stem within the canal, acknowledging an asymmetric cement mantle.

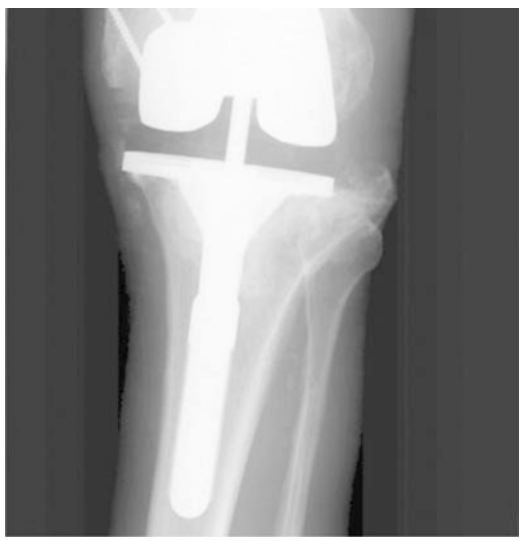


Fig. 12.5 Following revision TKA using a press-fit intramedullary tibial stem, the tibial component is noted to overhang medially, leaving the lateral plateau uncovered. The position of the tibial component is dictated by the placement of the stem and does not always result in symmetric coverage of the tibial plateau

If an intramedullary extension stem is used, component position will be dictated by the position of the intramedullary rod. In a previous study, we sought to determine whether the use of a press-fit, canal-filling, cementless intramedullary extension stem in revision TKA resulted in asymmetric placement of the tibial component [29].

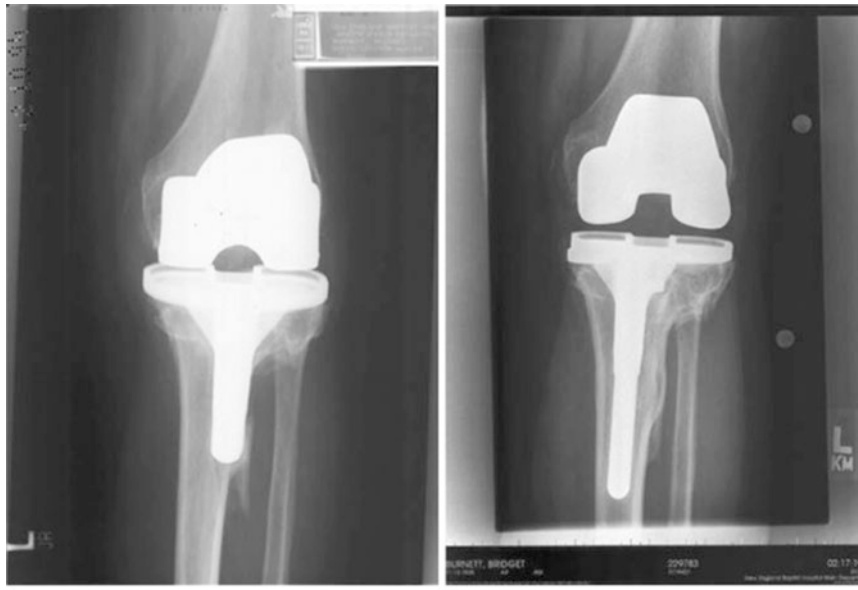
Results of Radiographic Data

Radiographs of 24 patients undergoing revision total knee arthroplasty with a stemmed tibial component were reviewed. The same modular revision implant system was in each case. There were 14 male and 10 female subjects, with an average age of 66.7 years (range, 37–93). Intramedullary tibial stem extensions were used in each case, with an average diameter of 14.9 mm (range, 10–20 mm) and an average length of 68.5 mm (range, 30–115 mm). Augmentation wedges were required in five patients, with two 10° full medial wedges, one 15° full medial wedge, one 15° half-medial wedge, and one 10° half-lateral wedge. Measurements of tibial component medial, lateral, anterior, and posterior displacement were made and corrected for magnification.

The tibial component was noted to be eccentrically positioned on the tibial plateau in 24 of 24 patients, with medial placement noted in 20, lateral in 3, posterior in 17, and anterior in 3. Medial tibial component overhang was most common (46%), averaging 2.5 mm (range, 1.7–4.3 mm). Of the 11 patients with medial component overhang, the lateral aspect of the tibial plateau was noted to be uncovered by an average of 5.4 mm (range, 1.8–9.9 mm) in 8 patients.

Implications for Revision Total Knee ARTHROPLASTY

Medial eccentricity of the tibial component was found to be the most common problem (20 of 24) encountered when intramedullary extension stems were used in revision TKA, resulting in medial overhang in 11 of 24 cases despite downsizing of the tibial component [33].



A B

Fig. 12.6 (**a**) An attempt to place the tibial component symmetrically on the tibial plateau results in nonanatomic placement of the tibial stem, illustrating the conflict between the intramedullary axis of the tibia and the anatomy of the tibial plateau. (**b**) A custom-made tibial component with an offset tibial stem allows for axial alignment of the stem with anatomic coverage of the tibial plateau

Posterior placement of the tibial component was similarly noted in 17 of 24 cases. This is the result of altered anatomy due to loss of proximal tibial bone stock and the restriction placed on tibial component positioning by the intramedullary stem. This finding suggests that an allowance for lateral and anterior offset be incorporated into tibial component design when used with an intramedullary stem extension (Figs. 12.7 and 12.8).

Therefore, if an intramedullary extension stem is used, component position will be dictated by the position of the intramedullary rod. Asymmetric placement of the component typically results. A component, which would be of appropriate size, is found to overhang on one side and be uncovered on the other. This typically requires downsizing of the component to remedy the overhang, which accentuates the amount of bone uncovered by prosthetic component. The results of this study confirmed our belief that the use of a canal-filling, cementless, press-fit intramedullary extension stem creates asymmetric positioning of the tibial component.

Unique Use of Intramedullary Nails in Total Knee Arthroplasty

Total knee arthroplasty is an effective reconstructive option for the patient with painful, posttraumatic arthritis of the knee; however, the presence of pre-existing hardware creates a unique set of surgical challenges that can affect clinical outcomes. Removal or retention of pre-existing hardware is a decision that should be contemplated both preoperatively and intraoperatively. Oftentimes, distal femoral or proximal tibial plates are removed prior to TKA in a staged fashion, so as to allow adequate time for soft tissue and bone to heal. Smaller implants, such as screws, can be removed during the TKA procedure or maintained if they are not felt to interfere with the prosthesis.

Hardware removal may allow for appropriate implant placement but also allows unrestricted access for intramedullary alignment devices and removes a potential source of soft tissue irritation. Yet, it may also prolong operative time, increase bleeding, infection risk, and length of

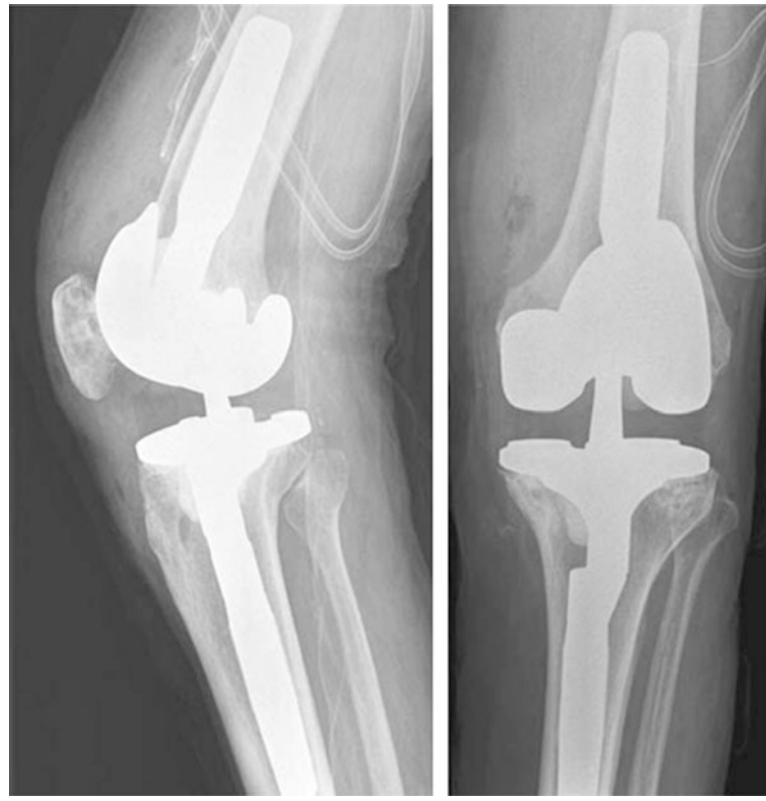


Fig. 12.7 A modular offset tibial stem is used to shift the tibial component laterally and posteriorly to allow symmetric coverage of the tibial plateau. The press-fit tibial stem is centered within the diaphysis and fills the canal

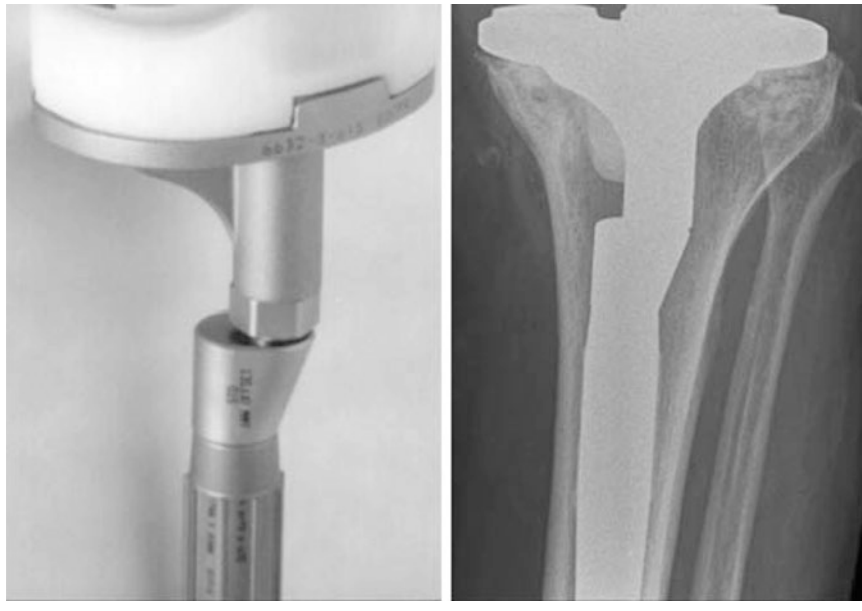


Fig. 12.8 An offset adapter (Stryker, Allendale, NJ) is available in 4, 6, and 8 mm increments and is used to shift the tibial component (360°) about the intramedullary axis, which is defined by the intramedullary extension stem

surgical dissection and require multiple surgeries if the procedures are staged. Furthermore, hardware removal may create a stress riser, which can lead to a periprosthetic fracture. Taking this into consideration, retention of hardware should be considered if removal is not a surgical necessity.

The presence of an intramedullary nail may provide a distinct set of challenges when planning for, or in the presence of a TKA. We described a technique in which a TKA was performed with retention of the retrograde femoral nail due to a non-united fracture in the presence of severe valgus gonarthrosis (Fig. 12.9) [34]. Following a standard approach to the knee, a screwdriver was placed in the endcap of the existing femoral nail (Fig. 12.10). With the handle removed, the shaft of the screwdriver served as an intramedullary guide rod and allowed the distal femoral cutting block to be placed over this construct, and the distal femur was cut at the desired angle and depth (Fig. 12.11).

Similarly, Wilson et al. discussed a patient who underwent clamshell osteotomy with subsequent retrograde intramedullary nailing due to the presence of a significant femoral deformity prior to TKA (Fig. 12.12a, b) [35]. Clamshell osteotomy is useful in patients with a complex diaphyseal deformity to restore anatomic alignment, correcting angular deformities of up to 20–30° [36]. With the retrograde nail in place, the TKA was performed at a later date using the intramedullary nail with screwdriver extension as an alignment guide. This technique may be more accurate than an extramedullary guide and may avoid extra surgical time.

In another paper, Shah et al. described a unique option for retrograde intramedullary nail removal with an existing TKA in the setting of a displaced femoral neck fracture requiring hemiarthroplasty (Fig. 12.13) [37]. As the nail was unable to be removed through the knee due to its larger diameter compared to the femoral prosthesis, it was removed in a retrograde fashion through the piriformis fossa. This was

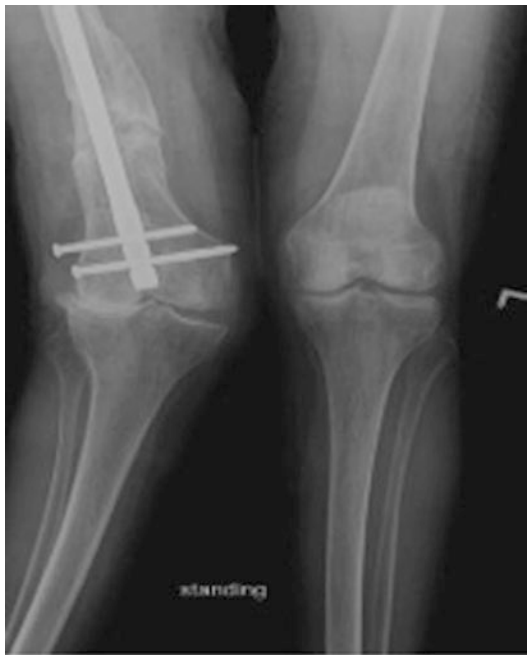


Fig. 12.9 Preoperative radiograph of both knees exhibiting distal femoral nonunion

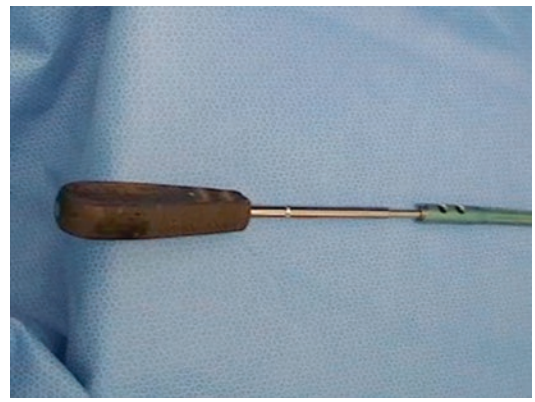


Fig. 12.10 Screwdriver inserted into endcap of nail

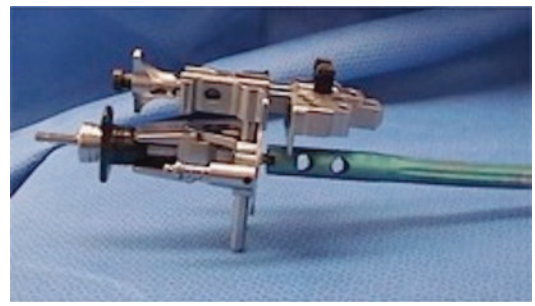


Fig. 12.11 Illustration of end cutting guide for distal femur placed over shaft of screwdriver

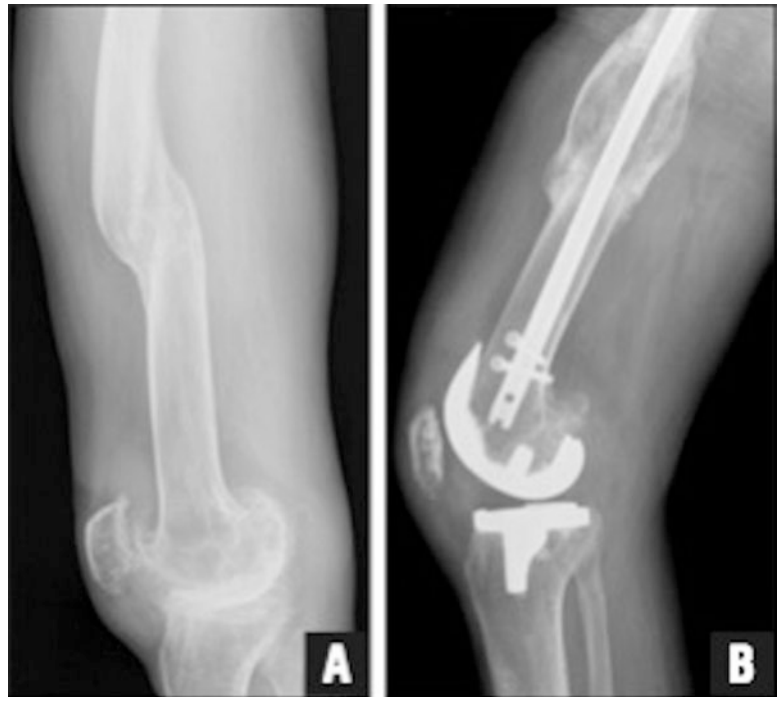


Fig. 12.12 Preoperative lateral radiograph of the right knee (**a**). Lateral radiograph of the right knee after total knee arthroplasty (**b**)

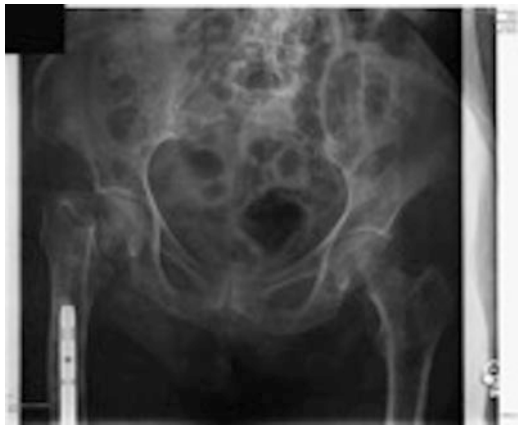


Fig. 12.13 Preoperative radiograph of right hip showing pre-existing retrograde femoral nail in the setting of a femoral neck fracture

accomplished following a standard posterior approach to the hip and subsequent neck cut. Following locking screw and endcap removal, a guide wire was placed retrograde through the nail via the knee incision, and sequential reaming was performed over the guide wire in an antegrade fashion at the proximal end of the femur down to the nail. After reaming to the diameter of the nail, the endcap was replaced and the nail was driven proximally and removed.

These cases not only express the importance of preoperative planning and intraoperative decision making, but sheds light on the fact that in the future as population ages, inevitably patients will be encountered with pre-existing hardware that requires removal prior to total knee or hip arthroplasty. Navigating around pre-existing hardware will be critical in continuing efforts to obtain optimal patient outcomes.

Discussion

Appropriate orientation of prosthetic components is crucial for arthroplasty survival. Postoperative alignment of the lower extremity has a direct effect on the durability of the implant. Significant varus or valgus malalignment may predispose the tibial component to early loosening.

Anatomic deformity can result from previous fracture (Fig. 12.14), sepsis, or metabolic bone disease (e.g., Paget's disease). Implant barriers to intramedullary alignment occur after fracture

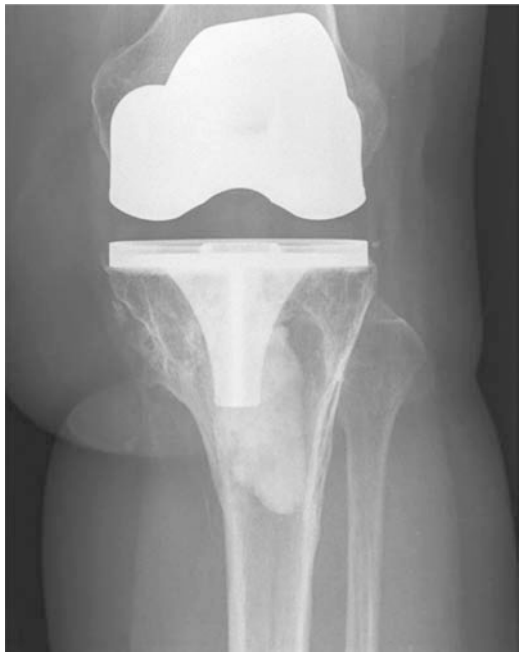


Fig. 12.14 Previous fracture has distorted the tibial metaphysis, which must be recognized in order to achieve proper alignment and fixation

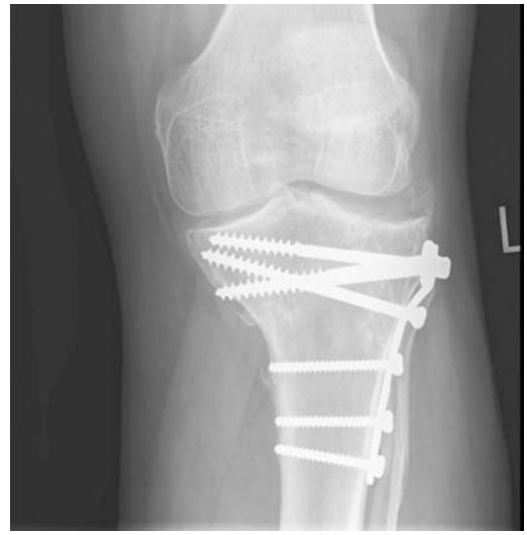


Fig. 12.15 Posttraumatic arthritis following ORIF of a tibial plateau fracture. The tibial metaphysis has been distorted. Hardware is removed before TKA

fixation (Figs. 12.15, 12.16, and 12.17), broken retained hardware, or below a femoral component in total hip arthroplasty.

Whether intramedullary, extramedullary, CAS, or PSI extramedullary alignment guides are used, accurate reproduction of bony cuts is a prerequisite for successful arthroplasty. Each technique relies on the similarity between the anatomic and mechanical axes. Our previously reported cadaveric tibiae data confirm this assumption; the anatomic axis approached the mechanical axis to within 1° on average in both the anteroposterior and lateral planes [22].

For the tibia, many surgeons prefer extramedullary alignment, using bony landmarks about the ankle as reference points. Because the center of the talus is slightly medial to the midpoint between the malleoli, the surgeon must estimate the center of the talus based on these bony landmarks, which may be obscured by soft tissue excess, bony abnormalities, or bulky surgical drapes. Even if CAS systems are employed, alignment is still based on where the surgeon estimates the center of the talus to be located. This can be particularly difficult in the obese patient, as evidenced by Lozano et al.'s study, which showed an increased surgical time in patients with a BMI >35 kg/m^2 when an extramedullary system was used compared to an intramedullary system for the tibial cut [38].

Some authors have suggested that for the tibia, intramedullary alignment is more accurate and reproducible than extramedullary alignment and allows consistent and accurate long bone cuts. Cashman et al. found that the intramedullary guide was significantly more accurate in determining tibial coronal alignment compared to the extramedullary guide in the Triathlon system (Stryker, Kalamazoo, MI, USA) [39]. Our cadaveric tibiae data confirm the reliability of intramedullary alignment in assessing the anatomic axis in total knee arthroplasty. However, when passage of the intramedullary guide rod is prevented from complete seating to the distal tibial physeal scar, the reliability of this technique in assessing the anatomic axis of the tibia is impaired. Simmons et al. were unable to template a long tibial intramedullary guide rod from a central entry point in 42% of cases. In addition, they were able to achieve a 90° cut to the long axis of the tibia in 30 of 35 knees (85.7%) when complete

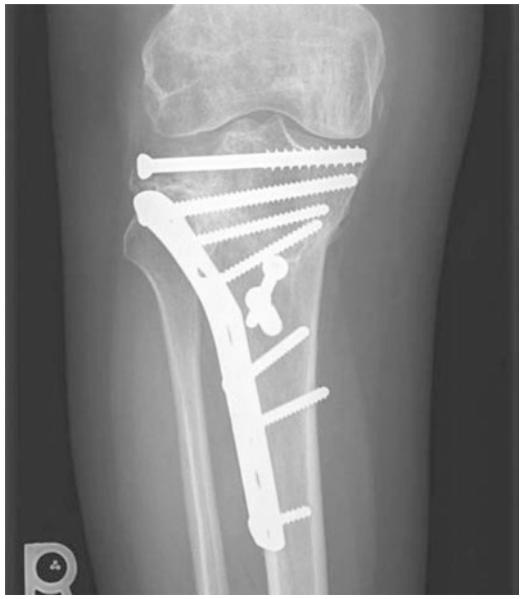


Fig. 12.16 A lateral tibial plateau fracture with bone loss. Hardware is removed before TKA

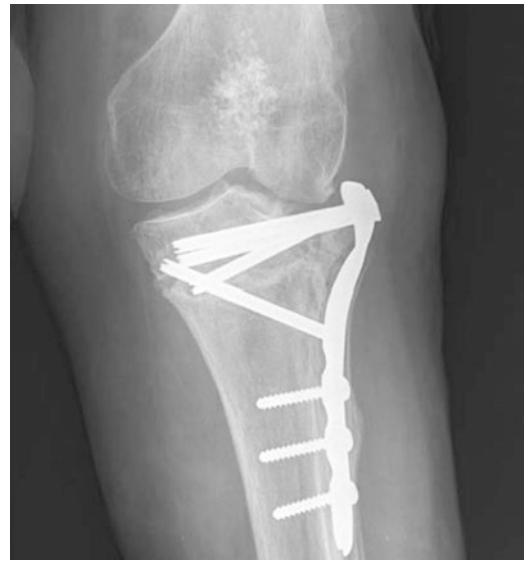


Fig. 12.17 A two-stage reconstruction is planned. The first stage consists of hardware removal with simultaneous creation of fasciocutaneous flaps, which tests the integrity of the soft tissues before implantation

seating of the guide rod was achieved and only in 2 of 25 knees (8%) when the long tibial intramedullary guide was incompletely seated [18]. Our data demonstrate that when penetration of the guide rod was incomplete, the resultant malalignment corresponded inversely with the depth of insertion. In cases in which penetration of the guide rod was complete (>80%), the accuracy of the intramedullary alignment system increased ($p < 0.05$) to within 1° in both the anteroposterior and lateral planes.

Angular deformities in the tibia can interfere with the use of intramedullary devices and prevent passage of the guide rod. Simmons et al. suggested that intramedullary alignment is less predictable in the valgus knee and may lead to malalignment [18]. Our data support the decreased accuracy of tibial intramedullary alignment in valgus versus neutral and varus tibiae ($p < 0.05$). Therefore, valgus deformity of the tibia may be a contraindication to absolute reliance on intramedullary alignment.

In addition to a valgus bow of the tibia, anatomic bony deformity may be a contraindication to the use of intramedullary alignment when performing total knee arthroplasty. Previous fracture, osteotomy, sepsis, or metabolic bone disease, such as osteopetrosis or Paget's disease, can result in a long bone deformity of the tibia that precludes the use of intramedullary alignment guides. Furthermore, retained hardware after fracture fixation or intramedullary cement/hardware after total knee arthroplasty acts as a barrier to intramedullary alignment. Careful preoperative planning with standing long-leg radiographs will identify the patient at risk for incomplete passage of an intramedullary alignment guide rod and should be obtained in all TKA candidates in whom an intramedullary alignment system is considered. It is in these circumstances where CAS or PSI may be particularly useful.

Retained retrograde intramedullary nails may provide a unique scenario in regard to femoral alignment in the setting of their retention. Two specific cases have noted that when the nails are retained, a screwdriver handle inserted on the endcap of the nail can serve as an intramedullary guide rod, thus allowing placement of the distal femoral cutting jig and an accurate bony resection [34, 35].

Conclusion

There is considerable debate whether intramedullary or extramedullary tibial alignment provides a more accurate reproduction of the mechanical axis of the affected limb [2, 17, 22, 40, 41]. In the absence of severe bowing of the tibia, which precludes complete seating of the guide rod, intramedullary tibial alignment is reproducibly accurate and consistent to within 1° in the varus-valgus and flexion-extension planes. Maximum accuracy of tibial intramedullary alignment requires complete seating of the device to the distal tibial physeal scar ($p < 0.05$) and is best suited for the non-valgus tibiae ($p < 0.05$).

Theoretical disadvantages of intramedullary alignment in TKA include the increased risk of fat embolization and medullary bone loss with guide rod passage to the tibia. A reduction in guide rod diameter from 8 to 6 mm, in conjunction with lavage and suction of the intramedullary canal, can help decrease the potential for fat embolization during insertion of intramedullary alignment devices. Anatomic angular deformity resulting from previous fracture, osteotomy, sepsis, or metabolic bone disease may represent additional contraindications to intramedullary alignment use. Furthermore, mechanical obstruction resulting from retained hardware after fracture fixation, osteotomy, or intramedullary cement/hardware after total knee arthroplasty may preclude the use of an intramedullary guide rod. Careful preoperative planning identifies the patient at risk for incomplete intramedullary guide rod passage. In these patients, the use of extramedullary alignment and intraoperative radiographs maximizes accuracy of tibial component position and improves implant longevity.

In revision TKA, alignment is equally critical. Our data have shown that the intramedullary axis of the tibia does not bisect the tibial plateau [33]. Therefore, if a cementless intramedullary extension stem is used, tibial component position will be dictated by the position of the stem. In the majority of cases, this results in asymmetric position of the tibial component with respect to the tibial plateau. This creates the potential for component overhang and diminished support. The use of offset cementless intramedullary extension stems is recommended to address these shortcomings. An asymmetric stem reduces the potential for component overhang while reclaiming areas of uncovered bone for component coverage. In most cases, the need to downsize components is eliminated, allowing a larger component to be used; this allows for an increase in surface area for component support and fixation. The results of this study support the use of an offset stem, which allows for both anteroposterior and mediolateral translation to maximize bony contact between the tibial component and host bone.

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The Use of Stems in Revision Total Knee Arthroplasty

13

Kevin Lindgren, Jeremy Gililland, and Thomas K. Fehring

Revision total knee arthroplasty is becoming an increasingly common reconstructive procedure. As the number of primary total knee arthroplasties continues to increase on a yearly basis, the need for revision surgery will likewise increase exponentially. Therefore, it is important to determine the best surgical techniques to manage revision problems as they are encountered.

Most major manufacturers of total knee replacement offer modular revision knee systems. They use modular augmentations to deal with tibial and femoral bone loss. Most also feature intramedullary jig systems to make accurate revision bone cuts. In addition, manufacturers provide a variety of stems to enhance fixation in revision situations. Variable length stems designed to engage in the metaphysis or diaphysis are commonly offered options. Offset stems are also available to deal with altered anatomy. This variety of stems can be implanted in a press-fit or cemented fashion.

Despite the wide array of options available, little comparative information exists to guide the revision knee surgeon in making a proper prosthetic selection for the patient. This chapter reviews the salient biomechanical literature available regarding stem fixation as well as reviews the effect of canal-filling stem fixation on limb alignment and implant position. Comparative data concerning methods of stem fixation is also presented, along with current recommendations for stem use in revision TKA.

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Biomechanical Considerations

Important biomechanical issues that have been studied in the laboratory include the length of stem necessary for fixation, the potential for juxta-articular stress shielding, and the type of stem fixation.

While stable fixation is an integral part of revision total knee surgery, how to achieve such stability in a revision situation with compromised periarticular bone remains controversial. To enhance stability, implants with extended stems

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have been used to transfer stress from the deficient plateau to the shaft [1].

There were early concerns that the use of such stems might cause significant periarticular stress shielding with subsequent failure. Bourne and Finlay [2] in a strain gauge study noted that the use of intramedullary stems was accompanied by marked stress shielding of the proximal tibial cortex over the length of the stem. They therefore discouraged the use of long intramedullary stems in revision total knee arthroplasty.

In contrast, the successful use of extended stems in revision knee surgery without significant stress shielding was predicted by a number of authors through biomechanical testing. Brooks et al. [3] noted that a 70 mm tibial stem carried approximately 30% of the axial load and relieved the deficient proximal bone to that extent. They concluded that it was unlikely that serious juxta-articular osteoporosis would result through the use of such stems. Reilly et al. [4] noted that if a 60 mm tibial stem was used with incomplete coverage, decreased proximal strains would be noted. However, if the tibial plateau was completely covered, no load bypass would occur. Jazrawi et al. [5] concurred with this assessment, noting no significant decrease in proximal tibial strain with the use of either cemented or cementless stems. The proximal tibia was substantially loaded in each stem construct tested by these authors.

Therefore, it seems that the use of extended stems is not harmful to juxta-articular bone in the form of stress shielding following long-stem revision surgery. While the use of extended stems has become a routine part of revision knee surgery, the ideal method of fixation for such stems remains controversial. The ideal stem type and fixation should be based on the individual clinical situation and may even be different on the femoral and tibial sides of the same patient. Biomechanical and clinical studies may help the operating surgeon determine which type of stem and method of stem fixation are optimal for a given situation.

Stern et al. [1] in a cadaveric study of tibial stems compared cemented and cementless implants. Configurations were subjected to axial as well as eccentric loads. Micromotion and magnitude of migration were quantified. These authors found that cemented implants were associated with significantly less micromotion compared with uncemented components for all configurations tested. They also noted a decreased magnitude of migration with the use of cement. It should be recognized that in this study when cementless stems were used, the tibial tray was not cemented. This is in contrast to the usual clinical use of cementless stems in which the tray is cemented and the stem remains cementless.

Bert et al. [6] in a biomechanical study that more closely mirrors clinical use of these stems compared fully cemented constructs with one in which only the tibial tray was cemented and the stem was press-fit. They found that a tibial tray implanted with a press-fit cementless stem had significantly increased micromotion compared with a fully cemented construct. They concluded that the tibial component should be completely cemented under the base plate and around the tibial stem. It should be recognized that this was a study of primary implants without extended length stems.

In another study, Jazrawi et al. [5] looked closely at the mode of fixation on tibial component stability in a revision setting. In evaluating cemented and cementless tibial stems in the laboratory, they noted that longer diaphyseal-engaging cementless stems had similar micromotion when compared with shorter cemented metaphyseal-engaging tibial stems. They did, however, note that cemented metaphyseal-engaging stems had significantly less tray motion than a cementless construct of the same length. These laboratory predictions from different centers consistently found less micromotion with the use of cemented stem fixation (Fig. 13.1).

Finally, when considering the incorporation of allograft into a revision construct, Completo et al. [7] investigated the effect that stems had in stress shielding of the graft. Cemented stems provide a reduction of 58% of the load transferred at the graft interface versus 17% in a press-fit construct. They concluded that the stress shielding encountered with cemented stems could lead to late resorption of the graft. In contrast, press-fit stems reduced stress more locally at the periphery

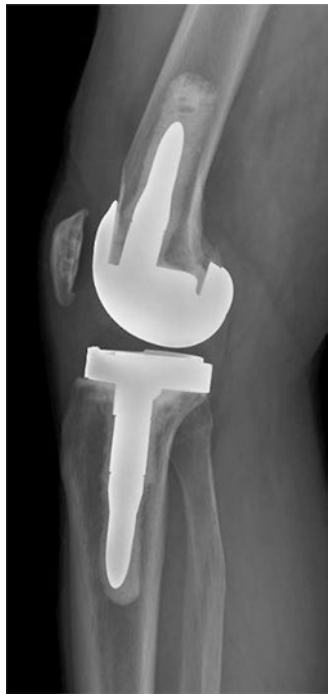

Fig. 13.1 Well-fixed cemented revision implants

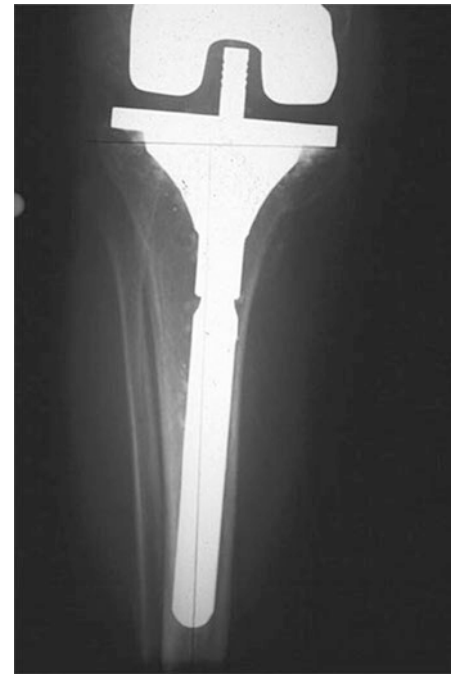

Fig. 13.2 Diaphyseal-engaging stem causing malalignment in a tibia with valgus bowing

transferring the load more centrally around the stem leading to better remodeling.

Stem Fixation and Alignment Issues

Another controversial aspect in revision total knee surgery deals with the type of fixation and ability to maintain normal axial and sagittal limb alignment with canal-filling stems. The revision knee surgeon must be aware of the potential malalignment issues that can occur with canal-filling cementless stems. On the tibial side, valgus bowing of the tibial diaphysis is not uncommon. Thus, when a canal-filling diaphyseal-engaging stem is used, axial malalignment can ensue (Fig. 13.2). In addition to the potential for axial malalignment, anteromedial overhang of the tibial tray may occur with the potential for postoperative anteromedial knee pain.

Hicks et al. [8] noted significant variability in the location of the tibial canal to the tibial plateaus. In their cadaveric review, they found that the intramedullary canal center was usually anterior and medial to the tibial plateau. This study highlighted the need for offset stems in revision total knee arthroplasty, especially if engaging the diaphysis of the tibia (Fig. 13.3).

Canal-filling stems can also have an effect on alignment on the femoral side. A canal-filling femoral stem can lead to anterior displacement of the femoral component. Such displacement overstuffs the patellofemoral space with the potential for limiting motion and increasing incidence of anterior knee pain. In addition, such anterior displacement by definition increases the flexion gap, which can lead to flexion instability (Fig. 13.4).

Strategies to prevent such translation include offset stems or stem bolts, which can move the stem anteriorly or posteriorly as necessary to prevent sagittal malalignment. Alternatively, a narrow cemented stem can be placed posteriorly in the canal limiting this effect. (Fig. 13.5).

A final alignment issue that can affect implant position occurs when the shaft of the femur is

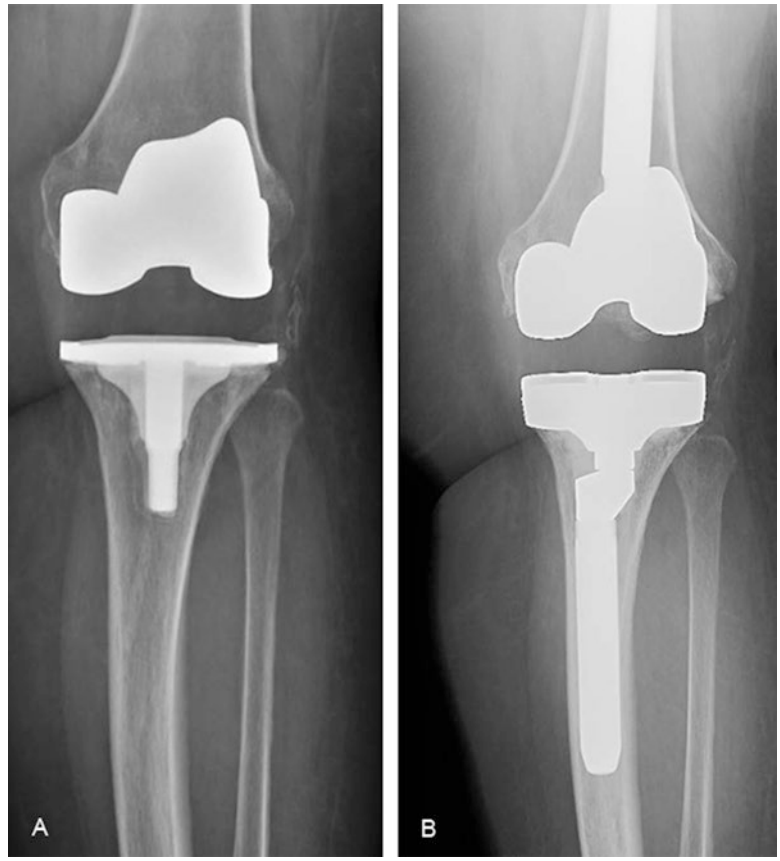

Fig. 13.3 (**a**) Aseptic loosening of tibial component in a patient with large valgus tibial bow. Standard tibial stem would lead to undersizing of the tibial tray and/or significant medial overhang. (**b**) Postoperative view after revision TKA with lateral offset stem and centered tibial base plate

slightly lateral to the condylar bone. If one uses a canal-filling stem in this situation, lateral shift of the implant occurs. This helps patellar tracking. However, the eccentric lateral box position can compromise distal femoral bone stock.

Many of the described axial and sagittal malalignment issues can be handled in one of two ways. A narrow cemented stem can be used in most situations to prevent the previously mentioned malalignment issues. The stem is simply placed eccentrically in the canal to prevent malalignment. Care must be taken to ensure an adequate cement mantle. Alternatively, most manufacturers now offer adjustable offset stems that can compensate for limb malalignment and implant malposition that can occur when using straight canal-filling stems.

An emphasis on preoperative planning to recognize potential malalignment issues will help the revision surgeon have the necessary equipment available at the time of revision.

Stem Fixation Options and Outcomes

From the previous discussion, one can surmise that cemented fixation has certain advantages over its cementless stem counterpart. In the laboratory less micromotion has been reported. In addition, the limb alignment and implant position problems noted previously rarely occur with cemented constructs. To determine what type of stem fixation is best for the revision knee patient, it is also important to review the literature to date on this subject.

Although no prospective study comparing cemented versus cementless stems in revision total knee arthroplasty is available, proponents of each method have reported their results [9–12]. Murray et al. [9] reported the clinical and radiographic results of 40 patients who underwent cemented long-stem revision total knee arthro-

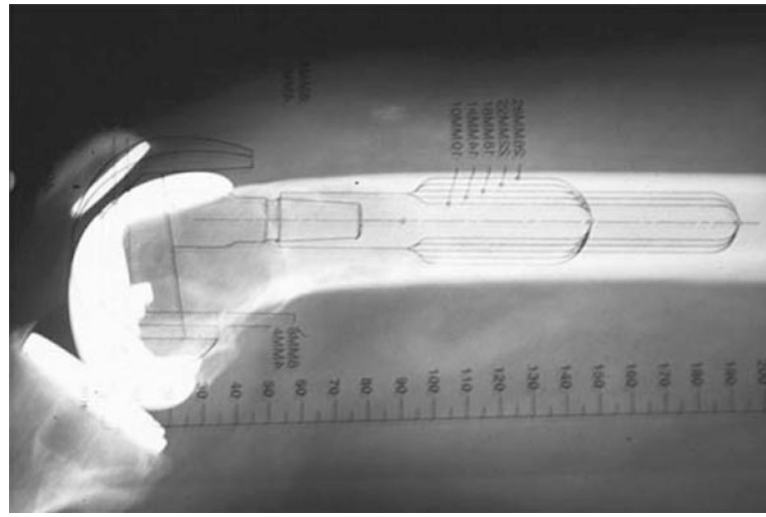

Fig. 13.4 Canal-filling stem template illustrating anterior displacement of the femoral component with corresponding increase in flexion gap

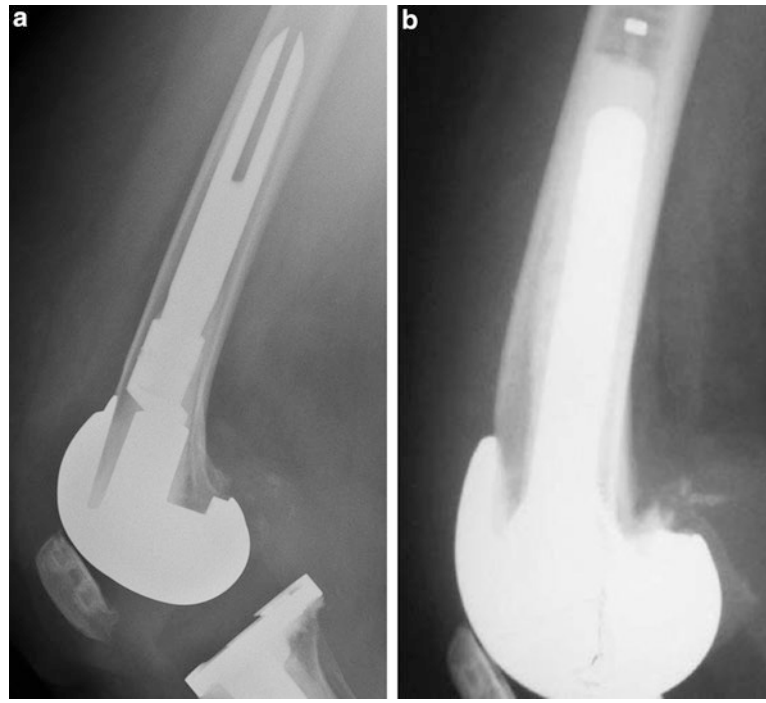

Fig. 13.5 (**a**) Diaphyseal-engaging cementless femoral stem with posterior offset to avoid anterior displacement of the femoral component. (**b**) Metaphyseal cemented femoral stem placed posteriorly in the femoral canal to avoid anterior displacement of the femoral component

plasty at an average follow-up of nearly 5 years. Only one patient had asymptomatic radiographic loosening of the femoral component, while no tibial component was categorized as loose. Mabry et al. [13] reported excellent long-term results with cemented modular stems with 5- and 10-year implant survivorship free of revision for aseptic failure of 98% and 92%, respectively.

Bertin et al. [12] first described the use of juxta-articular cementing with the use of long uncemented stems in their analysis of 53 revision total knees. At a follow-up of only 18 months, 18% had complete radiolucent lines at the femoral bone-cement interface, while 21% of the tibial implants had a complete radiolucent line at the tibial bone-cement interface. The widths of the radiolucent zones were not thought to be progressive by the authors. Thin white lines were frequently seen around the cementless stems in Bertin's study. Of the 73 stems with radiopaque

lines next to the stems, 18 were tightly approximated to the stem, 40 were parallel within a few millimeters of the implant, while six had divergent sclerotic lines. The authors believed that these lines did not imply loosening but needed to be followed longer to establish their significance as the follow-up in this study was extremely short.

Haas et al. [10] reviewed 65 patients who underwent revision total knee surgery for aseptic loosening. Each patient had cement used on the cut surfaces in the metaphyseal region of the femur and tibia along with a cementless fluted stem. While the Knee Society Radiographic Scoring System was used to determine location of radiolucent lines, implants were not categorized according to Knee Society guidelines as stable, possibly loose requiring close follow-up, or loose. Radiolucent lines at the bone-cement interface were noted in 33% of the femoral implants and 64% of the tibial implants. Most were 1–2 mm and nonprogressive. Complete radiolucent lines at the bone-cement interface were noted in 7% of the tibial components and 1% of the femoral components.

Peters et al. [11] in 1997 reviewed 57 revision total knee arthroplasties performed for aseptic failures. Eighteen tibial stems and 34 femoral stems were used in this group of revisions. Thirty-two of these stems were cemented, and 20 were cementless. Adequate radiographs were available for only 39 of these 52 implants (75%). In Peters' series, radiolucent lines were more prevalent adjacent to press-fit femoral stems compared with cemented constructs ($p < 0.02$). There was no significant difference in the total number of radiolucent lines around cemented and cementless tibial stems in their series ($p = 0.73$).

Peters et al. [14] in a subsequent article of 184 consecutive revision total knee arthroplasties done with press-fit fluted cementless stems at an average of 49 months follow-up. Average Knee Society Scores improved significantly, and despite the presence of radiolucent lines as previously documented, no knees were re-revised for aseptic loosening. Of the 15 failures seen in their series, 13 were septic failures, one malalignment, and one periprosthetic fracture.

Fehring et al. [15] sought to determine which type of stem fixation was superior in a large series of revision total knee arthroplasties. They had experience with cemented and cementless metaphyseal-engaging stems in revision total knee arthroplasty and therefore reviewed their experience.

Between 1986 and 2000, 475 revision total knee arthroplasties were performed in 419 patients. Of the 475 TKAs, 393 full-component revisions in 279 patients were performed using 484 stems. The remaining 82 revisions were performed without the use of stems. Of these 279 patients, 85 patients with 131 stems were deceased, re-revised within 2 years, or revised with diaphyseal-engaging stems. Eighty-seven patients with 151 stems had less than 2-year follow-up. The final data set was 113 patients with 202 metaphyseal-engaging stems implanted at the time of full component revision. Radiographic analysis was performed using the Knee Society Radiographic Scoring System.

Of the 202 metaphyseal-only engaging stems, 107 were cemented and 95 were cementless. The average follow-up was 57 months. Of the 107 implants with cemented stems, 100 (93%) were categorized as stable, 7 (7%) require close follow-up, and none were loose. Of the 95 implants placed with cementless stems, only 67 (71%) were categorized as stable, 18 (19%) required close follow-up, and 10 (10%) were loose (2 tibial and 8 femoral implants). Implants placed with cemented stems were significantly more radiographically stable than those implanted with cementless stems. This difference was significant at the $p = 0.0001$ level. They concluded the radiographic appearance of metaphyseal-engaging cementless implants was concerning, while the cemented metaphyseal-engaging stems worked well at midterm follow-up.

With the demonstrated higher failure rate of cementless metaphyseal fixation over cemented fixation, Gililland et al. [16] examined a more clinically typical hybrid fixation of proximal cementing and diaphyseal-engaging press-fit versus cemented stems for clinical superiority. In a retrospective review of 82 revision total knee arthroplasties performed for aseptic failure, they looked at the clinical and radiographic outcomes of cemented versus diaphyseal-engaging cementless

stems. All diaphyseal press-fit stems evaluated had a minimum of four centimeters of engagement. The follow-up averaged 76 and 121 months for the cemented and cementless groups, respectively. They found no statistically significant difference in failure rates between the groups. They concluded that both stem types provided reliable fixation and would be viable options in revision TKAs performed for aseptic failure.

In contrast to this study by Gililland, Edwards et al. [17] compared cementless vs. cemented stem fixation in the second stage of two-stage revisions performed for septic failure. In a retrospective review of 114 second-stage revision TKAs with 228 total stems for review, they compared 102 cemented stems to 126 cementless stems with mean follow-up of 52 and 45 months, respectively. Similar to the study by Gililland, all of the cementless stems in this study had minimum 4 cm of diaphyseal engagement. Additionally, antibiotic cement was used in all of the second-stage revisions. The stems were evaluated radiographically and classified as stable, closely observe, or loose by the modified Knee Society radiographic score. Rates of aseptic re-revision and septic re-revision were both comparable between the cemented and cementless groups. However, higher rates of radiographic failure were seen in the cemented group with 32% of the stems being classified as closely observe or loose compared to only 17% in the cementless group. The authors concluded that the higher failure rate of the cemented stems might have been due to the fact that aggressive canal debridement during the first-stage revision removes the majority of available cancellous bone, creating a relatively sclerotic tube and thus compromising cemented stem fixation.

Adjuvant Metaphyseal Fixation

Metaphyseal bone loss is common in revision total knee arthroplasty. We have learned through the years that construct stability that bypasses this region and relies solely on stem fixation for success performs poorly over the long term. This occurs regardless if either a cemented or a cementless stem is used for fixation. When periarticular proximal tibial or distal femoral bone is severely damaged, it is critical to obtain stability of the construct in the metaphyseal region (Fig. 13.6). When classified according to the Anderson Orthopaedic Research Institute (AORI), severe defects, such as type 2-B and type 3, require bone void filler and fixation options historically done with allograft or metal block augments. In the last few years, early results have been published concerning the concomitant use of cones and sleeves to manage severe metaphyseal bone loss. These offer the ability to improve metaphyseal fixation, restore joint line, and work with a variety of stem fixation options.

This can be accomplished through a variety of strategies. Cemented sleeves can be used if the metaphyseal bone is still cancellous in nature and able to accept cement interdigitation readily (Fig. 13.7). If the periarticular bone is sclerotic in nature, cementless metaphyseal fixation in the form of porous metal cones or porous coated sleeves should be used. Cones can be implanted free hand with the use of a burr or implanted with a milling system. If sleeves are used, they are implanted with a broaching system. Regardless of the type chosen, intimate contact of the bone prosthetic interface is mandatory to ensure ingrowth (Fig. 13.8).

Derome et al. [18] looked at the short-term clinical and radiographic outcomes of trabecular metal cones used in revision total knee arthroplasty. At an average follow-up of 33 months from implantation, the mean Knee Society Score and functional score statistically improved without showing any evidence of radiographic loosening or migration of the constructs. Additionally, an osseointegration rate for cones of 99% was documented in a study by Brown et al. [19] Studies of the short- and midterm success of metaphyseal sleeves also yield promising results. An overall aseptic survival rate of 98.3% was reported in one study at a mean of 3.6 years, while another cohort showed no revisions for aseptic loosening at 36 months with statistically significant improvement in range of motion and Knee Society Scores [20, 21].

Once the periarticular metaphyseal bone has been adequately reconstructed, the length and

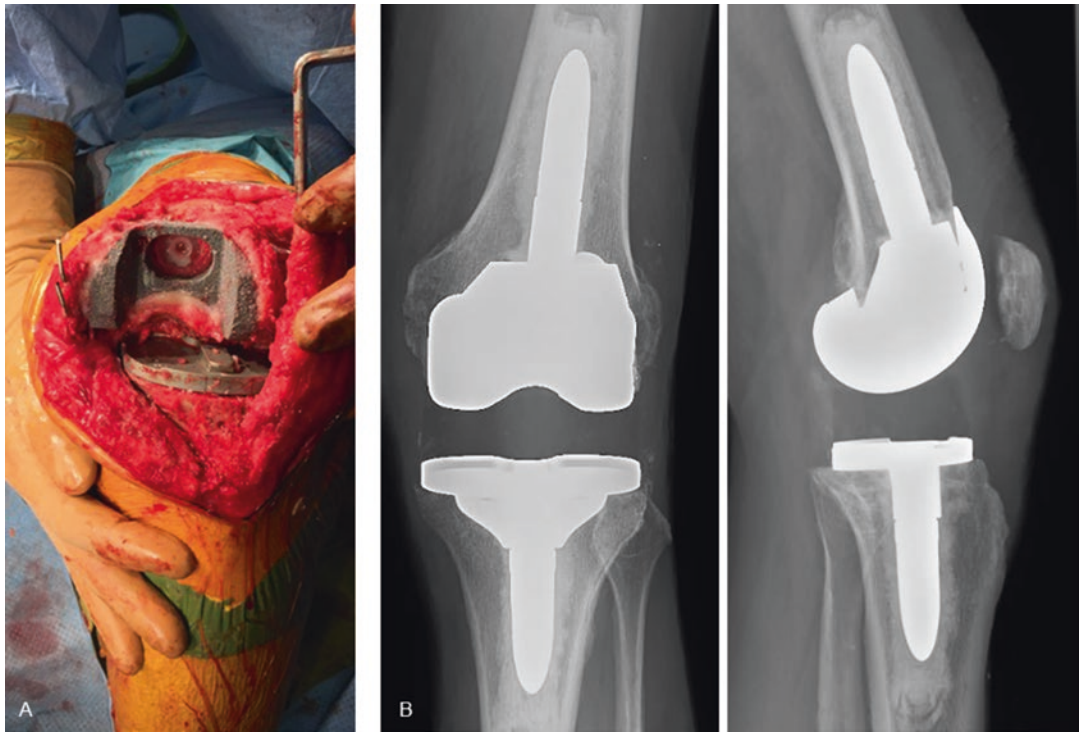

Fig. 13.6 (**a**) Significant distal femoral metaphyseal bone loss with press-fit porous tantalum cone used to fill this "goal-post" femoral defect at time of second-stage revision TKA performed for prior septic failure. (**b**) Post-op images of the revision TKA construct with press-fit porous tantalum femoral cone combined with short cemented femoral stem

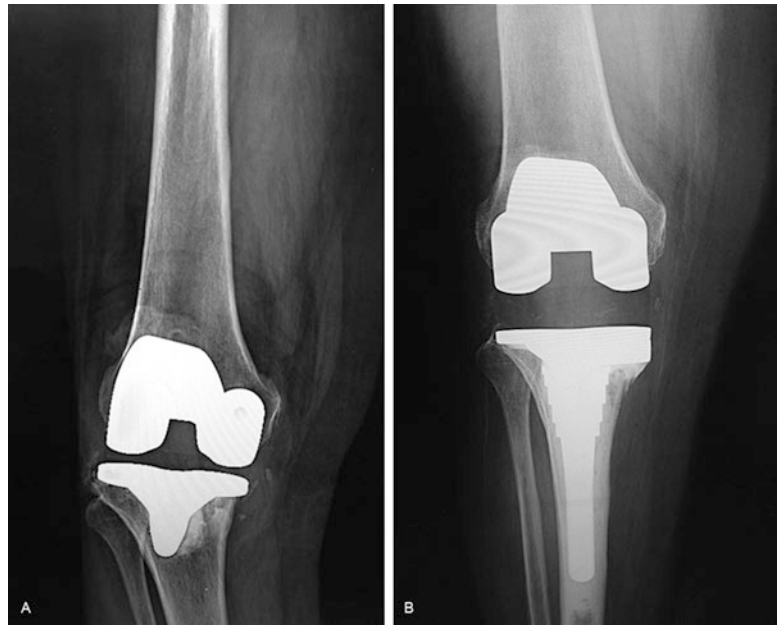

Fig. 13.7 (**a**) Preoperative image of failed TKA secondary to aseptic loosening and subsidence of the tibial component with metaphyseal bone loss and medial tibial cortical bone loss. (**b**) Postoperative image of the revision TKA construct utilizing a cemented tibial sleeve, medial tibial augment, and cemented stem

type of fixation can be chosen based on the integrity of the bone within the canal as well as surgeon preference. When proximal metaphyseal reconstruction is required through the use of cones or sleeves, the stem is used to help stabilize the construct until bony ingrowth ensues. This is in contrast to previous strategies of building up the periarticular bone with metal augments and relying on extended stems solely for fixation.

The senior author's revision experience has evolved incorporating the use of multiple strategies depending on the periarticular bone loss present and the integrity of the intramedullary canal. If the metaphyseal bone has little damage and the canal has good cancellous bone available, a short 30–60 mm. cemented stem is used. If there is moderate metaphyseal bone damage and the canal has good cancellous bone available, a cemented sleeve is used along with a 60 mm. stem extension (Fig. 13.7). If the metaphyseal bone damage is severe, a cementless cone or sleeve is used (Figs. 13.6 and 13.8). If the intramedullary canal has good cancellous bone available, a cemented stem is used. If the intramedullary canal is sclerotic from previous surgical trauma, a cementless diaphyseal-engaging stem is preferred.

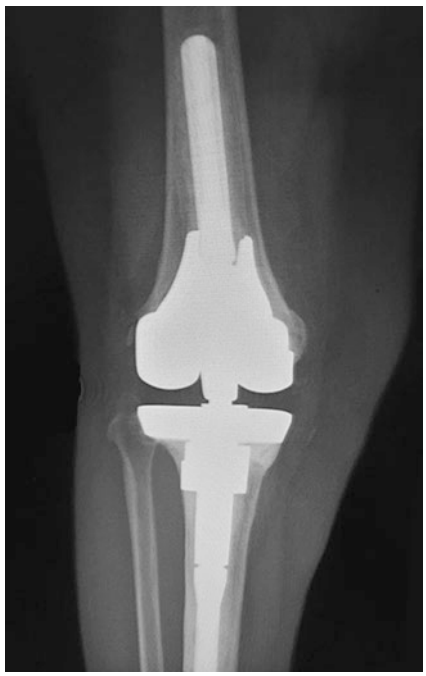

Fig. 13.8 Femoral and tibial porous cones used in combination with cemented stems on both sides in a constrained revision TKA construct

Conclusion

A variety of fixation options exist for today's revision knee surgeon. Surgical decision-making should be predicated on the degree of bone loss present and the integrity of the intramedullary canal. An attempt to envision the bone remaining following implant extraction will help aid the preoperative planning to ensure long-term success.

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14 Restoration of Stability, Maintaining Joint Line, Gap Balancing, and Constraint Selection in Revision Total Knee Arthroplasty

Kelly G. Vince

Stability and motion comprise the "kinematics" of primary and revision knee arthroplasties. This fits the engineering definition of "kinematics" as "the branch of mechanics concerned with the motion of objects without reference to the forces that cause the motion" [1]. All motion of a knee joint and its parts can be defined as either "translation" (movement of a body from one point of space to another such that every point of the structure moves in the same direction and over the same distance, without any rotation, reflection, or change in size) or "rotation" (change of orientation or "turning" around an axis). These two motions on three axes of physical space, *x*, *y*, and *z* (Fig. 14.1), constitute the "six degrees of freedom" of the physical world and describe all possibilities of knee motion and component position. They define stability and how to achieve it with surgery.

Borrowing from a classic text on spine injury, we can describe stability in a knee arthroplasty as the ability of the joint to maintain its structure and yet permit motion within functional limits when subjected to physiologic loads [2]. When the quadriceps muscle contracts, the knee extends fully but not into recurvatum. The hamstring muscles contract, and the tibia rotates around the "*x*-axis" (flexes), translates slightly on the "*z*-axis" (femoral rollback), and rotates internally a few degrees under the femoral condyles around the" *y*-axis" (screw-home mechanism). (Fig. 14.2). Similar rules apply to the patella. To a lesser degree, the tibia and femur displace in the frontal or coronal plane under varus-valgus bending moments as the collateral ligaments absorb energy and deform elastically.

The title of this chapter makes two assumptions: that stability must necessarily have been lost (in order to be restored) and that something described as the "joint line" needs to be retained in a specified position. The former is not a problem in every revision as some arthroplasties fail for reasons other than instability [3]. However, the revision technique for any mode of failure must still ensure stability when components are replaced.

Revisions differ from primary surgery in many ways, including the role of conventional soft tissue releases that are used to correct arthritic deformity and stabilize a primary arthroplasty [4]. These techniques are rarely feasible in revision surgery unless the releases should have been done at the primary surgery but were not. "Rerelease" of ligaments is not viable. Stability in revision surgery is the product of the existing soft tissues and the component's size, position, and design. A mechanically constrained implant

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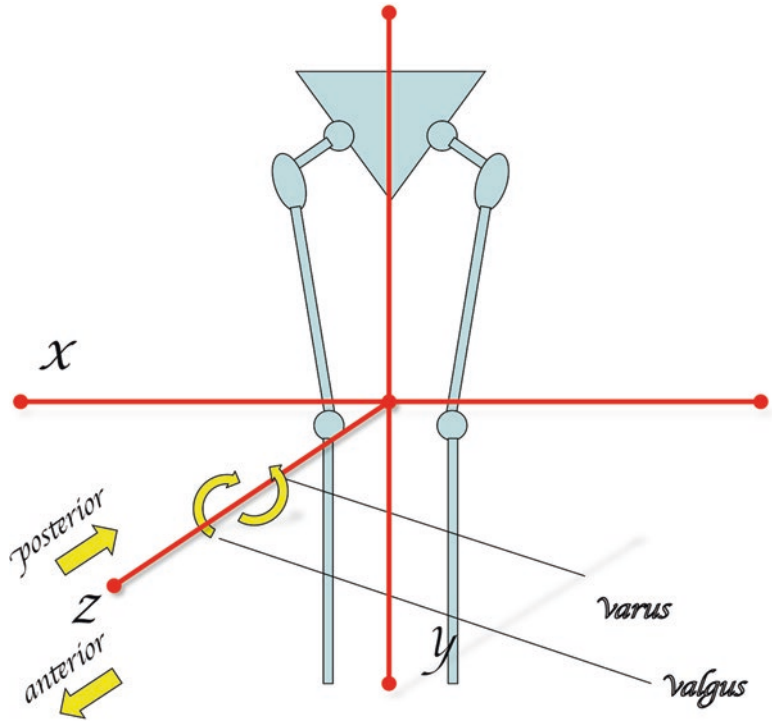

Fig. 14.1 *x*, *y*, and *z* axes. The three-dimensional universe can be plotted on the axes: *x*, *y*, and *z*. Considering that objects in space may either translate (move to another location without reorientation) or rotate (turn, spin, and be reoriented), these two types of motion on three axes represent the "six degrees of freedom" that engineers use as a constant frame of reference. The permutations for position, considering that translation and rotation can each proceed in positive or negative directions, are huge. Component position in knee arthroplasty can be described precisely as departures from a neutral position according to translation (millimeters or length) and rotation (degrees). In this figure, the *z*-axis is used to define varus-valgus as rotation around the "*z*"-axis and "anterior and posterior" as translation on the same "*z*"-axis

is not necessarily required unless ligaments required for stability have failed. Specific indications for constraint are described below.

Secondly, that the "joint line" should be a primary key to revision surgery is contentious. As with all aspects of surgery, basic precepts and received wisdom should be challenged if revision knee arthroplasty is to be practiced expertly and improved in the future.

Stability and Instability

TKA instability has been reviewed [5, 6]. Several principles guide revision knee arthroplasty and are pertinent to cases of instability. First, no surgery can be recommended before clear steps are planned to solve specific problems that caused a recognized mode of mechanical failure [3, 7, 8] (Fig. 14.3). A generic "repeat arthroplasty," one performed without an explanation of pain, instability, or stiffness, is likely to fail, as was established in 1988 [9]. The era of "exploratory" or diagnostic surgery has long passed; every failed knee replacement should be evaluated systematically and comprehensively [10]. The patient's description of symptoms is essential information but does not constitute a diagnosis [5, 11].

There is an unfortunate tendency to equate "instability" with ligament failure. This works in the assessment of native knee dysfunction after trauma or sports injuries but is a premature

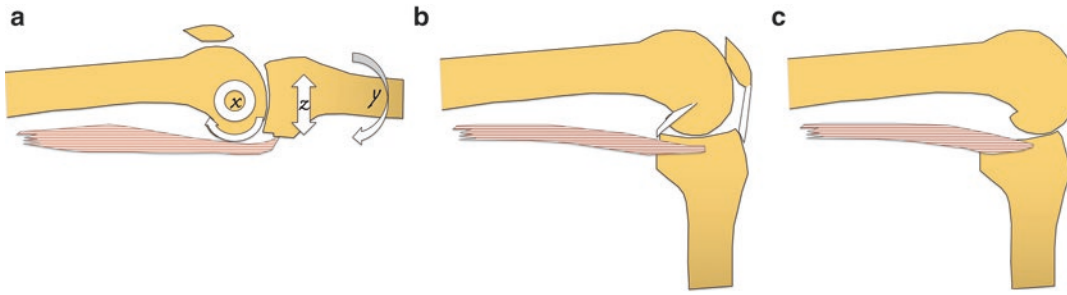

Fig. 14.2 Stable knee flexion. **(a)** The hamstring muscles contract, and the tibia rotates around the "*x*-axis" (flexes), translates slightly on the "*z*-axis" (femoral roll-back), and rotates internally a few degrees under the femoral condyles around the "*y*-axis" (screw-home mechanism). **(b)** The tibia does not however dislocate posteriorly once it reaches 90 degrees of flexion, as would happen if only the hamstrings were managing motion. The posterior cruciate and the extensor mechanism help convert hamstring tension into knee flexion. **(c)** Without the PCL and extensor, the hamstring is likely to sublux the tibia posteriorly. Constraint, including an ultra-congruent articulation, posterior stabilization, and non-linked constrained implants and hinges, can help restore stability, ensuring that hamstring tension continues to result in knee flexion. The essence of stability is to be able to maintain structure and physiologic motion under load

conclusion when a patient describes instability or "giving way" of a knee arthroplasty. Another unfortunate tendency is to plan revision surgery with a highly constrained prosthetic product whenever a patient reports instability. It is essential to identify why a knee joint is giving way and to correct the cause.

Instability is a symptom similar to pain: there can be many causes [11–13]. Indeed pain itself can be a cause of instability through "pain inhibition." Any physical action that incites pain will be curtailed. The patient who steps off a curb and suffers anterior knee pain may experience quadriceps inhibition, with unopposed knee flexion and buckling. They might report that the knee "gives out," and this may be misconstrued as a case of "instability." A painful infected knee may buckle, especially if a large effusion prevents full extension. Pain may originate from an ipsilateral arthritic hip or quadriceps weakness from lumbar disease [14, 15]. These examples represent "functional," secondary, or dynamic instabilities. They are not, strictly speaking, cases of knee "instability." The source of pain requires attention, but the knee may not benefit from revision.

Not all knee arthroplasties that require revision will be cases of instability even if the patient describes the knee as "unstable." The periprosthetic fracture is an example. Every surgeon would agree that a fracture makes the joint "unstable" but that the solution to the problem is neither ligament reconstruction nor necessarily a constrained implant, but rather fixation of the broken bone.

And so, a knee may lack stability due to a structural problem that should not be characterized primarily as instability. Other examples include instability from component loosening and bone loss or implant breakage [16]. These may require revision arthroplasty, but not necessarily with a highly constrained implant [17] (Fig. 14.4). Mechanical constraint is indicated specifically for ligamentous incompetence, not bone loss. Correction of the primary problem restores comfort, function, and stability by placing good ligaments under functional tension, thus avoiding the problems of constrained implants.

True tibial-femoral instability might be described as: "failure to maintain the structure of the arthroplasty or failure to limit excursion of the joint under load as a result of failure (plastic deformation) of ligaments or deficiencies with component size and position that fail to place good ligaments under physiologic tension." The two phenomena are related: a TKA with excess valgus alignment may overload the medial collateral ligament, which fails in tension. The cause of instability will be valgus alignment that results

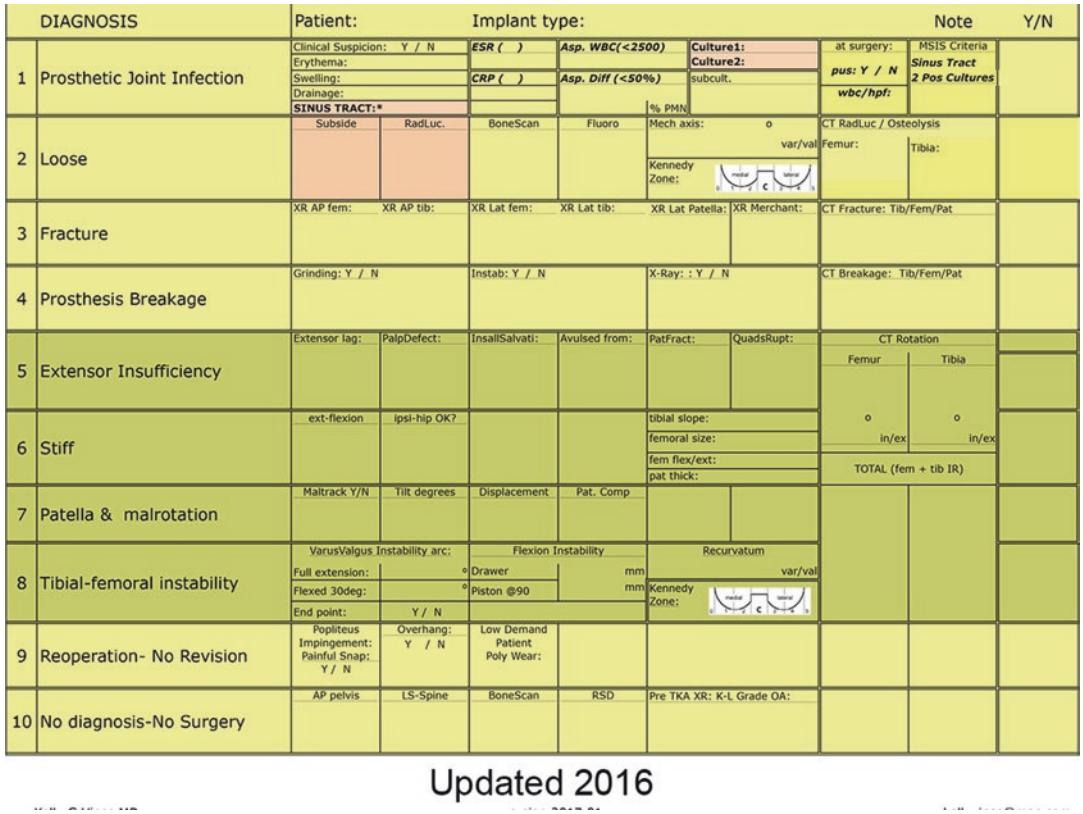

Fig. 14.3 Modes of failure planning worksheet for the failed knee replacement. This version is based on mechanisms of failure described by Moreland [8] and has been updated from an earlier version [3]. The eight indications for revision knee arthroplasty are listed on the second column on the left. The sequence, first to eighth, represents a clinical algorithm for consideration of the failed arthroplasty. For each diagnosis, the essential data points that should be recorded are in the columns on the right. The process is intended to be systematic and comprehensive. This sheet represents the system, which can be applied to every problem TKA. To be comprehensive, all eight diagnoses must be considered, even if one diagnosis is established. For example, infection can accompany any other mechanical failure. A knee can be stiff and loose. Because infection should be suspected in all cases, this is listed at the top. It may be considered a "biological" failure. Loosening, fracture, and prosthetic breakage are grouped sequence as "structural failures," and extensor insufficiency, stiffness, patellar tracking, and tibial-femoral instability are "kinematic" failures. Tibial-femoral instability is listed last, as any of the above can present with a report of buckling, instability, or giving way. Three modes of instability are listed in the columns to the right: 1. varus-valgus, 2. flexion, and 3. recurvatum

in medial soft tissue failure. Revision surgery must mitigate the cause (realign the knee) and then restore stability, perhaps with a constrained implant or, uncommonly, a ligament allograft [18].

Several modes of instability must be considered: (1) Varus-valgus, (2) plane of motion, and (3) flexion (Fig. 14.5). Varus-valgus instability (more frequently valgus) is the prototypical manifestation of the unstable TKA. Varus instability, for example, results from loads and an alignment that induce an insupportable bending moment (or torque) across the knee joint in the coronal plane. As the deformity increases, the moment arm of the load and the bending moment across the joint increase. Deformity and instability increase in a positive feedback loop until the knee collapses (Fig. 14.6).

Loads across the knee are not symmetrically compressive as we might idealize from an anteroposterior radiograph (Fig. 14.7). The knee is usually subject to bending moments that

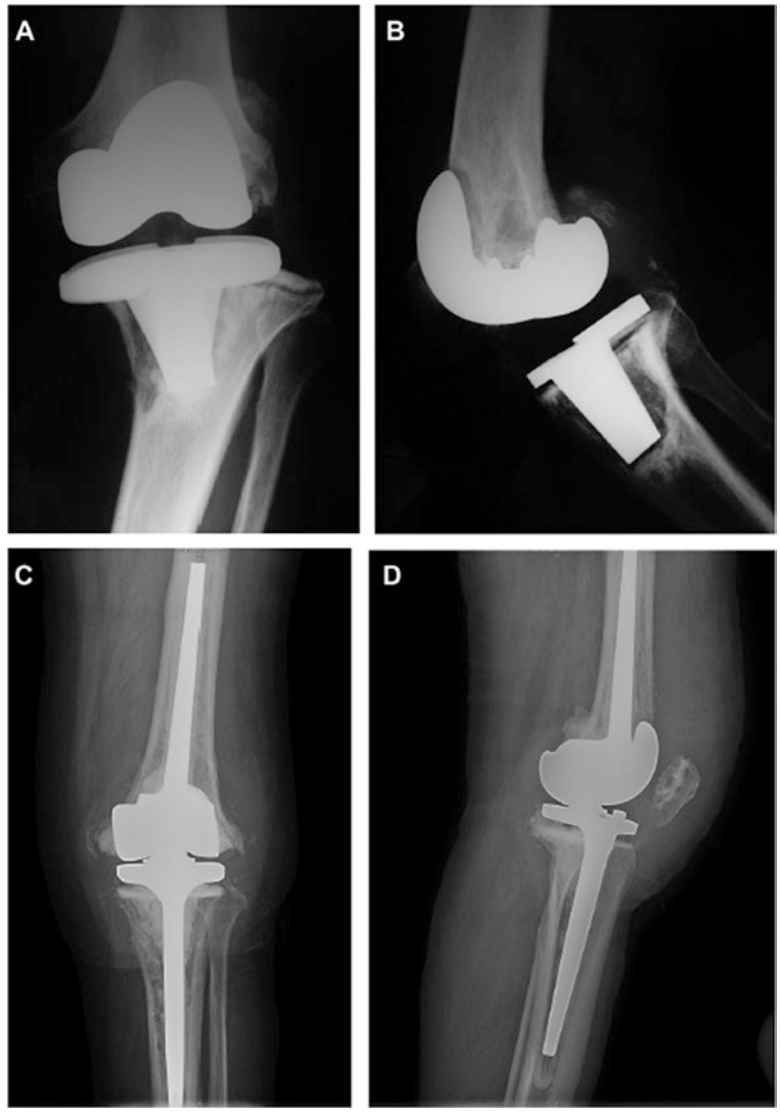

Fig. 14.4 **(a–d)** Loosening not true instability. This dramatic failure is Fig. 1 in a paper entitled "Revision knee arthroplasty with a rotating-hinge design in elderly patients with instability following total knee arthroplasty" [90]. Though the knee joint is clearly unstable, this is a case of component loosening with bone loss, (plus perhaps even infection), but it is not primarily a case of knee instability. In all probability stability could have been restored to this arthroplasty with a non-constrained device. Failure into varus, like this case, protects the medial collateral ligament, which is then available for reconstruction. The use of a constrained device can be defended if it was difficult to balance ligaments at the revision. This paper highlights the difficulty with definition of "instability." True cases of instability result directly from failure of ligaments or are due to the size and positioning of the prosthesis. This distinction is important because it guides the reconstruction accurately and avoids unnecessary constraint (From Rodriguez-Merchan EC, Gomez-Cardero P, Martinez-Lloreda A. Revision knee arthroplasty with a rotating-hinge design in elderly patients with instability following total knee arthroplasty. J Clin Orthop Trauma. 2015;6(1):19–2, with permission)

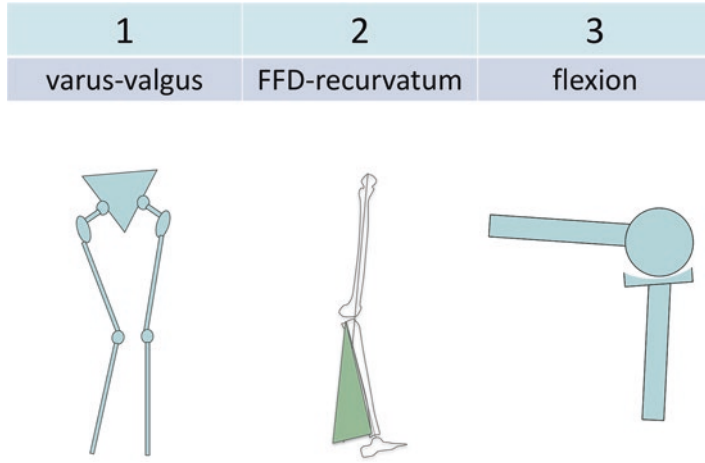

Fig. 14.5 Modes of instability. True tibial-femoral instability of the knee can be identified in 3 basic forms, each of which has a different cause and requires a different approach at surgery. Some unstable arthroplasties of course may exhibit more than one mode, and they will require more complex techniques for reconstruction. On the left is the prototypical instability, in the frontal plane, also described as "varus-valgus" instability. It results from problems with tibial-femoral alignment, aberrant loading during gait, and failure of the collateral ligament envelope on medial and lateral sides. The middle is instability in the plane of motion. It is encountered less frequently and is often described as "buckling." If this occurs because of patellar maltracking, then the case belongs in that category where attention to component rotation, etc. will be required (see Fig. 3, failure mode #7 "Patella and Malrotation"). If it occurs due to fixed flexion deformity and quadriceps fatigue, then the issue is stiffness (Fig. 3, mode 6). If it occurs due to recurvatum, then it is a true form of tibial-femoral instability, where the root cause is often extensor deficiency. The third mode is described on the right, instability of the knee in flexion, where generally the tibia subluxes posteriorly under the femoral condyles. This is a problem of flexion and extension gap mismatch

create compression in one compartment and tension in the opposite collateral ligaments. Alignment and stability are both important to knee joint function. However, the unstable arthroplasty fails immediately, whereas the malaligned knee may take years to succumb to wear, osteolysis, and loosening. Stability is important because it ***controls*** alignment. The stable knee has one alignment (with minor physiologic deflections under load), but an unstable knee suffers many alignments, unfortunately always the worst one for a given load: a valgus load increases valgus alignment, increasing the destructive lever arm (Fig. 14.8).

Physical activity loads the knee unpredictably. Surgical alignment can modulate the moments across the knee joint, but only statically and not in response to loading. If we lean to the left side, for example, the left knee cannot go "into varus" to reduce compression in the lateral compartment. By contrast, the extensor mechanism can respond to greater load with more forceful contraction or by changing the flexion angle. Less flexion requires less power from the quadriceps for stability. A person carrying groceries avoids walking in a squat.

Two sides of the stability equation must be considered: mitigation of deforming loads and restoration of stabilizing forces. Limb alignment, gait abnormalities, and spinal deformity (scoliosis) may contribute to knee joint overload and instability. Failure to correct valgus deformity in the arthritic knee combined with failure to substitute for an incompetent medial collateral ligament predictably results in instability. Similarly, failure to equalize the lengths of the medial and lateral ligaments, (balancing the knee) after correction of deformity, results in instability. A constrained implant alone is not a complete solution to the problem of instability. Although the majority of arthroplasties function very well, the ideal alignment for any given knee

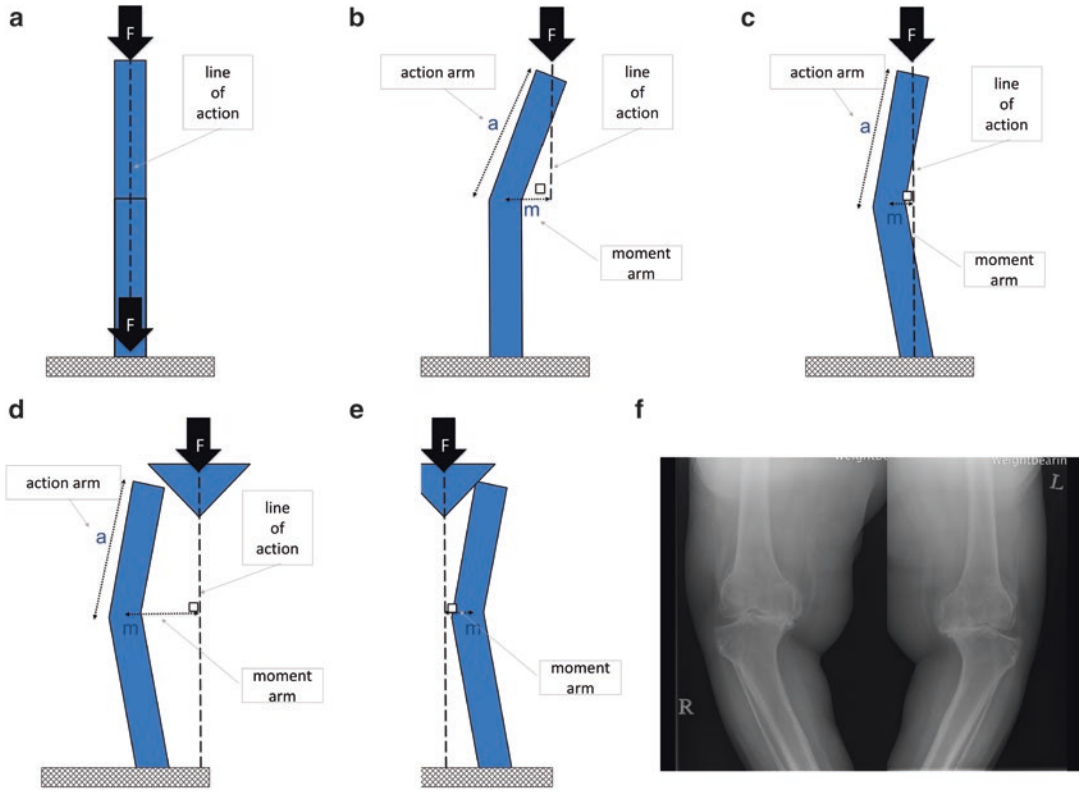

Fig. 14.6 (**a–e**): Moment arm – alignment and stability. (**a**) The effect of lever arm (redrawn from Einhorn et al. [93]). If a load of magnitude "*F*" is applied symmetrically to the top of a (nonelastic) column, that same load is eventually delivered through the column to its base. (**b**) If the load "*F*" is applied to this structure from above, a lever arm is created, with moment arm equal to "*m*." This lever arm will increase as the angle between the two limbs of the "column" increases. The "action arm" will remain unchanged despite the angle. The torque or "bending moment" created at the apex will equal the moment arm times the force: $m \times F$. (**c**) The lever arm can be redrawn to resemble a knee with a crude varus alignment. Now the line of action has been altered, and the moment arm is increased. (**d**) We must remember however that the force "*F*" is actually applied to the weight-bearing limb in stance phase from the center of gravity of the human body, generally in the front of the 4**th** sacral vertebra. This increases the moment arm and the bending moment on the "knee." (**e**) Conversely, valgus alignment decreases this moment arm. Assuming stability in the articulation, this valgus alignment diminishes the destabilizing force at the articulation. (**f**) Varus instability, for example, results from loads and an alignment that induce an insupportable bending moment (or torque) across the knee joint in the coronal plane. As the deformity increases, the moment arm of the load and the bending moment across the joint increase. Load, pain, deformity, and instability increase in a positive feedback loop until the knee collapses

joint, much less all knee replacements, is difficult to specify [19]. Consider how loading changes in a typical knee with the usual anatomic valgus alignment of five degrees if thigh girth is increased, resulting in a wider stance (Fig. 14.9). Though we may not be able to predict the ideal alignment, we might draw useful conclusions regarding alignment for a revision if varus or valgus instability had been the reason for failure of the primary.

Plane of Motion Instability

"Plane of motion stability" depends on the relationship of the static stabilizing structures in the back of the knee and the extensor mechanism in the front. The posterior structures limit hyperextension, and the quadriceps controls spontaneous flexion (buckling). If the quadriceps muscle cannot resist loads across the knee joint, flexion occurs without control.

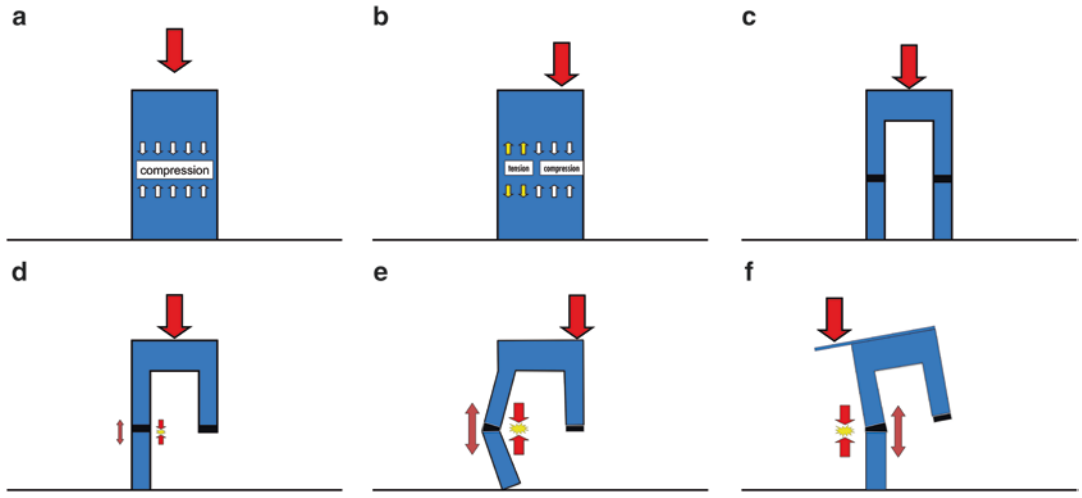

Fig. 14.7 (**a**) In a simplified model, load applied to a rigid structure creates uniform compression. (**b**) Eccentric loads create compression and tension. (**c**) The monolith can be rendered as two columns, representing lower limbs. (**d**) In single stance phase, uniform compression is replaced by a strong bending moment, with compression on the media side and tension on the lateral side. (**e** and **f**) Varus alignment or aberrations in gait that might shift the application of load away from the affected joint increase the moment arm at the knee as well as the compressive and tensile loads. There will be a point at which structures fail and instability results. Alignment therefore is an important factor in maintaining or restoring stability. Conversely, valgus instability, observed frequently in knee arthroplasty, is exacerbated by loads applied from outside the lower extremity (scoliosis and coxalgic gait), and only the medial collateral ligament is available to resist tension—there is no counterpart to the dynamic muscular stabilization of the iliotibial band

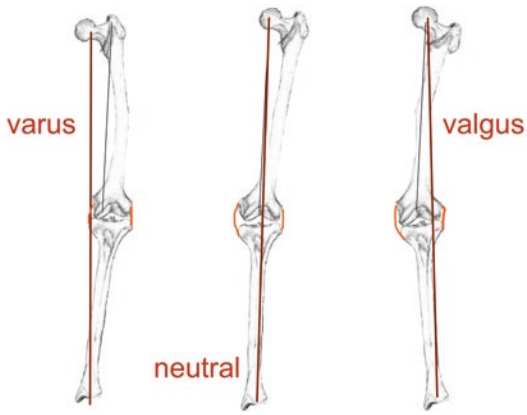

Fig. 14.8 Stability and alignment. Stability means that *ONE* alignment angle will be maintained. Instability means that there are many alignment angles—always the worst one for the load applied. As the knee is loaded in varus, the alignment shifts to maximum varus and the destructive lever arm is maximized. Unfortunately, the arthroplasty literature studies alignment and stability separately. When studies report "alignment," they rarely evaluate whether the arthroplasty was actually stable and vice versa

Lack of quadriceps control may be apparent in the physical examination as an inability to extend the knee fully, even when the joint is capable of full extension (extensor lag). Disruptions of the extensor mechanism anywhere from the quadriceps muscle to the tibial tubercle create gross extensor insufficiency. Quadriceps atrophy, denervation, and general deconditioning may be responsible for functional extensor weakness. The patient with a patellectomy or a thinned patella from a prior arthroplasty may suffer relative extensor insufficiency due to loss of mechanical advantage despite a strong muscle [20]. These situations are similar in their effect on stability.

Patients with a deficient, weak, or dislocating extensor mechanism often compensate by locking the knee in full extension or hyperextension, during stance phase. This was first recognized in polio patients who lack quadriceps strength. Similar compensation may be observed in the obese patient whose extensor mechanism is close to normal strength but incapable of sup-

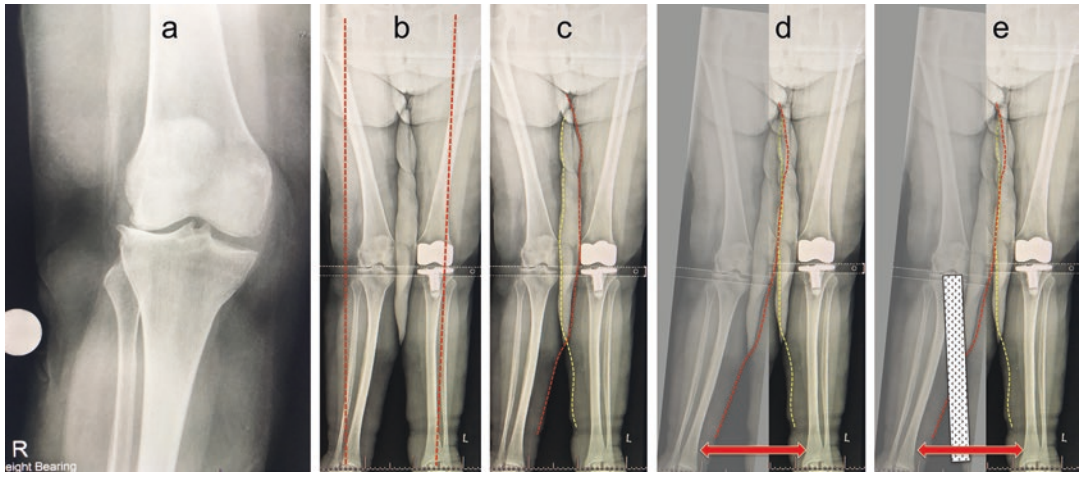

Fig. 14.9 Thigh girth. (**a**) Short radiographs can only depict anatomic alignment: the angle between the shafts of the tibia and femur. This is an incomplete depiction of the loads across the joint. (**b**) Full-length bilateral standing radiograph of patient with bilateral valgus deformities, predominantly lateral compartment osteoarthritis on the right knee, and a valgus instability of the primary total knee arthroplasty on the left knee. *Dotted lines* depict the mechanical axes of the limbs as lines from the center of hips to the center of ankles. These pass outside the arthritic joint and through the lateral compartment of the arthroplasty. Radiographs and simple angles do not depict the loading pattern in detail. (**c**) Note the *dotted line* depicting the skin contour of each medial thigh. These are overlapping as the radiographer has forced the patient to include both limbs on one cassette. This is clearly not how the legs are positioned as the patient walks: the feet must be separated further, stance widened, and the distance from the ankle to the center of gravity of the body will increase. This increases the bending moment across the knee. To maintain balance, many patients like this will shift their center of gravity over the affected limb with each step, accelerating the torque across the knee. (**d**) If we modify the radiographic image by abducting the right limb at the hip so that skin contours can clear each other during swing phase, we appreciate the necessary width of stance and the bending moment on the right knee in valgus. (**e**) Rather than planning the right knee arthroplasty at a standard angle, in this obese patient, it seems that a very few degrees of valgus (*stippled box*) might establish a more reasonable stance width (foot separation) and a decreased lever arm across the joint. Diminished valgus alignment raises concerns about the risk of medial overload and loosening. However, we must remember that the patient with osteoarthritis and valgus deformity is at greater risk of failure from instability than loosening [94]

porting increased body weight: they tend to walk with a stiff knee. Patients with patellofemoral pain, especially if obese, also limit knee flexion with a "patellar avoidance gait" that reduces anterior knee pain [21]. They may develop severe arthritis without a fixed flexion contracture because of this gait pattern. Eventually, just like the polio patient without L4 anterior horn cell function, the posterior soft tissues stretch and recurvatum ensues.

Patients with recurvatum instability as the result of discontinuity or attenuation of the extensor mechanism are best considered for revision arthroplasty as cases of "extensor mechanism deficiency," not instability. The solution to the cause of trouble is restoration of extensor strength, often with an extensor mechanism allograft [22]. Neurologic compromise of the quadriceps with recurvatum instability has traditionally been considered a contraindication to arthroplasty surgery [23] and more reliably treated with arthrodesis. Linked constrained implants (hinges) that allow the knee to lock in slight hyperextension have been recommended for the polio patient [24]. Once the "hyperextension" stop in the prosthesis engages, however, the forces on the implant and its fixation are high: the lever arm resembles a common crow bar. While short-term success is feasible, later failure may be catastrophic. If hyperextension is completely eliminated with any prosthesis in these patients, the knee will tend to buckle. A prosthesis may replace the joint, but it cannot provide extensor power.

Just as instability from extensor deficiency is a failure mode distinct from "tibial-femoral instability," patellar maltracking is also separate. Maltracking, though it may cause buckling and instability, is generally the result of combined internal rotation position of the tibial and femoral components [25–27]. The solution to patellar maltracking is a revision that corrects the rotational position of the components.

Fixed flexion deformities, though seemingly the converse of recurvatum, may also result in "instability" or buckling. The patient who cannot fully extend the knee becomes exhausted walking with a crouched gait as they expend more energy [28]. Many elderly patients experience this problem [29], especially if kyphosis requires flexion at the hip and knee to maintain the body's center of gravity over the feet (Fig. 14.10).

Restoring full extension is an important goal in revision knee arthroplasty. However, a flexed knee posture will recur in some patients with multiple balanced contractures, for equilibrium. These individuals should probably not undergo revision if a fixed flexion contracture is the only knee problem, even if they report the joint as unstable. The patient with good function in other joints, whose knee arthroplasty is buckling due to a flexion contracture and muscle fatigue, should be considered in the category of the "stiff knee" as this prescribes the appropriate surgical techniques to restore function.

Meding and colleagues reviewed arthritic knees with recurvatum deformities prior to primary arthroplasty. They emphasized the importance of identifying recurvatum due to neurological deficiency and eliminating residual hyperextension at arthroplasty surgery [30, 31]. These principles apply to the failed arthroplasty with recurvatum instability. Surgical techniques have been described to correct non-neurologic recurvatum with primary arthroplasty [32]. This deformity often results from subsidence of a loose (femoral) component, such that the posterior structures are no longer under tension. Restoring the length of the posterior soft tissues by compensating for bone loss with revision surgery is generally successful.

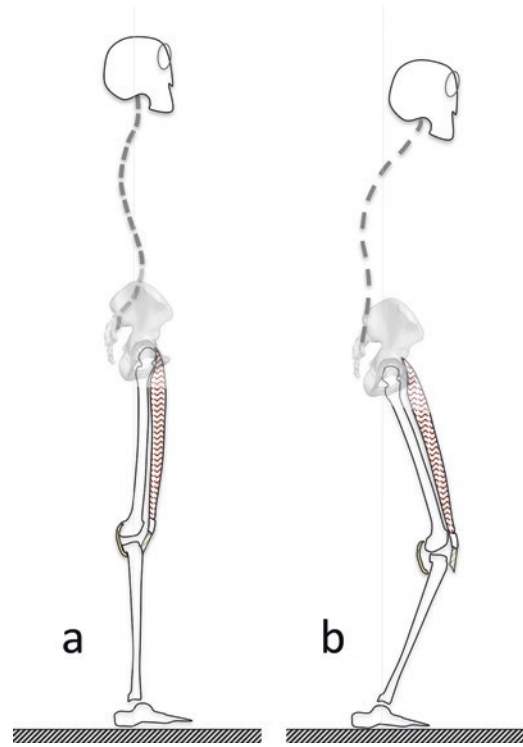

Fig. 14.10 Posture and knee stability. (**a**) Schematic depiction of youthful posture. Physiologic lumbar lordosis and thoracic kyphosis lead to a nicely balanced torso, with weight centered over the feet. (**b**) Increased thoracic kyphosis obliges other changes in posture to maintain balance. Notably knee flexion shifts the center of gravity posteriorly, restoring balance, but also increasing the risk of knee buckling. Surgery to correct a knee flexion contracture in this setting is likely to fail as flexion is essential to balance

Flexion Instability

Flexion instability describes a TKA with a flexion gap that is larger or more lax than the extension gap, where the modular polyethylene insert has been selected to stabilize the extension gap at the expense of the flexion gap [33]. A larger insert in these cases would limit extension and require treatment for stiffness i.e. flexion contracture. Flexion instability is not generally the result of an incompetent posterior cruciate ligament, as one might expect in the non-arthroplasty knee.

The problem was first described in 1998 by surgeons at the Mayo Clinic [34]. The clinical presentation includes (1) a sense of instability

without frank giving way, (2) recurrent knee joint effusions, (3) soft tissue tenderness involving the pes anserine tendons and the retinacular tissue, (4) posterior instability with a positive posterior drawer (not apparent with posterior stabilization) or a posterior sag sign at 90 degrees of flexion, and (5) above average motion. They reported 22 cases revised to posterior-stabilized implants and three cases where only the polyethylene insert was changed. Nineteen of the twenty-two (86%) revisions were improved, but only one of the poly exchanges was better off after surgery. The authors concluded that a "revision operation that focuses on balancing the flexion and extension spaces, in conjunction with a posterior-stabilized knee implant, seems to be a reliable treatment for symptomatic flexion instability after posterior cruciate retaining total knee arthroplasty" [34]. An isolated modular polyethylene exchange, because it tightens both the flexion and extension gaps equally, would not be expected to correct the problem unless it were actually a case of global instability and not "flexion instability."

Comprehensive evaluation is necessary in any case that presents with symptoms of flexion instability, to ensure that all components are well fixed, correctly sized, and appropriately rotated before recommending an isolated revision of the femoral component to a larger size as a direct means of tightening the flexion gap. A simple technique for balancing gaps in any revision surgery is described below.

The same investigators later reported that flexion instability can complicate posterior-stabilized prostheses [35] highlighting the importance of surgical technique over implant design. Nine of ten revisions for flexion instability in that series were successful. The logical emphasis was placed on implanting larger femoral components. In concept, however, the same sized femoral component might be repositioned more proximally, with additional resection of distal femoral bone, to increase the size of the extension gap such that a thicker polyethylene could stabilize the knee in flexion. The joint line position would be altered, but the complication eliminated. This approach is useful, because in some cases of flexion instability, the femoral component will already be maximally large, i.e., extending from the medial to the lateral cortex. A larger component would overhang the distal femur. The etiology of flexion instability in some cases may be an uncorrected flexion contracture, not an incorrect femoral component size (Fig. 14.11).

Arthritis with a fixed flexion contracture is perhaps the most common condition leading to flexion instability [33]. If a surgeon performs the primary arthroplasty in this situation with a measured resection or "kinematic" style procedure, but without soft tissue releases, the extension gap will end up smaller and tighter than the (more normal) flexion gap. If the surgeon then selects the modular polyethylene that permits full extension without a critical evaluation of stability at 90°, flexion instability is likely. While some low-demand patients may function reasonably well with a lax flexion gap, enjoying easy flexion, more active individuals will experience pain with activity, difficulty on stairs, recurrent effusions, and periarticular tenderness.

Surgeons from the Mayo Clinic, who originally identified flexion instability, recently published an algorithmic approach to the problem. They recommend: "reduction of tibial slope, correction of malalignment, and improvement of condylar offset. Additional joint line elevation is needed if the above steps do not equalize the flexion and extension gaps" [36]. Elevation of the joint line results directly from resection of distal femoral bone to increase the size of the extension gap so that thicker polyethylene can be used to eliminate flexion instability. Joint line position is subservient to balancing the flexion and extension gaps in their analysis. This is a highly reasonable and practical approach.

More severe cases of flexion instability may result not just in pain, swelling, and tenderness but frank dislocation, usually of the flexed tibia posteriorly under the femur. The mechanisms are the same, but the discrepancy in the relative sizes of the flexion and extension gaps is greater. In some cases there will have been a profound mismatch between an arthritic deformity, the design of the implant, and the surgeon's skills: the wrong surgeon implanting the wrong implant into the wrong patient [37]. Dislocation may be

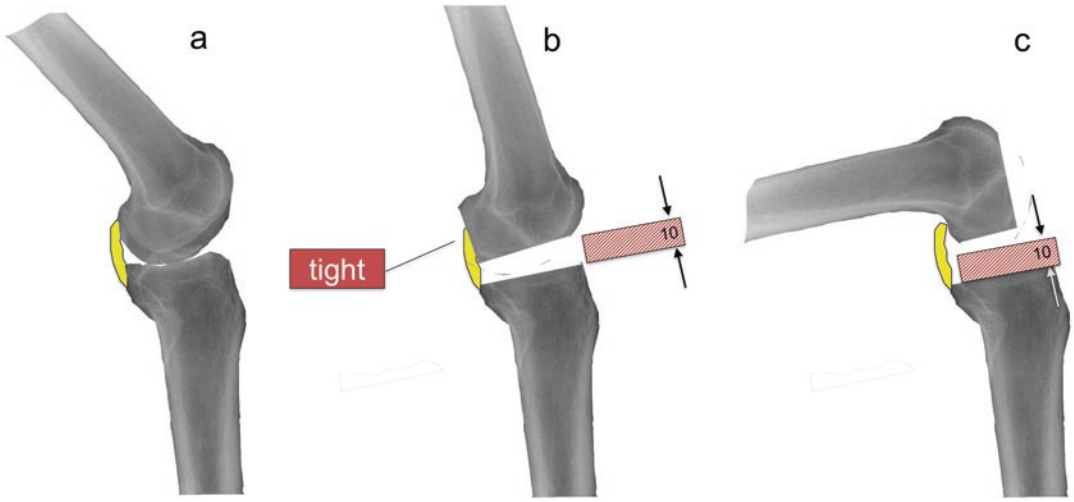

Fig. 14.11 Flexion instability. (**a**) The patient with arthritis and a knee flexion contracture actually has a smaller, tighter "extension gap" than a person with a normal knee joint. (**b**) If total knee arthroplasty is performed with a typical "measured resection" type of technique, the relatively tightness of the extension gap can be appreciated by surgeons who look for it. (**c**) The flexion gap is actually "normal" but correspondingly larger and more lax than the extension gap. This is probably the typical origin of "flexion instability," when the surgeon fails to appreciate the flexion-extension gap discrepancy and selects the articular polyethylene to achieve full extension

exacerbated in patients with spasticity of the hamstring muscles [38, 39].

Anterior dislocation, of the tibia under the femur, is unusual and generally accompanies extreme recurvatum deformity [40, 41]. Late onset cases generally result from polyethylene wear, not ligamentous failure [42, 43]. Some grossly unstable arthroplasties may be held together by the extensor mechanism, which when it ruptures results in knee dislocation [44]. These should not be interpreted as isolated extensor mechanism ruptures and require full revision with an extensor mechanism allograft [22]. Arthrodesis may be preferred.

The clinical presentation of a posterior-stabilized arthroplasty with the tibial spine dislocated under the femoral cam in flexion will be dramatic, although the lateral radiograph will show only posterior subluxation of the tibia. The patient will be in great pain with a knee locked at close to 90 degrees of flexion [45–50]. These can usually be reduced with hyperflexion and an anterior drawer maneuver to the proximal tibia. Forced extension is a mistake. General anesthesia may not be required, and recurrent or irreducible dislocations will require surgery for flexion instability.

Mid-flexion instability is a contentious entity. Whether it is distinct from either "flexion" or coronal instability is unclear. One cadaver study associated joint line elevation in the primary arthroplasty with instability in the midrange of flexion [51]. Though frequently quoted, this study is not the final verdict [52, 53]. There are no published reports of revision surgery for "mid-flexion" instability.

Clinical Evaluation of the Unstable TKA

There are numerous methods to evaluate a problem arthroplasty prior to surgery. The best will be *systematic*, following the same sequence of steps or algorithm for every case, and *comprehensive,* meaning that even if one problem is identified, all others are still considered. A common example of multiple problems presenting as one would be loosening resulting from infection. If only loosening is diagnosed, revision surgery will fail. Comprehensive evaluation of gross clinical instability may reveal that the actual cause is loosening and bone loss, perhaps caused by infection.

Prosthetic joint infection is considered first in the diagnostic scheme presented here, as it may accompany any other problem [3, 7]. The Musculoskeletal Infection Society developed criteria for the definition of prosthetic joint infection [54] largely corroborated by an international consensus meeting [55]. Reliable steps to establish or eliminate the diagnosis of infection have also been published [56, 57]. Instability is considered last in this diagnostic scheme because so many other problems may be at the root of perceived or apparent instability and should be eliminated as possible diagnoses first (see Fig. 14.3).

In the evaluation of any problem arthroplasty, including the unstable knee, crucial information from the history includes experiences that increase suspicion regarding periprosthetic infection. Increased clinical suspicion or elevated inflammatory markers mandate an aspiration of synovial fluid for cell count, leucocyte differential, and culture with antimicrobial sensitivity [57].

Sources of referred pain responsible for muscle inhibition must be identified. Physical examination clarifies the mode and quantity of instability. Varus-valgus instability may be recorded as millimeters of joint opening (medial opening to a valgus stress) or as degrees of varus-valgus arc. An early sports medicine principle explained that varus-valgus stability must be tested not only in full extension when the posterior structures may give the false impression of stability, but in slight flexion to relax those structures and isolate the collaterals [58].

Flexion instability is suspected from history and confirmed by physical examination. The drawer test, useful in the non-arthroplasty knee, is less reliable in an arthroplasty, especially if there is a posterior-stabilized implant. Flexion laxity is more accurately assessed as the patient sits on the exam table with the tibia dangling and the knee flexed to 90°. With one of the examiner's hands on the anterior distal femur and the other pushing the tibia upward to close the flexion gap, the excursion before the tibia contacts the posterior femoral condyles can be estimated. With the patient still seated on the edge of the table, angular foot posture is a good indicator of rotational position of the tibial component: the externally rotated foot suggests internal rotation of the tibial component [33]. Objective measures of knee arthroplasty instability have been suggested [59].

Full-length radiographs [60] are essential in the preoperative evaluation of the unstable knee (Fig. 14.12), but the limb must be rotated accurately [61]. CT scanning for rotation positioning of the tibial and femoral components is similarly important because of its association with patellofemoral problems [27]. A more reproducible CT scan technique has been proposed [62].

The Joint Line

The joint line, usually referring to a line through the distal femoral condyles on an AP radiograph, has received considerable attention from surgeons interested in revision arthroplasty results and technique. The proximal-distal position of the femoral component (translation on the "*y*-axis") probably caught the attention of practitioners because only primary components were available for the first revision procedures [63]. Accordingly, femoral bone loss requires a smaller femoral component to fit or "grip" the residual bone, and this increases the size of the flexion gap. Commensurate bone loss from the distal femur could equalize the flexion and extension gaps that can then be balanced with a very thick polyethylene tibial component. The most striking feature of postoperative radiographs in this situation would be a proximal position of the femoral component (Fig. 14.13).

The worse the failure, the greater the bone loss, ligament compromise, and proximal joint line migration [64]. These features would be worse still in second and third revisions. In this respect, proximal joint line migration is a confounding variable that correlates with severity of failure and poor outcome. Simple failures, likely to do well after revision, usually had a familiar joint line position, whereas complex revisions likely to fail would have aberrations of the joint line height. Techniques for revision surgery have been suggested that are based primarily on reestablishing a specified proximal-distal relation of the femoral component to some osseous landmark [65–69].

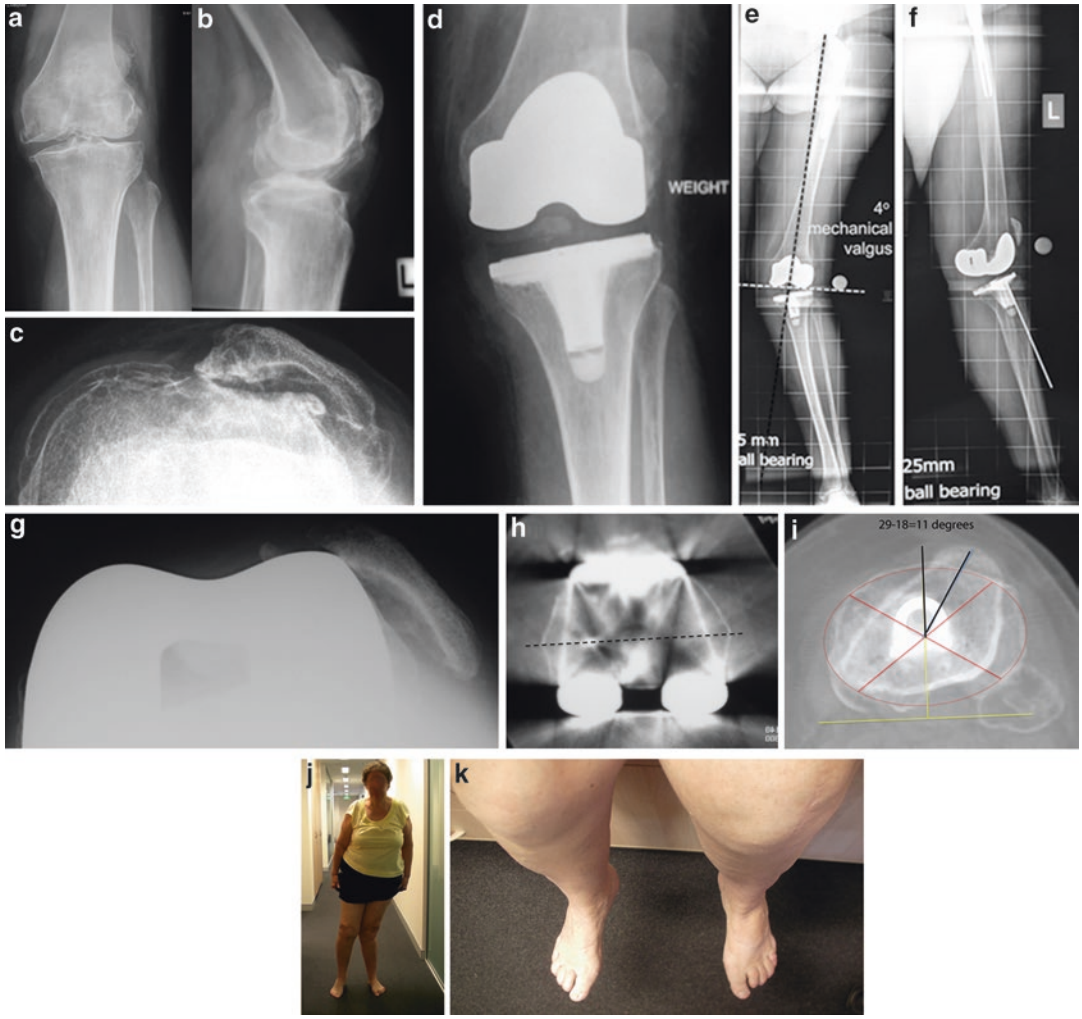

Fig. 14.12 Pre-revision evaluation of the unstable TKA. (**a**) Anterior and (**b**) lateral radiograph of an ostensibly unremarkable pre-arthroplasty knee with tri-compartmental arthrosis. The anatomic alignment of the knee is valgus suggesting that minimal soft tissue balancing would be required to achieve the desired postoperative alignment. (**c**) Patellofemoral joint is severely affected suggesting inflammatory arthropathy and inadequate bone for resurfacing. There is a tendency to lateral tracking of the patella in the trochlea. (**d**) The primary TKA is unstable in valgus. A surgeon might try MCL repair, but this is unlikely to work and would be based on an incomplete evaluation of the problem. Full-length radiographs (to evaluate alignment) and CT scan (to quantify rotational position) are essential before treating the unstable TKA. Note that the tibial component has been imaged symmetrically, but only by rotating the limb such that the fibular head is partially concealed behind the tibia. The problem is not simply the MCL. (**e**) The essential full-length AP radiograph to diagnose causes of instability and plan a successful revision. The medial joint line is open indicating failure of the MCL. However, the femoral component has been implanted with 4° of *mechanical* valgus, equivalent to a distal femoral cut in 13° of anatomic valgus in this knee. Hip arthroplasties will contribute to valgus instability if there is abductor weakness with a resultant "moment-sparing" gait. (**f**) The full-length lateral radiograph, not frequently included in the evaluation, shows recurvatum, a mismatch in the rotation of tibial and femoral components, patella alta, and posterior slope on the tibial component in excess of the 7° built into this device (the tibial component stem, if continued distally, would broach the anterior cortex (*solid white line*)). (**g**) Patellofemoral radiograph demonstrating frank dislocation of the patella associated with valgus instability and raising immediate concerns about the rotational position of the tibial and femoral components. (**h**) CT scan at the level of the femoral epicondyles showing that the femoral component has been rotated close to parallel with the trans-epicondylar axis. (**i**) Overlay of three CT scan cuts: (*i*). through the tibial component to establish the "tibial component angle" (TCA), (*ii*). Immediately below the tibial component to establish the Fig. 14.12 "geometric center (GC) of the proximal tibia," and (*iii*) at the level of the tibial tubercle (TT). If the TCA is extended from the back of the knee through the

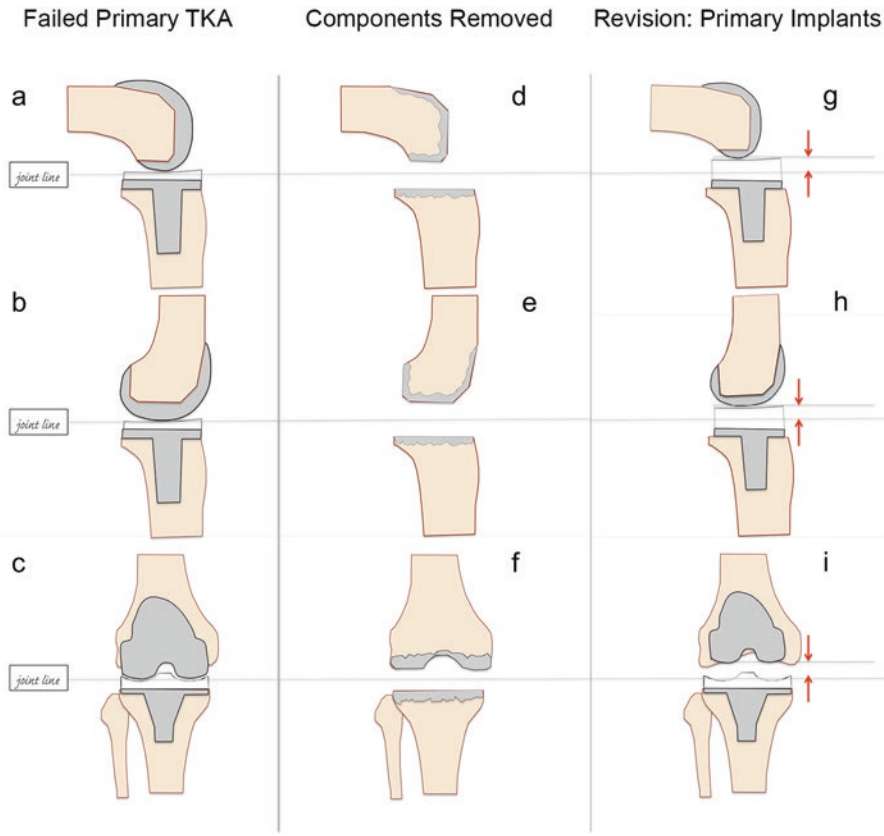

Fig. 14.13 Origins of the problem with joint line in revision TKA. Matrix illustrating the problem of joint line at revision knee arthroplasty when primary components were used for reconstruction. The columns depict the temporal progression: (i). **a**-**b**-**c** show the failed primary, (ii). **d**-**e**-**f** show the removed components at revision, and (iii). **g**-**h**-**i** show the completed revision with primary implants. The rows show different perspective: (i). **a**-**d**-**g** show the lateral projection of the flexion gap, (ii). **b**-**e**-**i** show the lateral projection of the extension gap, and **c**-**f**-**h** show the AP view. The joint line is indicated by the fine solid *gray line*. **a**: Depicts an ideal joint line in a primary arthroplasty that is to be revised. **d**: Shows the bone ends after component has been removed with the inevitable loss of some bone. The worse the case, the more bone will have been lost or debrided. **g**: A primary component that fits the residual bone has been implanted. Unavoidably it is smaller as bone has been lost from the AP femur. This means that thicker polyethylene is required and the joint line in flexion is higher. The undersized femoral component in flexion is the origin of the problem. **b**: Joint line is appropriate in the failed primary. **e**: Resected bone showing a similar situation to "d" above but in extension. **f**. Inevitable proximal position of the joint line in extension but balanced gaps and full extension without recurvatum. **c**: Typical view on AP radiograph. **f**: Bone loss at revision after removal of components. **i**: Appearance of post-op revision radiograph, with the undersized femoral component (see **g** above) and elevated joint line. The solution to this problem lies in "**g**" by selecting the size of femoral component that restores tension to the collateral ligaments, with fixation, then assured with the use of augments. Arbitrarily migrating the femoral component distally (**f** to **i**) fails to address joint line and stability issues in flexion

Fig. 14.12 (continued) GC and if a second line is drawn from the GC to the center of the TT, we have the (internal) rotation position of the implant. Given the asymmetry of the bone, up to 18° has been cited as the acceptable upper limit to this angle [27]. This patient has 11° in excess of this limit. (**j**) Clinical photo with valgus instability left TKA. Note how patient must shift center of gravity to the left to stabilize weight over unstable knee. (**k**) Patient with unstable TKA sitting over the edge of exam table. The tibial component on the left TKA has been implanted with internal rotation position. Usually this would exert an external rotation posture of the foot, except that this knee is unstable in flexion and so the foot "self-centers." The CT scan shows the rotation problem

There are conceptual limitations to techniques that focus on "restoring the joint line." First, the articulation of the tibia and the femur is not a line, despite the appearance of an AP radiograph, but a complex series of "lines" as the contact between tibia and femur courses along the femoral component with flexion. The "line" is actually the topography of the distal and posterior femoral component. The proximal-distal position of the femoral component (translation on the "*y*"-axis) is only part of the requirements for a stable arthroplasty. Poor revisions result from techniques that relocate an undersized femoral component accurately on the "*y*-axis," using modular distal femoral augmentation [70], but fail to restore the joint level or, worse, stability, in flexion (Fig. 14.14).

The "joint line," though ostensibly obvious on an AP radiograph, is notoriously difficult to measure in any meaningful way. For example, what axis will be chosen along which to measure changes in the joint line? Will it be the mechanical axis of the tibia, the femur, or the limb? Given that most surgeons accept a "neutral" orientation of the tibial component relative to either the anatomic or mechanical axis of that bone, the simple conversion of the varus native orientation [71] to the acceptable neutral constitutes a change in the level of the joint line. Changes in alignment will change the axis along which joint line migration can be measured (Fig. 14.15).

Few papers on joint line height after revision knee arthroplasty specify whether patellofemoral mechanics [72] or collateral ligament function [73] is the reason that joint height is important; most simply insist that it is. One study addressing this question failed to identify specific support for either factor [73]. Whether one is of greater importance will be relevant in cases of patella baja; is it reasonable to translate the joint line distally if the patellar tendon is scarred and short? Alternately how could collateral ligament mechanics matter to a fully constrained (hinged) implant?

Perhaps the greatest deficiency of joint line-based techniques is the fact that the soft tissue environment has often altered profoundly and unpredictably in the failed arthroplasty. A brief thought experiment is illuminating (Fig. 14.16). Consider a failed arthroplasty, with large and uniquely configured bone defects in conjunction with missing anterior and posterior cruciate ligaments, plus unknown changes in the collateral ligaments, the posterior capsule, and extensor mechanism. If we could restore the normal bone and (even the hyaline cartilage) to that knee (i.e., a perfect joint line even in three dimensions), would the residual soft tissue envelope necessarily produce motion and stability? Imagining a 100 or more failed replacements, some failed by stiffness and others by instability, would generate a wide range of soft tissue environments. Sports medicine experts would respond that the combination of a perfect three-dimensional joint "line" with a profoundly compromised soft tissue environment would not be expected to function well. A serviceable revision technique should assess the soft tissue environment and select size and position components accordingly**.** The technique should accommodate the reason(s) for failure.

Surgical Technique for Maintaining or Restoring Stability, Gap Balance, and an Optimal Three-Dimensional Joint Line Height

The unstable arthroplasty usually requires revision surgery. Ligament reconstructions, though appropriate in reconstruction of the unstable native knee, address only one side of the stability equation in an arthroplasty, ignoring the factors that create instability. Isolated soft tissue reconstruction is rarely successful in the failed arthroplasty. The forces that destabilized the arthroplasty will destroy the reconstruction. The principle that isolated ligament repair was inadequate for the unstable arthroplasty was established early [74]. Disappointingly, surgeons continue to learn this lesson through avoidable failures [75]. Revision for instability must mitigate the destructive forces that accrue from component size and position as well as limb alignment. The guiding principles behind surgical treatment of varus-valgus instability were established by Krackow in the 1980s: component

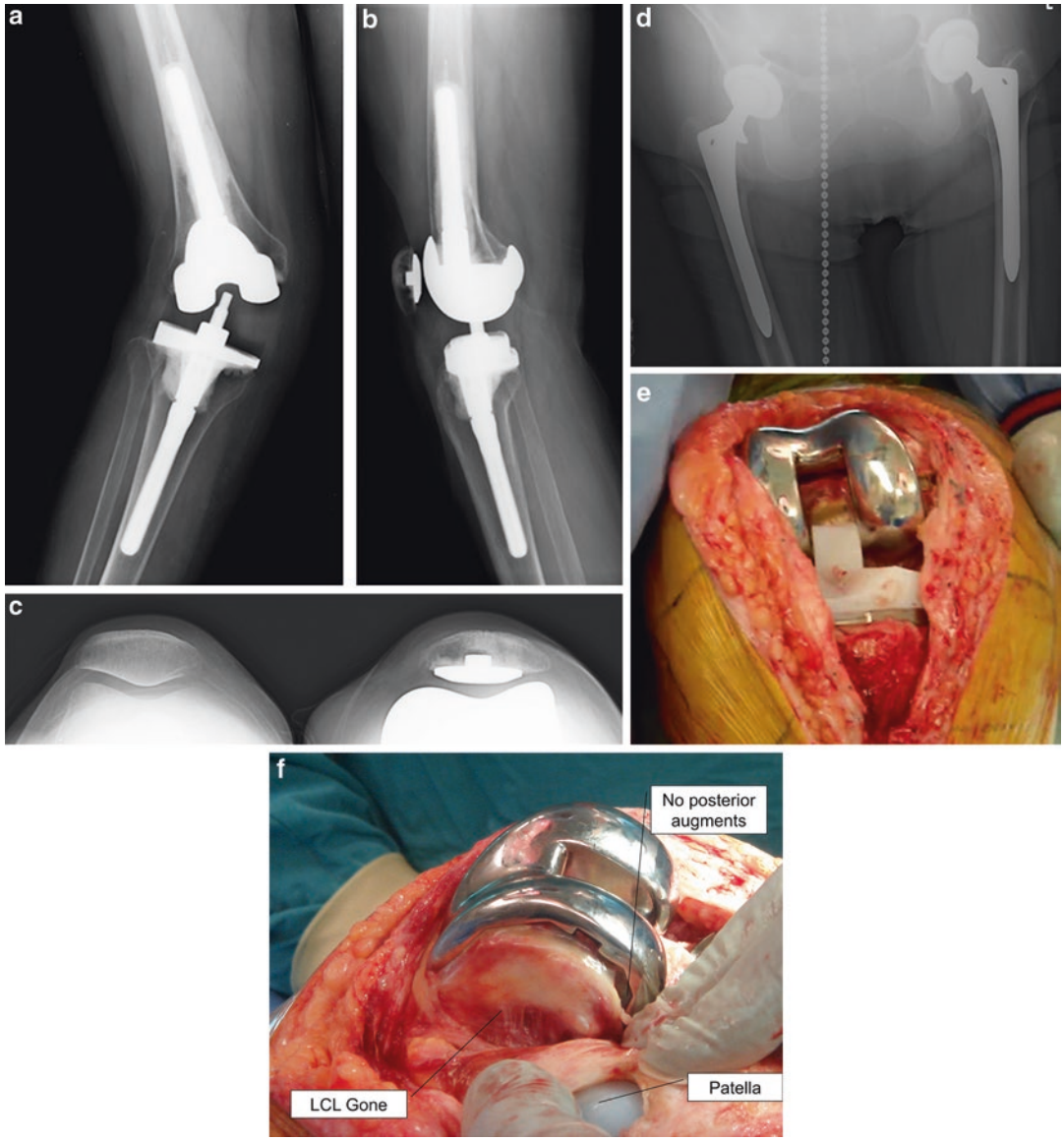

Fig. 14.14 Gross instability after joint line first RevTKA. (**a**) Gross valgus instability of a non-linked constrained revision TKA. The primary TKA was revised for the same problem. The surgeon reestablished the distal femoral articulation using distal femoral augmentation, following a "joint line first" approach and inserted an undersized nn-linked constrained device with distal but not posterior augments. When this failed, another surgeon logically performed an arthrotomy and inserted a custom fabricated angled bearing insert to decrease the valgus deforming force (seen in this radiograph). (**b**) Lateral radiograph. (**c**) Centrally tracking patella arguing in favor of good rotational position of tibia and femur. (**d**) Bilateral total hip arthroplasty plus scoliosis (plumb line) raise questions about the dynamics of gait. (**e**) At the third revision, there was gross instability in flexion, shown here as the tibia and femur are distracted with the knee in 90 degrees of flexion. (**f**) The patella is indicated in the bottom of the figure for orientation. The LCL is absent, and the MCL was grossly attenuated. Despite the gaping flexion gap, the femoral component was undersized, and no posterior augments had been used. At the definitive revision that reestablished stability, a new femoral component that was fully two sizes larger, could easily be accommodated without overhanging medially or laterally. Using the distal femoral articulation as a guiding landmark, the original surgeon neglected to reestablish stability on flexion. When this particular implant flexes fully, it is easy for the tibial to rotate out of the intercondylar housing. This then predisposes to valgus instability

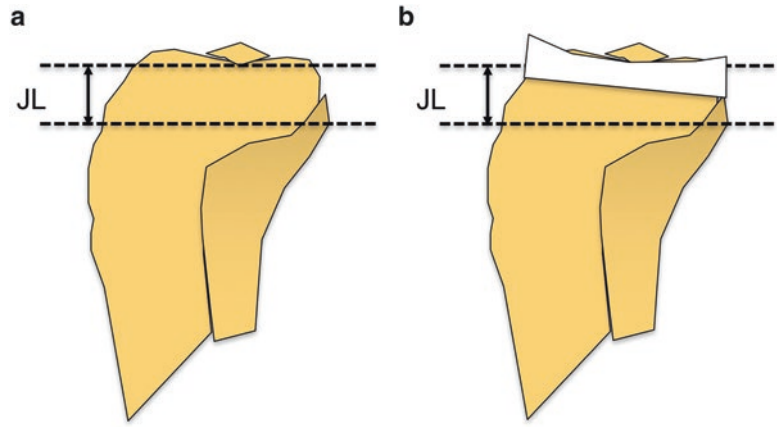

Fig. 14.15 Joint line definition and measurement. (**a**) This is one of many techniques for the radiographic measurement of knee joint line. The original version was used to calculate the joint line in primary TKA [95]. It depends on having access to the pre-primary radiographs, although contralateral films may suffice. The attachment of the patellar tendon must be identified reliably from one study to the next. (**b**) It was adapted to revision by Partington et al. for revision surgery [64]. It may be one of the more reproducible methods, as it is based on lateral radiographs. This means that changes in varus-valgus alignment should not have significant effects on the outcome. Alterations in tibial slope however will

position and overall axial alignment are key to managing the load across the knee joint [76].

The principle of 1977 that "stability depends as much on precise surgical technique as it does on prosthetic design" still applies [77]. A failed knee arthroplasty can be reconstructed in three simple steps after component removal, regardless of the mode of failure [63, 78–82]. This sequence restores or maintains stability and will indicate clearly when mechanical constraint is required. The guiding principles are those of early condylar resurfacing arthroplasties that depended heavily on coronal alignment and balanced gaps for durability, motion, and stability. In the course of these steps, each of the six degrees of freedom must be defined for each component. The technique reconstructs a three-dimensional joint line that will function with altered soft tissues (Fig. 14.17) [63, 78–81].

Step 1: Reestablishment of a Tibial Platform

The failed arthroplasty can be daunting, leaving a surgeon confused as to where to start. A trial tibial baseplate stabilized by a press-fit diaphyseal-engaging trial stem without concern for bone defects satisfies an important goal early in the reconstruction: it is a reference or platform that is common to both the flexion and extension gaps. The term "platform" was used deliberately in the first published description of the technique [78] to describe a foundation from which an arthroplasty can be re-created. There are no implications at this stage regarding the joint line, which depends on femoral component size and position.

The results of revision arthroplasty with primary implant systems are poor [83, 84]. In the preliminary reconstruction, some type of temporary press-fit fixation is required using the only reliable anatomic location in every revision arthroplasty: the medullary canal. Whether fully cemented or press-fit stem extensions are eventually selected for fixation, long press-fit trial stems define and maintain position temporarily, while the "big picture" of component size and position is established. The tibial component should be rotated toward the tibial tubercle of the extensor mechanism, so that the patella and its tendon are delivered to the femoral trochlear groove. In this step, only the tibial baseplate is required without an articular surface. Tibial component rotation, AP position, and slope will be established.

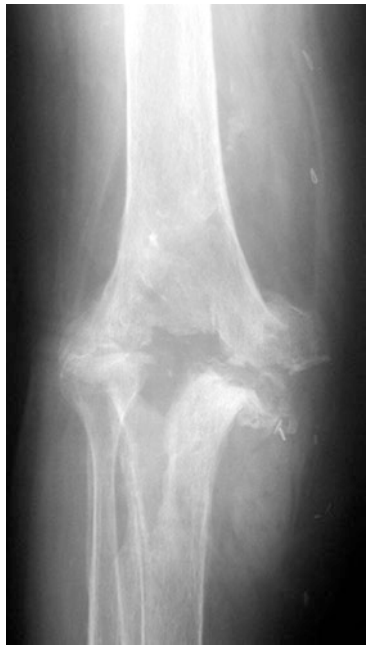

Fig. 14.16 Thought experiment. If the joint line is a dependable target for revision arthroplasty, then it should ensure that stability and mobility are restored at revision surgery. Consider this thought experiment regarding joint line. Imagine a failed arthroplasty with all of the attendant problems. If all the bone and even the articular cartilage were restored to a knee like the one above, guaranteeing that not only the distal femoral articulation but the entire three-dimensional surface that accounts for the joint line in every position of motion would be restored. However, if the soft tissue environment were left the same (no cruciates and indeterminate effects on the collateral, extensor, and posterior structures), would that knee necessarily function normally?

Step 2. Stabilize the Knee at 90 Degrees of Flexion

Step 2a. Rotational Position of the Femoral Component

Given that the trochlear groove no longer exists in a failed arthroplasty, the "anteroposterior (AP) axis" of Whiteside is unavailable [85]. Accordingly, the trans-epicondylar axis (TEA) will be the most reliable indicator of femoral component rotational position. Most revision femoral components have a relatively large intercondylar box. Bone cuts in the distal femur that accommodate this box define the rotation of the revision femoral component at right angles to the TEA. Femoral component rotation on the "*y*-axis" and flexion extension or rotation on the "*x*-axis" will be satisfied.

Step 2b. Flexion Gap Stability

The size and to a lesser extent the anteroposterior position of the femoral component are the primary means of restoring tension to the collateral ligaments at 90 degrees of knee flexion [86]. Again, long modular press-fit stems hold the trial component in position yet will allow it to be pushed proximally in step 3. Duplicating the size of the failed component and measuring radiographs of the contralateral unoperated knee have long been suggested as ways to determine the revision femoral component size or joint line. These ideas were not new in 2014 [87]. These strategies are unreliable, as neither method acknowledges the mode of failure (failure may have resulted from a poor choice of femoral component size) nor the state of the soft tissue environment after the primary failed.

As a simple guide, the *largest* femoral component that can be implanted in any knee will be the one with a medial-lateral (M-L) dimension equal to the patient's femur. Anything larger overhangs and is inappropriate. The ideal femoral component may be the largest possible (as in a case of flexion instability) or any of a number of smaller implants, in cases of poor flexion for example. Stability in flexion is the product of the femoral component coupled with a modular tibial articular surface and baseplate. At this stage, if the largest possible femoral component combined with one of the thicker tibial inserts cannot restore stability in flexion, it will be clear that the soft tissues have failed and that mechanical constraint will be required to stabilize the flexion gap. Multiple combinations of femur and tibia can stabilize the flexion gap: a larger femoral component and thinner tibia insert or smaller femoral component and thicker tibial insert. Which combination is preferred?

Step 2c. Joint Line in Flexion

Different combinations of femoral component size and tibial component thickness result in different levels of the joint line in flexion.

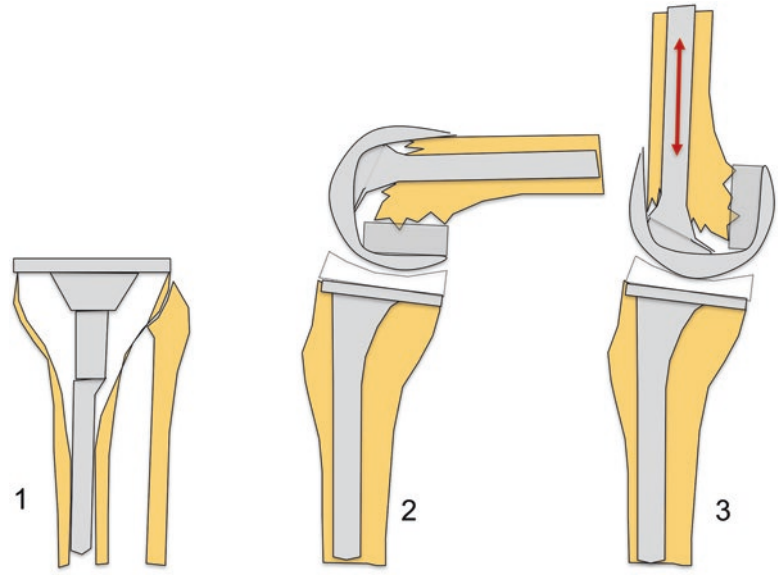

Fig. 14.17 Three-step technique for revision TKA. *1*. Establish a tibial "platform." This is not the joint line but rather a stable surface formed by a trial tibial baseplate on a diaphyseal-engaging press-fit stem. As the tibia is an asymmetric bone, some type of offset in the tibial stem design will be useful to achieve a press fit, maintain alignment, and center the component on the tibia above. *2*. Stabilize the knee in flexion. Three important goals will be achieved: a. rotate the femoral component to the epicondylar axis, b. select femoral component size to restore tension to the collateral ligaments and use augments to ensure fixation, and c. evaluate the joint line relative to the patella as a function of whichever femoral component size and tibial thickness have been selected. *3*. Seat the femoral component proximally or distally to create an extension space that is equal to the flexion space. If stability cannot be achieved in steps 2 or 3, then constraint is indicated. This technique requires diaphyseal-engaging press-fit trial stems to hold the trial components in place and determine the need for augments. Smaller fully cemented stems may be substituted according to the surgical plan for fixation or diaphyseal engaging stems can be implanted.

Several different combinations may stabilize the knee in flexion, assuming the collateral ligaments are intact. Several indicators might be considered as a measure of joint line height. Assuming a near normal length of the patellar tendon on a lateral radiograph [88], the level of the inferior pole of the patella relative to the articulation is visually accessible and practical. The three phases of step 2 reveal whether ligaments are present and capable of stabilizing the knee in flexion. When stability is lacking, constraint is indicated. In addition, the joint line will have been set at a highly functional height in flexion. That same joint line level will automatically be reproduced in the third and final step, as the selected components are used to locate the femoral component in precisely the correct proximal–distal position for full extension.

Step 3. Extension Gap

The third step finishes the reconstruction kinematically and completes the "big picture" of component size and position. By extending the knee fully, recurvatum (femoral component needs to be located more distally) and flexion contracture (femoral component must be positioned more proximal) are eliminated. It is unlikely that an inordinately thick polyethylene will be selected in step 2 for stability in flexion. As a result, the femoral component will not be driven proximally to create the type of joint line elevation that has been associated with poor results.

As a practical maneuver, if the femoral trial is left a few centimeters proud of the residual distal femoral bone, during step 2, extension of the knee, with all of the trial components in position,

will "push" the femoral component to precisely the correct location as the knee is extended. The posterior structures are of greater importance at this point than the collateral ligaments: they determine the proximal distal femoral component position. If the collateral ligaments cannot provide varus-valgus stability, a constrained implant will be required. As mentioned above, a false sense of coronal plane (the plane of the x- and y-axes) stability may result from testing in forced extension where the posterior structures provide stability. Varus-valgus loads should also be applied with the knee flexed to about 30 degrees to relax the posterior structures and eliminate their contribution to rotational stability about the z-axis, (varus-valgus) thus testing the collateral structures in isolation.

In the rare case where recurvatum cannot be eliminated with this simple sequence, some surgeons consider a hinged implant with a hyperextension stop. This places large and potentially destructive forces on the implant and its fixation. Structural recurvatum, as opposed to neuroligically induced recurvatum, usually results from bone loss that exceeds the capability of standard distal femoral augmentation to control the extension gap. Porous metal augments and structural allografting might be used to restore tension to the posterior capsule and muscles and avoid mechanical hyperextension. Recurvatum due to quadriceps paralysis and a "back-knee gait" may destroy posterior soft tissue integrity no matter what stability is achieved at revision. Neurologic recurvatum is one of the unanswered problems in arthroplasty surgery. Arthrodesis, the ultimate stabilizing procedure, has traditionally been the procedure of choice.

Constraint

Constrained prostheses are indicated when soft tissue stabilizers are deficient. If instability results from bone loss, this deficit should be reconstituted with appropriately sized components and augments or structural allografts. Constraint is a poor solution for bone loss, as it increases the demands on fixation in situations where bone loss impairs the surgeon's ability to achieve durable fixation. There are many opinions as to which constrained devices are indicated in specific situations. Most guidelines are offered with confidence and good intentions but little substantiation [89].

There are reports of revision arthroplasty specifically for instability with hinged implants in selected cases (elderly patients) [90]. The oft-quoted but rarely validated concept is that if one ligament is absent completely, then a hinge will be required. Most of these recommendations do not discuss the importance of alignment or of destabilizing forces that originate outside the joint, such as limb alignment, spine deformity or gait pathology. Many experienced surgeons rely on non-linked constrained implants for virtually all revision procedures [17]. A flexion gap bereft of soft tissue integrity, where the so-called "jump height" or potential separation of the tibia from the posterior femoral condyles in flexion, exceeds the dimensions of the non-linked stabilizing post on the tibia, might be a compelling indication for a linked implant. In some of these situations, closure of the capsule with an intact extensor will make it unlikely that the femur could jump over a constrained condylar style tibial implant.

Results of Treatment of Instability

The results of revision knee arthroplasty surgery in general and revisions for instability specifically are poorly understood despite numerous reports [91]. In general, however, the unstable arthroplasty is the easiest to revise, given that stability can be restored to the unstable knee with constrained implants in a way that motion cannot be restored with a device to a stiff arthroplasty. Aseptic loosening with osteolysis may be more problematic than instability because of the challenge of restoring lost bone and ensuring fixation. Infection may recur despite a surgeon's best efforts, and durable reconstruction of the ruptured extensor mechanism is a formidable challenge that depends for success on the behavior of soft tissue allograft. Compartively, instabilty is a minor problem.

Azzam and colleagues reviewed 67 patients undergoing revision surgery for "instability." The problem persisted in a surprising 22% of cases, with the conclusion that "revision of both components and the use of femoral augments seem to offer the most predictable outcome" [70]. This is consistent with the technical recommendations made in the current chapter. Song and colleagues adhered to a classification of instability consistent with that presented here and emphasized that constrained implants may or may not be required, but that identification of the mode of instability is essential so that the underlying pathology might be corrected [92]. Analyses of successes and failures in revision arthroplasty for instability lead to similar conclusions: accurate diagnosis is important, secondary causes of apparent instability should be identified and treated according to the cause, and specific modes of instability should be identified.

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Management of Extensor Mechanism during Revision Total Knee Arthroplasty

15

Paul K. Edwards, and Mathew Levine, C. Lowry Barnes

Disruption of the extensor mechanism during total knee arthroplasty may result in devastating complications and outcomes. Most commonly there are seven problems encountered with the extensor mechanism following total knee arthroplasty. These are quadriceps tendon rupture, patellar tendon disruption, patellar crepitus, periprosthetic patellar fracture, soft tissue impingement, patellofemoral instability, and osteonecrosis of the patella [1]. In a revision scenario, there are often many barriers to a straightforward exposure in which to avoid/address these issues. Difficult exposure can often place the extensor mechanism at risk. This chapter will address the techniques for proper exposure, risk factors for extensor mechanism problems, and the management and reconstruction of extensor mechanism injury.

Exposure

In the setting of revision total knee arthroplasty, there is often a struggle to achieve adequate exposure and maintain function of the extensor mechanism. Several risk factors such as arthrofibrosis, patella baja, significant bone loss, and multiple previous surgical incisions with adherent, poor-quality skin and soft tissues make revision total knee arthroplasty exposure very difficult [2]. These risk factors can lead to wound healing complications placing the patient at increased risk for infection. Proceed cautiously in patients with multiple incisions, previous skin grafts or flaps, angular or rotational deformity, or known insufficient soft tissue coverage [3]. Proper delineation of the previous surgical incisions and the planned approach must be in the forefront of the surgeons mind. In the setting of multiple previous incisions, the lateral-most incision should be used in order to prevent further compromise to the skin flap. Large full-thickness flaps should be maintained to ensure adequate vascular preservation and provide adequate tissue for wound closure (Fig. 15.1). In patients with previous vascular flaps, a thorough understanding of the skin flap and its associated vascular pedicle should be identified when planning the surgical approach. Patients with adherent, thin, poor-quality skin and soft tissue may benefit from a plastic surgery consultation for consideration of a soft tissue expansion procedure or

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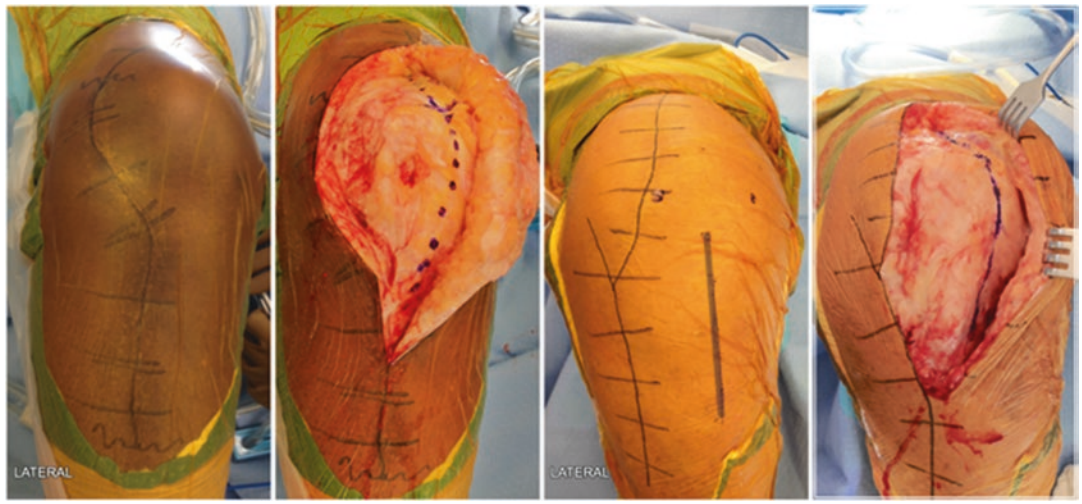

Fig. 15.1 Lateral incision with a full-thickness medial flap should be utilized when multiple incisions are present. The medial parapatellar approach is performed easily despite the lateral skin incision.

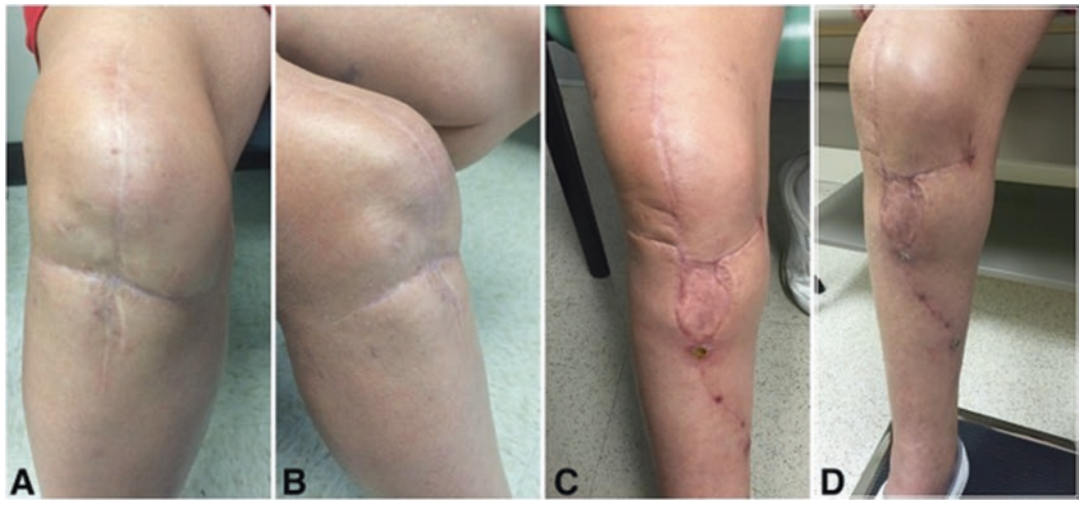

Fig. 15.2 Chronic severe extensor lag after a failed primary repair of a patella tendon rupture. (**a**–**d**) The dense, adherent scar tissue with multiple anterior knee incisions required plastic surgery closure with a rotational gastrocnemius muscle flap and split thickness skin grafting after the completion of the extensor mechanism reconstruction.

staged/simultaneous local or free muscle flaps, in conjunction with split-thickness skin grafting (Fig. 15.2) [3–13]. The medial parapatellar arthrotomy is recommended to allow for a reproducible exposure capable of proximal and distal extensile exposure as indicated. Extensile exposures will be discussed later in the chapter. In the revision setting, extensive scar tissue can make identification of anatomy very difficult. Care must be taken to locate the quadriceps tendon, vastus musculature, patella, and tibial tubercle. Prior to the medial parapatellar arthrotomy, it is often easier to locate the patella and quadriceps tendon edges with the knee in full extension.

After the completion of the medial parapatellar arthrotomy, the knee is kept in extension, and

a 90° bent Hohmann retractor is placed along the medial and lateral joint line (deep to the patellar tendon) to expose the bone-implant interface. The deep MCL is elevated in standard fashion, and release of the medial gutter is performed. By placing limited lateral tension on the patellar tendon, adhesions and scar tissues can be identified and released within the lateral gutter allowing an improved excursion of the extensor mechanism. Avoiding over-retraction of the lateral patellar tendon is essential to avoid avulsion of the patellar tendon at its tibial tubercle attachment.

For the patient with limited preoperative range of motion, care must be taken to not avulse the patellar tendon at the tibial tubercle with knee flexion. Some advocate placement of a threaded Steinmann pin or a staple through the patellar ligament insertion at the tibial tubercle in order to disperse forces on the attachment during exposure. Another technique is to place a towel clip placed into the patellar ligament across the tibial tubercle to protect its attachment. Subluxation of the patella lateral has shown excellent results with no reported patellar tendon avulsions and a limited need for patellar eversion [14].

Removal of the polyethylene insert will also facilitate exposure. It is imperative to understand the manufacturer's polyethylene locking system in order to execute an efficient means for its removal. Passing a quarter-inch osteotome between the polyethylene and the tibial tray is often adequate to disengage the locking mechanism. Occasionally, an Allen wrench is necessary to remove the polyethylene locking mechanism. In some constrained knee replacements, a high-speed burr and/or quarter-inch osteotomes may be needed to cut the constrained polyethylene post allowing for removal of the metal support post prior to disengaging the locking mechanism.

Once the polyethylene implant has been removed, exposure to the femoral implant is achieved with deep flexion. Using straight and offset Moreland osteotomes, the anterior, distal, and posterior cement interface of the femoral component is disrupted. Removal of the femoral implant is achieved with several mallet blows to a tamp along the anterior flange and distal surface both medially and laterally. At this point, bent Hohmann retractors are replaced medial and lateral to the tibial implant protecting the skin, medial and lateral collateral ligaments, and the patellar tendon. A PCL retractor is carefully inserted posterior to the tibial implant to accentuate facilitate exposure. Moreland osteotomes or a single-sided reciprocating saw or short oscillating saw blade is passed along the medial and lateral tibial implant to disrupt the cement-bone interface. This can be completed with Moreland osteotomes. Once the cement-bone interface is completely disrupted, a Moreland tamp is used to explant the tibia. Following tibial implant removal, the posterior capsule scar tissue and any remaining bone and/or meniscus can be carefully excised. Release of the medial and lateral gutters, as well as resection of any residual posterior scar tissue, will significantly improve the mobility of the extensor mechanism.

Options for Extensile Exposure

Even with proper medial parapatellar arthrotomy technique, adequate exposure may still not be accomplished. In this scenario, it is important to consider extensile exposure techniques. Proximal extensile techniques include quadriceps/rectus snip and V-Y incision turndown. Distal extensile techniques include tibial tubercle banana peel and the tibial tubercle osteotomy [15–21].

The quadriceps snip, discovered by chance according to Insall, creates excellent exposure while limiting the risks of the turndown procedures [18, 19]. A 45° oblique incision is performed at the proximal-lateral aspect of the quadriceps tendon and extended distal-medial across the tendon to the usual origin of a standard parapatellar arthrotomy. This technique allows significant improvement in exposure of the implants by releasing the adherent, scarred soft tissues in the lateral gutter. This release is repaired primarily at the end of the surgery with nonabsorbable suture. There have been numerous studies showing similar clinical outcomes in patients after quadriceps snip versus standard arthrotomy [19, 22, 23]. It may be necessary to include a

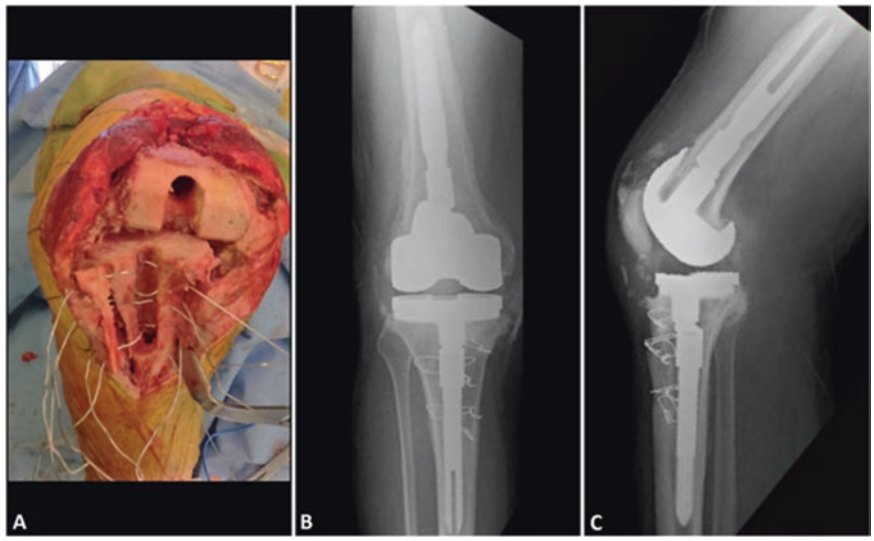

Fig. 15.3 (**a**–**c**) Tibial tubercle osteotomy provided extensile exposure for this revision total knee arthroplasty. 18-gauge wire was utilized for repairing the osteotomy.

lateral patellar retinacular release in order to provide adequate exposure and assist with patellar tracking [24].

While infrequently necessary, the V-Y turndown described by Coonse and Adams provides a very wide exposure; however, it places the extensor mechanism blood supply in jeopardy [15]. Due to these concerns, modifications of the Coonse-Adams approach have been described to limit the lateral extension of the incision, therefore minimizing disruption to the lateral superior genicular artery [16, 17]. This type of extensile exposure repair requires a delay in physical therapy to allow healing. It is the author's opinion that the associated complications from this extensile exposure do not outweigh the potential benefit, and adequate exposure can be achieved by any of the other previously described techniques.

Often the adherent soft tissues or tight structures occur distal along the lateral tibial plateau and patellar tendon. In these scenarios, a distal-based exposure approach may be more appropriate. As described by Lahav and Hoffman, the "banana peel" technique offers improved exposure while maintaining the integrity of the proximal extensor mechanism [20]. With this technique, the patella tendon is elevated as a periosteal sleeve from the tibial tubercle. The authors describe using this technique in combination with a quadriceps snip in 102 consecutive patients, with a minimum 24-month follow-up (mean 39 months), achieving good results [20].

Other times, a more aggressive distal-based approach may be necessary in the setting of press-fit keels, cemented long stems, or porous bone in-growth cone fixation in the proximal tibia. In this scenario, a tibial tubercle osteotomy (TTO) will open the tubercle from medial to lateral, leaving a lateral periosteal hinge (Fig. 15.3) [21, 22]. Although there is a technique described using a smaller osteotomy of the tibial tubercle, it has limited support due to potential complications of failure of repair [25]. In the setting of reimplantation or revision total knee arthroplasty following two-stage treatment of infection, tibial tubercle osteotomy has been shown to be an effective, safe approach [26].

Depending on implant selection and surgeon preference, the osteotomy fragment is repaired with an 18-gauge wire and/or 4.0 or 5.0 cortical screw/washers. Allowing early range of motion is key to obtaining good outcomes. The technique described by Whiteside and Rorabeck, utilizing wire fixation, allows the patient to undergo early range of motion [21]. According to Ries, a modification

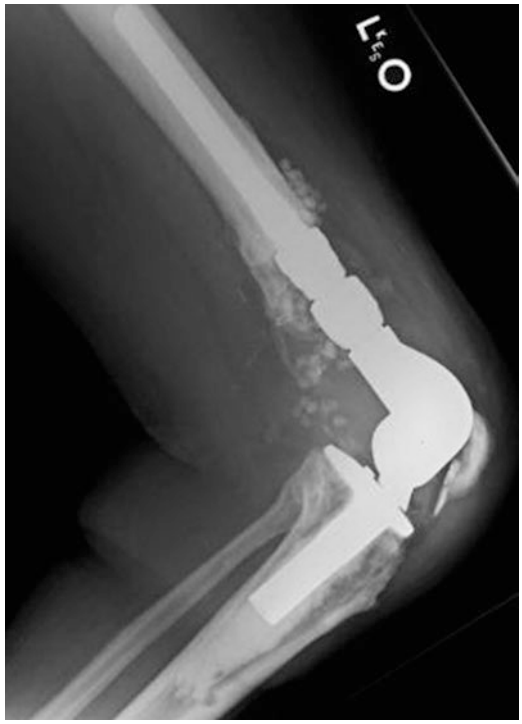

Fig. 15.4 Painful, limited flexion several years after distal femoral replacement for two-stage reimplantation for infection. The patient required an isolated patellar implant revision for the loose patellar component seen in the radiograph.

of this osteotomy attempts to decrease the distal stress riser by using a distal taper to the fragment [27].

Sun et al. recently compared quadriceps snip and tibial tubercle osteotomy for revision or reimplantation total knee arthroplasty after two-stage revision for infection [28]. Twenty-seven patients underwent TTO and 20 patients had quadriceps snip technique; there were no statistical differences in HHS score, WOMAC score, flexion contracture, and maximal flexion. The authors recommend paying specific attention to osteotomy fixation in an effort to avoid nonunion. Utilizing fresh-frozen human knee specimens, Wall et al. conducted a biomechanical comparison of "banana peel" technique and TTO [29]. Cyclical loading was used to measure mean failure strength as well as change in the distance from the inferior pole of the patella to the tibial diaphysis. There was no difference in mean failure strength on tendon distance between the two techniques. Another prospectively randomized study compared TTO with early rehabilitation protocol versus quadriceps snip for the second-stage revision for infection [30]. The TTO patients had a higher mean KSS, increased maximum knee flexion, and a lower incidence of extensor lag. There was no difference in complications or reinfection rates.

Although proximal and distal extensile exposure techniques can be combined to improve exposure, ideally the surgeon should attempt to determine which single technique provides the greatest exposure. Carefully determining the region where the soft tissue restraints are most limiting and choosing one of the appropriate techniques usually will be sufficient to ensure proper exposure.

Management of Patellar Component

In the revision scenario, it must be decided if the patella implant is to be left alone, removed, or revised. Furthermore, it can be difficult at times to assess a loose patellar component. Rosenberg described five radiographic signs to assess when determining if a patella implant is well fixed: patella fracture/fragmentation, increased bone density in the patella, trabecular collapse of the bone, bone-cement radiolucency, and lateral subluxation of the patellar bone [31]. If the implant is determined loose, proper visualization must be achieved at the implant bone interface (Fig. 15.4). This interface is often obscured by excess fibrous soft tissue that forms within months of the primary surgery; it is imperative to remove this tissue prior to assessment [32, 33]. Another potential indication for patellar implant revision is a metal-backed patella. It has been previously reported that metal-backed components may cause a high incidence of polyethylene wear [34, 35]. Although some have reported good clinical results, if metal-backed patella is identified at time of revision surgery, revision of the implant should be considered [36].

Patellar implant revision in the setting of infection can be technically challenging. In a recent study by Glynn et al., various methods of patellar revisions such as resurfacing, patelloplasty, augments with trabecular metal, impaction grafting, and patellectomy were attempted during two-stage revision for infection. KSS scores were most improved with patellar resurfacing [37]. This study highlights the importance to preserve as much patellar bone stock as possible at the total knee resection. A previous study by Pagnano et al. suggests that resection of the patellar component during revision or reimplantation total knee arthroplasty may be a reasonable approach for patients with markedly compromised patellar bone stock; however, mild or moderate anterior knee pain can be expected to persist in as much as 1/3 of these patients [38].

Technique for Removal of Patellar Component

Ease of patellar component removal is dependent on the type of implant, implant fixation, and remaining bone stock. First, stabilize the patella using two Lewin clamps perpendicular to the quadriceps tendon and patellar tendon at the superior and inferior patellar pole. The polyethylene implant on a metal-backed patellar components can usually be disengaged from the metal portion with an osteotome, thereby giving adequate exposure to the metal implant. Care must be taken to avoid patellar tendon injury when using osteotomes; it is recommended to pass the osteotomes from the proximal and lateral position only. Stacking osteotomes can be successful in the removal of the metal implant. However, in the case of the metal-backed implant, we recommend using a high-speed burr to safely and quickly remove the metal implant while preserving patellar bone stock. For removal of a cemented polyethylene implant, an oscillating saw with a short wide blade is used to cut the button from the cement mantle. A high-speed burr can be used to section cut the patellar button as well remove the polyethylene/cement from the peg holes. Care must be taken to cover the wound so debris is not spread throughout the knee.

Using Patella to Establish Joint Line

Re-establishing patellar height is a challenge in revision knee arthroplasty. Without proper restoration of the joint line, knee kinematics can be adversely affected leading to anterior knee pain, increased patellofemoral wear, patellar-polyethylene impingement, and decreased flexion [39, 40]. Ideal placement of the patellar component should be 25 mm distal to the medial epicondyle or about the width of a finger above the tibial polyethylene articular surface. Patients with significant distal femoral bone loss may need distal femoral augmentation to restore the appropriate joint line thereby avoiding patella baja and possibly improving clinical outcomes [41]. An improvement in clinical outcomes has been observed if the joint line is within ±4 mm of the unaffected side [42].

Other challenges occur due to long-standing patella baja prior to revision (Fig. 15.5). Whiteside has previously described a tibial tubercle osteotomy where the tendon is proximalized [43]. Typical risk factors and postoperative management associated with tibial tubercle osteotomy must be considered following the use of this technique.

Addressing Patellar Remnant after Removal of Prior Patellar Component

During a primary total knee arthroplasty surgery, maintaining patellar thickness is relatively easy to achieve by adding a component with the same thickness as the amount of bone removed. In the revision scenario, the deficient patella can be a challenging issue to manage. Patella thickness should be kept greater than 12 mm to avoid fracture; this is frequently not possible during revision total arthroplasty (Fig. 15.6). Seo et al. recommend a technique using transcortical wiring for patella with less than 8 mm in thickness [44]. At a mean of 36.6 months, satisfactory results

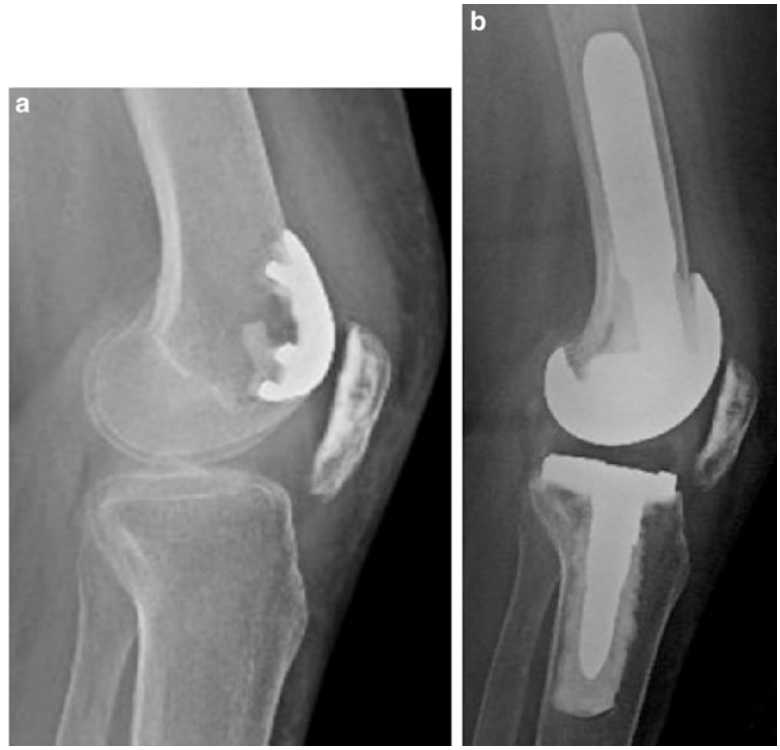

Fig. 15.5 Patella baja reduces the excursion of the patellar tendon making exposure very difficult to during revision surgery. Placing a threaded pin at the tibial tubercle may reduce the stress on the patellar tendon insertion thereby preventing avulsion and avoiding the need for a more extensile exposure.

were noted with a significant improvement in KSS scores. Only 1 patient of 28 (30 knees) experienced a fracture at 1 week postoperatively.

Revising a patella with inadequate bone stock is often very difficult and may not be an option. If no implant is possible, the remaining bone may track lateral over the femoral condyle rather than within trochlear groove, contributing to further pain and quadriceps weakness. In this scenario a gull-wing patellar osteotomy is indicated [45]. This technique consists of a sagittal osteotomy on the articular surface of the patella. The medial and lateral "wings" are then displaced anteriorly into a V shape, allowing the convex surface the ability to track into the concave trochlear groove [45].

Maintaining the patella assists in preserving the moment arm of the extensor mechanism [46]. Without this mechanical advantage, hamstring and quadriceps torque production are compromised [47]. This is especially noted in early range of motion approximately 15%–30% of flexion to 30% of full extension [46]. In the setting of total knee arthroplasty, this weakness through range of motion can lead to flexion instability [48]. Furthermore, worse functional outcome has been noted in patients who underwent previous patellectomy [47, 49–51].

There have been multiple techniques described in order to reconstitute insufficient patellar bone stock [52–55]. In one study, of 100 consecutive revision total knee arthroplasties (both tibial and femoral components), only 9 had a "patellar shell" remaining [53]. A patellar pouch was created along the peripheral patellar rim using peripatellar fibrotic tissue or a free tissue flap from the fascia lata or the supra-patellar pouch. Initial patellar thickness ranged from 7 to 9 mm; after the pouch was filled with cancellous bone graft, the average thickness was 22 mm measured on immediate postoperative Merchant radiographs. At final follow-up (mean 36.7 months), patellar thickness averaged 19.7 mm. The overall arc of range of motion improved from 82.8 to 97.8° [53]. One case series has utilized a modification of Hanssen's technique, and the proximal portion of the patellar tendon is augmented with Achilles tendon allograft and sewn into the distal aspect of the quadriceps. The author reported improved

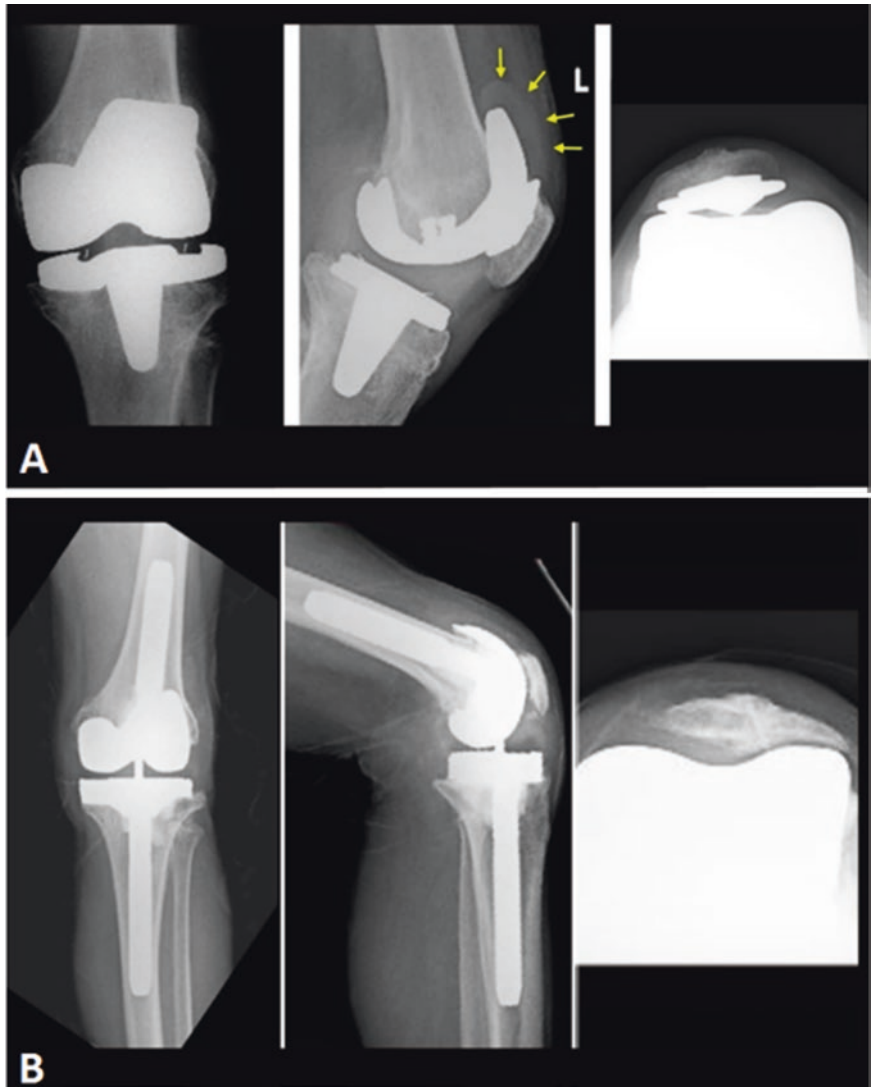

Fig. 15.6 (**a**) The well-fixed metal-backed patella is a source of metallosis leading to osteolysis, chronic synovitis, and implant loosening. The extent of the metallosis is observed in the supra-synovial pouch (*yellow arrows*). (**b**) Hybrid fixation of the tibial and femoral implants with resection of the metal-backed patella. The remaining patella bone was very thin and therefore left unresurfaced.

WOMAC scores, absence of extensor lag, and 110–125° of flexion [55].

Patellar Fracture Prior to Revision or Fracture during Removal of Patellar Implant

Etiology of patella fracture is often avascular in nature. Lateral release, fat pad excision, previous surgery, or quadriceps tendon release are often seen in relation to this injury [56]. Various types of knee arthroplasty patella fractures have previously been described by Goldberg [57]. **Type I** fractures do not affect the implant and are usually isolated to the upper and lower poles. **Type II** fractures involve the extensor mechanism, with the fracture extending through the central aspect of the patella or the quadriceps. **Type III** fractures are divided into IIIA and IIIB. **Type IIIA**

involves the inferior pole with disruption of the patellar tendon. **Type IIIB** involves the inferior pole but lacks disruption of the patellar tendon. A **Type IV** fracture has a loose implant disrupted from the bone interface with an associated fracture of the patella.

There may be an increased incidence of intraoperative fractures following revision of metal-backed patellas [58]. Osteolytic defects may also weaken the bone and predispose the patella to fracture. Other challenges relate to the avascular nature of the patella and predict healing problems. The surgeon may choose to treat non-displaced fractures without surgery. In one study, patients with non-displaced fractures, defined as less than 2 mm displacement, were placed into a cast in extension for 6–8 weeks and allowed to weight bear [59]. Results were noted as satisfactory for nonoperative treatment in these patients. Fracture displacement and extensor lag often require surgical treatment [57, 59, 60]. Windsor has advocated patellectomy if there is loosening of the implant or disruption of the extensor mechanism [60]. However, flexion instability and extensor lag are common complaints after patellectomy. As an alternative, patelloplasty may decrease anterior knee pain compared to patellectomy. Furthermore, a larger percentage of patients were able to climb stairs [39]. Extensor mechanism reconstruction may be another option if avascular necrosis of the patella fracture fragment exists and the patient has a significant extensor lag (Fig. 15.7).

Best Management for re-Rupture of Patellar Tendon

Patellar tendon disruption following total knee arthroplasty is a devastating complication. The prevalence of patellar tendon rupture has been reported 1.4–3.2% [61]. The primary repair failure rate is greater than 90% when utilizing the following fixation methods: staples, screws, screws with washer, and nonabsorbable suture (Fig. 15.8) [62].

Autograft fixation has been studied as well. Semitendinosus has been utilized and passed through a tunnel transversely through the patella and passed distal to the tibial tubercle [63, 64]. Following this procedure, the knee is kept immobilized for about 6 weeks. However, there are serious concerns that autograft or allograft tendon augmentation, along with suture fixation, may be insufficient repair [65]. In order to prevent undue stress on the final repair/augmentation, appropriate proximal and distal releases should be utilized.

Browne and Hanssen reported on a series of patients that underwent reconstruction using a knitted monofilament polypropylene graft for subacute or chronic patellar tendon rupture. Although there were several failures, 9 of the 13 patients had an extensor lag less than 10° and no loss of passive extension or flexion at final follow-up [65]. The authors have shown this technique can produce successful results while

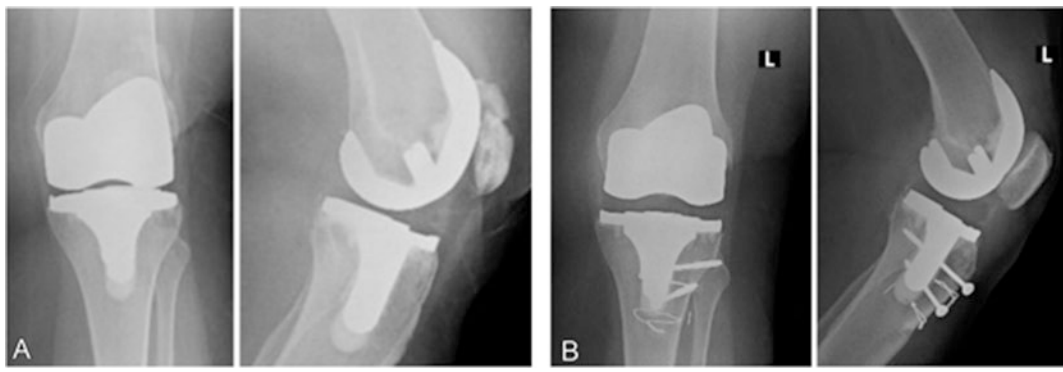

Fig. 15.7 (**a**) Chronic displaced superior pole patella fracture with a 50° extensor lag. (**b**) Whole extensor mechanism reconstruction with screws and 18-gauge wire repair technique.

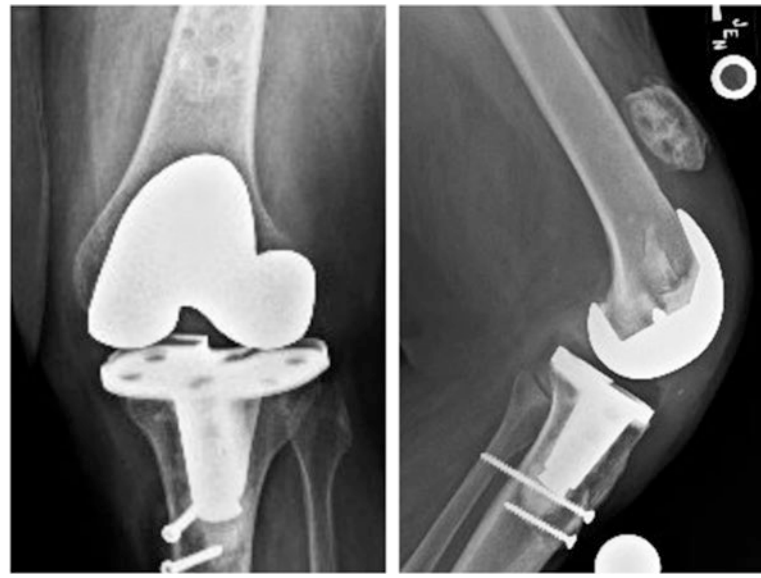

Fig. 15.8 Significant retraction of the quadriceps mechanism following a failed primary repair utilizing screw fixation only.

limiting risk of disease transmission associated with allograft tissue (Fig. 15.9).

Chronic patella tendon rupture, limited patella bone stock, and previous failed extensor mechanism repair/reconstruction were described by Emerson as the indications for whole extensor mechanism reconstruction [66]. Early results of extensor mechanism allograft reconstruction were largely clinical failures. Extensor lag was reported between 20 and 59°, depending on the study [67–69]. However, good clinical outcomes have recently been reported for this type of reconstruction with incorporation of a few key techniques. Nazarian and Booth recommended tensioning the allograft in full extension; they attributed this technique modification to the improved clinical outcomes with an average 13° of extensor lag at 3.6-year follow-up [70]. A comparison of techniques was performed by Burnett; the non-tensioned extensor mechanism allografts went on to clinical failures, whereas the tensioned allograft average extensor lag was only 4.3°, and these patients had improved Knee Society Scores [71]. Various factors are predictors of good outcomes following allograft reconstruction of the extensor mechanism: solid, rigid tibial fixation, tensioning of the graft in full extension, not testing the completed repair, and proper patient selection [72, 73].

A few technical aspects regarding whole extensor mechanism reconstruction deserve specific discussion. A midline arthrotomy with subsequent "shelling" out of the entire patella maintains the medial and lateral extensor mechanism of soft tissues and improves the available tissue for closure after the reconstruction. Inspection of the graft itself is of great importance prior to initiating reconstruction. To obtain adequate tibial fixation, the tibial bone block should be at least 5–7 cm in length. The trough cut into the tibial bone is typically 5–7 cm length, 2 cm depth, and 2 cm width. Furthermore, a proximal reverse beveled tip allows the proximal bone graft to securely fit into the tibial trough. This trough should be made no closer than 15 mm to the tibial joint surface to prevent fracture of the anterior tibial cortex and subsequent proximal graft escape. Often a tibial stem is present; care must be taken so that the trough and tibial bone block do not interfere with placement of the tibial stem. To secure the tibial bone block, either three 16- or 18-gauge wires can be placed through drill holes and tensioned with a needle driver. Another method of tibial bone block fixation includes placement of cortical screws with washer to secure the graft. If this technique is chosen, it is critical to over-drill the tibial allograft to prevent fracture while tightening the screws. After obtaining

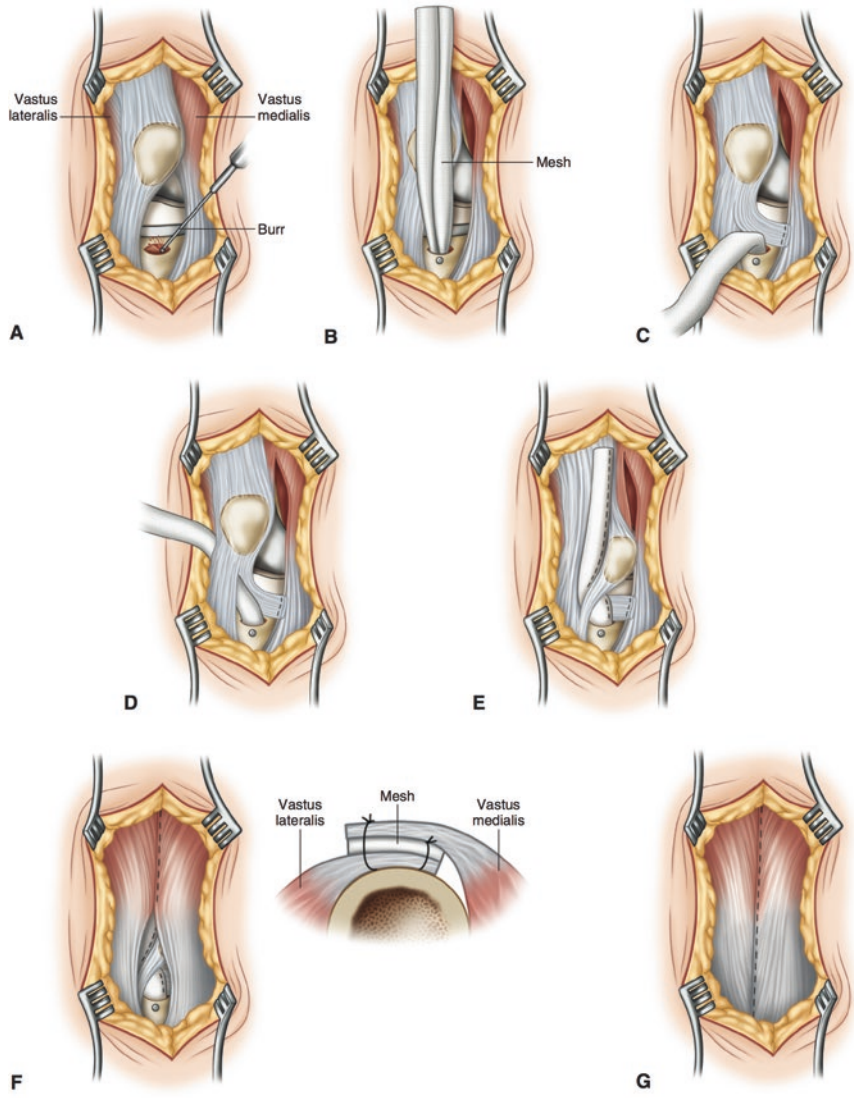

Fig. 15.9 As described by Browne and Hanssen, these illustrations (**a**–**g**) depict an extensor mechanism reconstruction technique utilizing Marlex mesh. (**a**) Assuming the tibial component does not require revision, a burr is used to create trough along the anteromedial tibia. (**b**) The graft is inserted into the trough and secured with polymethyl methacrylate cement and a transfixion screw and washer. (**c**) Next, the tissue is elevated with a laterally based flap, and the mesh is placed over the medial soft tissue and secured with nonabsorbable sutures. The lateral flap is then placed between the polyethylene implant and the graft. (**d**) The graft is passed from deep to superficial through an opening created in the lateral soft tissue. In order to reestablish patellar height, the quadriceps and patella are tensioned distally. (**e**) The graft is then sutured to the vastus lateralis, quadriceps tendon, and lateral retinaculum. Mobilization of the medial retinaculum and vastus medialis allow soft tissue to cover and inset the mesh graft in an overlapping fashion as illustrated in the cross sectional drawings. (**f**) This repair is secured with the vastus lateralis deep and the vastus medialis as the superficial soft tissue flap. (**g**) Lastly, closing the arthrotomy provides soft tissue coverage over the mesh graft.

fixation distally, the leg is brought into extension. The previously placed Krakow sutures along the medial and lateral proximal quadriceps allograft tendon are pulled from distal to proximal up and through the proximal host quadriceps. An assistant applies constant tension to these sutures, pulling the allograft tendon up and under the host quadriceps. Maintaining constant tension, #5 nonabsorbable sutures are passed in "vest-over-pants" fashion from the native quadriceps tendon through the allograft quadriceps tendon and back through the native quadriceps tendon. It is recommended to keep the knee fully extended for 6–8 weeks prior to starting range of motion (Figs. 15.10 and 15.11) [73].

What to Do if Patella Is Subluxing Lateral?

Basic tenets should be observed throughout revision total knee arthroplasty to ensure proper patellar tracking. Intraoperative lateral patellar subluxation in the revision setting is most often a function of scarred and contracted tissue in the lateral gutter and should be addressed at the time of the revision surgery. As described by Laskin, proper reconstitution of the trochlear surface along with axial realignment assists in centralizing the patella. During revision surgery, there is often fibrous overgrowth of patellar tissue contributing to lateral patellar tracking and ultimately may limit the range of motion. Lateral gutter release of this scar tissue combined with debulking the patellar overgrowth tissue will improve patellar tracking [74].

However, when revising a patient for lateral patellar tracking, an understanding of the etiology is crucial to the success of revision surgery. Most commonly, improperly rotated implants are the cause of patellar maltracking. The culprit is typically an internally rotated femoral or internally rotated tibial implant. It is critical to understand lateral gutter release; lateral patellar release and/or patellar debulking will not resolve the lateral tracking patella if the underlying component malposition is not addressed. Parvizi et al. retrospectively reviewed 35 knees (31 patients) over an average follow-up of 7.9 years. Their work demonstrated that those who underwent isolated patellar resection arthroplasty were more likely to have continued pain versus those with simultaneous revision of both femoral and tibial components [75]. Another study by Leopold described failure of 15 of 40 knees (38%) that underwent isolated revision of the patellar component [76]. These studies demonstrate the need to pay careful attention to appropriate femoral and tibial component rotation. In the revision setting, this can be challenging with minimal or no bone landmarks. As typically described with primary total knee arthroplasty, the trans-epicondylar axis,

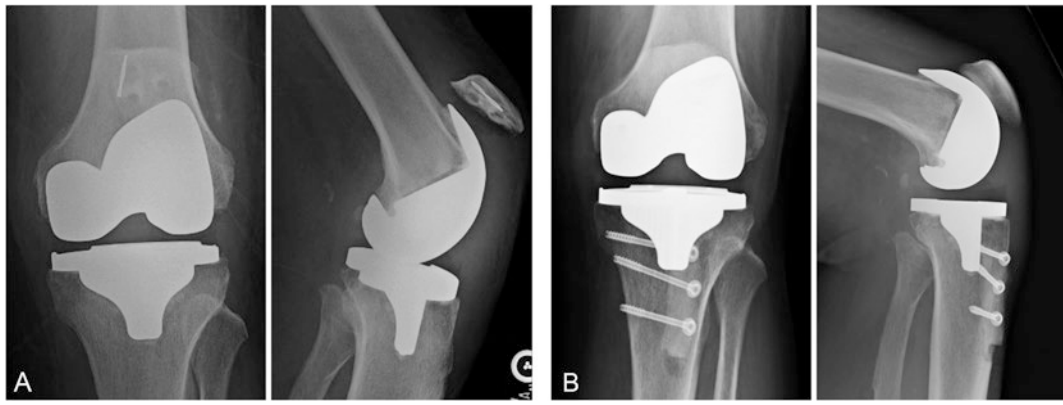

Fig. 15.10 (**a**) Chronic retracted quadriceps muscle and patella alta after failed transosseous patella suture repair. (**b**) Secondary to the chronic nature of the injury, whole extensor mechanism allograft reconstruction with screw fixation was performed. One-year follow-up radiographs show excellent incorporation of the allograft bone.

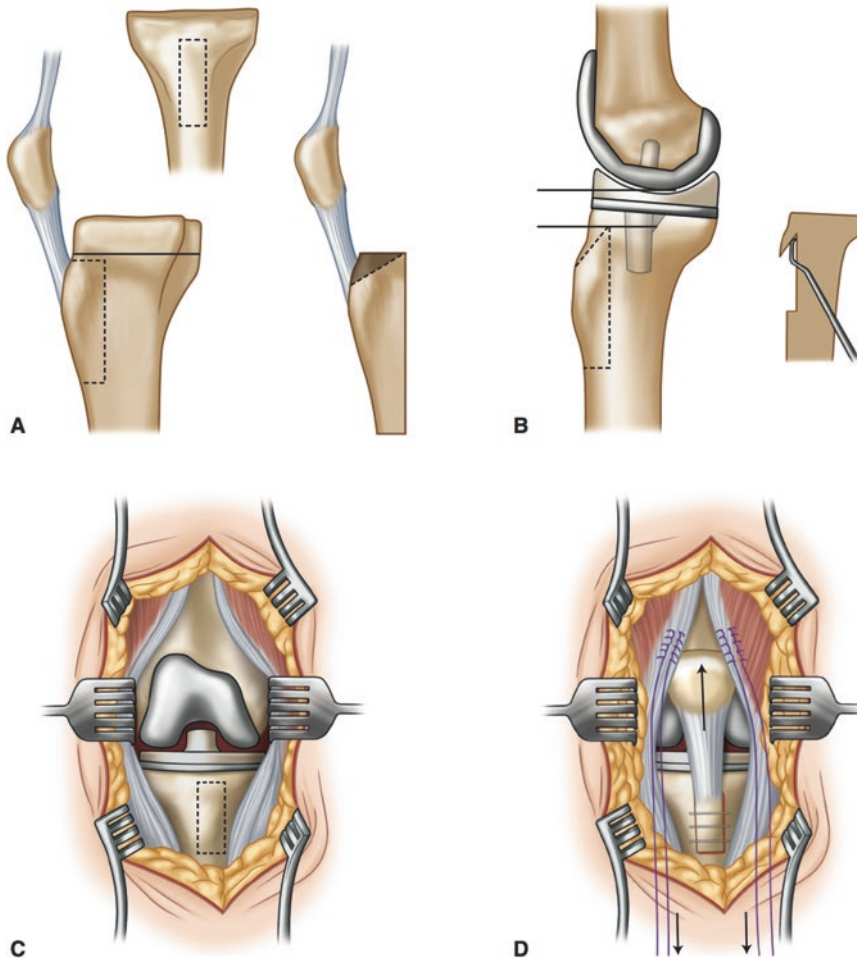

Fig. 15.11 As previously described by Burnett et al., these illustrations (**a**–**d**) highlight the importance of graft preparation, tibial trough preparation, proximal suture repair, and distal screw/wire fixation repair. (**a**) Pre-inspection of the tibial bone block-patella tendon-patella-quadriceps tendon allograft is critical for good success. The proximal portion of the tibial bone block should have a reverse bevel cut at the proximal aspect as illustrated. (**b**) The tibial trough should start 1.5–2 cm distal to the tibial implant. The proximal aspect of the trough requires a corresponding reverse bevel cut to accommodate the allograft. (**c**) The tibial trough should be cut approximately the same size as the allograft. (**d**) The tibial allograft is wedged gently into position and secured with 18-gauge wire or screws and washer from a medial to lateral direction. Medial and lateral Krakow sutures are placed into the proximal quadriceps allograft and the host medial and lateral vastus. Next, the allograft tendon sutures are passed under and up through the corresponding vastus medialis and lateralis quadriceps muscle. With constant tension pulling the overlying host vastus distally and the allograft quadriceps tendon proximally—interrupted figure—eight sutures are placed through the host vastus and the allograft quadriceps tendon. After closure of the incision, patient is placed in a long leg cast with an anterior window to assess the incision.

midtrochlear line or "Whiteside's line", or the posterior condyles aid in the establishment of femoral rotation [77–79]. When trialing the revision femoral implant, care should be taken to ensure a posterior condylar bone void does not artificially internally rotate the femoral implant (Fig. 15.12). A posterior condylar bone deficit can be addressed by utilizing a screw and cement rebar method to augment or "build up" the posterior lateral femoral condyle or with the addition of a 5 or 10 mm augment to the posterolateral aspect of the femoral revision implant. Malposition of the tibial implants is also a common error leading to knee pain, patellar maltracking,

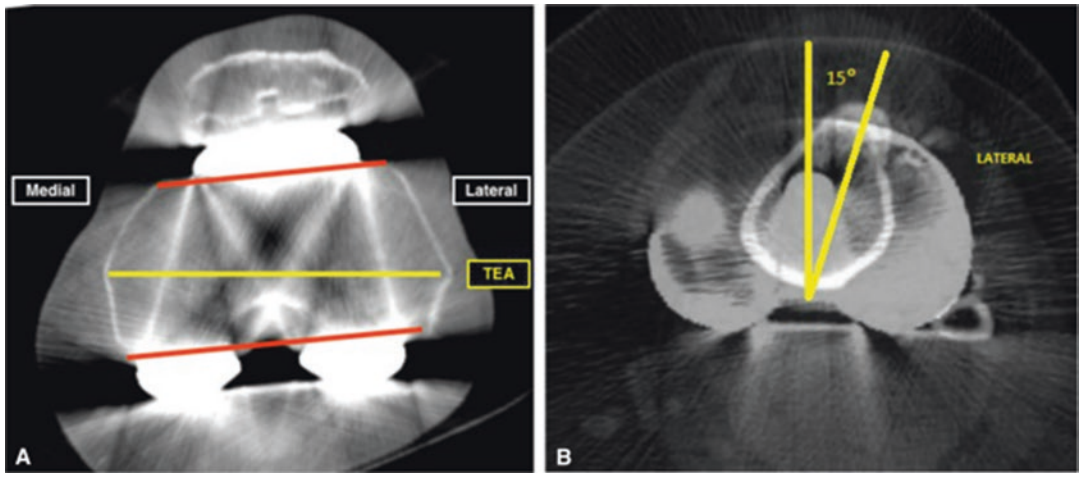

Fig. 15.12 Implant malposition can lead to patellar maltracking, limited range of motion, and pain. To evaluate implant position, a CT scan of the knee is most helpful. Most commonly, internal rotation of the femoral implant (**a**) or internal rotation of the tibial implant (**b**) is observed.

and may lead to early polyethylene failure secondary to increased stresses on the contact surface (Fig. 15.12) [80]. The surgeon should strive to align the component with the medial third of the tibial tubercle [80]. Trialing the implant to ensure the PS or constrained tibial post is tracking centrally in the box of the femoral implant will confirm proper rotation of the tibial implant.

When revising a patella implant with adequate bone stock, the implant should be medialized on the native patella to facilitate appropriate tracking. Furthermore, confirming patellar tracking while using a "no-touch" technique with the tourniquet inflated may lead to an unnecessary lateral patellar release [74]. Care should also be taken to restore native patellar thickness and not "overstuff" the patella; biomechanical studies have shown knee flexion decreases exponentially as patellar thickness increases [81].

Appropriate management of the extensor mechanism during revision total knee arthroplasty is critical to good clinical outcomes and satisfied patients. Although many techniques have been described to solve extensor mechanism complications, it is apparent that prevention is paramount to facilitate a superior outcome.

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16 Restoration of Stability, Maintaining Joint Line, Gap Balancing, and Constraint Selection Through the Use of a Trial Cutting Guide

Michael A. Masini and Jeffrey Wilde

Total knee arthroplasty (TKA) remains the treatment of choice for patients with advanced degenerative joint disease of the knee. The number of TKAs performed annually in the United states is increasing exponentially with more than 650,000 TKAs performed in 2012 [1]. Even with modest annual revision rates, the number of patients requiring revisions will continue to increase as well [2]. Despite the continual technological innovation along with advancements in the understanding of knee biomechanics and kinematics, there has not been a substantial decline in revision TKAs over the past decade [3]. Consequently, it is critical that the arthroplasty surgeon is familiar with the evaluation and treatment of these increasingly more common problems.

The evaluation of painful TKAs can be challenging, but adhering to a standardized, systematic approach to each patient will create more predictable surgical outcomes. It is critical that the surgeon identify the cause of pain prior to performing a revision because the literature has demonstrated that revision TKAs done for unexplained pain have a very low probability for success and are ill-advised [4]. Additionally, the possibility of infection must also be considered when addressing any failed knee arthroplasty.

The demographics regarding revision TKA have changed substantially in the past decade. Infection remains the most frequent indication for revision, but revision for osteolysis is now relatively uncommon. Aseptic loosening, instability, and malalignment now account for more than 50% of revisions. In addition, the median interval between primary and revision TKA has decreased. Thiele et al. found that the median time to revision in their study was 4 years (range 0–20 years) [3]. Although the data is skewed due to early infections, the high incidence of early revision for technical issues such as instability and malalignment is noted.

The goals of revision TKA should be the same as with a primary TKA: obtaining excellent motion, function, stability, and pain relief. Revision TKAs are often complex procedures, and proper surgical technique is essential for successful outcomes.

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This chapter will focus on four key principles to revision TKA including restoration of stability, maintaining the joint line, gap balancing, and constraint selection. The chapter will also explain how to use a trial cutting guide to address these clinical scenarios in a systematic way.

Identification of the Unstable Total Knee Arthroplasty

Instability following TKA is now recognized as a common mode of failure in primary TKA. It was first described in a small series of 25 patients that were all successfully revised for instability [5]. This same group of surgeons noted that nearly one third of all early revisions at their center were due to instability [6]. A recent study in 2014 demonstrated that approximately 25% of all first-time revisions in this series were due to instability [7]. Instability in TKA is defined as structural failure of supporting soft tissues or the inability of these tissues to function properly due to the component size and/or position. Instability thus is due to either a disrupted soft tissue sleeve or improper placement of implants within an intact soft tissue sleeve. The approach to treating instability in a TKA is different from treating an unstable knee without an arthroplasty, and it has long been understood that isolated ligament reconstruction in an unstable TKA tends to be unsuccessful [8]. Arthroplasty involves placement of intra-articular components that can change the knee in ways that may destabilize the joint and, unless the components are corrected, would overwhelm the ligament reconstruction resulting in failure. In addition to ligamentous integrity, component alignment and size are paramount to stability in TKA. Consequently, instability is not only a "soft tissue" problem and often is due to implant size and/or position and necessitates a complete revision to restore adequate stability. Gu et al. performed simulated resections using four common total knee techniques with a computer software model on Caucasian knees. Their study elegantly illustrates the extreme complexities involved in performing a TKA and appropriately balancing the knee even in the "normal" knee, let alone the challenges involved in balancing an arthritic TKA [9].

Revision surgery for instability involves five major components to be successful: (1) control over the mechanical axis and restoration of the joint line, (2) appropriate gap balancing, (3) the assessment of collateral ligament integrity, (4) the assessment of bone loss, and (5) the assessment for the need for constrained implants [10].

Diagnosis

Gross instability as a result of an incompetent medial collateral ligament or posterior cruciate ligament is often easily recognized in the office, but subtle instability in a TKA is often difficult to diagnose because patients are describing a symptom rather than a diagnosis. They may complain primarily of catching, giving way, or anterior knee pain, and these patients often experience recurrent bloody knee effusions which demonstrate a predominance of red blood cells when aspirated [5]. Diagnosis in these subtle cases is difficult and requires a systematic and comprehensive approach to discern the problem as these symptoms can often correspond to alternative pathology in the knee.

Imaging

All patients undergoing evaluation for an unstable TKA should have AP, lateral, and sunrise view radiographs. Additional full-length radiographs showing the hip, knee, and ankle on the same image are recommended to discern whether malalignment of the components is contributing to instability at the knee. The surgeon should also consider obtaining an AP pelvis to rule out hip pathology as a source of referred pain. Cases of varus/valgus instability with well-positioned components, without evidence of axial malalignment or joint line malposition, often indicate a soft tissue problem

exists. The use of stress radiographs can often be helpful in these situations to distinguish between varus/valgus instability versus anterior-posterior instability (Fig. 16.1). A CT can provide information regarding component rotation and will help identify cases of axial malalignment [11, 12].

Classification System for Instability

Parrate and Pagnano defined three types of instability after TKA—extension instability, flexion instability, and genu recurvatum [13]. They were further subdivided into symmetric and asymmetric instabilities. The instabilities may be accentuated by component malposition, size, or overall limb alignment considerations. Extension instability is caused by relative over resection of the femur, tibia, or both. Correction can be managed by augmentation of the femur or increased tibial insert thickness. The joint line must be considered when addressing extension instability. Raising the joint line excessively can lead to limited knee flexion, altered patellofemoral mechanics, and midflexion instability.

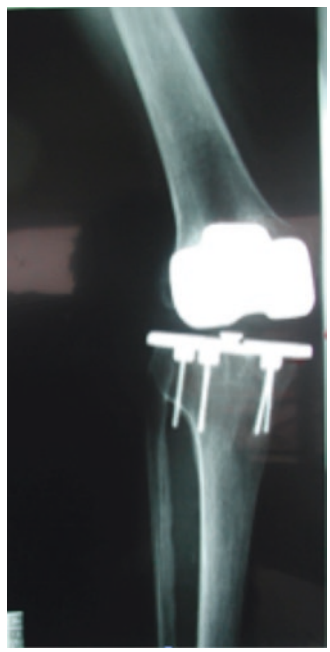

Fig. 16.1 Stress X-ray indicating degree of medial opening in a painful TKA

Asymmetric extension instability occurs usually due to the lack of appropriate correction of varus and valgus deformities at the time of primary TKA. The most common occurrence is inadequate medial collateral ligament release at the correction of varus deformity. Inadequate correction of valgus alignment is more commonly the culprit when performing a primary TKA for valgus deformity and arthritis. Both inadequate ligament release and lack of correction of alignment deformities usually result in recurrence of the deformities and failure of the TKA due to instability or later asymmetric wear.

Flexion instability is most often seen in the patient with a well-aligned knee in the coronal plane and well-fixed components. It may occur in PCL-retaining knees when the PCL is disrupted or stretched. It occurs in PCL-substituting knees when the femur is undersized, displaced anteriorly, or with soft tissue stretching of the posterior capsule and secondary restraints to the flexion space. Dislocation of the knee may occur with either design and is a dramatic but fortunately rare event. Surgeons should become familiar with examining knees in flexion over the side of the examining table so they can become familiar with acceptable and unacceptable flexion space laxity. The presence of a "posterior sag sign" may be demonstrated in posterior cruciate-retaining knees. Recurrent effusion, repeated aseptic aspirations, and difficulty descending and ascending stairs are frequent clinical complaints in patients with flexion instability.

Recurvatum deformity is very difficult to treat and often associated with neurogenic causes such as polio or end-stage rheumatoid arthritis with recurrent synovitis and capsule laxity. Relatively minor deformities in patients without polio or RA can be managed with intentional under-resection of the distal femur (or augmentation with a standard resection) or possibly posterior transfer of the femoral origins of the MCL

and LCL as described by Krackow and Weiss [14]. Practically, however, this deformity is most reliably treated with a hinged prosthesis with an extension stop. The hinge should be positioned such that the patella component is properly positioned relative to the trochlea as this condition is often accompanied by significant quadriceps weakness, and optimal patellofemoral mechanics should be an important secondary goal [13].

Gap Balancing in Revision Total Knee Arthroplasty

The earliest examples of flexion instability were recognized in early cruciate-sacrificing devices implanted in patients with patellectomies who ultimately sustained posterior tibial dislocations [15]. The kinematics of flexion initiation at the knee are complex and begin with a posterior pull from the hamstrings on the posterior proximal tibia. The first motion of the tibia is posterior translation relative to the femur. In a normal knee and cruciate-retaining TKA, the PCL then resists this translational movement, and the force is converted to a flexion motion at the knee. Cruciate-sacrificing knees are dependent on the "uphill principle" which causes the collateral ligaments to tighten as the femur translates anteriorly on the tibia resulting in flexion rather than dislocation [15]. Additionally, the patella helps prevent posterior dislocation by buttressing against the anterior femur and resists too much posterior translation of the tibia through the patellar tendon attachment.

Changes in the flexion/extension gap will alter the kinematics of this process and may result in a poorly functioning TKA. Consequently, understanding the basic kinematics of the knee is critical to the concept of balanced flexion and extension gaps. This principle is foundational to ensuring that the prosthetic knee flexes, extends, and remains stable in both primary and revision knee arthroplasty [16]. Failure to obtain proper balancing results in asymmetry in the collateral ligaments during either flexion or extension leading to increased polyethylene wear, decreased range of motion, and anterior knee pain [17, 18]. Rotational malalignment must also be considered in the unstable TKA, which can accentuate the ligamentous imbalance. When balancing a primary or revision TKA, the surgeon must understand the distinction between ligament tension and gap size. The tension is largely affected by the management of the soft tissue envelope around the knee, while gap size is modulated primarily by the implant size and position [19, 20]. A properly balanced knee will have correct axial alignment, symmetric tension on the collateral ligaments throughout both flexion and extension, and the flexion and extension gaps will be equal.

The ultimate goal of gap balancing is to obtain equal gap size in flexion and extension with appropriate alignment and stability. Ries described three general principles that should be considered when balancing the knee: (1) tibial insert thickness or tibial augments affect both the flexion and extension gap equally, (2) extension gap problems can be corrected by adjusting the distal femoral cut with either augmentation (loose extension gap) or further resection of the distal femur (tight extension gap), and (3) solitary flexion gap problems are handled on the femoral side with anterior/posterior shifting of the femoral component or changing the femoral component size (effectively increasing the AP diameter of the implant) with the use of metal augments as necessary [21, 22]. The process can be simplified by obtaining the correct flexion gap first and matching the extension gap to the flexion gap. This decreases the number of possible combinations from nine to just three: equal flexion/tight extension, equal flexion/equal extension, and equal flexion/loose extension [19]. In reality, however, the surgeon must be *simultaneously* considering the flexion and extension gaps as decisions are made as to proper augmentation, implant size, and tibial insert thickness to avoid altering the joint line and patellofemoral mechanics.

The flexion gap stability is often a bigger challenge than the extension gap as it is affected by more variables: posterior tibial slope, size of the

tibial/femoral components, polyethylene thickness, posterior femoral bone loss, and revision stem offset. In contrast, the extension gap is decided primarily by the proximal/distal femoral position. Because of this, many authors advocate correcting the flexion gap as the first step in the algorithm. The size of the flexion gap is best modulated by the size of the femoral implant which increases primarily in AP diameter as the component sizes increase. The surgeon can utilize posterior femoral augments to decrease the flexion space or to allow component upsizing in the presence of posterior condyle bone loss. Offsetting of the femoral component is possible with most modern revision systems and is used to assure the anterior flange of the femoral component is positioned against the anterior femoral bony cortex. This step assures the entire femoral thickness is used to "fill" the flexion space. There are several ways to fix components with stems and include rigid press-fit stems without cement fixation, "hybrid" cement fixation with "snug" stems and implant and metaphyseal cement fixation, or totally cemented stems (with or without cement plugs). All have their proponents and have been used successfully. The current trend is to avoid rigid cementless stems and offsets as there appears to be higher rates of (stem tip) pain in these patients. Fixation methods will be discussed in further detail later in this chapter.

Management of Bone Loss/Joint Line Restoration

Complex revision TKA cases can present with significant bone loss, which can make the subsequent revision reconstruction challenging. The etiology of bone defects is multifactorial and can include subsidence of loose implants, prosthetic wear resulting in osteolysis, infection, periprosthetic fractures, osteonecrosis, or stress shielding [23]. Since the ultimate goals in revision TKA are to create a pain-free knee with a functional range of motion, this is accomplished by correction of coronal and sagittal alignment, balanced flexion/extension gaps with an appropriate-sized implant and optimized ligamentous stability, stable and durable fixation of the implants, and preservation of as much host bone as possible [24]. There are a variety of reconstructive options available including cement and screws, metal augments, impaction and bulk allografts, metaphyseal cones and sleeves, or mega-prostheses [25–28]. The selection of these is dependent on the location and quantity of osseous defects present at the time of reconstruction as well as which soft tissues are intact.

Classification of Bone Defects

There are multiple different classification systems that have been developed to categorize bone loss and to guide treatment preoperatively, though ultimate determination of the bone defect is made in the operating room once the previous implants are removed [23]. The Anderson Orthopaedic Research Institute (AORI) is simple and is useful in describing bone defects and is now probably the most widely accepted classification for bone loss during revision TKA [29]. Bone defects in the distal femur and proximal tibia are divided into three types: type 1 has minor osseous defects not compromising component stability with intact cortical rim and relatively preserved joint line. Type II has more extensive bone loss with damaged metaphyseal bone and is further classified into subtypes (A and B) depending on if one or both condyles/plateaus are involved. Type III defects constitute cases with extensive metaphyseal bone loss compromising a major portion of either condyle or plateau and may involve compromise of the patellar tendon or collateral ligaments (Table 16.1) [29]. The validity of this classification system was analyzed by Mulhall who compared preoperative films to intraoperative observations and found that the AORI system predicted the bone loss correctly 67% of the time in the femur and 82% of the time in the tibia on the preoperative films [30].

Table 16.1 AORI bone defect types

Type 1 defect	Intact metaphyseal bone
	Good cancellous bone at or near a normal joint line level
Type 2 defect	Damaged metaphyseal bone
	Loss of cancellous bone that requires cement fill, augments, or small bone grafts to restore a reasonable joint line level
	2A, one femoral or tibial condyle
	2B, both femoral and tibial condyles
Type 3 defect	Deficient metaphyseal bone
	Deficient bone compromises a major portion of either condyle or plateau; these defects usually require a large structural allograft, a rotating hinged component, or custom component

Treatment Options for Managing Bone Loss

The guiding principles in managing bone loss in revision TKA are to preserve as much native bone stock as possible and to rebuild bone stock where defects exist. This ideally creates a foundation to obtain initial and long-term fixation of the components. The surgeon must be aware of ligamentous integrity and the integrity of the extensor mechanism preoperatively as well. Instability may be both secondary to bone loss and ligamentous failure or imbalance.

Tibial Bone Loss

Increased Resection

Small, contained bone defects measuring less than 1 cm in depth (AORI type I) can usually be managed with cement, metal augments, or increased bony resection. Increasing the bone resection from the proximal tibia and distal femur seems to be a simple "fix" to minor bone defects and can be useful if minimal resection remedies the problem. However, the surgeon must realize that there is bone loss associated with the index arthroplasty, additional bone loss associated with the TKA failure, and further bone loss from component removal at the time of revision arthroplasty. Further resection could result in decreased metaphyseal bone strength and a decrease in the tibial component size which can increase contact forces on the tibia. A study by Harada demonstrated an abrupt decrease in tibial bone strength after 5 mm of resection from the joint line [31]. Consequently, removal of substantial bone should be limited, and no more than 1–2 mm should be resected at the time of revision [23]. Cortical implant contact and stem augmentation can help remedy the weakened bone encountered with tibial bone resection at the time of revision surgery. Metaphyseal cones are creatively a relatively new way to augment metaphyseal bone loss as well.

Component Shift

The surgeon can consider shifting the tibial component to areas with greater bone stock to avoid small osseous defects (<5 mm). This is of limited value in larger defects because significant shifts in the component placement can have deleterious effects on ligament kinetics [23]. Additionally, a study by Lee suggested that the tibial tray not be shifted more than 3 mm medially, and Daines and Dennis recommend no more than 2 mm lateral shifting of the component [23, 32]. In addition, shifting the component more than 3 mm which results in implant-bone overhang can result in pain. Additionally, the use of offsets in the tibia can create complex problems in implant removal should the knee need revision in the future.

Cement Reconstruction

Polymethyl methacrylate (PMMA) cement, with or without the use of screws, is another option for smaller bony defects. This is often indicated in peripheral defects of ~10% or less of the total condylar surface [33]. This is a simple and economical fix for smaller osseous defects, but is not a good option in larger defects (>10 mm) [23]. There are several pitfalls related to using PMMA when managing bony defects. First, large masses of cement create a significant exothermic reaction that can lead to osseous necrosis. Secondly, during the curing process, PMMA can lose 2% of its volume resulting in some collapse and loss of

support [34]. This loss of volume will be accentuated with larger masses of cement. Lastly, PMMA has demonstrated inferior load transfer properties than metal augments and should be avoided in larger defects [34]. If used in the small defects, PMMA has demonstrated good results in primary TKA. Ritter demonstrated 13 of 47 primary TKAs with bone defects treated using PMMA with an average of 6.1 years of follow-up had evidence of radiolucent lines on radiographs but no progression to component loosening [35].

Prosthetic Augments

Metal prosthetic augments are useful in uncontained type IIA defects and type IIB (bicondylar) defects of moderate size >10 mm [36]. Tibial augments come in a variety of shapes including both full and hemiplateau blocks and angular wedges with sizes that typically range from 5 to 15 mm. These augments allow alteration to both the flexion and extension gaps by permitting the filling of bone defects and placement of the implant closer to the joint line.

Femoral Bone Loss

The AORI classification system applies to femoral bone loss as well. Minor defects in the condyle can be filled with morcellized graft or femoral augments [36]. Femoral augments are generally block shaped and can increase by increments of 5–20 mm in size depending upon the implant system used [36]. When comparing prosthetic augment wedges to blocks in a biomechanical study, blocks were more stable and have been shown to have superior strain distribution from the implant to the underlying supporting bone [37, 38]. These augments can be applied quickly, allow for intraoperative custom modifications, offer excellent biomechanical properties, require very little initial bone resection, and are effective at restoring the joint line in revision settings [36]. They have been used with generally good success rates with 84–98% good to excellent results in several series [24, 33, 36, 39].

Localized Impaction Grafting

Morcellized autograft or allograft can be used to fill small contained lesions (type I or II) and is a good option in younger patients where restoration or preservation of host bone stock is preferable [40]. This has shown good results at midterm follow-up with several studies demonstrating new osseous trabeculation at the graft site and stable fixation of the components [27, 40–42]. More recently, some centers have advocated the use of impaction grafting for large uncontained defects. These centers use a wire mesh to transform the uncontained lesion into a contained defect for the impaction grafting. The early results with this technique are promising; Lonner used this technique in 14 revision TKAs with large uncontained defects and demonstrated significant improvement in knee society scores with an average increase in 47 points and no revisions at 2 years of follow-up [27, 43].

Structural Allografts

Structural allografts are a common option for large uncontained type II defects that are too large for augmentation alone and some type III defects. Dorr recommended using structural allografts in tibial defects affecting greater than 50% of the tibial plateau [40]. Femoral head, distal femoral, or proximal tibial allografts are the most commonly used allografts for large bone defects in revision TKA (Fig. 16.2). They provide

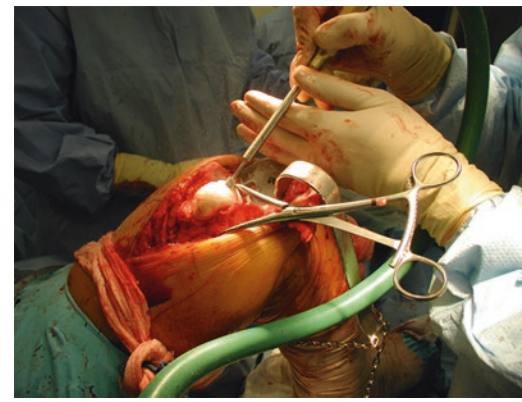

Fig. 16.2 Allograft used to replace lateral femoral condyle

the advantage of potentially restoring bone stock and are customizable at the time of surgery. Unfortunately, they are technically challenging to use, and bony incorporation takes a substantial amount of time and may never completely incorporate. Additionally, there is a very small theoretical risk of disease transmission [44]. The technical keys to large allograft reconstructions include developing a healthy, bleeding host bone interface to accept the graft, maximizing the host bone-allograft bone contact, and achieving stable fixation, which is often difficult to obtain [23]. Despite having a high complication rate for these cases reported in the literature, there are several studies that have demonstrated a high rate osseous integration when stable fixation is obtained at the time of reconstruction with implant survival rates ranging from 75 to 93% with medium- to long-term follow-up [25, 26, 45, 46]. Many of these defects will be managed by metaphyseal cones in the future.

Metaphyseal Cones/Sleeves

Large central contained cavitary or combined cavitary-segmental defects in the femur or tibia can be treated using metaphyseal sleeves or porous cones. The ultimate advantage of these devices is the long-term biologic fixation and avoidance of nonunion, resorption, and collapse of the structural allografts used in revision TKA [47]. Porous metal cones achieve ingrowth, and any type of revision prosthesis can be cemented to the center surface. Porous cones are modular in nature and allow the surgeon to choose a size and position that will best fit the defect. Metaphyseal sleeves are implant specific and are not as customizable as the porous unlinked cones. The primary difference between titanium or trabecular metal cones and sleeves is at the implant interface. Metaphyseal sleeves utilize a morse taper junction with the prosthesis rather than cement as with the unlinked tantalum or titanium cones. Results have been good in regard to osseous integration and implant stability for both cones and metaphyseal sleeves. One group followed 16 patients for 31 months after using tantalum cones for reconstruction and had no failures due to aseptic loosening [48]. Meneghini also followed 15 patients that had cones placed at the time of reconstruction for an average of 34 months with no reported failures [49]. Midterm data for the use of metaphyseal sleeves has also demonstrated good osseous integration with few failures [50, 51].

The surgical technique for tantalum or titanium cone placement begins with good exposure to adequately assess the bony defect of the metaphysis of the tibia and/or femur and the need for metaphyseal cone fixation. The most common scenario is a severe contained or uncontained osseous defect of the medial plateau or condyle with some degree of lateral plateau or condyle bone loss but with enough lateral bone present to provide some support. In more severe cases, both plateaus and condyles have large defects and the tapered shape of the cone creates an interference fit with the remaining cortical bone to provide all the structural support [47]. A trial stem or a reamer may be used to help align the finishing cut and to ensure proper position of the cone in the metaphysis. Once the correct size and shape is selected from the trial cones, specialized reamers or a high-speed burr are utilized to contour the metaphyseal bone to match the cone. Newer stem and reamer-based instrumentation has been developed to machine for the cones. Stability of the cone is achieved in two different ways: creating a press-fit wedge or by resting on intact bone distally. The cone is then impacted into place using an impactor. Once the cone is impacted into position, the surgeon may now insert the tibial tray and stem or femoral trial and stem to allow assessment of joint alignment, joint line height, stability, and motion. The central portion of the cone creates an artificially reconstituted proximal tibial metaphysis or distal femoral metaphysis that is receptive to cementation at the time of final implant positioning. Any remaining voids/defects around the periphery of the cone can be filled with morcellized cancellous bone graft and/or augments and cement.

Condyle-Replacing Hinge Prosthesis

Massive type III defects with loss of collateral ligament integrity often require a hinged prosthesis and should be considered, particularly in older, low-demand patients. The most significant advantage to using this technique is reduced sur-

gical time and early fixation with the ability to mobilize the patient immediately postoperatively. These implants can also address bone and soft tissue defects that other implant systems cannot treat. It is generally wise to have a hinge implant system available as backup whenever tackling more than the simplest revision case.

Trial Cutting Guides in the Performance of Revision Total Knee Replacement

A trial cutting guide is a cutting guide which is shaped like a trial femoral implant. The guide is sized and shaped like the final implant but has cutting slots or surfaces that permit the performance of augment and/or box cuts through the trial (Fig. 16.3). These devices permit a trial reduction to be performed before the resections and, more importantly, allow the resections to be performed while the guide remains in place. Such devices permit evaluation of the flexion and extension gaps before bone resection and allow more reliable determination of bone loss versus soft tissue integrity. This permits selection of the appropriate augments required to establish a stable implant construct at the time of revision arthroplasty.

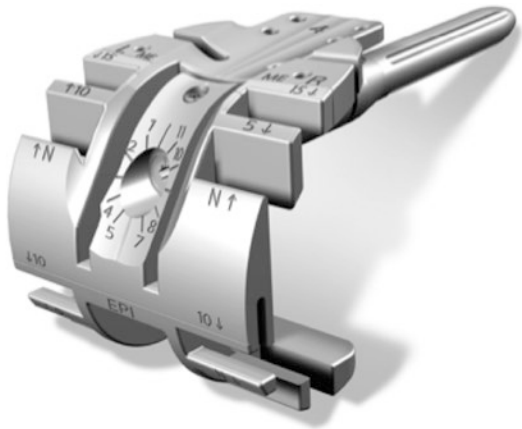

Fig. 16.3 Stryker Triathlon trial cutting guide with offsetting capability, augment cut surfaces, and box cut surfaces. The cuts can be made 5 mm increments supporting augments up to 15 mm at both the distal femur and posterior condyle. This allows one guide to perform all resections leading to improved accuracy and reproducibility

Surgical Technique: Trial Cutting Guide

Prior to incision, it is important to establish the collateral ligamentous integrity with an exam under anesthesia. This information is helpful and may indicate the level of constraint needed for the revision implant. Loose implants can mimic ligament instability, and thus the exam should be performed both before and after arthrotomy. As in all revision TKAs, good exposure is critical to successful surgery and safe removal of the previous implants. The implants should be removed carefully to avoid damage to the collateral ligaments, excessive bone loss, or damage to the extensor mechanism.

Once the implants are removed, the initial bone cut should be made at the proximal tibia and should be minimal to preserve host bone. Typically, a neutral proximal tibial slope resection is made, unless dictated differently by the revision implant being used. Sloped cuts in the revision situation can create asymmetric flexion and extension gaps and can be difficult to perform in the face of variable bone loss. Intramedullary-based cutting guides can significantly increase the accuracy of the cut. From a practical standpoint, cutting the tibia first gives the surgeon a platform to place the tibial tray and then control the extension gap and the flexion gap and provide a reference for femoral rotation. Trial inserts can be used to estimate the joint line in conjunction with a trial cutting guide (Fig. 16.4).

The author (MAM) prefers the Stryker trial cutting guide due to its functionality, but several companies offer similar devices (Fig. 16.3). The advantage of trial cutting guides is that they permit evaluation of all of the essential parameters of revision TKA before making a resection—the extension gap, flexion gap, femoral rotation, the joint line, bone loss, ligament laxity, patella position within the trochlea, and even patella tracking. Only once these parameters are evaluated are the resections performed. Because the cuts are performed with a single guide which remains in place, enhanced accuracy and reproducibility of the resections are possible.

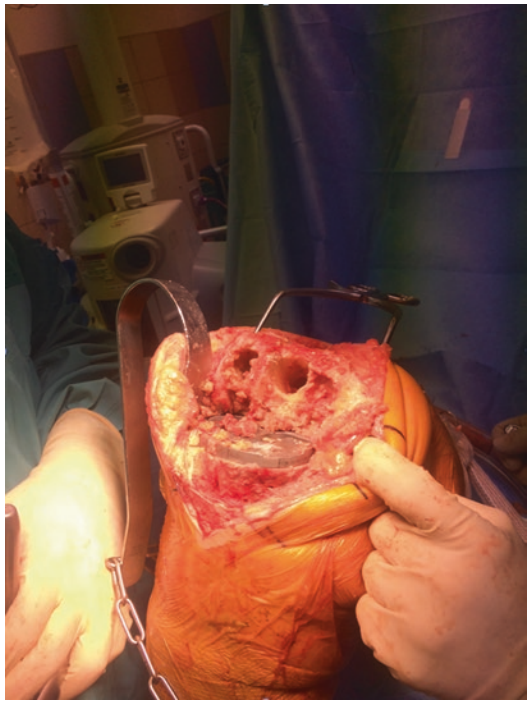

Fig. 16.4 Type 2A femoral defect based on the AORI classification. The tibia has been cut with a neutral slope, and a tibial component is placed. This technique allows for better control of the extension and flexion gaps as well as judging femoral component rotation

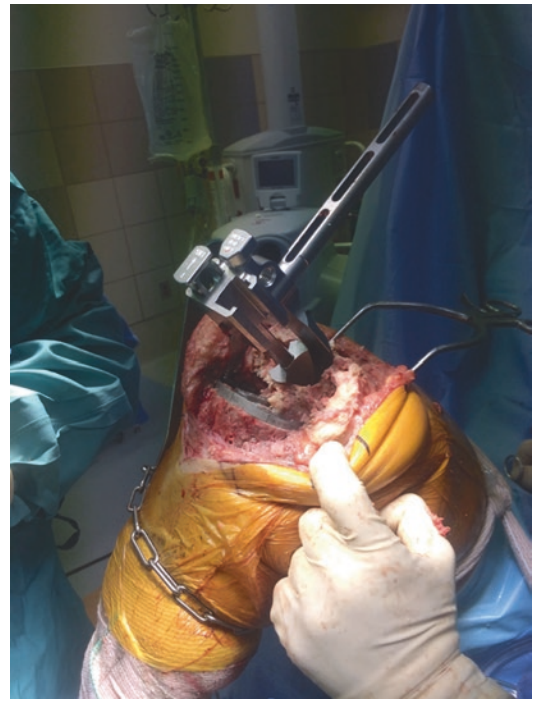

Fig. 16.5 Intramedullary-based instrumentation for femoral cone preparation

The trial cutting guide may be used in different ways depending upon the revision scenario in question. Aseptic loosening with an intact soft tissue sleeve is arguably the easiest revision situation and addressed in a relatively simple manner. The tibia is prepared first (Fig. 16.4), a resection performed, the trial tibia and stem placed, and then a femoral cutting guide the same size as the femoral component removed (provided it was the correct size for the patient) is placed on the distal femur after reaming. Reaming should be initiated as posterior as possible within the canal so the flange of the femoral component is against the anterior cortex. In this manner the entire femoral component is used to "fill the flexion space." This principle should be followed in all revision scenarios. The distal femur could then be prepped to accept a femoral cone, if needed. This is accomplished by using intramedullary-based instrumentation for femoral cone preparation (Fig. 16.5).

The ME (medial epicondyle) line should be placed at the apex of the medial epicondyle (Fig. 16.6). This sets the proximal/distal position of the femoral component. An additional reference would be the proximal pole of the patella at the superior aspect of the implant trochlea (provided no patella baja or patella alta exists). Once positioned, a trial insert of the appropriate thickness to maintain full extension is placed. The extension space is "filled" when the tibial insert and femoral component are positioned to maintain the knee in full extension. The MCL, LCL, gastrocnemius tendons, and hamstring tendons provide soft tissue support. The flexion space is maintained by the appropriate-sized femoral component on the tibial insert of the thickness needed to reestablish the joint line and to set the femoral rotation (Fig. 16.7). The posterior capsule provides the soft tissue support. The gastrocnemius tendons and hamstrings provide no support in flexion, and thus gap balancing in cases of midflexion instability and flexion space disruption of the capsule or extensive synovitis

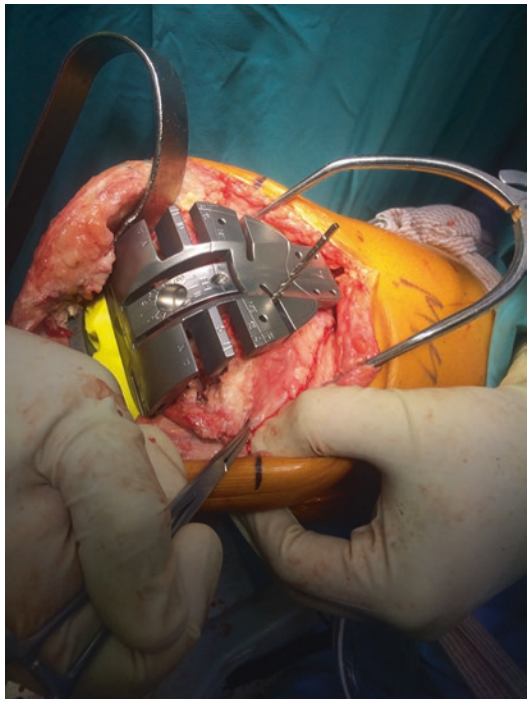

Fig. 16.6 The ME laser-etched line should be placed at the apex of the medial epicondyle as demonstrated by the location of the hemostat in this picture. This sets the proximal/distal position of the femoral component

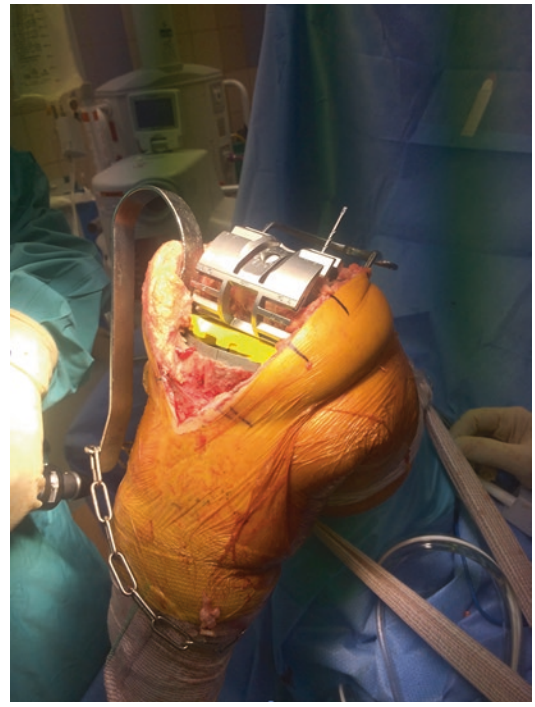

Fig. 16.7 Once the trial cutting guide is placed, a tibial insert is used to fill the extension space. This technique can also be used to judge the femoral rotation with the trial cutting guide as demonstrated in this image. Once the rotation is set following several flexion/extension cycles, the cutting guide is pinned in place to make the femoral cuts

can be particularly challenging in revision TKA. Once positioned in the proximal/distal dimension, the cutting guide is fixed through a stabilization slot.

This technique creates a more reproducible way of recreating the appropriate femoral rotation than when using anatomic landmarks alone (Fig. 16.7). In primary cases, the surgeon will use anatomic landmarks such as Whiteside's line or the transepicondylar axis to judge femoral rotation. In revision cases, Whiteside's line may not be present due to the previous bony resections, and the transepicondylar axis is often difficult to determine due to bone loss or significant scarring from the index procedure. If the transepicondylar axis is identifiable, it can be used as a secondary check to confirm the correct femoral rotation [52, 53]. Once the correct rotation is identified, the trial cutting guide is pinned in place through a stabilization hole, and the augment cuts are made. It should be understood that the tibial cut is used as the reference for rotation of the femoral component. The stemmed trial cutting guide can rotate within the femoral canal (occasional trimming of the anterior or posterior femur may be required), and the ligaments are tensioned at their proper tension before fixing the rotation of the trial cutting guide through a pin hole as opposed to the initial fixation through the proximal/distal fixation slot.

The use of a trial cutting guide allows these steps to be performed simultaneously, before making any cuts on the distal femur. If there is flexion/extension mismatch, then a different-sized femoral trial cutting guide is placed (usually a larger component). This is a particular advantage in cases of flexion and midflexion instability. The femoral cutting guide essentially serves as a decision-making guide. The appropriate augment thicknesses are easily determined

Fig. 16.8 The trial component is assembled on the back table with trial augments based on the augment cuts from the trial cutting guide (no augment, 5 mm augment, 10 mm augment, 15 mm augment). A trial cone was used in this example to assure good fit. Once assembled, the trial cutting guide is removed, and the trial component is inserted and used to assess for gap balancing and varus/valgus stability. Once trialed, the final component can be assembled based on this trial component

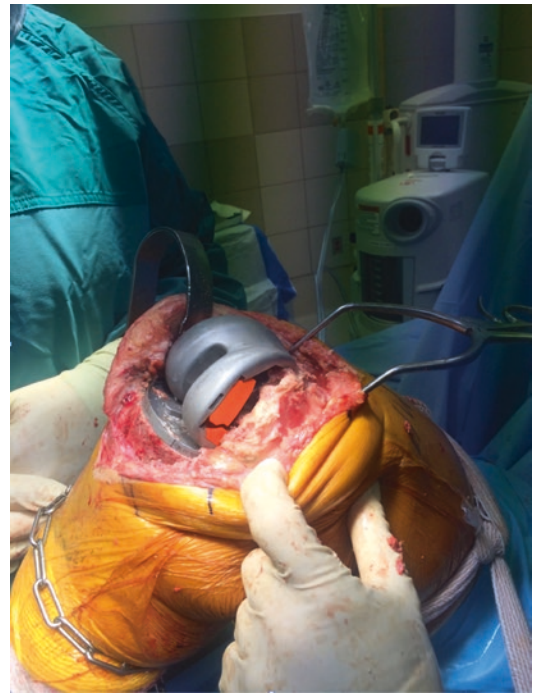

Fig. 16.9 The assembled trial implant is inserted and lightly impacted into position. A non-varus/valgus constrained liner will be used to get an accurate assessment of the collateral tension and integrity

and completed. The box cuts can also be performed with the guide in place adding accuracy to the cut surfaces as they are completed by a single guide. A separate trial femoral implant is assembled with any augments attached and used to confirm the cuts are accurate, and the ultimate insert thickness that will be used to achieve flexion and extension stability is assessed at this time (Fig. 16.8).

Final testing of the trials should be done with non-varus/valgus constrained inserts to get an accurate assessment of the collateral tension and integrity (Fig. 16.9). The author (MAM) uses primary insert trials without a post for all revisions to try to establish a stable implant/soft tissue envelope construct prior to performing the cuts and after the trial femoral implant is assembled. Once satisfied with the trial components, the final implant can be assembled on the back table to match the trial component. The trial components are removed, and the final cone implant is impacted into position to prepare the distal femur for the implant (Fig. 16.10). The final implant is then cemented into position using a hybrid cement fixation technique (Figs. 16.11 and 16.12). Only after the final implant is assembled is the ultimate insert thickness and constraint selected. Additionally, it is important to test for both AP stability and jump height [19]. There will be situations in which a revision TKA cannot achieve appropriate balance. In these cases, the use of constrained implants should be considered. Ultimately, the surgeon should not leave the operating room without either obtaining a balanced revision TKA or compensating for imbalances with a constrained implant. A hinge backup should be available whenever performing major revision TKA surgery.

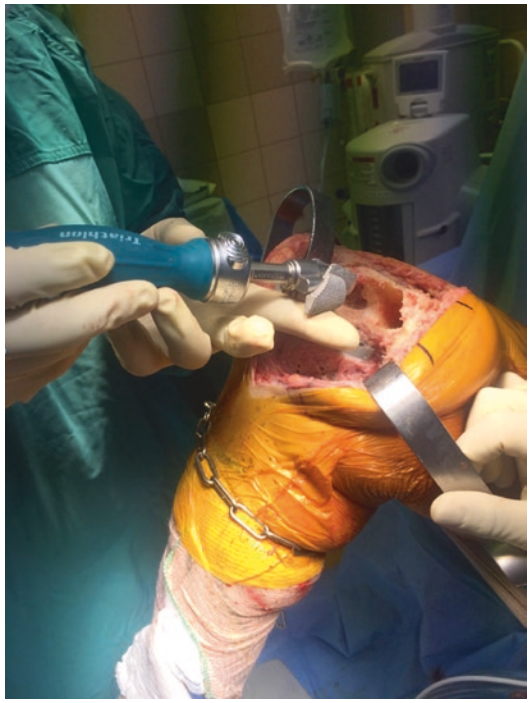

Fig. 16.10 Insertion of the final conical femoral implant. This is impacted into position into the prepared canal to allow for a solid foundation for implant fixation

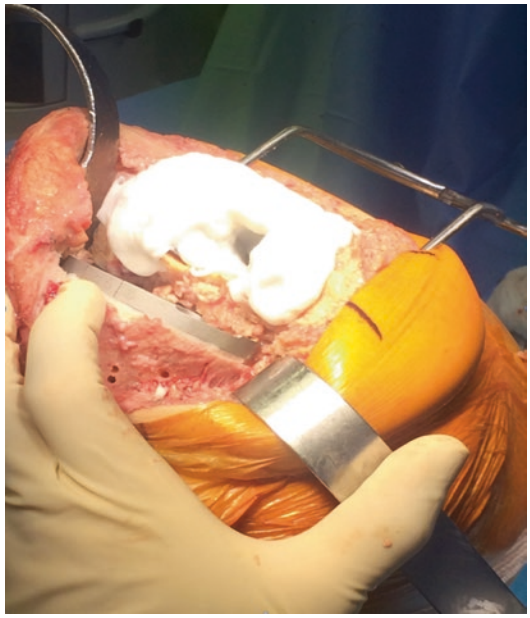

Fig. 16.11 Hybrid cementing technique of a revision femoral component

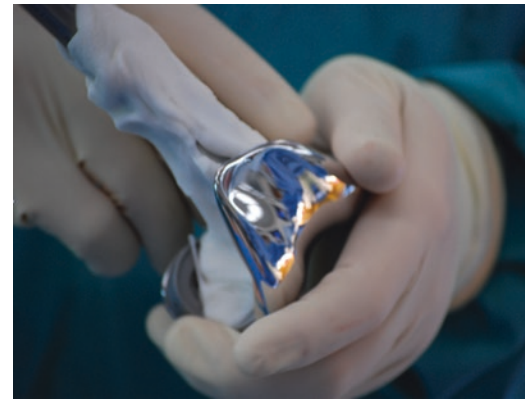

Fig. 16.12 The final component is cemented into position. Cement is applied liberally to cover the entire stem and the posterior aspect of the femoral component. No cement plug is used, and care is taken to not allow cement distal to the tip to facilitate easier removal if ever needed in the future. Also, minimal cement is used on the posterior condyles to prevent cement extravasation posteriorly which can be very difficult to remove

Joint Line Management in Revision Total Knee Arthroplasty

Joint line restoration when performing either primary or revision TKA has been shown to be important to the clinical outcome of the surgery. Figgie demonstrated inferior clinical results in primary TKA with an elevation in the joint line of greater than 8 mm [54]. Partington also described this same threshold of 8 mm in revision TKA [55]. Restoration of the joint line is often very difficult in complex revision settings when normal anatomic landmarks are not as evident intraoperatively. The most cited method to identify the correct joint line height was described by Figgie in 1986 [54]. In this study, they described measuring the distance from the top of the tibial tubercle (TT) to the top of the tibial component on the lateral knee x-ray and compared this to the preoperative films [54]. One major criticism of this method is that many times the revision surgeon does not have the native knee films to compare this to. Other groups have advocated using the epicondyles as the reference point and considering the ratio of the distance between the medial epicondyle and the joint line tangent to the transepicondylar width of the femur [56].

Masini and colleagues used radiographs, cadaveric measurements, and measurements at the time of primary TKA to identify the joint line as being 28 mm distal to the apex of the medial epicondyle. Servien advocated restoration of the joint line to the previously reported epicondylar radiographs of 0.28 (0.23–0.34) on the lateral side and 0.34 (0.28–0.42) on the medial side based on an MRI study of 200 native knees [57].

A variety of other landmarks can be considered to help restore the joint line in revision settings. The joint line sits approximately 1.4 cm proximal to the fibular head and 3 cm below the medial epicondyle and 2.5 cm below the lateral epicondyle [58], though using the fibular head as a landmark has been shown to be unreliable as a primary measurement because of the significant variation among patients [57]. Additionally, there are limitations with using the epicondyles for a reference point as they may not be present in cases with significant bone loss [59]. In complex cases where this may be evident, Iacono advocate using the ratio between the distance from the adductor tubercle to the joint line and the femoral width, as described in their paper, to restore the proper joint line [59]. While there is agreement in the literature regarding the importance of joint line restoration for knee function and good clinical outcomes, the best method of establishing the joint line in the revision setting has yet to be determined. Consequently, it is important for a revision arthroplasty surgeon to have familiarity with a variety of these methods to ensure the best chances for joint line restoration during a revision TKA.

Fixation in Revision TKA

Fixation of the components in the revision setting is critical to the long-term success of the surgery. Unfortunately, there is no clear answer in the literature to guide the surgeon on which type of fixation is the best option. Ultimately, the goal of stem fixation in the revision TKA is to enhance the mechanical stability of the construct, provide a load-sharing support for the host bone, and to protect host bone or allograft bone. The current options available for stem fixation include cemented and uncemented stems [19]. Both options are able to bypass metaphyseal defects and provide metaphyseal and/or diaphyseal fixation and create a load-sharing construct to help stabilize the prosthesis. The main advantage of cementless fixation over cemented stems is easier removal if a future revision is required. This is often combined with cemented metaphyseal tibial and femoral components resulting in the technique termed hybrid fixation (Fig. 16.12) [60]. The major disadvantage of cementless stems is the reliance on good diaphyseal bone stock, and fixation may be limited in patients with poor bone stock. Additionally, the diaphyseal-engaging stem can dictate the placement of the components and result in malpositioning of the femoral and tibial components and often necessitates the use of offset stems to avoid this complication [19]. Diaphyseal stems are also associated with a higher incidence of "stem tip pain" which can be difficult to treat. Cemented stems provide immediate fixation, and the component positioning is not dictated by the stem. The major disadvantage is the difficulty of cement removal if another revision is required. In addition, the bone cuts performed must provide a stable interface prior to cementation to avoid malposition at the time of cementing. Results for both types of fixation have been generally good with survivorship for aseptic loosing being >95% at ~11-year follow-up for the cemented stems and 71–93% with short- to midterm follow-up for the cementless stems [24, 61–65]. There are biomechanical studies in the literature that suggest that cemented stems may be favorable with significantly decreased micromotion in the fully cemented constructs compared to cementless stems [66, 67]. Additionally, a study by Fehring concluded that cementless diaphyseal-engaging stems were significantly more unstable than cemented stems with long-term follow-up (>53 months) [61]. Survivorship of cemented stems was 93% versus 71% for the cementless stems in this study [61]. Currently, there is no definitive answer regarding the best method of stem fixation. Some studies suggest that cemented stems provide a more stable construct, but if

cementless stems are used, it is evident that they must be diaphyseal engaging. Regardless of fixation method, stems should be utilized in high constraint implant systems to achieve a more stable construct. (Malkani and Masini—hybrid).

Constraint

Most revision TKAs can be made stable using either deep-dished polyethylene or PCL-substituting implants. Constraint is a tool utilized by surgeons to substitute for incompetent soft tissues around the knee. This results in increased stress on the implant and at the implant-bone interface and may result in early failures. Because of this, the implant with the least amount of constraint necessary to obtain a stable construct should be used [5, 68]. Currently there are five different degrees of stability available for the surgeon: PCL-retaining arthroplasty, PCL resection arthroplasty with deep-dished polyethylene, PCL-substituting arthroplasty, total stabilized (TS) or condylar-constrained arthroplasty (CCK), and hinged arthroplasty. PCL-retaining arthroplasties are rarely used in the revision setting but could theoretically be considered in early revisions of failed unicondylar knee replacements. It necessitates an intact PCL and collateral ligaments to function.

Some first-time revision cases can be managed with PCL resection arthroplasties with deep-dished polyethylene liners or PCL-substituting arthroplasties. PCL insufficiency after cruciate-retaining TKA is a cause of dissatisfaction for many patients and can be corrected with either of these implant options [19]. These patients may not present with "instability", instead they may complain of anterior knee pain due to extensor mechanism overuse and dysfunction. Several studies have shown inferior results when using primary implants in a revision scenario, and they should be used with caution and definitive goals.

Mediolateral instability is a larger problem and usually requires increased levels of constraint. It is first addressed with appropriate soft tissue balancing as constraint cannot substitute for this step. Most often, the MCL competence is what dictates the amount of constraint necessary to achieve a stable revision TKA. A lax or completely incompetent MCL necessitates a TS/CCK or hinge implant to provide stability. TS/CCK implants have a taller and wider post that is highly congruent with the femoral box resulting in increased mediolateral and rotational constraint. Because of the increased constraint, the TS/CCK knees have increased stresses at the implant-bone interface though several studies have shown good results with ~5-year follow-up [69, 70]. Excessive stress to TS posts in the revision scenario must also be considered. There have been several recent studies indicating post breakage and wear, and thus posts must be considered as augmenting the soft tissue envelope, not replacing it (Fig. 16.13). Consideration for more rotational freedom in a TS insert that provides varus/valgus constraint makes intuitive sense as well. Barrack describe four criteria that must be met to consider a TS/CCK implant in a revision setting with mediolateral instability: (1) flexion/extension gap difference of less than 10 mm, (2) the ability to restore the joint line within 10 mm of the physiologic joint line, (3) the ability to reconstruct the femur in the AP dimension, and (4) some degree of collateral ligaments must be intact. If all four of these criteria are not met, a hinge implant should be selected (Figs. 16.14 and 16.15) [19, 71]. Other indications for a hinged implant include global instability, severe bone loss as a result of a periprosthetic

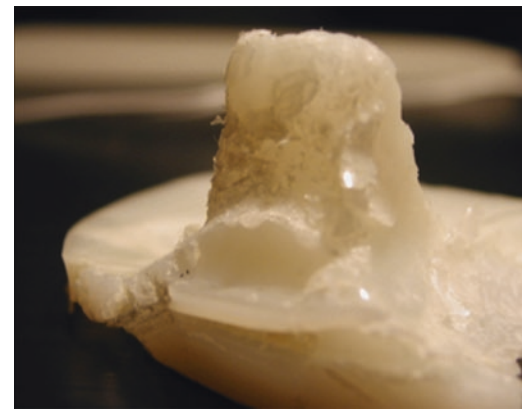

Fig. 16.13 Constrained post exhibiting extreme wear

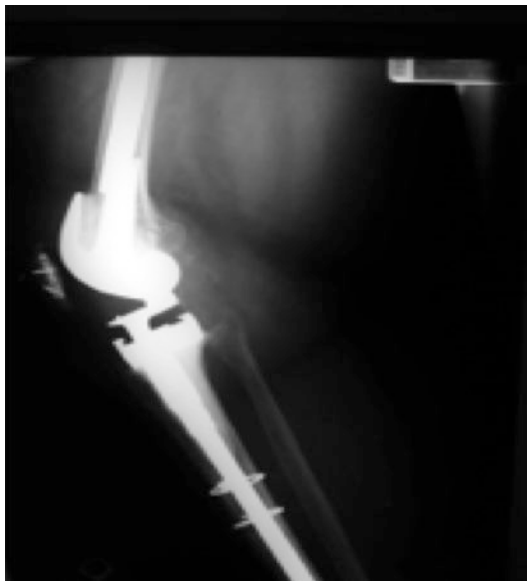

Fig. 16.14 Hinged implant to address combined soft tissue and bone loss. The patella is positioned at proximal femoral trochlea in extension

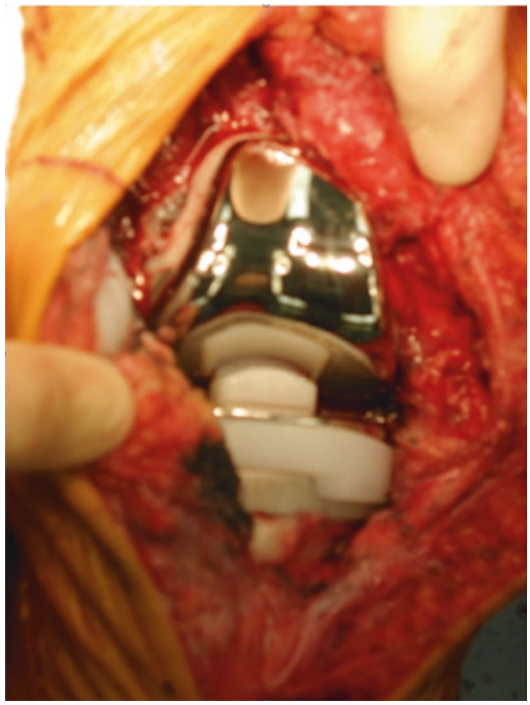

Fig. 16.15 Modular rotating hinge implant in position

fracture, nonunion or malunion, or a failure of an appropriately positioned TS/CCK knee [19, 68]. If used for the correct indications, hinged implants have been found to have good results with long-term follow-up (no revisions at 65 months) in one study [72]. These should all be used in conjunction with a stemmed implant to help control the amount of stress seen at the bone implant interface.

In a patient with an unstable TKA, revision to a constrained implant can greatly improve their clinical outcomes. It should be selected carefully with clear indications for higher levels of constraint and whenever possible the surgeon should select the implant with the least amount of constraint necessary to achieve a stable, well-functioning knee arthroplasty.

Summary

The management of failed TKA can be challenging, but with a systematic approach that includes a thorough history and physical examination along with radiographic examination, the etiology of the TKA failure can often be determined. The cause of failure is what ultimately dictates what must be done in the revision TKA. This same stepwise and systematic approach to the operation is paramount to success in the revision setting. Having a thorough understanding of these principles provides a foundation for the arthroplasty surgeon to address complex revision TKA cases with successful results.

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III

Special Considerations

Infection in Total Knee Arthroplasty

17

Abraham D. Kim, Samir Mehta, and Jess H. Lonner

The specter of deep infection continues to temper the optimism regarding total knee arthroplasty (TKA), despite an incidence of less than 1–3% [1–3]. Infection after TKA is a topic of interest because of its diagnostic challenges, requisite intensity of care, and compromised outcomes. Efforts at reducing the rate of infection have allowed the identification of significant risk factors and the establishment of protocols for prevention [4, 5]. Substantial progress has been made in the approach toward the diagnosis and treatment of the infected TKA [6].

The primary goal of treatment in most patients with an infected TKA is the eradication of the infecting pathogen. Efforts aimed at achieving this goal should ideally result in a painless and functional extremity; however, function is occasionally sacrificed to clear the infection.

The cost of treating the infected TKA can be a burden for the patient, surgeon, hospital, and society. Kapadia et al. [7] compared the cost of care between those who underwent a two-stage revision for a periprosthetic infection and a matched cohort who underwent uncomplicated TKA in Baltimore between 2007 and 2011. Infected TKAs required a mean annual cost about four times higher compared to that of primary TKAs, requiring significantly longer hospitalizations, more readmissions, and more clinic visits. The annual cost associated with revision surgery for periprosthetic joint infection (PJI) in the United States increased from $320 million to $566 million between 2001 and 2009 and is projected to exceed $1.62 billion by 2020 [8]. This chapter reviews the currently available options for the diagnosis and management of infected TKAs.

Risk Factors for Infection

TKA infections are primarily the result of bacterial infections, which gain access to the knee intraoperatively or hematogenously, but fungal and viral infections have also been reported [9]. Host factors play a critical role in the establishment of infection. The immunocompromised state refers to a gradient of immune dysfunction, ranging from severe leukopenia to the more subtle effects of malnutrition. Leukocytes are instrumental in warding off infection, and any disease process affecting leukocyte count or function potentially increases the susceptibility of a TKA to infection [10, 11]. Relatively recent evidence also suggests that the local synovial environment provides protection from infection by producing

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defensins, a family of antimicrobial peptides [12, 13]. Although the role of local defense has not been completely elucidated, further research may prove that its dysfunction is also a form of immunocompromise.

During a TKA, possible sources of contamination include the operating room environment as well as the patient's own skin. Sterile techniques, iodophor drapes, laminar flow, and self-contained exhaust suits, among other things, attempt to minimize infection by addressing these sources of bacterial contamination, but the most important element is 24–48 h of antibiotics, with the first dose given approximately 30 min before TKA. Bacteremia from any invasive procedure or chronic infection may also gain hematogenous access to the site of TKA. Dental, urological, gynecologic, gastrointestinal, and podiatric procedures may all cause a transient bacteremia. Distant infection, such as chronic ulcers, dental abscesses, cellulitis, and urinary tract infections, may also provide a source of organisms for the infection of TKAs. In the absence of obvious sources, one must be concerned of occult sources of bacteremia, such as endocarditis, that have systemic implications.

Overall, *Staphylococcus aureus* and *S. epidermidis* are the most commonly implicated organisms infecting TKA. In a review of 590 infected TKAs [14] comparing debridement versus direct exchange for the treatment of infected TKA, the most commonly infecting organisms were *Staphylococcus aureus* (48.7%), *Staphylococcus epidermidis* (16.3%), polymicrobial (5.4%), *Pseudomonas* (5.1%), *Streptococcus* (4.8%), *Enterococcus* (4.5%), and others (15.2%). However, specific clinical scenarios are often associated with particular types of organisms [6]. For example, early superficial infections tend to involve a high proportion of *Staphylococcus epidermidis*, while hematogenous infections often involve streptococcal organisms. Fungi have rarely been found to infect a TKA. Unlike native joints, infected more commonly by *Coccidioides immitis*, *Blastomyces dermatitidis*, and *Sporothrix schenckii*, TKA infections more commonly involve candidal infections [15].

The ability of bacteria to form *biofilms* has been implicated as a factor that impedes our ability to treat PJI. A biofilm is a bacterial aggregate that is protected by a slimy layer of polysaccharide and protein matrix [16]. Intercellular signaling molecules have been shown to provide a form of primitive communication that enables the formation of these bacterial communities [17]. Bacterial survival is enhanced within a biofilm, which not only serves as a barrier to the human immune system but also protects against the diffusion and activity of antibiotics [18]. When inhabiting a biofilm, organisms are shielded from the immune system and may survive without causing symptoms, although they may serve as a nidus for future infection. The exact conditions [19] that promote biofilm formation and methods of overcoming them have not been completely described.

Bacteria may also develop resistance by undergoing genetic changes that ultimately inactivate or block antibiotic action. Resistance in this form is usually specific to a certain type of antibiotic, as is demonstrated by vancomycin resistance and methicillin resistance. Resistant organisms are more difficult to eradicate because the antibiotics available for their treatment are fewer in number, often more difficult to administer, and sometimes not tolerated by patients. Antibiotic resistance is a concerning trend that has been associated with a higher rate of treatment failure. Salgado et al. [20] found that patients with methicillin-resistant *Staphylococcus aureus* PJI had longer hospital stays, higher risk of treatment failure, and greater need for hardware removal when compared to matched patients with methicillin-susceptible infections. It is hoped that the development of improved treatment strategies and novel antibiotics will improve our ability to treat TKAs infected with resistant organisms.

Host Risk Factors and Host Classification

The host immune status has a tremendous influence on susceptibility to infection and the eventual response to treatment. Immunocompromise

may consist of an obvious deficiency to the immune system, such as neutropenia or hematologic malignancy. Alternatively, the more subtle effects on the immune system caused by conditions such as malnutrition, tobacco use, and advancing age may also result in states of immunocompromise. The identification and optimization of host factors are important for planning appropriate treatment. Furthermore, host factors should be considered when discussing the expectations and risks of TKA with the patient.

The maintenance of proper homeostasis in the local anatomic environment is critical to provide adequate defense against infection. At a microscopic level, tissue blood flow, oxygen tension, and cellularity are all factors that support local defense. Macroscopically, sufficient soft tissue coverage of the prosthesis is necessary to prevent skin breakdown and contamination. A vast number of local changes may compromise the ability to ward off infection. Areas of reduced blood flow and oxygen tension may result from skin bridges between multiple incisions, arterial disease, and venous stasis. Previous soft tissue injuries, fractures, and irradiation cause changes to the local tissue composition. Abscesses, sinuses, and active infections compromise local tissue coverage and may provide a nidus for reinfection.

Systemic illness is also associated with an increased susceptibility to infection. In addition to affecting local tissues surrounding a TKA, these diseases compromise the cellular and molecular responses that are critical for defense and the eradication of organisms. Systemic immunocompromise is known to result from major organ insufficiency and diseases such as diabetes, immunodeficiencies, and malignancy. Environmental influences such as tobacco use, malnutrition, excessive alcohol consumption, and certain medications (e.g., steroids, chemotherapy agents, and some disease-modifying agents of rheumatoid disease, such as methotrexate and Enbrel) are also known to compromise the immune system.

Recognizing the importance of host factors, staging systems have been created to classify patients into host groups. McPherson et al. [21] reviewed 70 patients with an infected TKA and evaluated their outcomes as a function of one such staging system. The staging system separately classified the infection type, the systemic host grade, and the local extremity grade in an effort to correlate stages with outcomes. They found that type III infections (late chronic) were associated with lower Knee Society Scores and more pain after reimplantation, in addition to more complications, when compared with type I or II infections. Poor lower extremity status correlated with a higher complication rate and amputation, while worsening systemic host grade correlated with persistent or recurrent infection and permanent resections. Cierney and DiPasquale [10] also studied the usefulness of a staging system to prospectively compare the outcomes after treatment for infected TKA. Using the osteomyelitis classification system, they classified patients based on local and systemic factors: Type A hosts are healthy and without healing deficiency, type B hosts are compromised by one or more systemic and/or local factors, and type C hosts are not able to withstand curative intervention due to concurrent illness. Of 43 patients in their study, 37 patients had wound healing deficiencies, and all were in patients with three or more comorbidities. All treatment failures, amputations, and mortalities were prospectively observed to involve high-risk patients.

Although host staging systems have not yet become standard practice, they raise an extremely critical concept that relates the patients' local and systemic health to the eventual treatment and outcome. The host-pathogen relationship defines the ability of an organism to establish a persistent infection. The identification of local and systemic host factors assists the surgeon in choosing an appropriate therapeutic intervention. For example, high-risk patients are not appropriate candidates for many of the same interventions that a healthy patient may receive. Additionally, the appreciation of host factors can help establish more realistic expectations after treatment of infected TKA or, in the most extreme cases, provide a basis for withholding TKA from certain at-risk patients [10].

Diagnosis

The timely diagnosis of infection is absolutely critical; a delay can negatively affect the ultimate outcome and impede the ability to eradicate the infection. A detailed history of the nature of the presenting symptoms can often offer clues to the possibility of infection. In the acute postoperative setting, the treating physician should be concerned about the patient who presents with delayed wound healing, ongoing discomfort, limited motion, and failure to progress; this patient may be infected. Hematogenous infections, however, often present with a less insidious course and with the acute onset of pain, swelling, and perhaps cellulitis. The presence of risk factors such as remote infections or dental, urological, or other invasive procedures should raise the suspicion for infection, although often there are no clear, identifiable associated risk factors. The presence of fevers, chills, or malaise, while uncommon in a deep knee infection, is symptoms that should raise the suspicion of infection.

Unfortunately, the most glaring signs of infection—fevers, chills, sinus tracts, and purulent drainage—are uncommon in most infected TKAs (Fig. 17.1). The more common presenting signs and symptoms—pain, swelling, warmth, and synovitis—are notoriously difficult to distinguish from aseptic failure. Nonetheless, patients who present with ongoing pain in the early postoperative period without clear reason or those patients who present with the acute onset of pain should be evaluated for the possibility of infection. As a general tenet, patients who present with acute knee pain should be assumed to be infected until proven otherwise. The majority of patients with an infected knee arthroplasty, whether acute or chronic, will have pain, although occasionally a patient presents with malaise and fatigue, in the absence of pain. The latter is a relatively infrequent presentation but one that should trigger suspicion regarding the possibility of a septic knee arthroplasty and septicemia. Cellulitis is an infrequent clinical sign, particularly in hematogenous infections, and it is often a challenge determining if the cellulitis is superficial or whether there is deep extension. As a general rule of thumb, cellulitis that is not accompanied by pain during knee motion is generally superficial and likely does not involve the deeper tissues, but aspiration of the knee joint through a non-cellulitic area should be performed in these situations.

Weight-bearing radiographs should be obtained on all patients presenting with a painful total knee arthroplasty. Radiographic signs of loosening are unlikely in the acute postoperative period or in late hematogenous infections that present acutely. TKAs with chronic long-standing infections may have evidence of loosening of the implants, but they are usually indistinguishable from those failures that occur for noninfectious reasons. Subtle findings, however, may be present with chronic infection, particularly when there is osteomyelitis, namely, endosteal erosion, reactive periosteal bone, and occasionally heterotopic ossification (Fig. 17.2).

While a variety of diagnostic tests have been advocated and used to evaluate the painful TKA, the frustrating reality is that many are inaccurate and cannot be relied on in isolation to clearly establish whether or not an infection is present. Nonetheless, when taken in concert, several studies

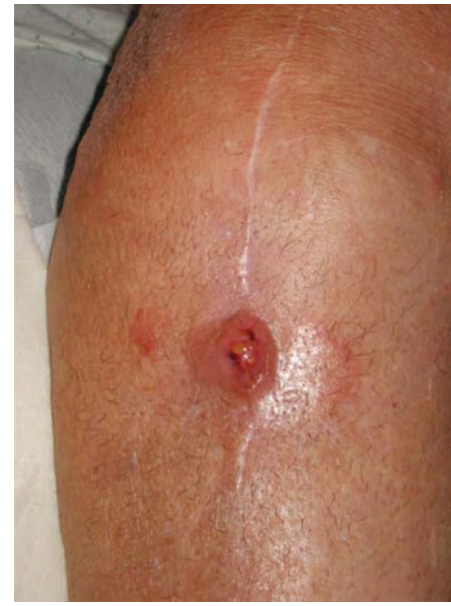

Fig. 17.1 A small sinus present around the incision several years after TKA should raise the concern regarding the likelihood of a substantial chronic late infection

can be helpful. Considering the cost of treating the infected TKA, which may be 3–4 times that of a primary knee arthroplasty, it is important that unnecessary diagnostic tests be avoided when evaluating the knee for deep infection [7]. Despite our best intentions, approximately 7–12% of deep infections after total joint arthroplasty are undetected by standard preoperative diagnostic tools [22].

Some serologic studies are more useful than others. The peripheral white blood cell count is rarely elevated in the setting of infections after total knee arthroplasty unless there is clear bacteremia. Windsor et al. [23] reported that only 28% of cases had peripheral white blood cell counts greater than 11,000 in the presence of deep knee infection. Erythrocyte sedimentation rate (ESR) peaks 5–7 days after surgery, normalizing gradually by approximately 3 months, whereas C-reactive protein (CRP) peaks 2–3 days after surgery and normalizes within 3 weeks [24, 25]. In a retrospective review of revision TKA patients, Bare et al. reported that ESR had a specificity of 63% and sensitivity of 55% for infection, whereas CRP had a specificity of 60% and sensitivity of 63% [25]. Austin et al. found that using ESR and CRP together made for an excellent screening test, with high sensitivity and negative predictive value as well as low cost in ruling out PJI after TKA [26].

Radioisotope scanning has been used in the evaluation of the painful joint arthroplasty, with variable results. Technetium scans have proven ineffective in the majority of cases, with a sensitivity of 60% and specificity of 65% [27]. In general, technetium scans are unnecessary in the evaluation of the failed total knee arthroplasty, because they are ineffective in distinguishing between mechanical and septic loosening. Technetium scans, however, may be effective in identifying occult loosening of a painful total knee arthroplasty, and a total body technetium scan might be considered in the evaluation of other joint arthroplasties to rule out metachronous polyarticular infection. Indium scans are moderately more accurate than technetium scans.

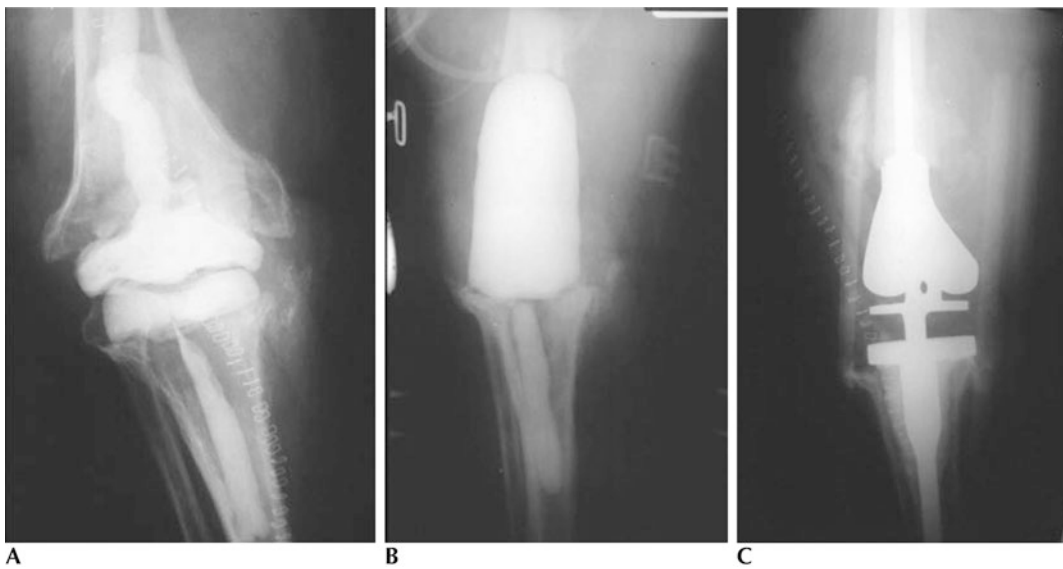

Fig. 17.2 (**a–c**) Anteroposterior radiograph of a knee after removal of an infected revision TKA and implantation of antibiotic-impregnated spacer blocks. Note the periosteal reaction of the medial and lateral metaphyseal flares of the distal femur. Intraoperative biopsies of these bony sites showed chronic osteomyelitis. Distal femoral resection was necessary to eradicate the extensive osteomyelitis of the distal femur, and eventually a hinged knee arthroplasty with distal femoral modular augments was necessary (From Lotke PA, Lonner JH, eds. *Master Techniques in Orthopedic Surgery: Knee Arthroplasty.* Philadelphia: Lippincott Williams & Wilkins, 2002, Fig. 22–29 A–C, with permission)

One study by Rand and Brown, which evaluated 38 total knee arthroplasties, found that indium scans had a sensitivity of 83%, specificity of 85%, and accuracy of 84% [28]. Scher et al. subsequently reported on 153 indium scans that were done to evaluate painful total hip, knee, or resection arthroplasties. In that series there were 41 total knee arthroplasties evaluated, and the indium scans had a sensitivity of 88%, specificity of 78%, positive predictive value of 75%, negative predictive value of 90%, and accuracy of 83% [29]. This study showed a high-percentage false-positive indium scan results in knees that were loose but not infected. It is not clear whether the tendency for false-positive scan results is related to the indiscriminant labeling of both acute and chronic inflammatory white cells, which may be present in infection or chronic inflammation of osteolysis, respectively, ongoing postsurgical inflammation, persistent joint inflammatory disease, or a combination of these factors [29]. The accuracy of indium scans may be enhanced by combining this study with a technetium-99 m sulfur colloid scan [30, 31]. The technetium-99 m sulfur colloid scan can detect increased density of bone marrow elements, which in the case of PJI are replaced by inflammatory mediators, including leukocytes, that inhibit the uptake of the technetium sulfur colloid. Matched areas on the indium and sulfur colloid scans are indicative of marrow packing and the absence of infection, thereby reducing the number of false-positive scan results [30]. In a study by Joseph et al., the combined indium/colloid scan was found to have 100% specificity, 46% sensitivity, 100% positive predictive value, 84% negative predictive value, and 88% accuracy. Sensitivity improved to 66%, negative predictive value to 89%, and accuracy to 90%, and specificity was reduced to 98% and positive predictive value to 91% when blood pooling and flow phase data were included [30]. The low sensitivity of these combined studies makes their routine use in the evaluation of the potentially infected total knee arthroplasty imprudent.

Aspiration of the knee is probably the most valuable diagnostic tool in determining the presence of deep knee infection [32, 33]. Aspirated fluid can be sent for cell count and culture. Historically, fluid and tissue cultures have been considered to be the gold standard but have since been found to result in a relatively high rate of both false-positive and false-negative results in 5–37% of cases and 2–18% of cases, respectively [34]. Recent efforts have been focused on synovial fluid analysis as a more accurate means of diagnosing potential PJI, namely, quantifying the synovial white blood cell count (WBC) and polymorphonuclear neutrophil (PMN) percentage (PMN%). Reported values have ranged from WBC counts of 1100–3000 cells/μL and PMN% of 60–73% to be used as thresholds for defining chronic infection, with an accuracy of up to 99% [34]. In the acute postoperative period, however, the threshold has been observed to be higher, with a synovial WBC count of 10,700 cells/μL and PMN% of 89% providing 92% accuracy in diagnosing acute PJI [35]. Barrack et al. observed improved the sensitivity, specificity, and accuracy of synovial aspiration if the initial aspiration was delayed at least 2 weeks after discontinuing antibiotics [36]. Clearly then, the aspiration should be delayed at least 2 weeks after discontinuing antibiotics to avoid the potential effect of suppression. The gross appearance of the fluid should be assessed as well, although turbid fluid can be found in total knee arthroplasties affected by noninfectious processes such as gout or calcium pyrophosphate disease. Also, intraoperative purulence per se was unreliable in diagnosing PJI, with a sensitivity of 82%, specificity of 32%, positive predictive value of 91%, and negative predictive value of 17% [37].

In situations where the diagnosis of infection is unclear, molecular diagnostic techniques or intraoperative frozen section histoanalysis can provide further clues regarding the presence of infection. Polymerase chain reaction (PCR) has been used to detect bacterial pathogens within synovial fluid after total knee arthroplasty. PCR amplifies bacterial DNA but unfortunately is extremely sensitive and suffers from a high rate of false-positive results [38]. Bergin et al. found that ribosomal RNA (rRNA)-based PCR helped overcome the aforementioned limitations of existing PCR techniques, demonstrating 100%

specificity and positive predictive value, with a sensitivity equivalent to that of intraoperative culture [39]. Furthermore, this novel technique detected bacterial rRNA 7 days after sterilization, potentially allowing it to identify infection even after antibiotic administration. Evolving methods to enhance the specificity of PCR and other molecular techniques will potentially make these important diagnostic tools in the future.

Histological analysis of intraoperative frozen sections can be helpful in a number of patients in whom the presence of infection is equivocal or uncertain. This method, however, has been limited by variations in histological criteria and reference standards employed to diagnose infection. The reported data are further confounded by whether the intraoperative frozen sections were obtained as a screening or confirmatory test. Histological criteria have ranged from one "inflammatory cell" per high-power field (HPF) in ≥10 HPFs [40] to >10 PMNs per HPF in ≥5 HPFs [41]. Using less stringent histological criteria would maximize sensitivity at the cost of greater false-positive results and decreased specificity, whereas more stringent criteria involving a greater number of PMN per HPF would improve specificity at the expense of sensitivity. Moreover, numeric criteria are complicated by variations in the visual field size of different microscopes, the location of the neutrophils relative to capillaries that compose granulation tissue, and the different baseline histologic appearance in patients with underlying inflammatory arthropathy [42].

Synovial biomarkers represent the most recent advancement in the ongoing efforts to more accurately and consistently diagnose PJI. Deirmengian et al. evaluated the diagnostic characteristics of 16 synovial fluid biomarkers and reported that five, in particular α-defensin 1–3, neutrophil elastase 2, bactericidal/permeability-increasing protein, neutrophil gelatinase-associated lipocalin, and lactoferrin, demonstrated 100% sensitivity and 100% specificity in diagnosing PJI as defined by the latest Musculoskeletal Infection Society definition [43]. Of these, α-defensin has garnered ongoing attention as the leading synovial biomarker in the detection of PJI. α-Defensin immunoassay outperformed the leukocyte esterase strip, whose interpretation in several samples was limited by blood interference [44]. In this study, α-defensin immunoassay demonstrated both a sensitivity and specificity of 100% for PJI versus a sensitivity of 69% and specificity of 100% for the leukocyte esterase test strip. The robustness of α-defensin was independently validated through a prospective study. Bonanzinga et al. performed the α-defensin assay on intraoperative synovial fluid samples obtained from 156 patients undergoing revision total joint arthroplasty. The results of the assay were compared to intraoperative tissue samples sent for cultures and histologic evaluation. The authors found α-defensin to be a reliable test, with a sensitivity and specificity of 97%, positive predictive value of 88%, and negative predictive value of 99% [45].

No single test, however, can identify infection in all painful or failing total knee arthroplasties. It is important that a careful history be taken in all cases and a high index of suspicion maintained. ESR, CRP, and aspiration can be invaluable in many patients.

A comprehensive and systematic approach is essential to diagnosing PJI. The American Academy of Orthopaedic Surgeons' Clinical Practice Guideline Summary contains a helpful algorithm that illustrates this principle and incorporates many of the aforementioned diagnostic tests in evaluating patients with suspected PJI [46].

Definition of Infection

Despite the myriad of diagnostic tools that have been developed and analyzed to detect PJI, a unified definition of PJI has remained elusive. This has made it difficult to standardize the diagnosis and reporting of PJI. To remedy this, the Musculoskeletal Infection Society (MSIS) convened a workgroup in 2011 to issue diagnostic criteria for PJI [47]. The MSIS definition included two major criteria, one of which would indicate PJI, and six minor criteria, four or more of which would indicate PJI. Subsequently in 2013, a consensus group convened at the International Consensus Meeting on PJI endorsed the existing MSIS definition and further refined it by adding

Table 17.1 Definition of PJI

Major criteria
Two positive periprosthetic cultures with phenotypically identical organism, ***or***
A sinus tract communicating with the joint, ***or***
Minor criteria
Elevated serum CRP ***and*** ESR
Elevated synovial fluid WBC count ***or*** ++ change on leukocyte esterase test strip
Elevated synovial fluid PMN%
Positive histological analysis of periprosthetic tissue
A single positive culture

From Parvizi J, Gehrke T. Definition of periprosthetic joint infection. *J Arthroplasty.* 2014;29 [7]:1331, with permission

PJI is present when one of the major criteria or three of the five minor criteria exist

Table 17.2 Threshold for minor diagnostic criteria

	Acute PJI (<90 days)	Chronic PJI (>90 days)
ESR (mm/hr)	—	30
CRP (mg/L)	100	10
Synovial WBC (cells/μl)	10,000	3000
Synovial PMN%	90	80
Leukocyte esterase	+ or ++	+ or ++
Histological analysis of tissue	>5 PMN per HPF in 5 HPFs (at x400 magnification)	Same as acute

From Parvizi J, Gehrke T. Definition of periprosthetic joint infection. *J Arthroplasty.* 2014;29 [7]:1331, with permission

leukocyte esterase test as a minor criteria (Table 17.1) and defining the thresholds for each of the minor diagnostic criteria (Table 17.2) [48]. This modified MSIS definition of PJI has since been adapted by the Centers for Disease Control and Prevention, along with 130 societies and organizations.

Classification of Infection

Classifying infection after TKA based on symptom duration and the interval from surgery is important because it puts into perspective the potential treatment options. Acute postoperative or late hematogenous infections with acute onset are often treated with methods that attempt to retain the components, while more chronic infections frequently require component removal. In an effort to classify the clinical presentation of an infected TKA, three main categories have been described [6, 21] (Table 17.3).

Table 17.3 Classification of prosthetic joint infection

Positive intraoperative culture
Early postoperative infection
Superficial
Deep
Acute hematogenous
Late chronic

From Tsukayama DT, Goldberg VM, Kyle R. Diagnosis and management of infection after total knee arthroplasty. *J Bone Joint Surg Am.* 2003;85-A(Suppl 1):S75–80, with permission

Early postoperative infections become evident within 4 weeks after index TKA. They may have started at the time of surgery or by hematogenous means. Aspiration should be done to rule out hematoma, the most common alternate diagnosis. CRP and ESR will likely still be elevated, as a result of the surgery, but very high values should raise concern. Gram's stain and culture are sent to identify the presence of organisms. Do not assume that bacterial growth in broth only is a contaminant; when in doubt, reaspirate.

Acute hematogenous infections are those that present with a short duration of acute symptoms in a previously well-functioning knee. These may occur after invasive procedures, such as dental or genitourinary interventions, after abrasions or lacerations, or after remote or unrelated infections, but often there is no identifiable source of infection. While an acute hematogenous infection with 4 weeks or less of symptoms is often considered amenable to open debridement and retention of components, the results are optimized when patients present within 1 week of the onset of the infection.

Late chronic infections present with greater than 4 weeks of symptoms and may be associated with osteomyelitis, sinus tracts, and loose components. These patients often have a long insidious course of pain, swelling, and stiffness. Patients

with chronic infections often present with a history of antibiotic use that decreases the sensitivity of cultures, making accurate diagnosis difficult, or limiting the identification of all organisms, in the case of polymicrobial infections [49]. Chronic infections involve organisms that have penetrated interfaces and tissues. They have often been subjected to a number of antibiotics and may have formed biofilms that resist nonoperative treatments. Therefore, these infections almost always require debridement with component removal and at least 4–6 weeks of intravenous antibiotics for complete eradication.

Treatments

Antibiotic Suppression

Antibiotic treatment alone will fail to eradicate infection from a surrounding total joint arthroplasty. However, in specific clinical scenarios, antibiotics may be used to suppress an infection (Table 17.4). Antibiotic suppression may be appropriate for patients who are poor candidates for surgical intervention. These patients are usually at a high risk of local or systemic complications and often have other medical issues that preclude an operative procedure. For successful antibiotic suppression, the organism must have low virulence and demonstrate susceptibility to an orally available and tolerable antibiotic. The success rate of antibiotic suppression alone is about 20% [50]. Patients with signs of advanced infection, such as loosening and sinuses, are unlikely to respond well to antibiotic suppression [1, 2, 51]. Attempting to suppress a deep prosthetic infection in the presence of other joint arthroplasties or artificial implants (e.g., heart valves) puts the patient at risk for metastatic implant infection and should be avoided if possible.

Table 17.4 Criteria necessary for successful antibiotic suppression

Surgical intervention contraindicated (patient health)
Low-virulence organism
Organism sensitive to antibiotics
Patient can tolerate antibiotic
No component loosening

Patients treated with antibiotic suppression should be routinely followed for signs of advancing infection. Failed treatment may manifest with either acute or insidious symptoms, such as increased pain, swelling, drainage, and erythema. Constitutional signs of bacteremia are a clear indication of failure of suppression.

Open Debridement with Component Retention

Open debridement of acute TKA infections is an attractive option, given the possibility of retaining a stable implant, avoiding revision, and preserving a functional limb. The currently accepted indications for this treatment option include acute postoperative or hematogenous TKA infections that are identified within weeks from the onset of symptoms (Table 17.5). The presence of loosening, sinus tracts, or osteomyelitis suggests more chronic infection and is associated with a high rate of failed debridement. This option is less desirable when other joint implants are present, unless performed within 1–2 weeks of the onset of symptoms.

An open arthrotomy and a complete synovectomy are performed to remove the proliferative, inflamed, and sometimes necrotic tissue. A polyethylene insert exchange provides access to interfaces and also assists with exposure of the posterior capsule. Four to six liters of saline, with antibiotics, are then used to irrigate the knee, and a standard closure using a heavy deep monofilament suture is completed over drains. Multiple intraoperative tissue and fluid samples are sent for the identification of infecting organisms. Four to six weeks of appropriately directed intravenous antibiotics is administered, followed by chronic oral antibiotics in select cases. Multiple debridements may enhance the outcome.

Numerous published series have evaluated the capability of early debridement at eradicating infection [14, 51, 52]. Despite the use of various methodologies, these reports reveal common themes that provide guidelines for the debridement of

infected TKA (Table 17.5). An evaluation of more than 20 published articles on this topic revealed a success rate ranging from 19% to 83%, with most studies reporting success rates less than 60% [24]. A 2002 meta-analysis of 530 patients treated with open irrigation and debridement for acute PJI showed an overall success rate of 33.6% [14].

The most important factor determining its success is the timing of debridement after the onset of infection [53–55]. Retrospective case series have demonstrated a statistically significant difference in outcome when comparing patients debrided soon after symptoms from those patients debrided after prolonged symptoms [54–57]. Marculescu et al. found the risk of treatment failure to be twice as high with symptom duration greater than 8 days [56]. Hsieh et al. identified short duration of symptoms (<5 days) as the only factor associated with success of irrigation and debridement in patients with gram-negative PJI [57]. It is likely that prolonged infections establish deeper penetration within tissues and interfaces and are more difficult to successfully debride. The development of protective mechanisms such as biofilms may be generated by the organism and contribute to failure [16]. Evidence of chronic infection such as sinuses, loosening, or osteomyelitis is generally considered contraindications to attempting component retention. In general, the literature supports component retention if debridement is done within 2–4 weeks after the onset of symptoms, but it is best done within days.

Patients who are young and healthy with an infection after primary knee arthroplasty are also more likely to have a successful debridement [58, 59]. Some authors have suggested that patients with multiple medical problems or immunocompromise are more difficult to treat with debridement and component retention [58]. Additionally, although exceptions have been reported, generally poor results have been found after debridement of hinged and multiply revised components [58].

Table 17.5 Criteria necessary for successful open debridement with component retention

Low-virulence organism
Organism sensitive to antibiotics
Acute infection (<4 weeks)
No component loosening
No osteomyelitis
No sinus tracts

Debridement is more likely to succeed with less virulent organisms such as streptococcal species and *Staphylococcus epidermidis*, whereas failed debridement has been associated with more virulent organisms such as *Staphylococcus aureus* and gram-negative organisms and in the setting of antibiotic resistance [54, 58, 59]. A statistically significant difference was found in outcome after the debridement of *S. aureus* infections versus infection with other gram-positive organisms [59]. Only 1 of 13 TKAs infected with *S. aureus* were successfully debrided in that series, compared with 10 of 18 successful debridements in patients infected with other gram-positive organisms. Likewise, Choi et al. observed that though initial infection control rate was much lower with prosthesis retention compared to removal, retention with polyethylene exchange can be selectively considered for patients with non-*S. aureus* infection [60]. In contrast, methicillin-resistant *S. aureus* infection is more difficult to treat with isolated irrigation and debridement, with one series demonstrating an 84% failure rate at a minimum 2-year follow-up [61].

Arthroscopic debridement generally has unacceptably poor results and should be avoided. It permits limited examination of the joint, precludes polyethylene exchange, and limits the ability to perform a complete and thorough synovectomy [24]. Waldman et al. reported on the arthroscopic irrigation and debridement of 16 infected TKAs [62]. Despite a strict definition of acute infection (≤7 days of knee symptoms), only six infected knees (38%) were successfully treated using this method. Similarly, Dixon et al. described an infection eradication of 60% in 15 patients treated with arthroscopic irrigation and debridement at a mean follow-up of 55 months [63]. Arthroscopic treatment for the acutely

infected TKA should be limited to patients who are medically unstable or anticoagulated.

Exchange Arthroplasty

Exchange arthroplasty involves removal of the infected TKA, thorough debridement, and reimplantation. Direct exchange (one-stage) arthroplasty involves open debridement of the infected TKA followed by immediate revision. Two-stage reimplantation involves open debridement, removal of the infected prosthesis, and delayed reimplantation, with an intervening time for antibiotic therapy.

Exchange arthroplasty is preferred for infections present for greater than 2–4 weeks or persistent infections that could not be eradicated with debridement alone. In order to successfully use exchange arthroplasty, the patient should be medically stable for multiple operative procedures, with an intact immune system that will aid in eradicating the infection. Furthermore, the inherent elements of the knee, such as bone stock, extensor mechanism, and soft tissue envelope, should be amenable to eventual TKA function.

Direct exchange arthroplasty with primary reimplantation involves prosthesis removal and thorough irrigation and debridement, followed by reimplantation of a new prosthesis in a single surgery. Goksan and Freeman [64] described a technique comprised of irrigation with saline, packing with iodine-soaked sponges, and a one-layer wound closure, followed by deflation of the tourniquet to allow for antibiotic perfusion for 30 min. After a complete replacement of all gowns, drapes, and gloves, the knee is prepared again with sterile technique, and the components are reimplanted with antibiotic-impregnated cement. With this technique, Goksan and Freedman reported successful eradication of infection in 16 of 18 patients treated with direct exchange arthroplasty, but clinical follow-up was short. A more recent prospective study compared the outcomes of one-stage and two-stage revisions in 28 and 74 patients, respectively [65]. Patients who underwent single-stage revision were carefully selected to ensure healthy soft tissues, known organism with known sensitivities to available antibiotic treatments, absence of immunocompromise, and good bone stock. At an average follow-up of 6.5 years, the single-stage patients had no reinfection and also had higher Knee Society Scores than the two-stage patients. The largest study to date on single-stage TKA revision studied 63 patients without methicillin-resistant organisms who underwent a one-stage revision for PJI of TKA. At an average follow-up of 36 months, the patients demonstrated an infection control rate of 95% and higher knee scores than two-stage revision patients [66]. Zahar et al. obtained the longest clinical outcomes on single-stage TKA revision patients, with an average follow-up of 10 years [67]. In this series, the 10-year infection-free survival rate was 93% in 11 patients who had undergone aggressive debridement of the collateral ligaments and posterior capsule with implantation of a rotating hinge construct. Even in patients with chronically infected TKA, one-stage revision can lead to infection control rate of 91% at 3 years [68].

The relative ease and seemingly encouraging outcomes of one-stage revision, however, are tempered by the absence of high-level evidence and limited outcome data based on studies with small cohorts. With proper patient selection and meticulous surgical technique, direct exchange has been associated with a rate of success comparable to two-stage exchange arthroplasty, even in chronically infected TKA [14, 65, 68]. This is particularly reassuring in those patients who undergo revision arthroplasty in the setting of previously undetected infection and highlights the importance of using antibiotic-impregnated polymethyl methacrylate (PMMA) cement in all revision TKAs, with or without known infection.

The two-stage approach, first described by Insall et al. [69], is considered to be the gold standard for definitive treatment of TKA PJI, especially with long-standing or late TKA infections, with reported success rates greater than 85–90% [55, 69–73]. A recent retrospective study of 253 patients found two-stage revision for infected TKA yielded an infection-free survivorship of 85% at 5 years and 78% at 10 years [74].

At the time of implant removal, a complete debridement must be performed to provide an optimal environment for eventual reimplantation. This includes not only an extensive synovectomy but also removal of necrotic and infected bone. The previous incision can almost always be used. Sinuses should be excised and muscle flaps used if coverage is a potential problem. On entering the joint, several samples of synovial fluid should be sent for culture and analysis. Synovial tissue, interface tissues, and tissue from the canals (when removing stemmed components) should also be sent for culture and pathologic analysis. When removing components, it is critical to preserve maximal bone stock. However, one must be sure to remove all fragments of cement and necrotic bone in an effort to reduce the interfaces available to organisms. Irrigation of the joint with several liters of antibiotic saline is performed, and a spacer is implanted. The capsular closure is performed over drains using a running monofilament suture.

Treatment variables exist in the type of spacer (static versus articulating), the dose of antibiotic used in the spacer, the length of subsequent antibiotic treatment, and the timing of reimplantation.

Early reports of two-stage exchange described an intervening resection arthroplasty before reimplantation [69]. However, in an effort to facilitate component reimplantation, some surgeons began using antibiotic-impregnated cement blocks [70] (Fig. 17.3). The intervening spacer has a dual role of delivering antibiotics to the knee environment and preserving the joint space and reducing soft tissue contracture. Although the use of antibiotic cement blocks has become widespread, interval bone loss and stiffness due to scarring have been identified as undesirable consequences [75, 76]. Comparison between static spacer blocks and articulating spacers by Emerson et al. [75] and Fehring et al. [76] showed no difference in the reinfection rate; however, the articulating spacer was found to limit bone loss, facilitate the surgical exposure at the time of reimplantation, and enhance motion after reimplantation. Additionally, patients tend to be more functional in the intervening period with an articulating spacer than with a static spacer.

The use of articulating spacers has been described in an effort to minimize these problems, while ensuring the local delivery of antibiotics [73, 77–84] (Fig. 17.4). Three types of articulating spacers have been described: preformed cement spacers, metal-on-polyethylene spacers, and cement-on-cement spacers. Preformed cement spacers are limited in the dose and number of antibiotics that they deliver [79].

Metal-on-polyethylene spacers are more versatile and utilize a new or recycled femoral component and a polyethylene insert, both loosely cemented to the distal femur and proximal tibia, respectively. One popular metal-on-polyethylene cement spacer system is the prosthesis of antibiotic-loaded acrylic cement (PROSTALAC) system (Depuy; Warsaw, IN), which was the first commercially available articulating spacer system, though not universally available in the United

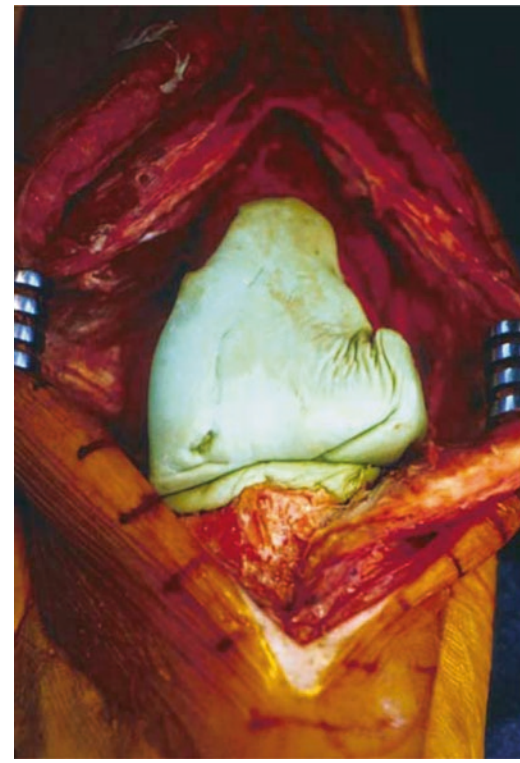

Fig. 17.3 Intraoperative photograph of a static spacer (From Lotke PA, Lonner JH, eds. *Master Techniques in Orthopedic Surgery: Knee Arthroplasty.* Philadelphia: Lippincott Williams & Wilkins, 2002, Fig. 22–28, with permission)

States. Acrylic cement and prefabricated articular surfaces are combined in a series of molds that create custom-sized femoral and tibial components [80, 81]. Alternatively, a more accessible option is that described by Hoffman et al. [82], in which the components removed at debridement are reused to construct an articulating spacer. In short, the femoral component is debrided, cleared of adherent bone and cement, autoclaved for 20 min, and coated with antibiotic-impregnated cement on its non-articulating surface. A fresh polyethylene insert is opened, and it too is coated on its non-articulating surface, and both are implanted with the cement in a doughy stage, so that there is limited interdigitation with bone.

A common cement-on-cement spacer system is the StageOne system (Zimmer-Biomet; Warsaw, IN), which is more widely available in the United States and is formed by injecting cement into preformed silicone molds that mimic the shape of the femoral and tibial components [83]. A more cost-efficient technique utilizing the explanted femoral and tibial components to create custom intraoperative cement molds has also been described and used successfully [84, 85].

Comparable infection control and range of motion were found among the various articulating spacer techniques [86]. Autoclaving and repurposing the original component had the lowest associated cost.

Fig. 17.4 Intraoperative photograph of an articulating spacer (From Lotke PA, Lonner JH, eds. *Master Techniques in Orthopedic Surgery: Knee Arthroplasty.* Philadelphia: Lippincott Williams & Wilkins, 2002, Fig. 22–25, with permission)

Antibiotic-loaded cement improves the success in two-stage exchange from 88 to 92% [87]. The amount and type of antibiotic used vary. Vancomycin, gentamicin, and tobramycin are commonly used powered antibiotics due to their heat stability. In general, 2–8 g of antibiotics are used per batch of cement, with higher doses creating greater porosity and voids in the cement, which leads to greater elution into the surrounding tissue [24]. A reasonable mixture is detailed by Emerson et al. [75] using Palacos impregnated with 3.6 g of tobramycin and 2 g of vancomycin per 40-g package of cement.

The ideal time interval between debridement and reimplantation remains elusive. Most surgeons prefer at least 6 weeks of intravenous antibiotics [24, 69, 75]. Success rates above 85–90% have been reported for treatment that used a 6-week interval of intravenous antibiotics before reimplantation [69, 88]. Some allow additional time for oral antibiotics, antibiotic-free intervals, and diagnostic testing to confirm the eradication of infection prior to proceeding with reimplantation [89–91].

The decision to proceed with reimplantation should depend on the presence of a healthy soft tissue envelope that does not have substantial inflammation after antibiotics have been terminated. Haddad et al. [65] found that the use of antibiotic-impregnated bone cement at the time of reimplantation significantly reduced the rate of reinfection.

Attempts to use diagnostic testing to identify persistent infection before proceeding with reimplantation have had mixed results. Nuclear studies have failed to show significant value in the identification of persistent infection [29]. However, laboratory studies may be of use. Although the ESR may be persistently elevated after debridement, the CRP value should trend toward normal after 6 weeks of intravenous antibiotics. Kusuma et al. found that ESR and CRP remained elevated in 54% and 21% of patients, respectively, who were proven to be infection-free at time of reimplantation [92]. The authors were unable to delineate an ideal cut-off value for either ESR or CRP prior to reimplantation.

Frozen sections from synovial tissues at reimplantation have proven marginally useful at this stage [93]. Variability due to tissue sampling and normal inflammation creates inconsistent results. However, Banit et al. [41] suggested that frozen section of knees at implantation may be associated with a sensitivity of 100% and specificity of 96% for infection when applying careful sampling technique and handled by experienced pathologists. Their standard for infection was a positive culture at reimplantation, not reinfection after reimplantation.

Aspiration of the knee before reimplantation has been used to identify patients who have persistent infection. Mont et al. [94] reported a protocol that used aspiration for culture 4 weeks after the discontinuation of intravenous antibiotics. All patients with a positive culture underwent a second round of debridement, intravenous antibiotics, and aspiration before reimplantation. This protocol significantly reduced the rate of recurrent infection when compared with a control group and has been the only reported method that appears to identify and treat patients who are persistently infected after one round of debridement and antibiotics. Only 1 of 34 (3%) patients in their study had a reinfection after negative aspiration and reimplantation.

Despite attempts to accurately identify and successfully eradicate infection prior to reimplantation, reinfection and failure of treatment can occur. Mortazavi et al. reported a 28% rate or reinfection after two-stage exchange knee arthroplasty in 117 patients at a minimum follow-up of 2 years [95]. Despite examining 15 presurgical and 11 surgical factors, the authors only identified infections with culture-negative and methicillin-resistant organisms as well as prolonged surgical time as risk factors for failure. A larger retrospective study looked at 548 patients who underwent two-stage exchange arthroplasty and found that female gender, heart disease, and psychiatric disorders increased the risk of PJI recurrence [96]. Prior treatment attempts, and subsequent failure thereof, may also adversely influence the outcome of two-stage exchange knee arthroplasty. A multicenter retrospective review of 83 knees that had undergone and failed prior irrigation and debridement found that 28 (34%) failed subsequent two-stage revision and required reoperation [97]. This failure rate was notably higher than previously reported failure rates of two-stage revisions. The authors suspected that host quality, thoroughness or debridement, and organism virulence may influence outcomes and cautioned that irrigation and debridement as a first treatment step may lead to higher failure rates of subsequent two-stage reimplantation. A more recent and much larger series, however, found no association between prior failed irrigation and debridement and subsequent failure of two-stage revision TKA [98].

Salvage Procedures

Patients with persistent infection are sometimes unable to retain a functional TKA. Repeated surgical procedures lead to bone loss and soft tissue compromise, necessitating a salvage procedure to relieve pain. Hanssen et al. [99] studied a series of 24 knees that became reinfected following reimplantation for an infected TKA. The average number of procedures per patient, including the index TKA, was 9.3. Only one patient had an uninfected TKA at most recent follow-up. The outcomes included ten patients with a successful arthrodesis, five with infected TKA on suppressive antibiotics, four with an above-the-knee amputation, three with persistent pseudoarthroses, and one with resection arthroplasty. Salvage procedures are sometimes necessary to eradicate infection and relieve pain.

Resection Arthroplasty

The use of resection arthroplasty as a definitive treatment for infected TKAs is generally reserved for patients who are medically ill and sedentary. These patients do not require the full function of a TKA and are served well by an extremity that accommodates transfers and can be flexed. However, resection arthroplasty results in a significant loss of function, instability, and potentially persistent pain.

Falahee et al. [100] retrospectively reviewed the results of resection arthroplasty in 26 patients (28 knees). Those with severe disabilities found resection arthroplasty to be a tolerable procedure and were satisfied with their outcomes. In contrast, those with minimal presurgical disability were more likely to experience unacceptable instability and persistent pain and eventually required arthrodesis.

Arthrodesis

Certain clinical situations preclude the ability to reliably reimplant components with good results. Patients with irreparable extensor mechanism disruption, an inadequate soft tissue envelope, and multiple recurrent infections may be more appropriately treated with arthrodesis. In general, when it is thought that reimplantation will have a high rate of failure, due to inadequate joint mechanics, soft tissue envelope, or immune system, then arthrodesis may be the treatment of choice. The relative contraindications to arthrodesis include significant contralateral limb dysfunction, coexistent ipsilateral ankle or hip disease, or inadequate bone stock for fusion. Wound coverage should be optimized with a muscle flap if necessary.

Different techniques have been described for arthrodesis after TKA infection. Subsequent to a thorough debridement and creation of a sterile environment, a method of internal or external fixation is used. Knees are fused in full extension to maximize osseous apposition; the limb shortening common in fusion for a failed TKA will ensure that foot clearance during gait is not a problem. In fact, patients commonly require shoe lifts. The success of arthrodesis is closely associated to the bone stock available for fusion [101, 102]. The minimum amount of bone necessary should be cut to preserve bone stock for fusion. The proximal tibia is cut perpendicular to the longitudinal axis, and posterior slope is introduced as necessary. The femur is cut to provide a limb alignment of 0–5° valgus. When positioned in apposition, the femoral and tibial surfaces should provide an adequate base of support with a vascular osseous bed to facilitate fusion. If the opposing surfaces of the femur and tibia do not have more than 50% contact, a variety of strategies for bone grafting may be used to augment the fusion.

Intramedullary nailing provides many advantages in certain clinical situations. Most surgeons perform nailing with a two-stage approach to prevent the propagation of organisms through the medullary canals [103, 104]. However, a one-stage approach has yielded successful results when used to treat non-purulent, gram-positive infections [105, 106]. Intramedullary nailing provides the advantage of rigid fixation, immediate weight-bearing, and success in the setting of severe bone loss. Currently used intramedullary nails include long nails that extend from the greater trochanter of the femur to the distal tibia or short modular nails inserted through the knee (Fig. 17.5). Nails may need to be removed if there is persistent or recurrent infection. If short modular nails are used, the fusion must be osteotomized to remove the nail; longer nails may be removed at the hip, with the fusion left undisturbed.

External fixation for arthrodesis of the infected TKA avoids the need for further soft tissue manipulation after debridement and has the advantage of leaving the joint free of interfaces that may serve as a nidus for reinfection [107–110]. Furthermore, the exact alignment of the extremity is more easily achieved. Although not attaining the success rate of intramedullary nailing, external fixation may be used in the setting of acute infection. Biomechanical studies have demonstrated that when a biplanar fixator is used with sagittal pins and a ventral frame, added rigidity is provided to counter the bending forces at the knee [109] and this can enhance successful union [107]. The clinical signs of union are usually evident by 10–12 weeks, when the external fixator is removed and a cast is applied for 4–12 weeks as necessary to achieve radiologic union.

The results reported for arthrodesis after infected TKA depend on the bone stock present before fixation. Brodersen et al. [101] demonstrated an 81% rate of union when treating patients with minimally constrained prostheses, compared with 56% in patients with prostheses

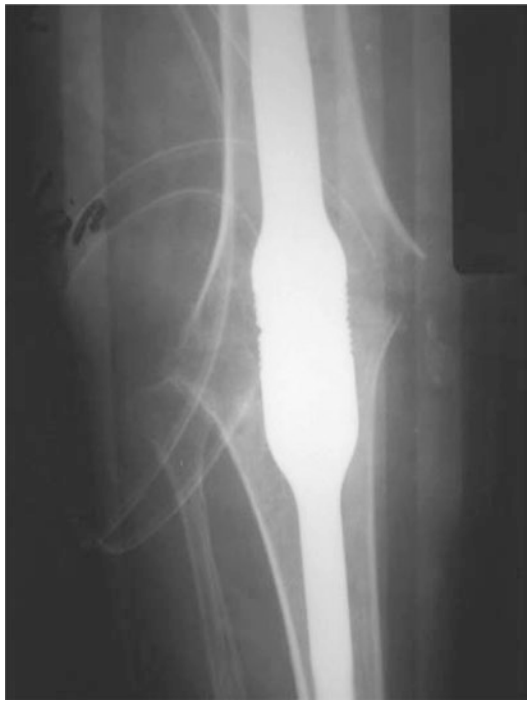

Fig. 17.5 Radiograph after successful fusion with a short modular intramedullary nail

that sacrificed more bone stock. With less bone stock, the ability to attain stable bone apposition is diminished, creating a more difficult situation for eventual union. Therefore, in cases with severe bone loss, the more rigid fixation provided by intramedullary nailing is preferred, yielding a fusion rate of 80–100% [103, 104, 106]. Both single and biplanar external fixators have shown a low rate of fusion under these circumstances [108, 109]. Use of a circular small wire or hybrid external fixator has yielded very successful results (93–100%); however, the complications involving pin tract infection and loosening are high [110–112].

External fixation and intramedullary rod fixation have demonstrated comparable fusion and reinfection rates [113, 114]. Schwarzkpof et al. found that the failure of arthrodesis was predicated more on preoperative elevation of inflammatory markers and postoperative complications [114], which may allude to the role of host factors.

Knee arthrodesis remains a reliable salvage option after failed two-stage reimplantation. Wu et al. employed a decision tree analysis to compare two-stage reimplantation, chronic antibiotic suppression, arthrodesis, and amputation for the treatment of infected TKA [115]. The authors' model recommended that arthrodesis should strongly be considered as the treatment of choice for patients with persistently infected TKA who have failed two-stage reimplantation. Nevertheless, recent registry data in the United States and Europe indicate that the rate of knee arthrodesis has recently been on the decline [116, 117]. However, these data also show that a greater number of revisions, performed in an attempt to preserve the knee, are associated with a greater risk of subsequent arthrodesis and amputation [117].

Amputation

Some persistent infections that have been treated with multiple revisions and consequent bone loss may create a situation in which further reconstructive options would be futile. This is particularly true in the setting of a compromised soft tissue envelope, a disrupted extensor mechanism, or overwhelming sepsis. Amputation is indicated when other attempts at salvaging the knee have failed and when further salvage procedures would likely be ineffective. Though a difficult decision to undertake, one expert opinion suggested that greater than six attempts at limb salvage and failed gastrocnemius flap were poor prognostic factors for which amputation should be indicated [118].

Similar to arthrodesis, the number of amputation procedures being performed for the treatment of chronically infected TKA has been on the decline [117]. Carr et al., however, noted an increasing recent trend toward above-the-knee amputation (AKA) over arthrodesis in the treatment of infected TKA [119].

Functional outcomes after AKA for infection after TKA are poor. Compared to patients who underwent arthrodesis for failed TKA, those who underwent AKA had worse function and ambulatory status [120]. Sierra et al. reported on 25 AKA after TKA. Many patients in their series were never fitted with a prosthesis, and those who

were seldom regained functional independence [121]. Similarly, Fedorka et al. retrospectively reviewed the functional outcomes of 35 patients who underwent AKA after failed TKA and found them to have low functional status [122]. The 14 patients in the series who were fitted for prostheses had higher activities of daily living scores but also tended to be younger with fewer comorbidities than those not fitted with a prosthesis.

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18 Use of an Antibiotic-Impregnated Spacer in Revision Total Knee Arthroplasty

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Infection is a devastating complication following total knee arthroplasty (TKA) with an incidence of 0.4–2% [1, 2]. The consequences of infection include but are not limited to chronic pain, severe disability, including need for amputation, and a high mortality, which may approach 2.5%. The cost of care associated with treating an infection is also extremely high, approximately $50,000 per episode [3]. Four types of periprosthetic joint infection have been identified: type I, acute postoperative (<4 weeks postoperatively); type II, late chronic infection (>4 weeks postoperatively); type III, acute hematogenous; and type IV, positive intraoperative culture identified postoperatively [4]. While many other staging systems have been proposed, most separate acute infection, which are identified within 2–4 weeks of the onset of symptoms or from the time of surgery, from chronic infection, presenting with more than 4 weeks of symptoms. Many different treatment strategies have been described, including irrigation and debridement with retention of the components with or without polyethylene insert exchange, one-stage exchange arthroplasty, two-stage revision surgery, chronic resection arthroplasty, as well as chronic antibiotic suppression. In many instances fusion or amputation is eventually required.

The gold standard for treatment of infection, however, remains two-stage revision with success rates ranging from 90 to 96% in multiple series [4–6]. Two-stage revision, for chronic infection was first described by Insall in 1983 [7]. In their review of 29 studies, Garvin and Hanssen reported that 82% of two-stage procedures were successful, compared with 58% of one-stage procedures [8].

The use of antibiotic-impregnated spacers has been recommended between stages to facilitate reimplantation [9]. Wilde and Ruth and Booth and Lotke were the first to use an antibiotic-laden spacer block and reported infection control rates of 80% and 96%, respectively [9, 10]. The goals of antibiotic spacer use are to improve soft tissue healing, prevent soft tissue contracture, improve patient comfort between stages, and deliver antibiotics locally [9]. Whether to use static or articulating spacers is still controversial and a matter of debate. Proponents of the use of static spacers argue that they are more effective at delivering

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antibiotics [11]. However, they can be associated with unexpected bone loss from migration of the spacer block, as well as a more difficult exposure at the time of reimplantation secondary to quadriceps shortening and adherence of the soft tissues to the exposed bone [12]. Articulating spacers on the other hand have the potential advantages of maintaining the joint space, allowing for weight bearing and joint motion, and providing better function during the interim period [12–18]. Several factors determine the clinical efficacy of antibiotic-impregnated cement spacers, including the elution characteristics of the antibiotics used, the mixing technique, and the strength of the polymethyl methacrylate (PMMA) cement [19]. This multitude of factors, in addition to the different postoperative treatment protocols, make comparison of the clinical results of static and articulating spacers challenging. Comparison among patient populations in this literature is also very challenging as the prognosis is clearly influenced by a multitude of patient factors including the infecting organism, the presence of diabetes, or the immune compromise and skin conditions to name a few. However, one general principle that has been demonstrated to improve the prognosis following two-stage revision surgery is the use of antibiotic-impregnated cement for the reimplantation procedure. The exact dosage or type of antibiotic and type of bone cement, however, remain controversial.

Cement Spacers as Antibiotic Delivery Vehicles

The release of antibiotics from cement spacers is a complex process, the exact mechanism of which is yet to be fully understood [20]. It relies on several variables, including the type of antibiotic selected and its elution characteristics, the type and strength of the PMMA cement, and the mixing conditions [21–26]. There seems to be a biphasic profile, with an initial rapid release period followed by a slower sustained release [27].Most of the release however occurs in the first 9 weeks, and only 10% of the antibiotic is allowed to elute effectively [28–30]. Even though PMMA has excellent biocompatibility, not all antibiotics can be incorporated in this cement [31]. In order to be included, antibiotics must display certain characteristics. Most importantly, the antibiotic must have thermal stability [4, 32]. It should be available in powder form with low serum protein binding and have low or no risk of allergy or delayed hypersensitivity [4, 20, 32]. In addition, the antibiotic should be broad spectrum and bactericidal at low concentrations [4, 32]. The two groups of antibiotics that satisfy these criteria are aminoglycosides (gentamicin and tobramycin) and glycopeptides (vancomycin), and hence the most commonly used within cement spacers [19, 27].

Elution of antibiotics from PMMA cement depends on the dosage of antibiotics, the combination used, and the type of cement [19]. Better elution has been shown with higher doses of tobramycin but not with vancomycin [33]. Combination of multiple antibiotics is not only important for eradication of the different organisms that infect a total knee arthroplasty (TKA) but also for enhancing the elution properties [19]. The term "passive opportunism" was first used by Masri et al. [33] to describe the synergistic effect between two antibiotics, namely, tobramycin and vancomycin. They reported that 3.6 g of tobramycin per 40.0 g package of bone cement might improve the release of 1.0 g of vancomycin. This phenomenon is believed to be due to the increased cement porosity caused by elution of one antibiotic, which in turn improves the elution of the other antibiotic [21, 33].

The type of PMMA cement is another variable affecting the clinical efficacy of antibiotic-impregnated spacers. Several reports have shown better elution of tobramycin from Palacos cement (Zimmer, Warsaw, IN) than from Simplex cement (Stryker, Mahwah, NJ) [34]. This is attributed to the increased porosity of Palacos cement. Hand mixing increases the porosity of cement as well, allowing better elution of antibiotics, in contrast to vacuum mixing [35]. In a recent study, two other factors, the relative volume of liquid monomer and the timing of antibiotic addition, were shown to have substantial effects on the antibiotic elution from bone cement [36]. Based on that

study, it was recommended, when preparing high-dose antibiotic bone cement, to add the antibiotic after the initiation of the polymerization process (delayed antibiotic technique) and to avoid incorporating additional liquid monomer [36].

The use of antibiotic-loaded bone cement is not without complications, and several concerns exist regarding its potential disadvantages. These include the negative effects on the mechanical properties of cement when mixed with antibiotics, the potential toxicity from high levels of antibiotics, and allergic reactions to the antibiotic used [32]. Despite the detrimental effects on the mechanical properties of cement, the incidence of cement spacer fractures has been relatively low, owing to the diminished functional demands of patients during the interim period before second-stage reimplantation [19]. The issue of systemic toxicity, such as nephrotoxicity, remains a potential concern. To date, however, the risk of systemic toxicity appears extremely low, if not purely theoretical, and there has been no clear evidence of systemic toxicity from the high-dose, hand-made spacers or the lower-dose commercial products in the literature [32]. There have been case reports suggesting that antibiotic bone cement may cause or contribute to nephrotoxicity in select patients. [37, 38.]

Local toxicity may also be a concern especially with high levels of antibiotics exceeding 2000 μg/mL [39]. Osteoblast and osteocyte functions seem to be affected the most, as shown in in vitro studies [32]. Significant decreases in alkaline phosphatase activity, total DNA levels, cellular replication, and ultimately cell death have been reported [40, 41]. These effects appear to be most notable with tobramycin and gentamicin and less so with vancomycin [42].

Finally, even though there have been no reports of allergic reactions, it is advisable to avoid using a particular antibiotic in bone cement if there is a documented allergy to that antibiotic [32].

While there appears to be a lack of consensus on the dosage and type of antibiotics, we have followed some general principles for safety and efficacy at our institution when constructing spacers and high-dose antibiotic cement (Table 18.1). We use a combination of vancomycin and tobramycin and simplex cement in most or all cases. A standard dose of antibiotics routinely used would be 3 g of vancomycin and 3.6 g of tobramycin per 40-g bag of cement. In younger healthy patients with either long-standing infections or more aggressive bacteria (MRSA, polymicrobial infection, etc.), consider increasing the dose to 4 g of vancomycin and 4.8 g of tobramycin per bag of cement. In frail elderly patients, potentially at risk for developing postoperative renal failure, or those with pre-existing renal insufficiency or other specific medical concerns, a lower-dosage strategy is employed such as 2 g of vancomycin and 1.2–2.4 g of tobramycin per bag of cement. A minimum of three bags of cement are required for static spacers, and fewer bags may be required for articulating spacers depending upon the type of construct. Prefabricated articulating spacers are never used without some form of high-dose antibiotic cement preparation. Typically, some antibiotic powder is added to the cement powder prior to the addition of the monomer, while additional antibiotic is added after a short period of mixing to facilitate mixing of all the antibiotic powder into the cement.

Table 18.1 Potential antibiotic dosing schemes for high-dose cement preparations in spacers

Healthy patients with long-standing infection and/or high-virulence organism	4 g vancomycin and 4.8 g tobramycin per 40 g bag of simplex bone cement
Standard dosing in patients with no major comorbidities	3 g vancomycin and 3.6 g tobramycin per 40 g bag of simplex cement
Frail, elderly patients or those with a history of renal insufficiency	2 g vancomycin and 1.2–2.4 g tobramycin per 40 g bag of simplex cement

Static Spacers

Booth and Lotke were the first to describe the use of antibiotic-impregnated cement spacers during the interim period before second-stage reimplantation of an infected TKA [9]. They had success-

ful results and reported infection control rates of 96% [9]. Spacers are classified as static or articulating, i.e., mobile [43]. A static spacer is a block of antibiotic-impregnated cement inserted between the femur and the tibia to maintain the joint space and to act as a local drug delivery vehicle. Better clinical results have been reported with static spacers than treatment regimens not involving any spacer [10]. Potential benefits, as mentioned previously, include prevention of soft tissue contracture, enhanced soft tissue healing, and increased patient comfort between stages [12]. In addition, static spacers provide some stability to the limb and allow the use of large doses of antibiotics [19]. Proponents of their use argue that they are more effective at delivering antibiotics than articulating spacers [11]. However, increasing the dose of antibiotics may not necessarily reduce the incidence of recurrent infection [19]. Springer et al. reported a 9% reinfection rate in their patient cohort of static spacers, using 4.0 g of vancomycin and 4.8 g of gentamicin per batch of Simplex P (Stryker) cement [44]. Disadvantages of static spacers on the other hand include spacer migration, soft tissue injury, bone erosion, quadriceps shortening, knee stiffness, and a more challenging second-stage reimplantation secondary to difficult exposure and tissue scarring [45].

Several studies have shown equivalent clinical outcomes regardless of the type of spacer used, with marginal increases in the range of motion with articulating spacers [11, 14, 15]. Emerson et al. reported similar reinfection rates with static and articulating spacers: 7.7% (2 of 26 knees) and 9.1% (2 of 22 knees), respectively, (P = 0.8) [13]. A recent meta-analysis of seven level-III comparative studies demonstrated a reinfection rate of 12% for static spacers and 7% for articulating spacers, which was not statistically significant (P = 0.2) [45]. The ultimate range of motion post-reimplantation was found to be better in patients treated with articulating spacers versus static spacers (101° and 91°, respectively, p = 0.0002). However, clinical and functional outcomes were similar among patients in both groups. There also appeared to be no difference in the complication rates when either surgical technique was used [45]. In a retrospective study comparing patients who received either a static (25 patients) or articulating spacer (15 patients), Fehring et al. [12] failed to identify a difference in Hospital for Special Surgery knee scores (83 and 84 points). However, there was a slight improvement in the range of motion in articulating spacers in contrast to static ones (105° versus 98°). Unexpected bone loss was evident during the second-stage reimplantation in 15 of the 25 patients with static spacers [12]. It is worth noting though that not all static spacers are the same and that most of the bone loss was encountered with the traditional early block-type spacers [46] (Fig. 18.1). A newer endoskeleton type of spacers may cause less appreciable bone loss, owing to a better load distribution [47]. In a recent study of four patients, Yoo et al. [47] described a novel technique using an endoskeleton-type static spacer. This consisted of an antibiotic-impregnated cement intramedullary nail, which can easily be fashioned intraoperatively using a straight thoracic tube and a

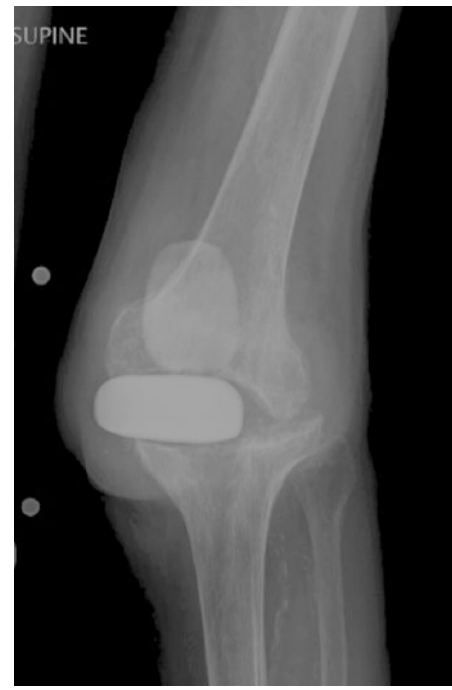

Fig. 18.1 Erosion of medial femoral condyle due to spacer migration

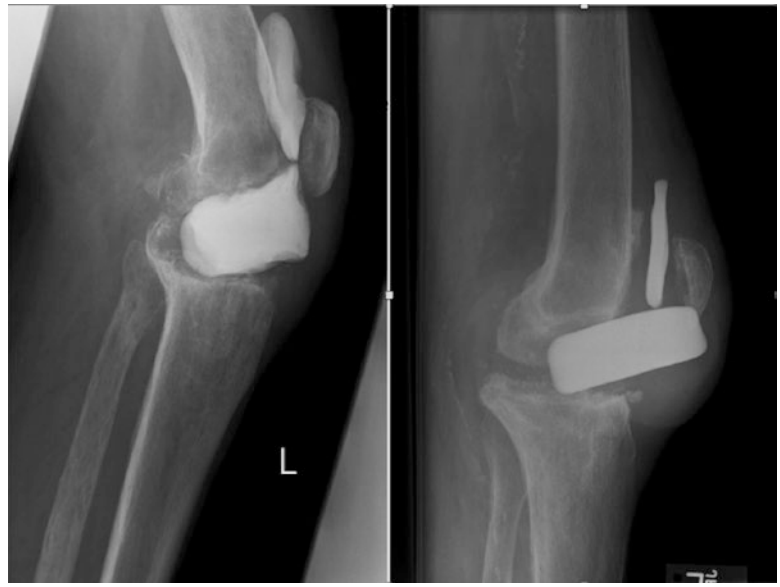

Fig. 18.2 Static spacer migration causing patellar tendon injury

Steinmann pin. They reported excellent outcomes with no bone loss and suggested that this technique could be an alternative to articulating spacers in patients with significant bone loss [47]. There appears to be a consensus that some type of stem on the tibial side or both sides of a static spacer provide better stability and prevent spacer migration to a greater degree than spacers without a stem (Fig. 18.2). Static spacers should also maximally cover the surface of the bone and maximize ligament tension without overtly impinging on the collateral ligaments, posterior neurovascular structures, or the extensor mechanism (Fig. 18.3). The use of a cast may also be prudent to prevent patient non-compliance and avoiding all even accidental attempts at flexion. This strategy is particularly important in cases of significant bone loss, such as infection following revision surgery as articulating spacers will not achieve appropriate stability and static spacers will be at higher risk of migration or dislodgement.

Articulating Spacers

Given some of the previously listed disadvantages of the static spacers, articulating spacers were introduced. They allow for limited weight bearing and knee ROM between stages. In addition, they maintain the joint space, facilitate reimplantation, and decrease some of the bone loss encountered with the early block-type static spacers. Since articulating spacers are limited in their fixation, there are multiple scenarios where certain bone and soft tissue deficiencies may preclude their use (Table 18.2). Three variations exist: cement-on-cement, cement-on-polyethylene, and metal-on-polyethylene [19].

Cement-on-Cement

Spacers with all-cement components can either be made intraoperatively using molds, or they can be prefabricated [43]. Successful results have been reported in multiple series, with infection eradication rates between 80 and 100% [11, 12, 15, 16, 48–50]. In a study of 24 patients with infected TKA, Durbhakula et al. [51] reported no reinfections and two cases of persistent infection. At the latest follow-up, ROM was 104°. Ha [52] also reported no reinfections in a study of 12 patients, and the ROM at final follow-up was 100°. Fehring et al. [12] in a retrospective comparative study between static and articulating spacers had a documented reinfection rate of 12% (3 of 25 patients) with static spacers and 7%

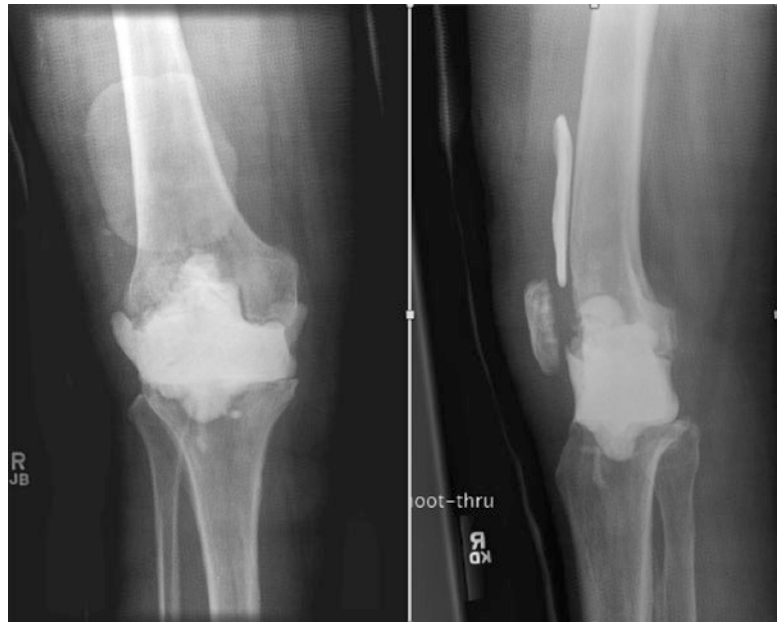

Fig. 18.3 Stemmed static spacers and use of long-leg cast prevent postoperative migration

Table 18.2 Considerations in selecting static versus articulating cement spacer in two-stage revision surgery

Static spacer	Articulating
• Major bone defects	• Multiple joint involvement or bilateral infection
• Major ligament insufficiency	• Need for immediate mobilization
• Poor soft tissue envelope or need for flap coverage	• Anticipate long-interval until reimplantation
• Extensor mechanism dysfunction	• Major comorbid illness that may preclude reimplantation

(1 of 15 patients) with articulating spacers. The ROM at 2-year follow-up was slightly better in the articulating spacer group in contrast to the static one (105° versus 98°). Bone loss was encountered during the second-stage reimplantation in 60% of patients treated with the static spacer, with no appreciable bone loss in any of the patients treated with the articulating spacer [12]. Prefabricated spacers are available as well; however there have been few reports in the literature on their use [53].

InterSpace knee temporary spacers (Exactech, Gainesville, FL) also known in Europe as Spacer-K (Tecres, Verona, Italy) are currently used in the United States [19]. In a report of 75 knees, using the Exactech spacer in three cases, Westrich et al. [54] failed to demonstrate any difference in infection eradication rates between different types of spacers. Pitto et al. [55] in a study of 21 patients using a different type of premade spacer showed a 100% eradication rate. Wan et al. [53] have also reported favorable results, achieving 91% eradication rate at a minimum 2-year follow-up interval. A potential disadvantage of the prefabricated spacers that may affect their clinical efficacy is the limited type and amount of antibiotics used [53]. The dosage of gentamicin in the InterSpace knee spacer ranges from 0.8 to 1.7 g, which is below the recommended dose of 3.6 g per 40.0 g cement [21]. This limitation however can be addressed by using higher doses of antibiotics in the batches of cement used for fixation of the spacers [53]. Other disadvantages of prefabricated spacers include potential fracture of spacers that are not metal reinforced and poor ROM and the potential generation of particulate debris from the abrasive and incongruent nature of the cement-on-cement articulation. Prefabricated generally come in limited sizes with relatively limited conformity to the bony anatomy that exists following component removal. Therefore, prefabricated spacers

should be augmented with high-dose antibiotic cement to achieve appropriate stability for the entire construct (Fig. 18.4).

Cement-on-Polyethylene

Evans described this technique, using an all-cement femoral component, hand-molded intraoperatively, and a stemmed, posterior-stabilized, all-polyethylene tibial component [17]. He used Palacos R cement (Zimmer, Warsaw, IN) with 4.8 g tobramycin and 4.0 g vancomycin. In his study, 28 patients (31 knees) with infected TKA were treated using this technique. He reported a 94% infection eradication rate at a minimum 2-year follow-up [17]. This is the only published series documenting the results of this particular type of articulating spacers. Further studies are needed to validate the efficacy of this technique.

Metal-on-Polyethylene

This design was first popularized by Hoffman et al. [56] in 1995, and their work and represents most of the data available on articulating spacers. It involves reimplanting the existing femoral component after sterilization mating it with a new polyethylene insert cemented into the tibia (Fig. 18.5). In their series of 26 patients, Simplex P bone cement (Stryker, Mahwah, NJ) with 4.8 g tobramycin per 40.0 g batch of cement was used. There were no cases of reinfection, the average Hospital for Special Surgery score was 87 points, and ROM was 5–106° at 30 months follow-up [56]. In a study of 37 infected TKAs, 27 of which had a metal-on-polyethylene spacer and 10 were treated using the cement-on-cement design, Masri et al. [57] reported a reinfection rate of 8% at a mean follow-up of 3 years. The average Hospital for Special Surgery score was 81 points, and the mean flexion was 91°.

In a recent report, Hoffman et al. [58] had lesser results using the same technique in 50 patients, highlighting the significance of host factors in eradication rates regardless of the technique or type of spacer used [19]. They showed a 4% (2 of 50 patients) reinfection rate with the same organism and 8% (4 of 50 patients) reinfection rate with different organisms [58]. Several studies on the metal-on-polyethylene knee spacers demonstrated favorable results with infection control rates between 88 and 96% [13, 48, 56, 59, 60].

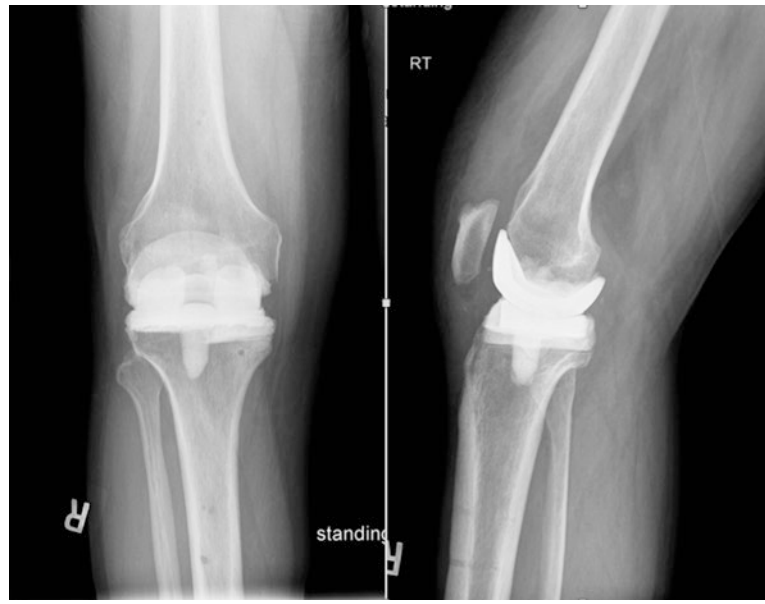

Fig. 18.4 Prefabricated cement spacer augmented with high-dose antibiotic cement for improved component fixation and local antibiotic administration

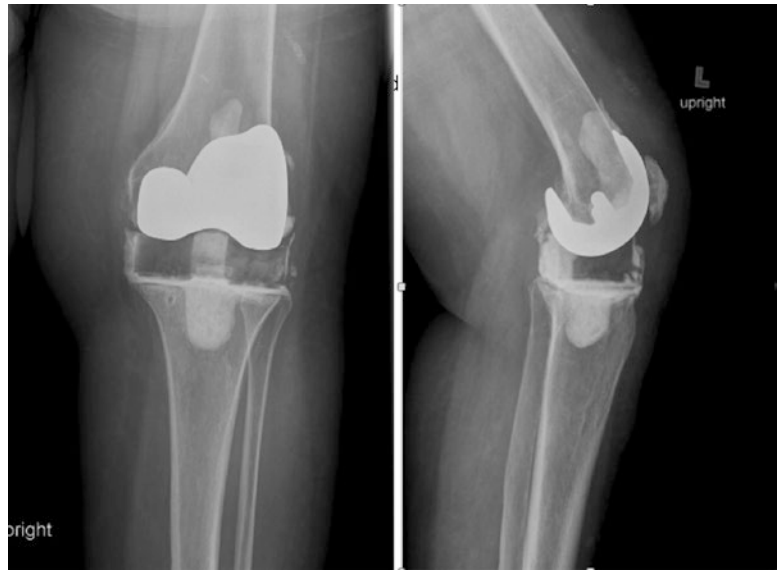

Fig. 18.5 Articulating spacer constructed with standard femoral component, polyethylene liner, and high-dose antibiotic cement

In Cuckler's series, only 1 of 44 patients developed a reinfection [61]. Emerson et al. [13], comparing patients treated with the static spacer technique to those treated with the Hoffman technique of articulating spacers, reported a reinfection rate of 7.7% (2 of 26 knees) and 9.1% (2 of 22 knees), respectively. Their spacers consisted of 3.6 g tobramycin and 2.0 g vancomycin per 40.0 g bag of Palacos cement. Better flexion was achieved in the articulating spacer group at 3-year follow-up (107.8° versus 93.7°). Similarly, Pietsch et al. [62] reported a low reinfection rate of 9% (3 of 33 patients). They used Palacos R cement (Zimmer, Warsaw, IN) with 1.0 g clindamycin and 2.0 vancomycin per 40.0 g package of cement. There are few reports in the literature comparing the different designs of articulating spacers. Recently, Jämeson et al. [48] investigated the outcomes of patients treated with the Hoffman technique and those treated with the cement-on-cement design. Surgical time was shorter (mean, 185 min versus 247 min, respectively; $P = 0.008$) with less blood loss (median, 425 mL versus 1500 mL, respectively; $P = 0.008$) during the second-stage reimplantation, for the Hoffman technique group compared with the all-cement group. In addition, Knee Society Scores were higher (11 of 22 versus 1 of 8, $P = 0.046$) and function scores were better (16 of 22 versus 3 of 8, $P = 0.027$) in patients treated with the Hoffman technique [48].

An alternative approach to resterilization of the original femoral component is to use the prosthesis of antibiotic-loaded acrylic cement (PROSTALAC) knee spacer system (Depuy, Warsaw, IN) [13]. This consists of a bicompartmental stainless steel femoral component articulating with a posterior-stabilized polyethylene tibial component. Haddad et al. [63] demonstrated successful results using this specific design. In a study of 45 knees, they reported a 9% reinfection rate (4 of 45) at a mean follow-up of 4 years. Also, knee ROM and Hospital for Special Surgery scores improved from the time of initial presentation to the final follow-up (71° to 94.5° and 42.4 to 71.4, respectively).

Because of the greater degree of articular congruency of the metal-on-polyethylene spacer, these patients may experience better ROM compared to other designs. Metal-on-polyethylene spacers may have enhanced fixation to the bone due to better conformity of the implants, providing better postoperative mobilization with less pain. This may be a better option for the elderly patient with significant medical history or others with unusual circumstances. These patients may experience prolonged delays during treatment or ultimately not have the opportunity for the

second-stage reimplantation procedure due to medical comorbidities, multiple joint infection, or unpredictable social issues.

Despite the favorable results reported with the metal-on-polyethylene variety of articulating spacers, there is a concern about glycocalyx formation and bacterial adherence, less so with the cement-on-cement designs [12]. In an in vivo study of 23 patients who underwent two-stage reimplantation using an all-cement antibiotic spacer during the interim period, Kendall et al. [64] couldn't identify any viable surface bacteria on the retrieved spacer. In contrast, there is no similar evidence in the literature on the metal and polyethylene constructs [12].

Summary

Two-stage reimplantation remains the gold standard for the treatment of infected total knee arthroplasty, with success rates ranging from 90 to 96%. It is currently the standard of care in North America when dealing with chronic periprosthetic joint infections. The use of antibiotic-impregnated spacers between stages has been advocated. Selection of antibiotic dosage and type of spacer is typically tailored to the individual situation. Two varieties of spacers exist, static and articulating, each with their benefits and disadvantages. The current literature shows no difference between both varieties in terms of reinfection rates. Even though, the ideal spacer design has not yet been established, articulating spacers seem to improve knee ROM and function scores in multiple series and may provide improved patient satisfaction during this difficult process.

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Periprosthetic Fractures After Total Knee Arthroplasty

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Andrew J. Marcantonio, Michael S. Kain, and William L. Healy

Over 600,000 primary total knee arthroplasty surgeries are performed annually in the United States, and this volume is expected to rise to 3.48 million procedures by 2030 (ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Dataset_Documentation/NHDS/NHDS_2010_Documentation.pdf). Outcomes after these procedures are generally excellent with resolution of pain, improved function, and quality of life. Periprosthetic fractures of the femur, tibia, and patella around a total knee arthroplasty (TKA) are relatively uncommon. The incidence of postoperative periprosthetic fracture of the femur, tibia, and patella varies from 0.3% to 2.5%, 0.4%, and 0.68%, respectively [1, 2]. The incidence of postoperative periprosthetic fracture is 1.1% after primary TKA and 2.5% after revision TKA in the Mayo Clinic Total Joint Registry [3]. These fractures are defined as occurring in the femur, tibia, or patella and within 15 cm of the joint line or 5 cm of the intramedullary stem. These injuries are devastating in the elderly patient and are associated with an increase in mortality and the need for additional surgery [4, 5]. Several clinical risk factors for periprosthetic fracture have been identified including glucocorticoid medications, osteoporosis, osteolysis, inflammatory arthritis, anterior notching of the femoral component, decreased knee flexion, revision surgery, cemented prostheses, female gender, older age, and neuromuscular disorders [6]. Prior studies identifying these associations involved a small number of cases with short follow-up and lacked multivariable-adjusted statistical analyses. Singh et al. identified a U-shaped relationship between age and periprosthetic fracture risk in primary and revision TKA. Patients ≤60 years old and patients with an age >80 years were associated with a similar risk of periprosthetic fracture. Previous nonunion and surgery with components removed were significant risk factors for periprosthetic fracture after revision TKA [3].

Proximal and Midshaft Femur Fractures

Proximal fractures involving the femoral head, femoral neck, or intertrochanteric region are rare and can occur in patients with osteopenic bone.

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Fracture can be caused by exuberant impaction of femoral trials or implants. Clinical clues such as a delay in postoperative mobilization or pain with weight bearing in the groin/thigh should raise suspicion for a proximal femoral fracture [7, 8]. These fractures must be treated appropriately to progress to weight bearing and rehabilitation of the TKA.

Femoral shaft fractures may occur during intramedullary alignment guide rod insertion and upon insertion of oversized stems on femoral components which can perforate the cortex. Technical factors to decrease fracture risk include enlargement of the distal femoral drill hole and careful, slow placement of the intramedullary guide rod. Critical inspection of preoperative radiographs allows proper placement of the distal femoral hole which is especially important when deformity is present. Unrecognized intraoperative femoral canal perforation can affect the alignment of the reconstruction and creates a stress riser in the femur. When placing large stemmed implants in patients with osteopenic bone, intraoperative imaging is helpful. When these fractures occur, supplementary fixation using plates, wires, and or cortical strut bone grafts may be necessary to ensure stability.

Distal Femur Fractures

Intraoperative Distal Femur Fractures

Surgical technique, bone quality, and component design are factors that can be associated with distal femur fractures during surgery. The torsional strength of the distal femur is reduced by 29–39% when femoral notching occurs, and osteopenia further decreases torsional load to failure [9–11] (Fig. 19.1). There is, however, a lack of consensus on whether notching increases the incidence of periprosthetic distal femur fractures [12–14]. The lack of statistical association between notching and fracture may be due to underpowered studies and very small numbers of observed fractures [15].

When using a posterior stabilized implant, the intercondylar box cut can be a source of fracture [16]. A fracture can occur during femoral trial or implant impaction if the notch is not deep enough or wide enough to accommodate the implant. The majority of these fractures occur at the medial condyle, and medial placement of the femoral component can increase this risk [16]. Inadequate enlargement of the depth of the box when converting to a more constrained implant which requires a deeper box can also increase the risk of fracture when the component is inserted [16].

Treatment of intraoperative fractures involving the distal femur requires radiographic identification of the fracture, adequate surgical exposure of the fracture, and stabilization. Potential intraoperative fracture should be anticipated during revision TKA, and stemmed implants to bypass the metaphyseal area should be available. Interfragmentary lag screw fixation

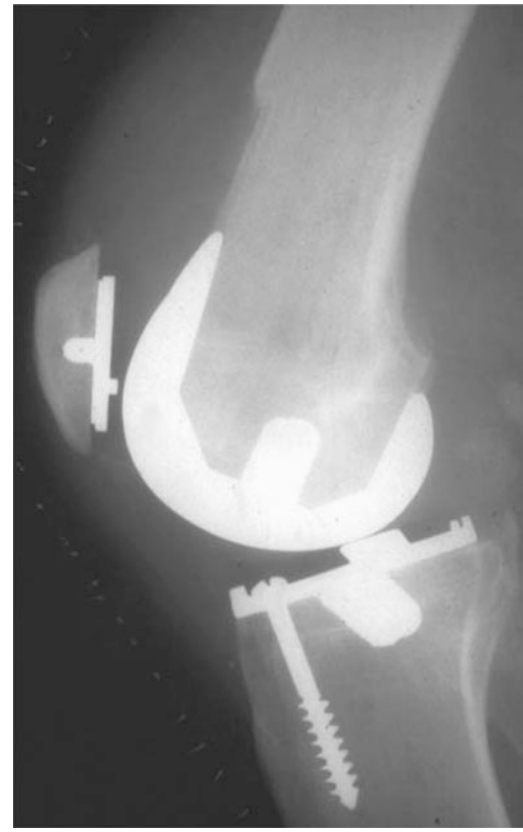

Fig. 19.1 Lateral radiograph shows a worrisome anterior notch on the distal femur, which could place this patient at higher risk for fracture. The surgical technique was also compromised by an asymmetric patella osteotomy

may be appropriate to stabilize nondisplaced condylar or transcondylar fractures. A stemmed femoral component is indicated to stabilize the condyle to the femoral diaphysis in displaced or comminuted fractures [17]. It is important that stems be long enough to reach the metaphyseal/diaphyseal narrowing and wide enough such that flutes or bone cement provides rotational stability. The use of bone cement should be limited at or proximal to the fracture to avoid interference with fracture healing. Protected weight bearing should be considered during the first 4–6 weeks when an intraoperative distal femur fracture is encountered [17].

Postoperative Distal Femur Fractures

The etiology of most periprosthetic distal femur fractures is trauma secondary to low-energy falls in older patients. Younger more active patients are more likely to encounter high-energy trauma. Restricted knee range of flexion increases the risk of periprosthetic fracture of the distal femur [18].

The most commonly used classification for periprosthetic fractures of the distal femur is by Lewis and Rorabeck which places focus on fracture displacement and knee prosthesis stability (Fig. 19.2).

- Type 1 include stable, nondisplaced fractures with an intact bone-prosthesis interface.
- Type 2 are displaced fractures associated with a well-fixed prosthesis.
- Type 3 have a loose or failing prosthesis regardless of fracture displacement [2, 18, 19].

Fracture location, which influences treatment decisions, is not part of this scheme.

The Su classification also takes into account fracture location (Fig. 19.3).

- Type 1 fractures are proximal to the femoral component.
- Type 2 begin at the proximal end of the component and extend proximally.
- Type 3 fractures extend distal to the proximal border of the femoral component [20].

Pain-free function is the goal of treatment for periprosthetic fractures of the distal femur. A well-healed fracture, with appropriate coronal (±5°) and sagittal (±10°) alignment and adequate range of motion (90°), represents successful treatment. Some shortening (up to 2 cm) of the femur may be accepted [18]. Nonoperative and operative methods of treatment have been reported [2, 10, 17, 21, 22]. However, there is a

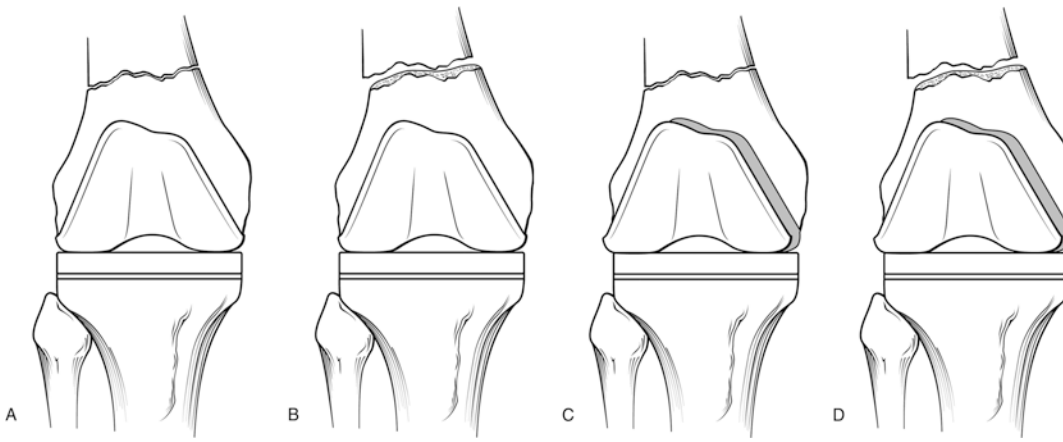

Fig. 19.2 Lewis and Rorabeck classification of supracondylar periprosthetic fractures proximal to total knee arthroplasty. (**a**) Type 1: undisplaced fracture—prosthesis intact. (**b**) Type 2: displaced fracture—prosthesis intact. (**c**, **d**) Type 3: displaced or undisplaced fracture—prosthesis loose or failing (i.e., significant instability or polyethylene wear) (Adapted from Rorabeck CH, Taylor JW. Periprosthetic fractures of the femur complicating total knee arthroplasty. Orthop Clin North Am. 1999;30(2):265-277, with permission)

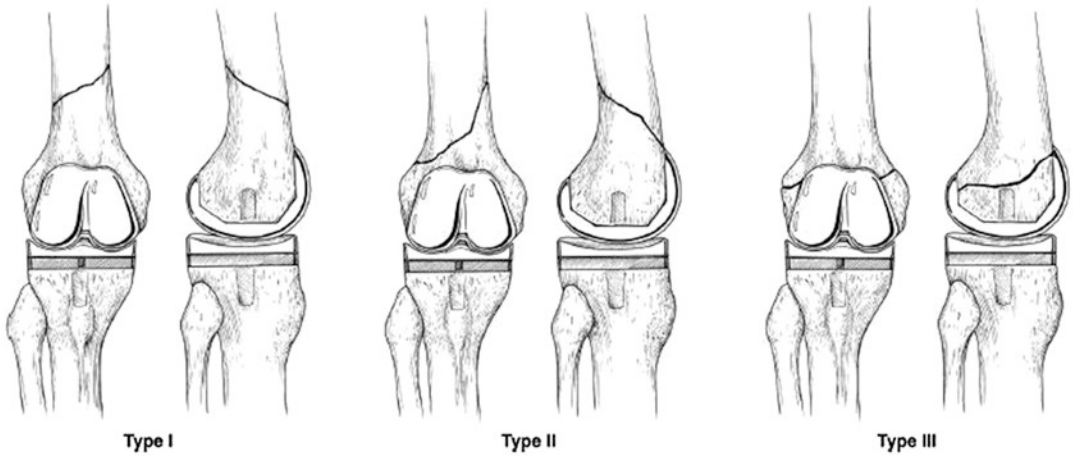

Fig. 19.3 The Su classification of distal femoral periprosthetic fractures. Type 1 are proximal to the femoral component. Type 2 are fracture that begin at the proximal end of the femoral component and extend proximally. Type 3 fractures extend to the distal to the proximal end of the component (From Su ET, DeWal H, Di Cesare PE. Periprosthetic femoral fractures above total knee replacements. J Am Acad Orthop Surg. 2004;12(1):12-20, with permission)

paucity of high level evidence comparing different treatment options for managing this relatively rare injury. Nonoperative treatment is indicated in nondisplaced fractures or for displaced fractures without skin and soft tissue compromise in nonambulatory patients or those not likely to survive the surgical procedure because of medical comorbidities. Improvements in surgical technique and numerous studies support a trend toward operative treatment [2].

Stability of knee implant fixation is a key factor in preoperative decision making, and stability should be determined preoperatively. Proper radiographs are essential. If the prosthesis is stable, treatment can focus on appropriate reduction and stabilization of the fracture. If the femoral component is unstable and well fixed to the bone, revision of the component must accompany fracture fixation, and the possibility of using allograft or tumor-type, constrained prosthetic reconstruction should be considered. Careful assessment of fracture location, displacement, knee implant stability, and adequacy of distal femur bone stock is critical. Periprosthetic distal femur fractures carry a higher mortality risk than hip fractures [5].

The presence of a TKA implant can present problems for fracture stabilization by interfering with or precluding the use of standard fixation methods. A TKA with a narrow or closed femoral intercondylar box may limit the diameter of a retrograde nail or obviate its use [23]. Conventional nonlocking lateral buttress plating is prone to varus collapse [24, 25]. Fixed angled implants such as the 95° angled blade plate or dynamic condylar screw are difficult to employ in very distal fractures or with implants that have a deep intercondylar box. These implants can be used when adequate bone above the femoral prosthesis is available [24–26].

The indications for using locking plates have expanded, and this method is most commonly used to treat these injuries. With locked plating, there is flexibility to place multiple large diameter locking screws in the distal fracture segment, which provide a fixed angle against varus collapse. Locking plates are especially useful with extreme distal periprosthetic distal femur fractures even when associated with a deep intercondylar box. "Joysticks" and fracture reduction clamps can be used to mobilize the distal main fracture segment. There is the option to employ locking screws in the diaphysis which can be helpful when dealing with osteopenic bone [15, 27]. Assuming an acceptable reduction is achieved, the technique can be performed percutaneously with submuscular insertion of the plate

proximally. The technique can be altered depending on the fracture pattern with indirect reduction and a bridge technique used for multifragmentary fractures and anatomic reduction and a compression plating technique for simple fracture patterns (Fig. 19.4). Proximal fixation is optimized with the use of relatively long plates, eight or more holes covering the proximal fragment secured with at least four screws. In order to avoid the most common problems with ORIF of these fractures (reduction in valgus), true AP radiographs are required and comparison to the contralateral limb should be employed to assure proper alignment [28].

Following stabilization of periprosthetic distal femur fractures, early rehabilitation is focused on knee range of motion and mobilization with partial weight bearing for 6–8 weeks. Touchdown weight bearing or up to 50% weight bearing is permitted if bone quality and fixation were both optimal. Transition to full weight bearing is typically made by 6–8 weeks followed by progressive resistive exercises and gait/endurance training [28, 29].

The results of locked plating of periprosthetic distal femur fractures are consistent with those of other series of locked plate fixation of native distal femur fractures suggesting that the presence of a TKA femoral component has little effect on outcomes [29]. Despite evolution of locked plating techniques and implants, nonunion continues to be a problem. Nonunion and implant failure remain a concern with rates as high as 22.2% and 8.3%, respectively, in one series [30]. Ebraheim reported

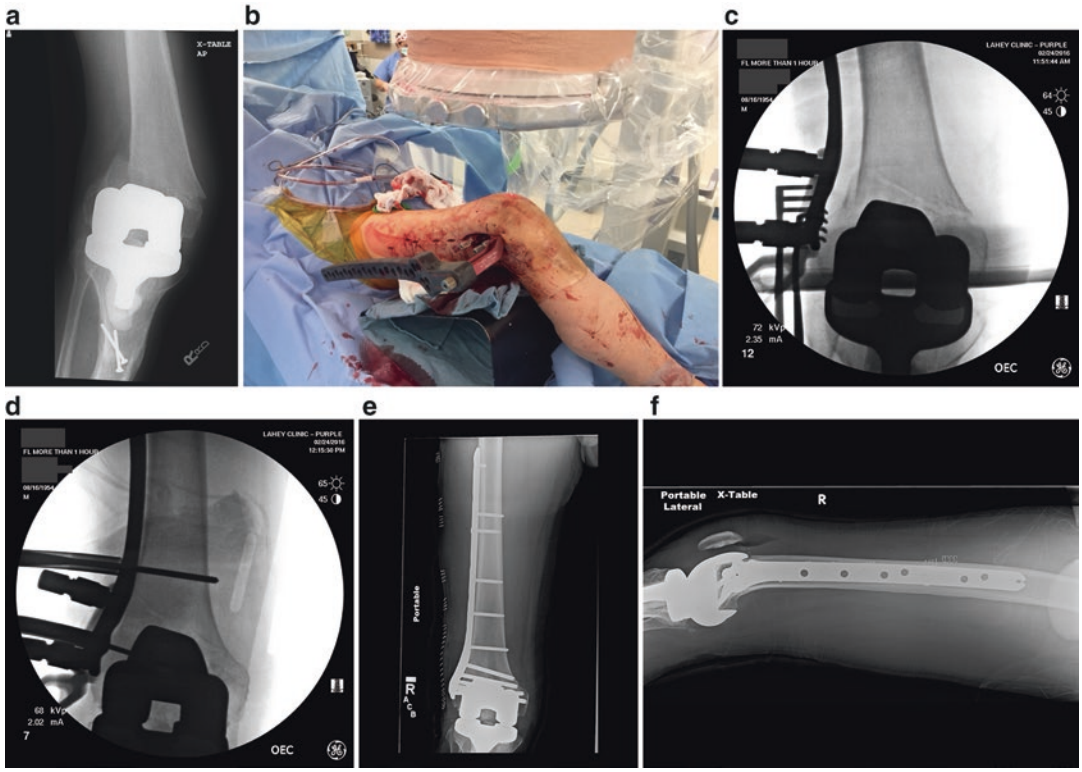

Fig. 19.4 Case example of a 65-year-old male with a periprosthetic distal femur fracture above total knee treated with a distal femoral locking plate using submuscular insertion technique. The injury AP (**a**) radiograph shows a distal femoral fracture above the femoral component with an intact femoral component. (**b**) Using the submuscular technique is aided by the use of a radiolucent gig attached to the distal femoral locking plate. Using fluoroscopic imaging (**c**, **d**) intraoperatively is used to ensure adequate alignment, and the plate is compressed to the bone prior to placement of locking screws. The final AP (**e**) and lateral (**f**) radiographs demonstrate final alignment of the distal femoral locking plate

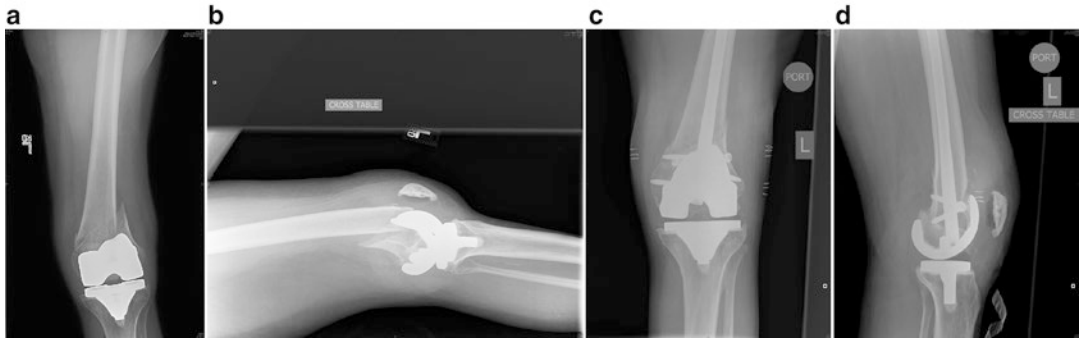

Fig. 19.5 (**a**–**d**) Retrograde femoral nails can be used to treat distal femoral periprosthetic fractures if there is room to insert the nail and enough room distally to place locking screws. The use of supracondylar nails with more locking options can be used to get increased fixation distally. The images here demonstrate a periprosthetic fracture about a cruciate retaining femoral component and the placement of retrograde femoral nail (Images courtesy of Dr. Paul Tornetta III, MD)

an 89% union rate with 7.4% delayed unions, 3.7% nonunions, and 26% fixation failures in a series of 27 patients with periprosthetic distal femur fractures [31].

Retrograde intramedullary femoral nailing (RIMN) is another commonly employed treatment option for periprosthetic distal femur fractures (Fig. 19.5). Advantages include the benefits of a load-sharing implant, indirect reduction, and minimal vascular disruption at the zone of injury. Challenges include the wide metaphyseal condylar fragment and inability to achieve stable distal fixation in a short osteopenic distal segment [32–34]. The distal fracture segment must also be large enough to ensure stable fixation with interlocking screws.

When RIMN is selected, it is imperative that the geometry of the femoral component accommodates the diameter of the driving end of a retrograde nail. The intercondylar distance of the posterior cruciate retaining total knee determines the size nail that can be placed. In a well-fixed posterior stabilized component, the intercondylar box blocks access to the medullary canal. A technique of opening the box with a diamond-tip metal-cutting burr to allow access to the canal has been described [23]. Reviewing operative reports, published reference lists, and radiographic total knee implant profiles should be part of the preoperative planning process [35].

Additional challenges when using this technique include maintaining fracture reduction. Even with a proper starting point, the nail can migrate to a different trajectory which can malalign the fracture. This can result in malunion particularly with an overly posterior starting point. Blocking (Poller) screws on both sides of the nail, medial and lateral to control varus/valgus, and anterior and posterior to control flexion/extension can help maintain reduction during canal reaming and nail insertion [36]. Placing as many interlocking screws as possible in multiple planes to support distal fixation in osteoporotic bone is important. A true lateral of the knee is required to confirm proper nail position relative to the knee prosthesis to avoid nail protrusion.

Early postoperative mobilization with partial weight bearing for 6 weeks is recommended. Knee range of motion is emphasized in the immediate postoperative period. Weight bearing is advanced to full from 6 to 10 weeks with an emphasis on endurance training.

Although reported union rates are favorable with this technique, the risk of malunion is high. Alignment at union is variable and this is a major challenge of treatment [37]. In a systematic review, 44 studies with 719 fractures were evaluated [38]. Pertinent outcomes considered were malunion, nonunion, and the need for secondary surgical procedures. Both locked plating and RIMN demonstrated significant advantages over nonoperative treatment. Some advantages were also observed

when locked plating and RIMN were compared with conventional (nonlocked) plates. Comparison of locked plating and RIMN showed no significant differences with regard to nonunion rates or rate of secondary surgical procedures. However, RIMN demonstrated a significantly higher malunion rate when compared with locked plating [38].

To explain the healing difficulties observed in prior series of distal femur fractures treated with locking plates, Bottland et al. suggested that the high stiffness of locking plates decreases micromotion at the fracture site, thereby limiting callus formation [39]. Far Cortical Locking (FCL) plating is a recent modification of the traditional locked plating concept. FCL plating constructs have been shown to form greater amounts of callus in bovine studies when compared to traditional locking plate constructs. These results suggest that further reducing plate stiffness may increase callus and optimize healing. FCL constructs promote callus by providing a biomechanical environment and healing response for locking plates similar to that provided by external fixators [40]. Callus formation is promoted since stiffness is decreased compared with traditional locked plating and motion across the fracture site is symmetric. Clinical data with this relatively new technique is limited [39].

External fixation has also been reported as a treatment for periprosthetic distal femur fractures [41, 42]. However, the inherent risks of external fixation make it a less than optimal choice for this indication. The need to place half pins closed to the joint capsule can lead to infection, and pin placement through the quadriceps muscle can decrease motion.

Revision TKA in the face of periprosthetic fracture of the distal femur is a considerable technical challenge. Care must be taken to restore the tibiofemoral joint line and normal rotation of the femoral component. Stable patellar and tibial components can be retained if they are compatible with the design of the revised femur. Revision options depend on the bone stock of the distal femur (Fig. 19.6). As

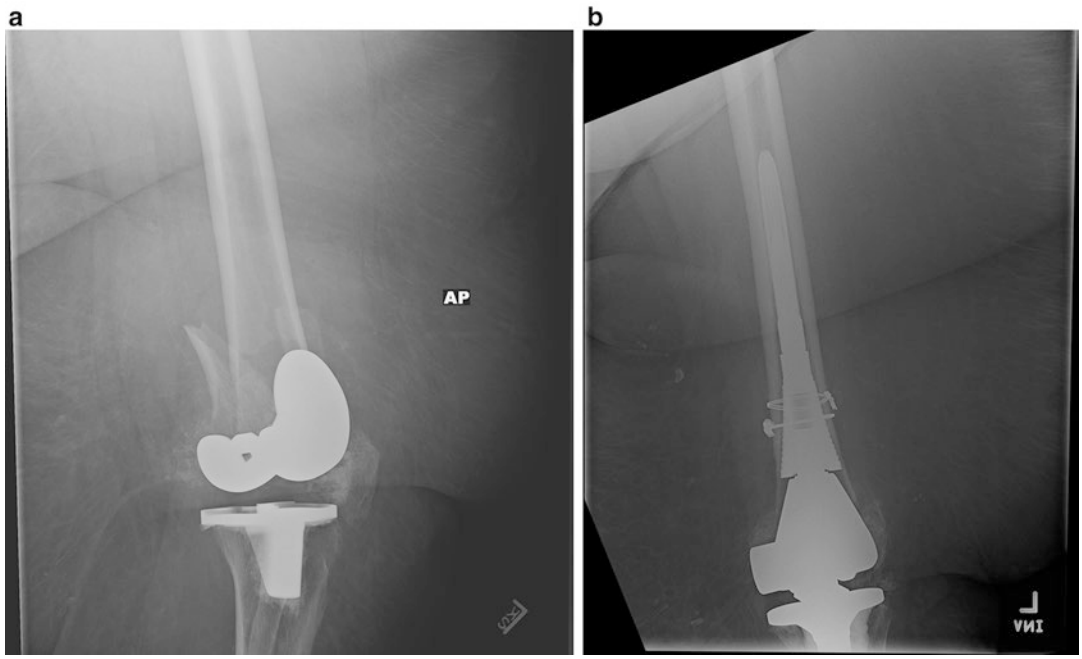

Fig. 19.6 With severe comminution, bone loss, or a loose femoral prosthesis, the use of distal femoral replacement or hinged prosthesis becomes an option one must consider to allow early mobilization and early weight bearing. The AP (**a**) radiograph demonstrates a severely comminuted and loose femoral component in an 87-year-old female. The use of a hinged distal femoral component was used (**b**) to treat this injury and achieve early motion and immediate weight bearing

more condylar bone is lost to fracture comminution or attempts to remove the existing femoral component, allograft-prosthesis composite can be considered to replace bone loss in the distal femur. When possible, implant fixation can be obtained in the diaphysis with press-fit stems. The use of cement in the diaphysis is discouraged because it may interfere with fracture healing. Wedges or blocks allow for reconstruction of smaller defects, and bone graft should be used. As the amount of bone and soft tissue injured increases, stability becomes a major concern, and constrained or rotating hinge prostheses become a necessity. Another option in the face of severe bone loss is the use of a hinged prosthesis which can allow for immediate range of motion and weight bearing in very elderly and low-demand patients.

Mortazavi et al. reported on the use of acute distal femoral arthroplasty (DFA) for the treatment of periprosthetic fractures after TKA. They retrospectively reviewed 20 patients (22 knees) with a mean age of 69.5 years who underwent revision with DFA. Average follow-up was 58.6 months, and the mean Knee Society knee and functional scores were 82.5 and 40, respectively. There were ten postoperative complications for five patients who required additional surgery. Given the high rate of complications, the authors recommend that this procedure be limited to patients where first-line treatments are not possible [43].

A retrospective study by Chen et al. compared patients who failed primary plating procedures requiring subsequent revision to distal femoral arthroplasty to patients who underwent primary DFA. Of the 13 patients (9.2%) who failed primary ORIF, causes included nonunion (53.8%), infection (30.8%), loosening (7.7%), and refracture (7.7%). There were significantly more surgical procedures for ORIF revision to DFA, compared to primary DFA. Complications for patients who underwent primary DFA included extensor mechanism disruption (8.3%), infection (5.6%), and dislocation (2.8%) [44]. The available clinical series indicate that this is a technically demanding procedure, and given the high rate of complications, it is recommended that acute DFA be reserved for patients where first-line treatment options are not possible [44, 45].

Interprosthetic Fractures of the Femur

Patients sustaining interprosthetic fractures, which occur between total hip and knee arthroplasties, are generally older and suffer from osteoporotic bone, which further increases the difficulty of treatment (Fig. 19.7). Overall, the incidence is 1.25% with ipsilateral hip and knee arthroplasties. Femur fractures between ipsilateral hip and knee arthroplasties have less bone

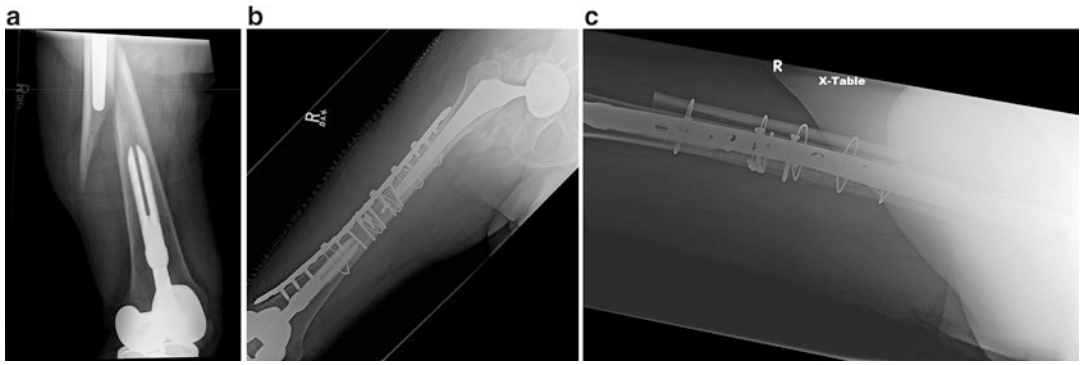

Fig. 19.7 Interprosthetic fractures are difficult problems that occur between hip and knee implants. The example here demonstrates the extreme of a femur fracture occurring between a hip stem and a revision total knee component (**a**). This was treated with a long locking plate, lag screws, cables, and an anterior strut (**b**, **c**).

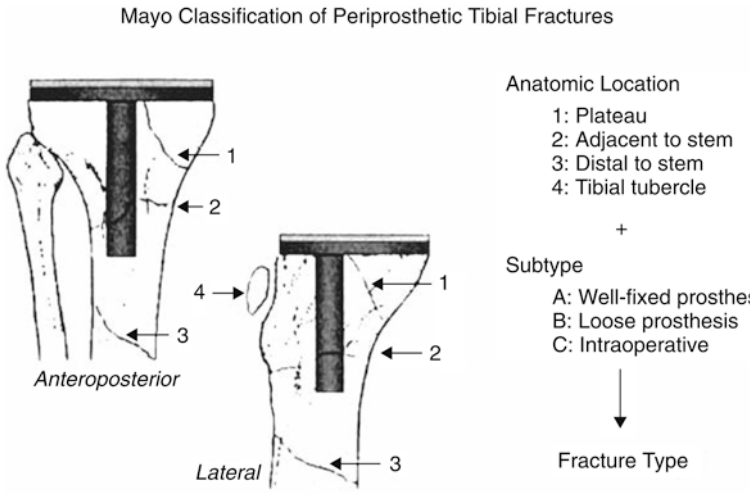

Fig. 19.8 Classification of periprosthetic fractures whereby selection of anatomic location combined with a subtype provides description of a specific fracture treatment group. Determination of subtypes includes timing of the fracture and the status of prosthesis fixation. Postoperative subtypes A and B are determined by whether the prosthesis is well fixed or loose, whereas subtype C shows the fracture that occurs during surgery (From Felix NA, Stuart MJ, Hanssen AD. Periprosthetic fractures of the tibia associated with total knee arthroplasty. *Clin Orthop Relat Res.* 1997(345):113-124, with permission)

available for fracture fixation secondary to the presence of hardware both proximal and distal to the fracture [46].

Hou et al. reported on 13 consecutive patients with interprosthetic fracture. Four fractures occurred around a clearly loose prosthesis, which were subsequently treated with long-stemmed revisions The remaining 12 fractures were treated with a locking plate. Two of nine patients (22.2%) died before fracture union. Follow-up averaged 28 months ± 4 months, with fracture union at an average of 4.7 months ± 0.3 months. All patients returned to their self-reported preoperative ambulatory status except one who developed a loose hip prosthesis at 3-year follow-up after fracture union. Laterally based locking plates are an effective method of treatment for interprosthetic femur fractures. Bypassing the femoral implant proximally by a minimum of two femoral diameters is recommended to prevent a stress riser [47].

Proximal Tibial Fractures

The incidence of periprosthetic tibial fractures is rare. The Mayo classification of periprosthetic tibial fractures is the most widely used classification system [48, 49]. Fractures are classified based on the anatomic location and proximity to the prosthesis (Fig. 19.8).

- Type 1 fractures are at the level of the tibial plateau and describe a split or widening of the plateau.
- Type 2 fractures occur more distal at the metaphyseal region or metaphyseal-diaphyseal junction adjacent to the tibial component stem or keel if there is one present.
- Type 3 fractures occur in the tibia shaft or diaphysis distal to the prosthesis.
- Type 4 fractures involve the tibial tubercle. Fractures are subclassified based on the stability of the tibial implant and when the fracture occurs. Subtypes A and B occur postopera-

tively, with type A fractures having a stable component and type B fractures having unstable components. Type C fractures occur intraoperatively.

Intraoperative Proximal Tibia Fractures

The Mayo type C fractures occur intraoperatively and typically occur due to retractor placement, during medullary preparation for a stemmed component, insertion of the stemmed component, tight trial reduction, impaction of the tibial implant, or torsional stress on the lower leg [49]. In the revision setting, fractures can occur with cement removal, and the surgeon should be aware of this complication. A type 1C fracture occurs in the tibial plateau region, and type 2C fractures occur in the metaphyseal region. Often, type 1C fractures can be stabilized with a cancellous or cortical bone screws to stabilize the plateau and prevent widening and provide a stable base for the tibial tray. Type 2C fractures are often vertical and nondisplaced as a result of cement removal. Treatment can be with a stemmed tibial component to bypass the metaphyseal defect. If nondisplaced, they can be treated with protected weight bearing and early motion with or without a brace [17]. Type 3C fractures occur distal to the stem, and treatment needs to be individualized based on the location. They often need ORIF if displaced. If nondisplaced and stable, these fractures can often be treated with bracing and nonweight bearing or weight bearing in a patella tendon-bearing cast [17, 49]. Type 4C fractures which involve the tibial tubercle are best avoided with careful techniques including medial dissection to the midcoronal plane and consideration of a quadriceps snip or tubercle osteotomy. If a type 4C tibial tubercle fracture occurs, it needs to be securely fixed with screws or wires and protected for 6 weeks [18]. In the revision setting these can be quite severe due to extensive osteolysis, and salvage with an extensor tendon allograft is a possible option [50].

Postoperative Proximal Tibia Fractures

Fractures occurring anytime in the postoperative period are classified as type A or B based on component stability, with the subclassification A indicating a stable tibial implant and B indicating an unstable implant. Fractures with stable tibial implants, type 1A and 2A, which are minimally displaced are generally treated nonoperatively with either protected weight bearing, bracing, or casting [48, 50, 51]. These fractures, adjacent to a well-fixed tibial stem, are generally related to a fall or other traumatic event. Displaced fractures that affect the mechanical alignment of the limb are a challenging problem, and open reduction and internal fixation is the preferred treatment. However, axial and rotational alignment must be maintained and there may be limited proximal bone for fixation. Revision TKA may be necessary, but this adds the risk of additional bone loss while removing the well-fixed tibia from the proximal bone [50].

Tibial stress fractures have been reported by Rand and Coventry in 1980 reporting on 15 medial tibial plateau fractures occurring distal to Geomedic and Polycentric knee implants (Howmedica, Mahwah, NJ) [52]. These type 1B tibial plateau fractures were associated with axial malalignment due to incorrect implant positioning. These fractures resulted in tibial implant loosening and revision was required in all cases [52]. While mostly related to older designs, these fractures have been reported with modern condylar knee designs. Stress fractures have also been reported in osteopenic women with neutral or valgus preoperative alignment receiving press-fit LCS knee implants (DePuy, Warsaw, IN) [53]. Revision with a stemmed component, and augments or graft as necessary, is the recommended treatment [49].

Type 2B fractures are metaphyseal fractures associated with a loose knee implant. These require revision with stemmed components. Bone loss can be extensive, and both structural and morselized grafting are often necessary [50]. Ghazavi and associates reported the successful use of proximal tibial allografts in three cases

[54]. Another option in the elderly is use of a hinged oncology prosthesis, which, when cemented, allows for early mobilization.

Type 3 tibial shaft fractures are usually associated with high- or low-energy trauma in the presence of a well-fixed implant. They can also be associated with poor alignment or with a prior tubercle osteotomy, creating a stress riser through which a fracture occurs [50, 55]. Treatment must be individualized based on stability and can often be nonoperative if patient can tolerate cast immobilization and or limited weight bearing. Felix et al. described successful treatment with cast immobilization and limited weight bearing in 14 of 15 reported cases [48].

Type 3B fractures involve the tibial shaft and a loose stem. Revision is required but the sequence of treatment should be individualized. In some cases it may be appropriate to treat the fracture first, then do a delayed revision once healing has occurred [50].

Type 4 fractures involve the tibial tubercle. These can be the result of trauma or related to a nonunion of an osteotomy [55, 56]. Nondisplaced fractures may be successfully treated by immobilization in extension. Displaced fractures require ORIF with a tension band wiring technique. Reinforcing this repair with a semitendinosus graft is described [13].

In general, if the knee implants are well fixed, nondisplaced periprosthetic tibial fractures and those fractures that can be reduced to a stable and anatomic position are amenable to nonoperative treatment. If the knee implants are loose, or the fracture pattern is unstable, long-stemmed revision is often necessary. Such revisions may need to be accompanied by open reduction and internal fixation with extramedullary plating as well as bone grafting. Displaced tibial tubercle fractures require open reduction and internal fixation to maintain the integrity of the extensor mechanism.

Patella Fractures

Patella fractures are the second most common periprosthetic fractures to occur in total knee patients after distal femoral fractures. The incidence of periprosthetic patella fractures is 0.2–21% in the resurfaced patella and 0.5% without resurfacing the patella [57–62]. The incidence of these fractures differs in the primary setting versus the revision setting, with fractures only occurring in 1.19% of primary TKA and can range from 0.15–12% with revision TKA [58, 59, 61–66]. Men tend to experience more patella fractures then women, and this increased prevalence may be associated with increased BMI and activity [67].

Fracture can occur both intraoperatively and postoperatively for a variety of reasons. The cause of these difficult fractures can be related to patient factors or surgical technique. Surgical factors that can lead to patella fractures include implant malpositioning, lateral release, fat pad removal, excessive bone resection, central pegged patella design, noncemented components, and revision TKA. Patient factors include rheumatoid arthritis, osteoporosis, high activity levels, trauma, and hyperflexion [64–66, 68]. An overstuffed joint can occur as a result of insufficient or eccentric patellar resection or with an oversized femoral component either in the AP dimension and/or an overly flexed femoral component. Thermal necrosis due to PMMA or a lateral release, or excessive stripping of the soft tissues that compromise the lateral geniculate blood supply, can result in osteonecrotic bone predisposing the patella to fracture.

Several classification schemes have been described, with the most commonly referred system described by Ortiguera and Berry [59, 65, 69, 70] (Table 19.1). Type 1 fractures have stable implants and an intact extensor mechanism. Type 2 fractures cause a disruption of the extensor mechanism with or without a stable implant. Type 3 fractures have an intact extensor mechanism but a loose patellar implant. Type 3 fractures can be subdivided into those with reasonable remaining bone stock (A) and those with poor bone stock (B) as defined by less than 10 mm of bone thickness or severe comminution of the patella. Treatment is ultimately based on restoration of the extensor mechanism.

Table 19.1 Ortiguera and Berry classification of the patellar fractures

Type	Definition
Type 1	Fractures with stable implants and intact extensor mechanism
Type 2	Disruption of extensor mechanism (with or without stable patellar implant)
Type 3A	Intact extensor mechanism but *loose implant, good bone stock* of patella greater than 10 mm of bone thickness
Type 4B	Intact extensor mechanism but *loose implant, poor bone stock* of patella less than 10 mm of bone thickness or marked comminution

From Ortiguera CJ, Berry DJ. Patellar fracture after total knee arthroplasty. *J Bone Joint Surg Am.* 2002;84-A (4):532-540, with permission

Intraoperative Patella Fractures

During primary TKA, patella fracture may occur during patella resurfacing. Fracture can be a result of an overresection of the patella, a deep hole drilled for a patella peg, or when using an inset design. These intraoperative fractures tend to be vertical or marginal fractures and do not disrupt the extensor mechanism, type 1 patella fractures (Lewis book). Marginal fractures can be excised and vertical fractures can be observed. Usually the surgeon is able to achieve stable fixation of the patella implant in the presence of these fractures.

During revision TKA, during the removal of a well-fixed patellar component, the chances of an intraoperative fracture are increased. A vertical fracture is usually stable as long as it does not compromise the extensor mechanism. The transverse fractures are problematic and require fixation to restore extensor function. A tension band technique is used to stabilize the patella, and placement of a patellar implant that would further compromise the patella should be avoided. If a stable patella cannot be achieved, than patellectomy should be considered, along with allograft reinforcement of the extensor mechanism [17].

Postoperative Patella Fractures

Periprosthetic fractures of the patella occurring postoperatively usually occur as a result of a trauma or as a result of fatigue of the remnant bone. Traumatic fractures can be transverse, vertical, or avulsion. Fatigue or stress fractures can be asymptomatic or symptomatic. If symptomatic, vertical nonoperative management with activity modification is the preferred treatment. Assessing implant stability and the extensor mechanism is the key to management. Just as in intraoperative fractures, the integrity of the extensor mechanism is the main driver of treatment.

In cases where the implant is stable to the bony fragments, a tension band technique to reconstruct the patella using k-wires, screws, or minifragment plates can be utilized, but poor results have been reported. Up to 50% of patellas fixed with internal fixation techniques fail [65]. If the pre-existing implant is loose, restoring the bony anatomy is first addressed, and then a decision is made as whether or not to re-resurface the patella. If bone stock is poor, then patellectomy is recommended with reconstruction of the extensor mechanism with allograft if necessary.

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Total Knee Arthroplasty After Failed High Tibial Osteotomy

20

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High tibial osteotomy (HTO) is a good alternative to arthroplasty in selected cases of medial compartment osteoarthritis because it enables high activity levels for the patient and delays the need for total knee arthroplasty (TKA). With the passage of time, these results deteriorate, and the most common means of treating a failed HTO is with revision to a TKA. As a result, the surgeon performing an HTO must be mindful of the potential need for subsequent TKA and avoid compromising its outcome. The available literature on this issue is divided. There are studies that show favorable results similar to primary TKA [1–5] and other studies that show inferior results [6–8] similar to those associated with revision TKA. There is an overall consensus, however, that an HTO does often make TKA more technically demanding, with a higher level of postoperative complications and less postoperative range of movement [1]. This chapter reviews the literature on TKA after a failed HTO, the factors that influence the outcome of the TKA, and the associated intraoperative technical factors and complications.

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High Tibial Osteotomy

The first reported HTO for osteoarthritis of the knee was in 1958 [9]. This procedure was then popularized by Coventry [10] and Jackson and Waugh [11]. Since this time there have been many reports in the literature documenting the success of this procedure [12–14]. Within the first 5 years, there is a high level of patient satisfaction, ranging from 80% to 94.9% [15, 16]. Long-term survivorship of the osteotomy, with TKA as the endpoint, has been reported at 98% at 5 years, 92% after 10 years, 71% after 15 years [17], and 85% at 20 years [18]. Those patients requiring further surgical intervention usually require a TKA. The results of a TKA post HTO are therefore an important consideration, as are the factors that influence the outcome of a TKA in this situation.

Factors that improved survival after HTO were age <55 years, higher preoperative function,

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and body mass index (BMI) less than 30 [19]. Niinimaki et al. reported favorable results in males as well as those younger than 50 years of age [20].

The reported early complications associated with HTO include peroneal nerve palsy, malunion, nonunion, intraoperative fracture, compartment syndrome, and infection. The incidence of reported complications varies considerably from 10 to 50% [17–19]. Late adverse sequelae include joint line distortion, patella infera, offset tibial shafts, problematic prior incisions, and retained hardware.

A well-corrected and maintained HTO in the ideal patient has a high likelihood of long-term success, is less likely to require a TKA, and would pose the least troublesome scenario at the *time* of conversion to a TKA. An HTO that fails early, due to malunion or nonunion, is most likely to present technical difficulties.

There is an ongoing controversy about the frequency with which the results of TKA are compromised after HTO. There are studies that show favorable results similar to primary TKA [1–5] and other studies that show inferior results, similar to results associated with revision TKA [6–8]. The majority of research on this issue uses matched-pair analysis comparing the results of primary TKA with those having TKA after failed tibial osteotomy [3]. Mont et al. [21] recommended more appropriate comparison groups, such as patients who have undergone revision TKA or ideally a group matched on multiple criteria.

Several authors have reported good or excellent results in 64% to 81% of their post-osteotomy patients at 2.9- to 6-year follow-up [6–8, 22]. These results are significantly less than their control groups of primary TKA with 88–100% good or excellent results at the same follow-up. Katz [6] reported an increased average operating time due to an increased incidence of technical difficulties, including difficulty with exposure and patellar eversion. A decrease in the average arc of motion with a flexion contracture and limited flexion post-osteotomy has been reported [1, 6, 23]. Nizard et al. [22] reported a statistically significant difference in the Knee Society Score and pain relief, but not in the function score between the primary TKA group matched with the post-osteotomy group. Using the Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index, which is a reliable and validated instrument to assess the functional outcome in knee arthritis, Karabatsos et al. [24] found a trend toward a significant difference in pain ($p = 0.07$), function ($p = 0.18$), and stiffness ($p = 0.14$), suggesting a poorer outcome in patients undergoing TKA for a failed HTO.

By including the cases with significant complications in the osteotomy group, there should be a tendency toward an overall less favorable outcome with TKA. Even with these cases excluded from the post-osteotomy group, Laskin [23] reported statistically inferior results and an increase in tibial radiolucent lines compared with primary TKA patients. This is in contrast to several studies that showed no increase in adverse outcome in the post-osteotomy arthroplasty patients [1–3, 5]. Meding et al. [2] acknowledged that in those patients with a previous osteotomy, there were important differences preoperatively, including valgus alignment, patella infera, and decreased bone stock in the proximal part of the tibia. However, the clinical and radiographic results of TKA with and without a previous HTO were not substantially different [2]. Amendola et al. [1] found comparable percentages of successful outcomes in those patients having a primary TKA (90%) and those having a TKA after a failed HTO (88%) at an average of 37 months. Staeheli et al. [5] reported an 89% successful outcome, at 4 years follow-up, in an unmatched group of 35 patients with TKA post-osteotomy, but also somewhat surprisingly reported that the intraoperative and postoperative rates of complications were not higher, and no untoward technical difficulties were encountered at surgery.

Mont et al. [21] report that for 60–80% of patients requiring a TKA for a failed HTO, the arthroplasty presents no significant difficulty. However, for the remaining 20–40% of patients, there are a variety of intraoperative challenges that require careful preoperative clinical and radiological evaluation, as well as intraoperative technical difficulties that need to be understood

and addressed by the attending surgeon (Fig. 20.1).

The key issues that potentially influence the outcome of a TKA post-osteotomy are reviewed. These issues include previous surgical incisions, intraoperative exposure, retained hardware, patella infera (baja), limited range of motion, joint line angle distortion, lateral tibial plateau deficiency, tibial rotational deformity, an offset tibial shaft, malunion, nonunion, collateral ligament imbalance, flexion and extension gaps, implant choice, peroneal nerve palsy, and reflex sympathetic dystrophy and infection.

Previous Surgical Incisions

Planning for surgery and avoiding potentially catastrophic skin necrosis require an awareness of the previous incisions used at previous knee surgery. A laterally based incision from the previous HTO should not provide significant difficulties as long as a skin bridge of at least 8 cm can be achieved. This may require a slightly medially based skin incision rather than a true midline incision. A previous transverse incision should pose no problem as long as the new incision is perpendicular to it. Where parallel incisions are present, the more lateral incision is recommended, as the blood supply to the extensor surface is medially dominant. Very rarely, a *sham* incision can be used before the definitive surgery, to more safely assess the potential wound healing. Jackson et al. [25] noted a 30% rate of primary wound healing in TKA after failed HTO, with a 20% incidence of deep infection (Fig. 20.2).

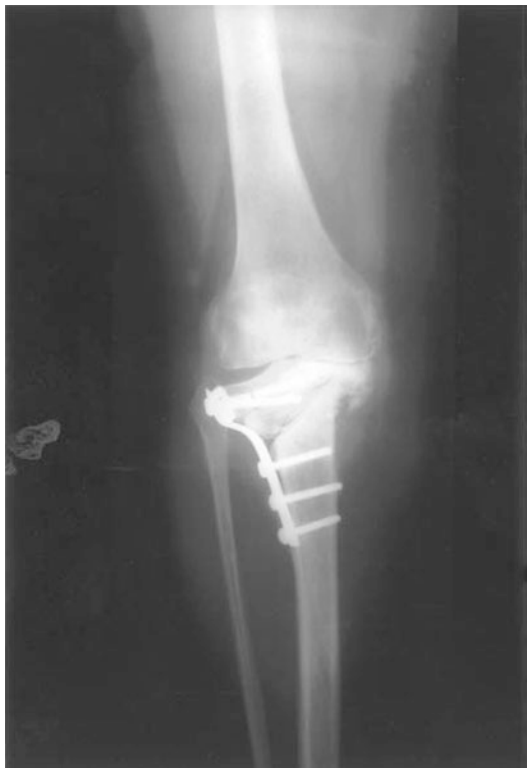

Fig. 20.1 An AP radiograph of a previous HTO with nonunion, retained broken hardware, proximal tibial bone loss, and a sloping joint line

Intraoperative Exposure

Scar tissue between the patellar tendon and the proximal anterior tibia often makes eversion of the patella after a previous HTO more difficult [22]. Release of this scar tissue and excision of a thickened fat pad can improve exposure. The patellofemoral ligament should be routinely released to improve lateral exposure. Meding et al. [2] reported that this was adequate to complete the tibial exposure in each case.

If difficulty with exposure is still encountered, then an early lateral release can be performed [8, 21]. Personal experience of the senior author (RDS) in 74 consecutive conversions of failed HTO to TKA is of a lateral release rate of 38% compared with a 30% lateral release rate in 1000 consecutive arthroplasties from the same era. Nizard et al. [22] reported a lateral release rate of 24% in their post-osteotomy group compared with just 2% in their control group. If exposure is still compromised, then a quadriceps snip is recommended. A tibial tubercle osteotomy should rarely be required for exposure, although Nizard et al. [22] used a tibial tubercle osteotomy in 7 of 63 post-osteotomy cases. Finally, a pin through the patella tendon insertion intraoperatively is strongly recommended, as a prophylactic measure to protect it from avulsing (Fig. 20.3).

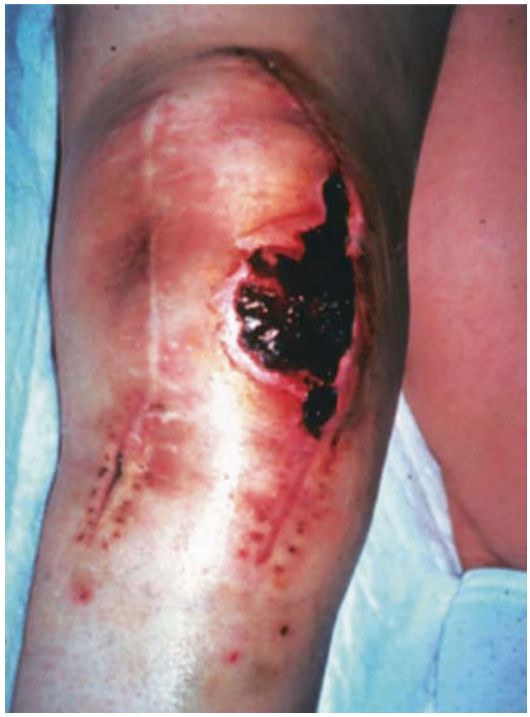

Fig. 20.2 Wound breakdown in a case with parallel incisions, a narrow skin bridge, and the medial incision parallel to previous lateral incision

Retained Hardware

Various fixation devices are usually used in HTO. Options include staples, a compression plate and screws, a blade plate, and other similar hardware. Preoperative planning is required to assess whether the hardware will interfere with the TKA (Figs. 20.4 and 20.5). If not, then the HTO fixation device does not require removal unless its presence is symptomatic to the patient.

If the hardware will interfere with the tibial jigs or implant, then the decision as to whether to perform the TKA in one stage or two would depend on whether a separate incision is required for hardware removal, the size and placement of the hardware, and the site of previous incisions.

For 2-stage arthroplasty, an interval of 6–12 weeks after hardware removal should be used to enable good wound healing before the TKA. Also, cultures of the osteotomy site should always be obtained at the first-stage procedure.

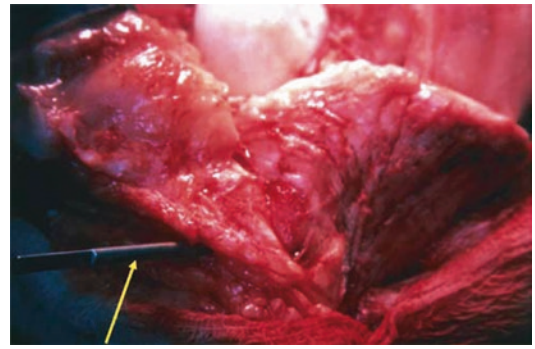

Fig. 20.3 A pin inserted in the tibial tubercle (*arrow*) to protect against patella tendon avulsion

Patella Infera

Patella infera is often seen after a closing wedge osteotomy where shortening of the distance between the tibial tubercle and the tibial plateau occurs, which results in secondary shortening of the patella tendon [2, 8, 21, 22]. This can easily be assessed with preoperative radiographs using the Insall-Salvati ratio, which is the ratio of the patella height to the length of the tibial patella tendon [26]. Patella infera is defined as a ratio of 0.8 or less.

Patella infera is also a problem with respect to elevation of the joint line. The easiest way to compensate for this intraoperatively is to resurface the patella with a smaller than templated patella button placed as proximally as possible. Alternatively, up to 5 mm of extra proximal tibia can be resected, while minimizing the bone resection from the distal femur. This lowers the joint line, or at least insures that the joint line is not elevated, which can improve the patella infera [27]. Finally, at capsular closure, an attempt should be made to advance the medial capsule distally on the lateral capsule, pulling the patella proximally. Patella infera is associated with a decreased arc of motion and potential impingement between the inferior pole of the patella against the anterior flange of the tibial prosthesis. Several studies have shown that the presence of patella infera is not necessarily associated with a less successful outcome of TKA for failed HTO [2, 21] (Fig. 20.6).

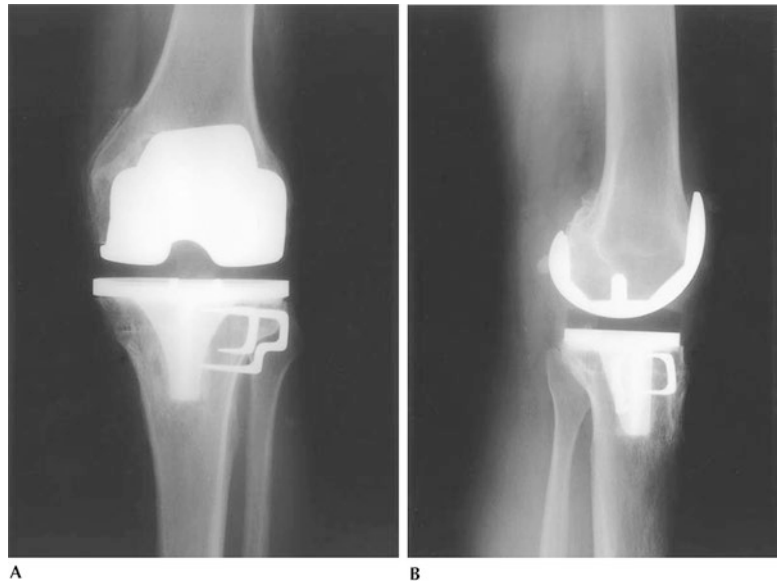

Fig. 20.4 Postoperative AP (**a**) and lateral (**b**) radiographs of a TKA with retained hardware

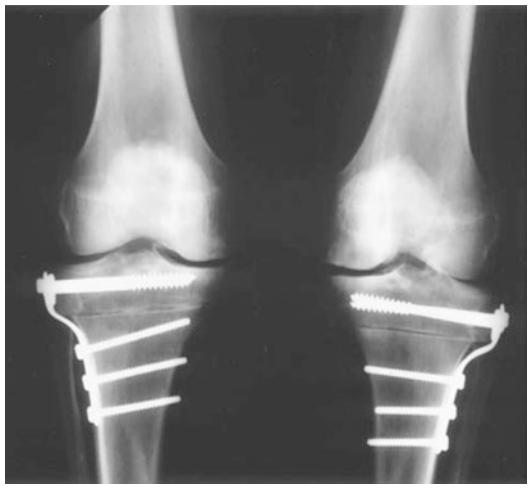

Fig. 20.5 Weightbearing AP radiographs of bilateral closing wedge HTOs with retained fixation devices

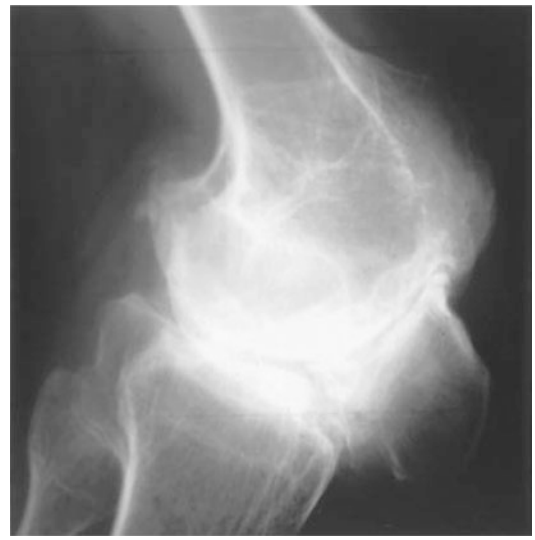

Fig. 20.6 A lateral radiograph of patella infera

Limited Range of Motion

Many studies, including reports that show no significant difference between primary TKA and TKA after failed HTO, report less flexion in the post-osteotomy group [1, 3, 6]. Amendola et al. [1] reported an average 14° decrease in flexion in the post-osteotomy group, but believed that this did not compromise the overall functional outcome. Poor preoperative flexion and/or poor intraoperative flexion against gravity after capsular closure warns of this possibility.

A fixed flexion deformity (FFD) can occur in patients after an HTO. The majority of cases of FFD can be addressed intraoperatively. Care must be taken if the patient has patella infera and a FFD, because the former requires a minimal distal femoral resection to avoid elevating the joint line, while a FFD is often addressed by

resecting more distal femur than usual. Careful removal of all posterior osteophytes with the addition of capsular stripping from the femur and tibia can be helpful.

Joint Line Angle Distortion and Deficient Lateral Tibial Bone

The post-osteotomy joint line is invariably distorted. First, after a closing wedge osteotomy, there is a valgus angulation of the tibia on the coronal view. Second, there is sometimes a loss of the normal posterior slope of the proximal tibial joint line on the sagittal view. In contrast to the anatomical deformity expected with a varus knee, the post-osteotomy valgus angulation of the joint line results in a thicker medial tibial resection than on the lateral side. The tibial cut should resect minimal or no bone from the lateral tibia, with any remaining bony defect managed with lateral augmentation or a structural bone graft if the defect is uncontained. A contained defect can be managed with morsellized graft or cement as required. With preoperative radiographic templating for the appropriate tibial cut, this should be identified hence eliminating intraoperative error (Fig. 20.7).

An osteoarthritis-induced valgus deformity of the knee will be due to a valgus deformity in both the femur and the tibia, whereas a valgus deformity post-osteotomy will be solely due to the tibial deformity. The tibial valgus deformity is compensated for by the varus deformity of the femur due to the initial medial compartment osteoarthritis that necessitated the original HTO. Mont et al. [21] stress the practical implication of this for the surgeon who, after making the routine valgus femoral cut, will make the valgus deformity worse.

The loss of the normal posterior tibial slope can present as either a neutral slope or in fact as an upsloping joint line (Fig. 20.8). The posterior slope must be recreated, necessitating minimal bony resection from the anterior proximal tibia to avoid excess posterior bony resection. Otherwise the potential for flexion and extension gap mismatch can occur, with resultant flexion instability. Once again, radiographic templating will prepare the surgeon for this unusual situation.

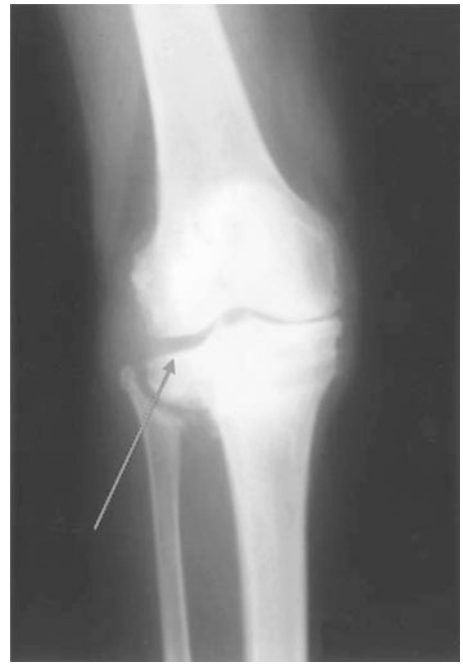

Fig. 20.7 An AP radiograph of a sloping lateral joint line (*arrow*)

Tibial Rotational Deformity

A closing wedge osteotomy has no inherent rotational stability other than that provided by the internal fixation. Inadvertent intraoperative tibial rotation or loss of fixation can result in either internal or external rotation of the tibia. As a result the medial one-third of the tibial tubercle may not necessarily be an accurate or reliable guide to tibial rotation. This will necessitate rotation to be determined from more distal landmarks, including the tibialis anterior tendon, the bony ridge of the tibial diaphysis, or the midpoint of the talus. It should be noted that external rotation of the distal tibia increases the Q-angle, which accentuates abnormal patellofemoral mechanics. Difficulty of surgical exposure also produces a tendency to internally rotate the tibial component, which increases the likelihood of patellofemoral subluxation.

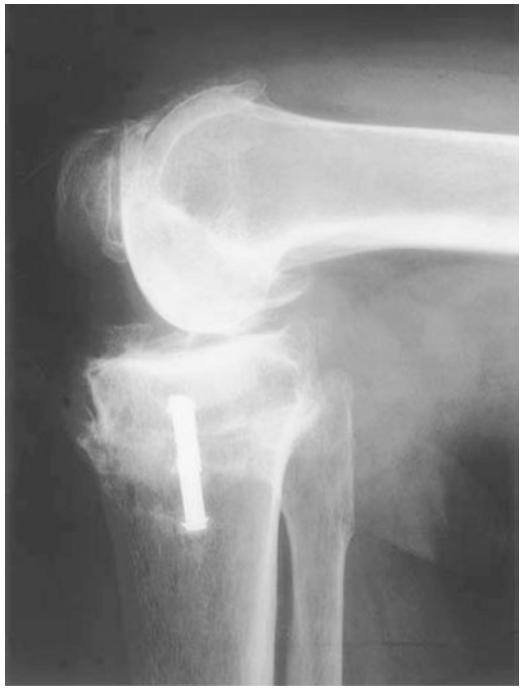

Fig. 20.8 A lateral radiograph of an upsloping joint line

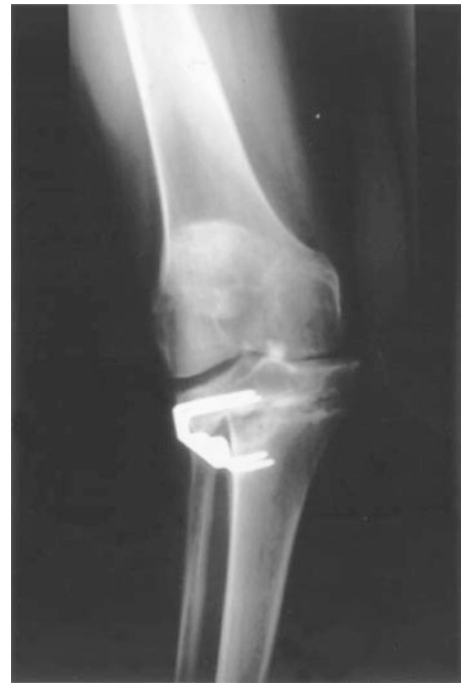

Fig. 20.9 An AP radiograph of a truncated lateral tibial cortex

An Offset Tibial Shaft

A closing wedge HTO will result in a lateral step-off at the osteotomy site due to the resultant disparity in the medial-lateral metaphyseal bone width. This will be accentuated if there is any secondary lateral collapse. Careful preoperative templating will help determine whether the chosen prosthesis will impinge on the lateral tibial cortex. Cutting the proximal tibia in slight valgus can help accommodate for a standard tibial prosthesis (Fig. 20.9).

If a stemmed implant is required, then it is important to confirm that medial offset stems are available to prevent potential medialization of the tibial tray, or a potential iatrogenic fracture of the proximal tibia (Fig. 20.10). Whether an intramedullary or extramedullary alignment guide is used is at the discretion of the surgeon [27, 28]. However, an extramedullary guide is recommended because the medullary canal may be offset medially, such that an intramedullary guide will have difficulty being positioned correctly.

Malunion of Osteotomy Site

A malunion at the osteotomy site is less common with rigid internal fixation. It is more common for a malunion to result in excess valgus than excess varus, due to the propensity of a closing wedge osteotomy to collapse on the lateral side at the level of the truncated metaphysis. Preoperative planning will determine whether correction of the malunion can be incorporated into the TKA. If not, then a one- or two-stage procedure incorporating an osteotomy of the tibia with a stemmed tibial prosthesis will be required. A dome or opening wedge osteotomy of the tibia is preferred over a closing wedge osteotomy in this situation to preserve lateral tibial metaphyseal bone stock before performing a TKA. However, a dome osteotomy is a difficult option if correction is required in two planes, as is seen in Fig. 20.11 (see also Fig. 20.12).

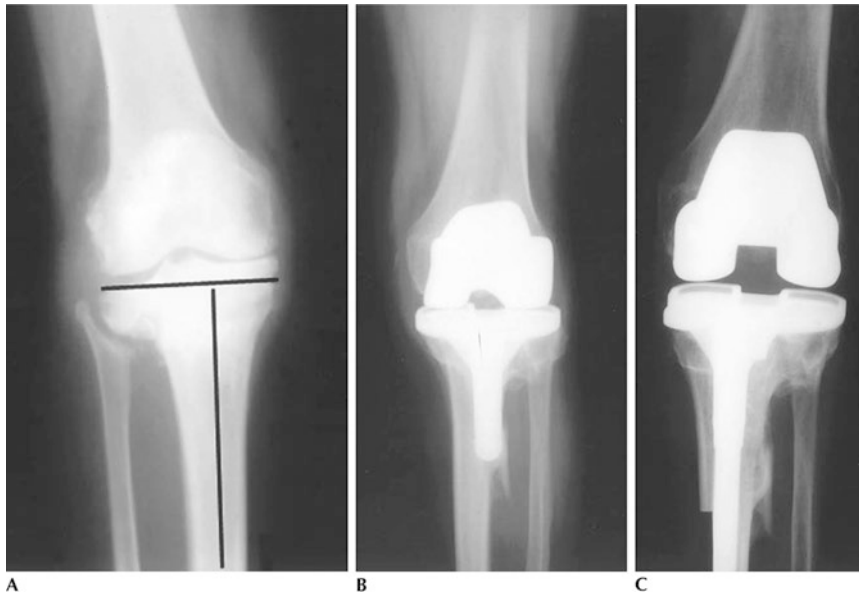

Fig. 20.10 An AP radiograph showing an offset tibial shaft post HTO (**a**), an iatrogenic fracture of the proximal tibia with a standard tibial stem (**b**), and the revision TKA with an offset stem bypassing the cortical defect (**c**)

Nonunion of the Osteotomy Site

Nonunion of the osteotomy is a rare complication, but poses a difficult challenge to the arthroplasty surgeon. The management of the nonunion and the arthroplasty can be performed separately or incorporated into a single procedure. It is imperative to determine whether the nonunion is septic or aseptic and atrophic or hypertrophic. A single-stage correction of the malalignment, bone grafting of the defect, and the use of a long-stem tibial prosthesis can address this difficult problem (Fig. 20.13).

Collateral Ligament Imbalance

The potential for lateral ligament balancing is to be expected during a TKA post-osteotomy [2, 29, 30]. This is especially the case if there has been a malunion into further valgus or severe overcorrection. Meding et al. [2] reported no significant increase in the rate of lateral ligament release in post-osteotomy TKA compared with a contralateral TKA in 39 consecutive patients. However, if there is a trapezoidal extension space that is tight laterally, then a lateral release in extension at the level of the joint line is performed [31]. Conversely, a trapezoidal flexion space that is tight laterally would require extension of the lateral release proximally above the level of the superior genicular artery.

If a valgus deformity of more than 20° is present, then a complex ligamentous reconstruction of advancing the lax medial collateral ligament, the medial hamstring tendons, and the posterior cruciate ligament [30] or a more constrained prosthesis may be required [31]. However, despite the benefit of a lateral release in cases with difficult exposure, the lateral release rate is not significantly higher in TKA post-osteotomy than in primary TKA [2].

Flexion and Extension Gaps

The general principles of balancing flexion and extension gaps apply in post-osteotomy TKA (Fig. 20.14). However, the routine external rotation of the femoral component, as referenced from the anteroposterior axis or the transepicondylar axis, does not routinely produce a

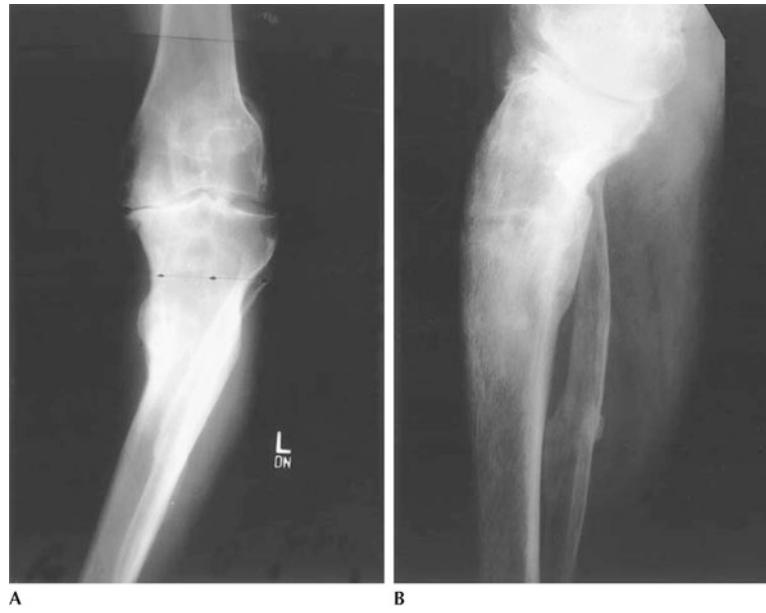

Fig. 20.11 (**a**) AP and (**b**) lateral radiographs of a left knee showing tibial malunion subsequent to a previous HTO using an external fixation device

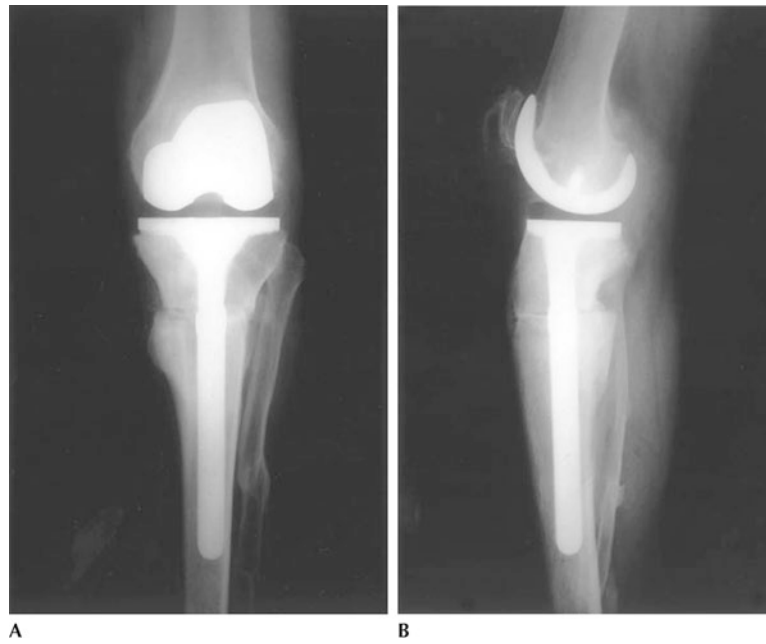

Fig. 20.12 Postoperative (**a**) AP and (**b**) lateral radiographs of a one-stage TKA and osteotomy for proximal tibial malunion

quadrangular flexion space, because of the abnormal valgus angulation of the joint line.

When the tibial resection is made perpendicular to the longitudinal axis, the flexion gap will potentially be asymmetrical. To correct this, the femur must sometimes be internally rotated to create a symmetrical flexion gap; alternatively an extensive lateral release in flexion could be considered, but this complicates flexion and extension gap balancing.

As previously mentioned, an upsloping tibial joint line post-osteotomy needs to be converted

into the normal joint line slope. Even with a minimal anterior proximal tibial resection, this can result in a thick posterior proximal tibial resection that can potentially create a larger gap in flexion than in extension. In these cases, a less pronounced initial posterior slope on the tibial cut is recommended. If the flexion gap is still larger than the extension gap, then the principles of using a larger femoral component with posterior augmentation or resecting more distal femur to increase the extension gap to match the flexion gap are required. The latter option requires a thicker polyethylene insert, which raises the joint line and exacerbates patella infera if present.

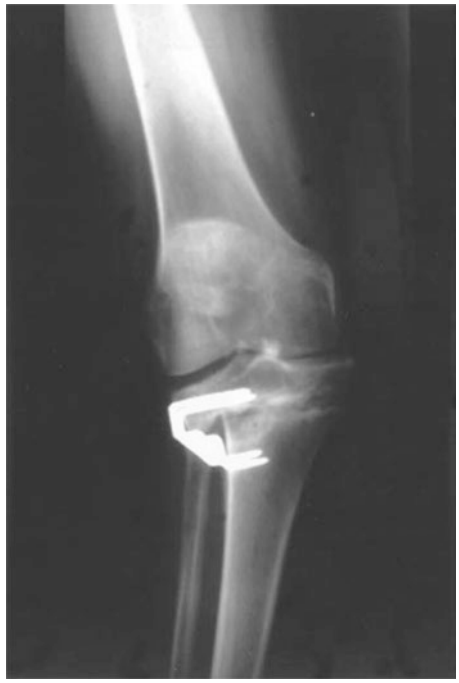

Fig. 20.13 An AP radiograph of nonunion of HTO

Implant Choice

Preoperative planning helps determine whether the surgeon's preferred implant will result in any impingement between the prosthesis and the lateral cortex. The selected implant should have standard and offset stem options available. Whether to substitute or preserve the posterior cruciate is the surgeon's decision. The senior author (RDS) has used a cruciate retaining prosthesis in 74 consecutive cases of TKA for failed osteotomy.

Peroneal Nerve Palsy

The reported incidence of post-osteotomy peroneal nerve palsy is approximately 5% [21]. A failed osteotomy with an unresolved peroneal nerve palsy needs careful clinical assessment to differentiate neurogenic from mechanically induced pain. The surgeon then needs to consider

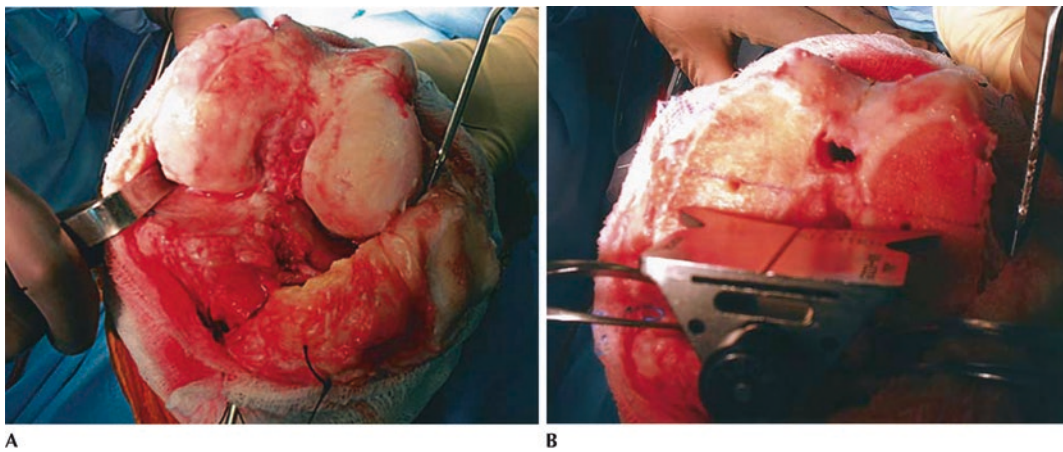

Fig. 20.14 Intraoperative photographs showing the valgus joint line post HTO (**a**), and the asymmetrical flexion gap that would result if femoral rotation was measured from the AP or transepicondylar axes (**b**)

whether decompression of the nerve is warranted. Thereafter, the decision is whether to primarily decompress the nerve or to do this at the same time as the TKA.

Reflex Sympathetic Dystrophy

Total knee arthroplasty in the presence of reflex sympathetic dystrophy (RSD) increases the likelihood of a fair or poor outcome. Cases in which features of RSD are present or in which there was no pain relief from the HTO should make the surgeon cautious to proceed with TKA. Even if previous RSD symptoms are quiescent, there is a high risk of recurrence (47%) of symptoms with further surgery [6].

Infection

Although the incidence of deep infection in TKA after failed HTO is not significantly higher than in primary TKA [2, 5], there is a tendency toward an increase in deep infections [22]. Of concern is a report by Jackson et al. [25] that noted 6 out of 20 patients with a TKA for a failed osteotomy had a failure of primary wound healing resulting in four cases of deep infection. In contrast, no wound healing problems or deep infections occurred in 23 patients requiring a TKA for a failed unicompartmental arthroplasty.

Conclusion

The available literature is divided as to the effect that a previous HTO has on the overall outcome of TKA. However, it is hard to refute that TKA after a failed HTO does present potential challenges to the surgeon. The key issues that potentially influence the outcome of a TKA post-osteotomy have been reviewed. An HTO is a good alternative to arthroplasty in selected cases of medial compartment osteoarthritis; however, with the passage of time, these results deteriorate, and the most common means of treating a failed HTO is with revision to a TKA. As a result, the surgeon performing an HTO must be mindful of the potential need for subsequent TKA and avoid compromising its outcome.

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Total Knee Arthroplasty Following Prior Unicompartmental Replacement

21

William P. Barrett

While the role of unicompartmental knee arthroplasty (UKA) in the treatment of arthritis of the knee has evolved since its introduction in the 1950s, the controversy regarding its use has been constant. For UKA to be a viable alternative in the treatment of degenerative arthritis involving one compartment of the knee, the results should be similar to total knee arthroplasty (TKA), with revisions that are easier than revising a failed TKA. In this chapter we review a brief history of unicompartmental arthroplasty, technical factors that lead to failure of these procedures, mechanisms of failure, techniques for revision of failed UKA, and results of revision of failed UKA.

Historical Perspective

In the 1950s, one-piece interposition metal prostheses were introduced to prevent bone-on-bone articulation of the joint surface and partially restore alignment of the knee (Fig. 21.1). These enjoyed moderate success [1, 2]. Scott et al. reported 70% good/excellent results at 8-year follow-up. Two-piece designs with a metal femoral runner and polyethylene tibial component were introduced in the 1970s. These were implanted with minimal instrumentation and limited sizes (Fig. 21.2). These first-generation implants yielded mixed results. Some authors reported poor results [3, 4], but included patients who were not ideal candidates for UKA, while others reported success rates comparable with those of TKA, in that era [5–8]. Lessons learned from these first-generation procedures included: overcorrection can lead to opposite compartment degeneration; narrow components can subside leading to contained defects; medial-lateral component malposition can cause iatrogenic subluxation of the knee; lack of secure posterior prosthetic fixation can contribute to femoral loosening. Failure was primarily due to loosening, the majority on the tibial side [9].

Second-generation implants were introduced in the 1980s, and corrected many of the problems noted with first-generation procedures. The implants were made wider to resurface the involved compartment and resist subsidence. The tibial implants were metal-backed to decrease focal stresses on the tibial bone. This led to a resultant thinning of the overall poly thickness of the tibial components. In some designs, peripheral polyethylene was only 2 mm thick (Fig. 21.3). Concerns over polyethylene wear led to modifications of the tibial implants. The articular geometry was made more congruent with thicker polyethylene and/or use of all-polyethylene tibial implants. This increased conformity in

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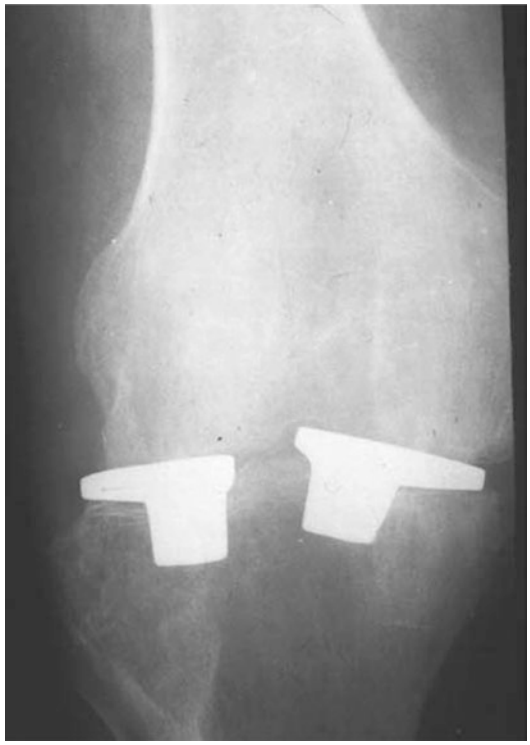

Fig. 21.1 Medial and lateral McKeever hemiarthroplasty implants

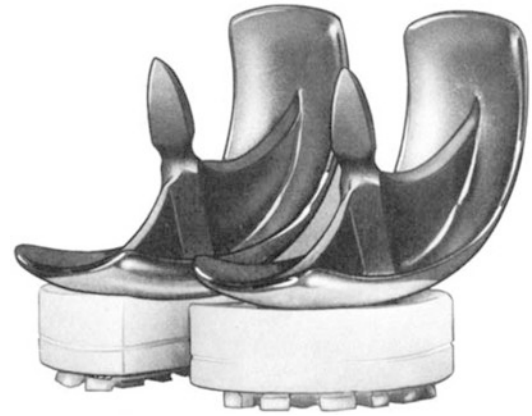

Fig. 21.2 Two-piece first-generation UKA implant

fixed-bearing knees led to increased interface stresses, particularly on the femoral side, and an increased rate of femoral loosening was noted with these implants [10]. However, increased conformity, when associated with mobile-bearing implants, performed well, both at early and long-term follow-up [11, 12].

The surgical technique for implantation of UKAs has evolved over the last four decades from primarily a freehand procedure to current techniques that use highly instrumented systems that facilitate proper alignment of the limb, as well as implant-to-implant alignment. This is accomplished using both intramedullary and extramedullary alignment guides that mate the tibial and distal femoral resections. In the early 2000s, the evolution of minimally invasive surgery led to smaller incisions, less dissection, and new instruments for implanting UKAs. Those changes decreased hospital stays and costs and in combination with improved pain management and rapid recovery protocols sped the recovery following surgery [13, 14]. However, performing this procedure through a 3-in. incision did increase the technical difficulty and raised the possibility of higher failure rates.

Where UKA fits into the treatment of the patient with knee arthritis continues to evolve. In comparison with high tibial osteotomy (HTO), it offers the following advantages: higher early and late success, fewer complications, and restoration of a relatively neutral mechanical axis rather than creation of a secondary deformity [15, 16]. The advantages of UKA, when compared with TKA, include better proprioception, increased range of motion, more normal gait, preservation of bone stock, and restoration of more normal knee kinematics with preservation of both the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL). Preference for UKA in patients with a UKA in one knee and TKA in the opposite knee has been documented by several authors [17–21].

Several studies have documented 10-year survivorship of UKA ranging from 70% to 98%. While a handful of 10-year follow-ups of UKA equal the results of 10-year follow-ups of TKA, the majority of reported series approach—but do not equal—the results of long-term follow-up of TKA [11, 12, 22–27].

Data from the 2013 Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) reveal that the use of UKA has dropped by 49% compared to its use in 2003.

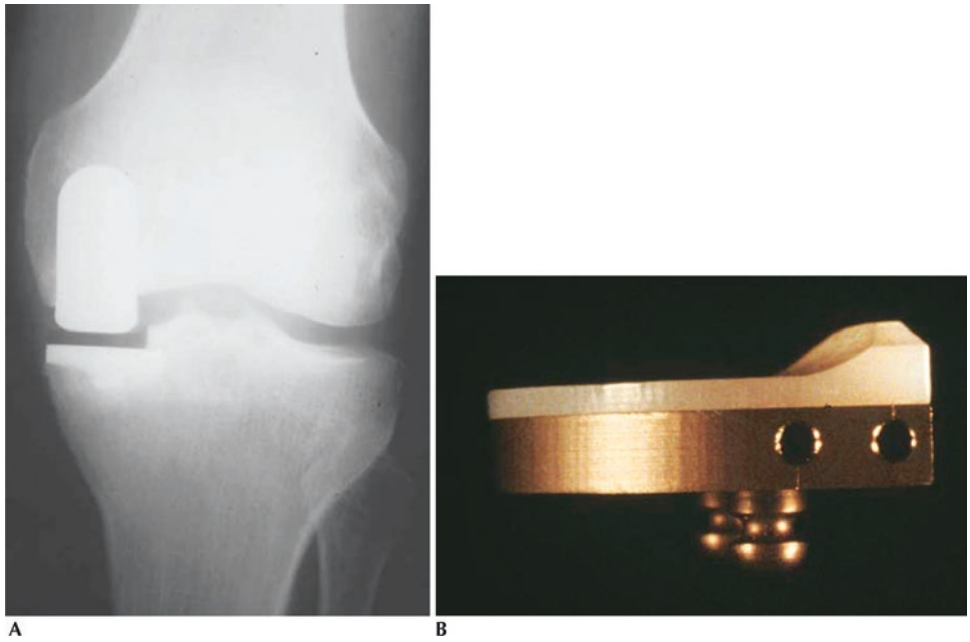

Fig. 21.3 (**a**) Radiograph of second-generation metal-backed tibial UKA. (**b**) Metal-backed tibial implant demonstrating the thin polyethylene at the peripheral margin of the implant

In 2003, UKA represented 14.5% of knee replacement procedures; in 2013 UKA was 4.1% of the procedures. This registry notes a 10-year revision rate for TKA to be 5.6% compared to 15.1% for UKA [28].

Review of more current results for UKA reveals single-center/single-surgeon series particularly from designing surgeons or early adopters demonstrate excellent results at greater than 10-year follow-up [11, 12, 29]. However, multicenter studies and review of various registries reveal higher failure rates particularly when compared to similar follow-up for TKA [30–33].

Curtin et al. compared 2848 UKAs with 61,767 TKAs using the Medicare 5% national sample data base between 2001 and 2007. The authors noted revision rates at 2 years of 3.6% for UKA versus 1.5% for TKA and, at 5 years, a revision rate of 4.7% for UKA versus 2.0% for TKA [34]. Liddle et al., using data from the National Joint Registry for England and Wales extracted in August 2012, compared 25,334 UKAs and matched these with 75,996 TKAs. The 8-year survivorship for UKA was 87% versus 95% for TKA. Mortality complications and length of stay were all higher for TKA versus UKA [35]. Niinimake et al., using data from the Finnish Registry, reported in 2014 on 4713 UKAs versus 83,511 TKAs; they looked at revision for any reason during the period 1985 to 2011. They found that the 2-year survivorship for a UKA was 81% versus 93% for TKA. The 15-year survivorship for UKA was 70% versus 89% for TKA [36].

Indications for Unicompartmental Knee Arthroplasty

The indications for UKA have evolved and have had an impact on the failure rate of the procedure. The classic indications, as noted by Kozen and Scott [37], include patients with degenerative arthritis in one compartment, age greater than 60 years old, weight less than 82 kg, low-impact work/lifestyle, minimal rest pain, minimum flexion of 90° with less than 5° of flexion contracture, angular deformity less than 10° of varus or 15° of valgus, intact anterior cruciate ligament, and intact opposite compartment. Using these criteria,

the use of UKA has been reported to vary from 6 to 30% of patients undergoing knee arthroplasty [12, 38, 39]. Some authors have advocated use of UKA in the younger, more active patient as the first in a series of arthroplasties because of the perceived ease of revisability [40, 41]. While the incidence of osteoarthritis has remained constant, the use of UKA has increased in the early twenty-first century due in part to the popularity of minimally invasive surgery (MIS). Over the last decade, the use of UKA has declined as reflected in the AOANJRR data, but it remains a viable option for OA of one compartment of the knee [28].

Factors that Contribute to Failure

Similar to any joint reconstructive procedure, there are patient-related factors, surgical technique factors, and implant-related factors that can contribute to failure.

The ideal diagnosis for unicompartmental arthroplasty is osteoarthritis or osteonecrosis without metaphyseal involvement involving either the medial or lateral compartment of the knee. Patients with inflammatory arthritis or chondrocalcinosis should be avoided. Some authors have noted increased failure rates in obese patient [9, 26]. Younger-aged patients (40–60 years old) were not associated with a higher revision rate [40]. However, the recent AOANJRR noted a significantly higher revision rate in patients less than 65 years old [28].

Surgical technique has evolved over the last two decades with use of intramedullary/extramedullary instruments, computer-assisted techniques, and robotic guidance. Some argue that UKA is technically more demanding than TKA, with a larger learning curve. If technical errors do occur, UKA is less forgiving than TKA. The experience of the surgeon and/or center has been associated with the rate of failure for this procedure [30]. In one study, a specialty center had a lower failure rate versus results from a multicenter group with less experienced surgeons. Seven of eight revisions in this series occurred in the first ten procedures at each hospital [41]. Review of data from the Swedish Knee Registry revealed the risk of revision for failed UKA to be 1.63 times greater for less experienced surgeons versus a more experienced group. In the United States, 70% of TKAs are performed by surgeons who perform 30 or fewer a year. If the indications for UKA are 10–20% of patients considered for arthroplasty, then the question of the minimum number of procedures to maintain proficiency is warranted.

Most authors have advocated slight undercorrection of the deformity in UKA to avoid overload of the unresurfaced opposite compartment. On the tibial side, avoidance of varus placement of the tibial component is important to avoid increase stress on the cancellous bone. The importance of implant-to-implant alignment and proper soft tissue tensioning have also been advocated. Bone cuts are conservative, but the surgeon must avoid overstuffing the compartment with implant. This leads to overcorrection and subluxation of the implants and joints. Extensive soft tissue releases are not necessary in patients undergoing UKA, as deformity is not typically significant. Fixation with cement has led to better short- and long-term results in UKA, versus use of cementless implants, and appears to be the most appropriate fixation at this time.

First-generation implants had all-polyethylene tibial components. Several authors cited thin polyethylene—less than 6 mm in thickness—as a risk factor for failure in these first-generation implants. Second-generation implants with metal backing had overall thinner polyethylene, particularly at the periphery, which led to an increase of polyethylene wear as a failure mode [9]. White et al. reported that the wear pattern of varus knees with early disease is anterior and peripheral. Retrieval of these second-generation implants revealed a similar pattern of wear [42]. Thus, the greatest stresses were placed on the thinnest polyethylene (Fig. 21.4). Polyethylene sterilized with gamma radiation in air and a long shelf life led to early catastrophic failure in a series of UKAs reported by McGovern et al. At a mean of 18 months after index UKA, 49% of the implants were either revised or scheduled for revision secondary to polyethylene wear [43].

Current UKA implants are resurfacing in nature. Fixed-bearing implants attempt to strike a balance between optimizing contact area and limiting constraint between the implants. Modular systems avoid thinner polyethylene at

Fig. 21.4 Metal-backed tibial component with wear through of the peripheral polyethylene in a pattern similar to anteromedial wear in an osteoarthritic varus knee

the locking mechanism and use polyethylene that avoids oxidative degradation. Mobile-bearing implants have a more constraining surface geometry, but fixation is not compromised due to the mobile bearing. Current designs of fixed and mobile-bearing implants make polyethylene wear in the first decade of use unusual.

Mechanisms of Failure

Mechanisms of failure have varied over the last three decades and from various studies. The most common causes are component loosening, progressive arthritis, polyethylene wear, and mechanical problems.

Loosening

Loosening of UKAs has been a primary cause of failure since the 1970s. Current designs, which are resurfacing implants, typically use some form of distal femoral resection and a more conservative tibial cut, making revision of the tibial side less challenging. The tibial cut for a medial UKA is very similar to the medial portion of a standard tibial cut for a TKA. The incidence of subsidence in association with loosening has also decreased, leading to smaller defects on removal of these implants. However, loosening on the tibial side is still the most common cause of failure in both single-center and joint registry reports.

Progressive Arthritis

Progression of disease has been associated with longer-term follow-up and technical errors such as overcorrection of deformity. Sierra et al. noted progressive arthritis as a cause of failure in 34% of 175 failed UKAs [44]. While some authors have reported the presence of patellofemoral degenerative changes at the time of index UKA, failure of UKA secondary to advanced patellofemoral arthrosis is rare. However, one report noted a 28% incidence of patellar impingement on the anterior edge of the femoral component. Twenty of 28 patients had erosive changes noted on the patella. This was more common in lateral compartment replacements (40%) versus medial compartment replacements (28%) [45].

Polyethylene Wear

Wear was rarely encountered in first-generation implants, but with the introduction of metal backing in modular implants and the associated thinning of polyethylene, wear became a predominant form of failure in second-generation implants. These and other design defects mentioned earlier have generally been corrected and, along with the use of high-quality polyethylene sterilized in a manner to avoid oxidative degradation, have decreased premature failure of the implant secondary to polyethylene wear.

Mechanical Problems

Mechanical issues can range from instability caused by flexion/extension mismatches, problems related to implant malpositioning, and bear-

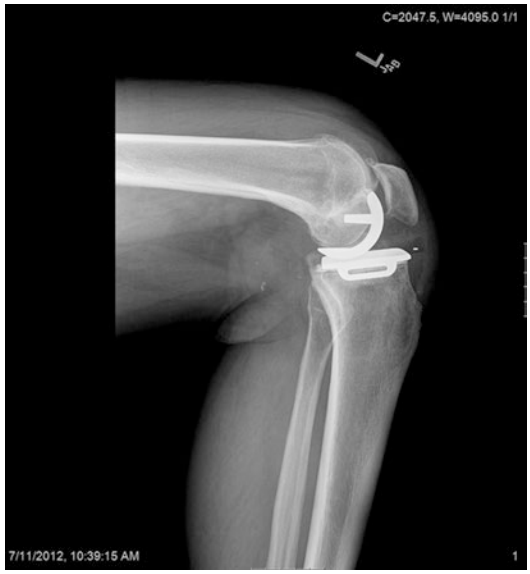

Fig. 21.5 Lateral radiograph demonstrating anterior dislocation of a mobile-bearing polyethylene insert

ing dislocation in mobile-bearing implants (Fig. 21.5).

Revision of Failed Unicompartmental Knee Arthroplasty

The initial evaluation of a patient with a painful UKA is similar to that of a patient with a painful TKA, and the approach outlined in Chap. 3 is used. As previously noted, revision for pain without a clear-cut etiology of the pain is only rarely successful. The surgeon must ask: "What has failed?"

Failure of polyethylene in a modular implant can be associated with an intact femoral component and tibial base plate, loosening of one or both implants, and associated osteolysis. Failure of fixation may occur with one or both implants and may be associated with some degree of bone loss. Progression of disease most likely will involve the opposite compartment, but occasionally the patellofemoral joint. This is confirmed with weight-bearing radiographs, as well as a sunrise view of the patella.

Revision Options

Depending on the cause of failure, options range from insert exchange to conversion to total knee arthroplasty.

Insert exchange: Indications include polyethylene wear, modular implant with intact fixation both on the tibial and femoral sides, acceptable implant design, and the absence of progression of disease in the opposite compartment and patellofemoral joint (Fig. 21.6).

Revision to unicompartmental knee arthroplasty: Revision to UKA may be indicated with loosening or failure of one or both implants, indications for UKA still present, no damage to the opposite compartment, and suitable bone stock available for revision.

Conversion to total knee arthroplasty: Conversion to TKA is indicated in the majority of failed UKAs. If any doubt exists regarding the indications for lesser procedures noted previously, conversion to TKA should be used.

Revision Technique

Preoperative Evaluation

After a complete history and physical examination, radiographs including standing AP, lateral, and sunrise views are obtained looking for signs of failure and possible bone loss. Three-foot AP views are obtained to check alignment and planned cuts at revision. Templating for revision TKA is performed with attention to joint line restoration, need for augments or stems, and appropriate sizing.

Necessary Equipment

A knee system with both primary and revision options, which include metal augmentation on both the tibial and femoral sides, and a variety of stems, both cemented and uncemented, and, in extreme cases, metaphyseal sleeves and/or cones are required. Cement and implant removal tools

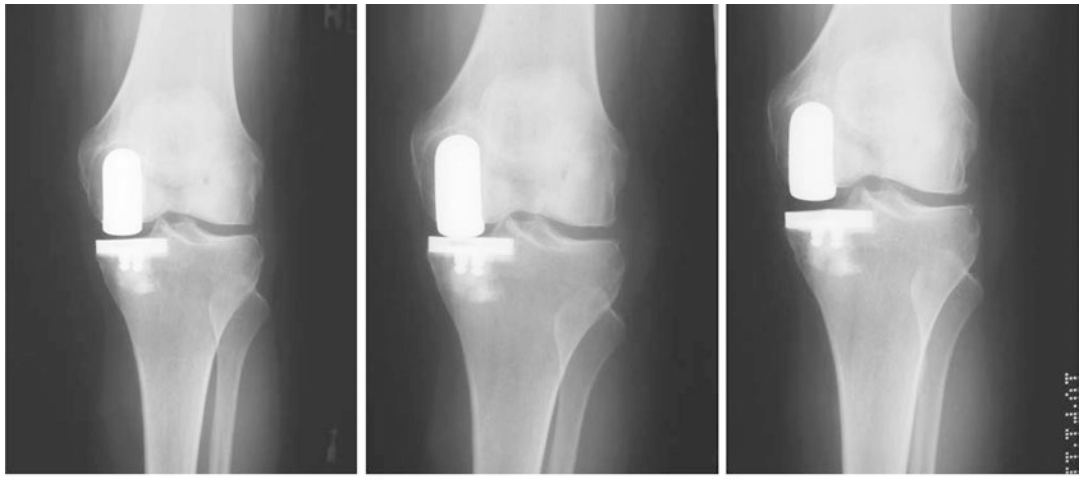

Fig. 21.6 (**a**) A 62-year-old patient postoperative medial UKA. (**b**) Patient 3 years after index UKA presents with pain and swelling secondary to polyethylene wear. (**c**) Workup negative for infection and loosening. Failure secondary to oxidative degeneration of polyethylene liner. Implant fixation and design satisfactory, so revision of liner performed

including standard and offset osteotomes, thin-bladed saws, and high-speed burs are useful.

Exposure

Previous incisions are used. If multiple incisions are present, the lateral-most incision is used. If a prior minimally invasive incision was used, this needs to be extended into a more traditional incision and arthrotomy. Exposure of the knee with a failed UKA is rarely difficult, but occasionally a quadriceps snip may be necessary in the tight knee. A synovectomy is carried out, and assessment of the unresurfaced compartment is made. If the decision is made to convert to another UKA, the loose or damaged components are removed. If tibial loosening is noted, a new tibial cut—using an extramedullary alignment guide—is made, referencing off the femoral component in extension, with appropriate ligament tension to facilitate implant-to-implant alignment. A thicker tibial component is used to fill the defect. Femoral component loosening is rare in minimally constrained UKAs. If femoral component loosening in a more constrained system is present, conversion to a total knee arthroplasty is preferable to perpetuating a poor design. In mobile-bearing systems, polyethylene wear is rare. Bearing subluxation or dislocation usually indicates improper soft tissue balance and is better served with a conversion to total knee arthroplasty.

The majority of revisions of failed UKA are converted to a TKA. After appropriate exposure and synovectomy, the implants are removed (Fig. 21.7c–f). The femoral component is removed by disrupting the prosthesis-cement interface using offset or straight osteotomes or short-bladed saws. After complete disruption of the interface, the implant can be removed with minimal damage to the underlying bone. Often the cemented lugs leave contained defects in the distal femur. All-poly tibial components can be removed by cutting the cement-implant interface, amputating the polyethylene pegs. The pegs and cement can be removed with curved curets or a pencil-tipped, high-speed bur. Metal-backed implants can be removed by disrupting the cement prosthesis interface, either with osteotomes or thin-bladed saws, and extracting the lugs from the cement bed. This can be accomplished with small extraction tools or wide osteotomes placed under the tibial tray and axial blows with a mallet. If the cement from the tibial holes is intact, it can be removed as noted previously.

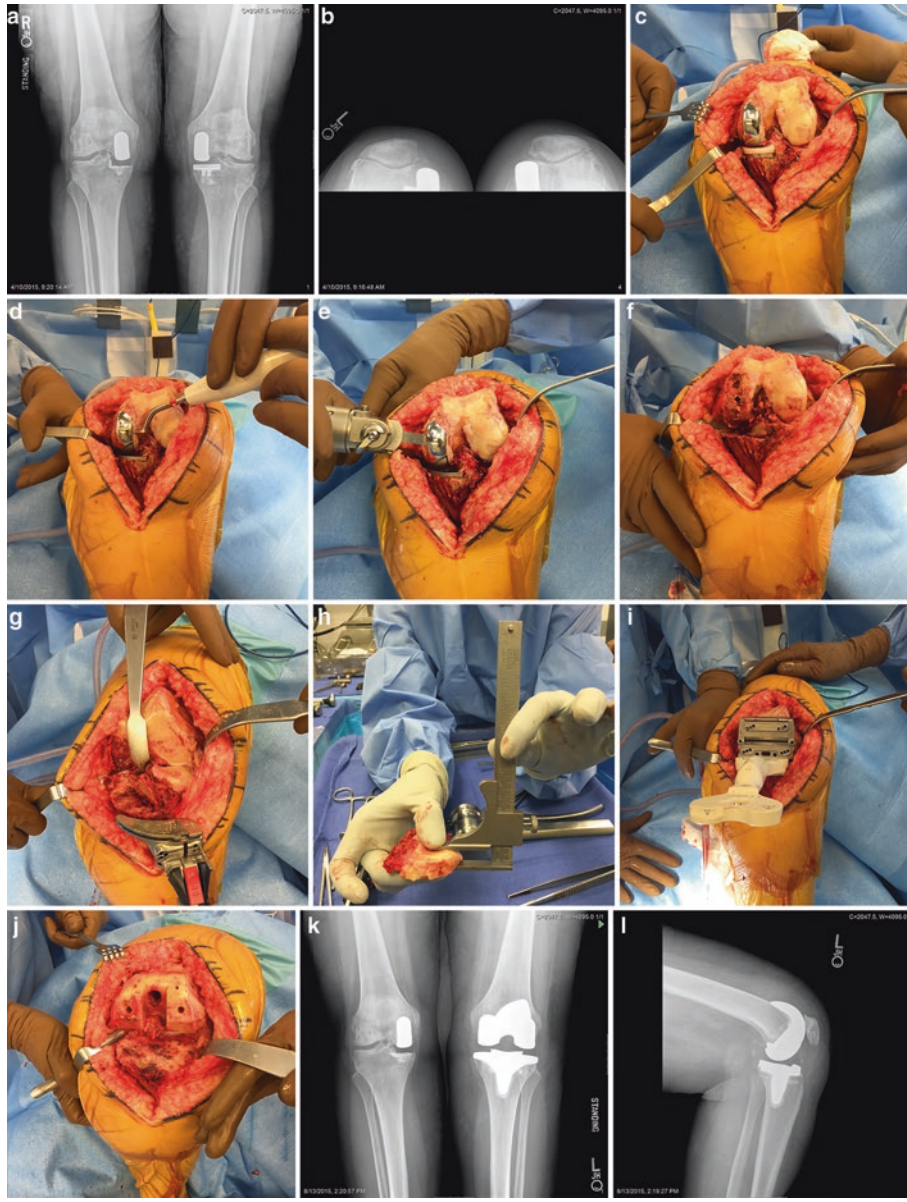

Fig. 21.7 (**a**, **b**) AP and sunrise view of a 70-year-old patient. 12 years s/p left medial UKA with progression of arthritis in lateral and patellofemoral compartment. (**c**) Exposure for revision to TKA. (**d**, **e**) After removal of modular poly femoral component, removal with offset osteotome or short blade saw. (**f**) After implant removal small contained defects are noted in distal femur and proximal tibia. (**g**) After distal femoral resection, proximal tibial cut is made with extramedullary alignment guide. (**h**) Tibial resection based off intact lateral plateau results in 11 mm resection. (**i**) After distal femoral—proximal tibial cuts are made rotation of femoral component and flexion—extension gap, balancing is performed. (**j**) After cuts are completed, minimal defects are noted, and standard primary implants can be used. (**k**, **l**) AP and lateral X-ray after revision of UKA to standard PS TKA

After removal of the implants, defects are assessed and determined to be either contained or noncontained (Fig. 21.7f). The significance of these defects can be determined after preliminary bony resections are made. A tibial cut to establish a flat tibial platform is performed using either an intramedullary or extramedullary alignment system based on the surgeon's choice. The level of resection is based off the intact opposite plateau. Resecting 8–10 mm of proximal tibia from the intact opposite plateau allows you to assess the degree of defect on the involved side (Fig. 21.7g). If a small residual defect persists, then increased tibial resection with a thicker polyethylene insert is an option. Alternatively, a slightly thicker layer of cement can be used to deal with a small defect. In the case of a contained defect, particulate autograft obtained locally can be used. In the case of an uncontained defect, either metal augmentation or bulk allograft can be used. The algorithm for defect treatment is as follows: less than 5 mm, defect treated with increased cement thickness; 5–10 mm, metal augmentation; and greater than 10 mm, bulk grafting. If significant defects are present and augments or bone graft support the implant, then modular systems which use metaphyseal sleeves or porous cones in association with stems should be used. (Figs. 21.8 and 21.9).

Once a flat tibial platform has been established, a distal femoral cut is made, resecting a standard amount of distal femur from the intact condyle, using an intramedullary guide in approximately 5° of valgus. After making a standard distal femoral cut (typically 9–10 mm), residual defects on the involved side are assessed. As before, increased resection for minimal defects can be performed but do run the risk of elevation of the joint line, which has greater significance in a cruciate-retaining system versus a cruciate-substituting system. Larger defects of the distal femur can be treated with either metal augmentation or bulk allograft, based on the previously mentioned algorithm.

Flexion-extension gap balancing is carried out using appropriate spacer blocks or tensor systems. Rotation of the femoral component is determined from several references: the cut tibial surface with appropriate soft tissue tension, the epicondylar axis, and AP axis (Whiteside's line) (Fig. 21.7i). Posterior condylar referencing cannot be used, because the posterior condyle on the affected side has been resected with the unicompartmental replacement. Anterior-posterior and chamfer cuts are then made for the appropriate-sized femoral component, based off preoperative templating and intraoperative measurements (Fig. 21.7j). Retention or substitution of the posterior cruciate is performed, based on the surgeon's preference. Final medial-lateral soft tissue balancing is confirmed, and definitive defect management is carried out. Use of stems is determined by the degree of defect, the use of augments and/or graft, and the integrity of the metaphyseal bone of the tibial and femur. Stem length and fixation are based on the surgeon's preference and are outlined in previous chapters. Patellar resurfacing is recommended and carried out in a standard fashion for the particular implant system used.

Results

As noted in the introduction to this chapter, if UKA is to continue to be a viable option for treatment of unicompartmental osteoarthritis, accepting that it has a higher failure rate, at 5 and 10 years, revision should be easier than a revision TKA and with better outcomes. The results of revision of a failed UKA are related to the implant and technique used at the initial procedure, the mode of failure, and the experience of the revising surgeon.

Revision of UKA to UKA

The Swedish Registry from 1975 to 1995 reported 14,772 primary UKAs were performed. Of these, 1135 (7.7%) were revised. Two hundred thirty-two of the 1135 revisions were to another UKA. At 5 years after revision, the cumulative revision rate for UKA to UKA was three times higher than the re-revision rate for UKA to TKA group. When the data was further stratified, to

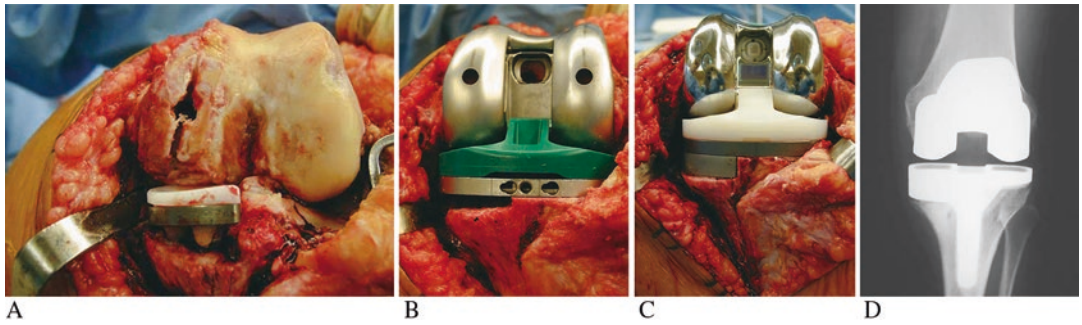

Fig. 21.8 (**a**) Revision of loose third-generation UKA with noncontained tibial defect. (**b**) After standard resections for femur and tibia, a substantial defect on the medial tibial surface persists. (**c**) Rather than increase the tibial resection, a medial metal augment is used. (**d**) With the augment supporting the medial plateau, a modular cemented stem extension is used to off-load the metaphyseal bone

revisions performed after 1986, the cumulative revision rate for UKA to UKAs was 31% versus 4.9% for UKA to TKA [39]. Pearse et al. reviewed the results from the New Zealand Joint Registry and found that UKA that was revised to another UKA had a 6.7% revision rate [46]. Hang et al. reported on 1947 revisions UKAs from the Australian Registry and found that the revision rate of a UKA to another UKA was 30% at 3 years compared to 15% at 5 years for a UKA to TKA group [47].

Epinette et al. reported a multicenter study that reviewed 425 UKAs requiring revision. A subset of 36 UKAs were revised to a second UKA for treatment of loosening. This represented 8.5% of their series of revision UKA. This compared to the 2012 Swedish Registry data that had a 5.6% revision UKA to UKA and the Australian Registry, which had an 8% rate of UKA to UKA revision. The authors concluded that in a carefully selected group of patients with loosening, in the hands of expert revision knee surgeons, good results can be obtained [48].

Revision UKA to TKA

Cross et al. reported on a multicenter study of 49 patients who underwent revision of a UKA to a TKA and compared them to 97 primary TKA and 43 TKA to revision TKA during the same time period. They noted similar Knee Society Scores, functional scores, and range of motion between the UKA converted to a TKA and primary TKA, and both were significantly better than a TKA converted to a revision TKA. Of note, 16% of their UKA to TKA required stems or augments [49]. These results were similar to Levine et al., who noted results of UKA converted to TKA were similar to results from a comparative group of primary TKA [50]. Multiple studies have demonstrated results of revision UKA to TKA that are better than revision of TKA to revision TKA but are inferior to primary TKA.

Sierra et al., in a multicenter study, reported on 175 medial UKA revised to TKA between 1995 and 2009. Time from UKA to revision TKA averaged 71.5 months. The most common reasons for revision were implant loosening 55%, progressive arthritis 34%, polyethylene failure 4%, and infection 3%. The prosthesis used was a cruciate-retaining TKA in 46%, a posterior-stabilized TKA 50%, and a varus/valgus constrained knee implant in 4%. Thirty-nine percent of the knees required stems and 30% augments. The re-revision rate was 4.5% at an average of 75 months. The authors noted that the revision rate of UKA to TKA was similar to that of a primary TKA to revision TKA and substantially better than a revision TKA to a second revision TKA [44]. Lunebourg et al. reviewed the results from two centers comparing 48 UKA converted to TKA. Stems were required in 72% of cases and augments in 29%. They concluded that revision of failed UKA to TKA is "technically less demanding than revision TKA, functional scores,

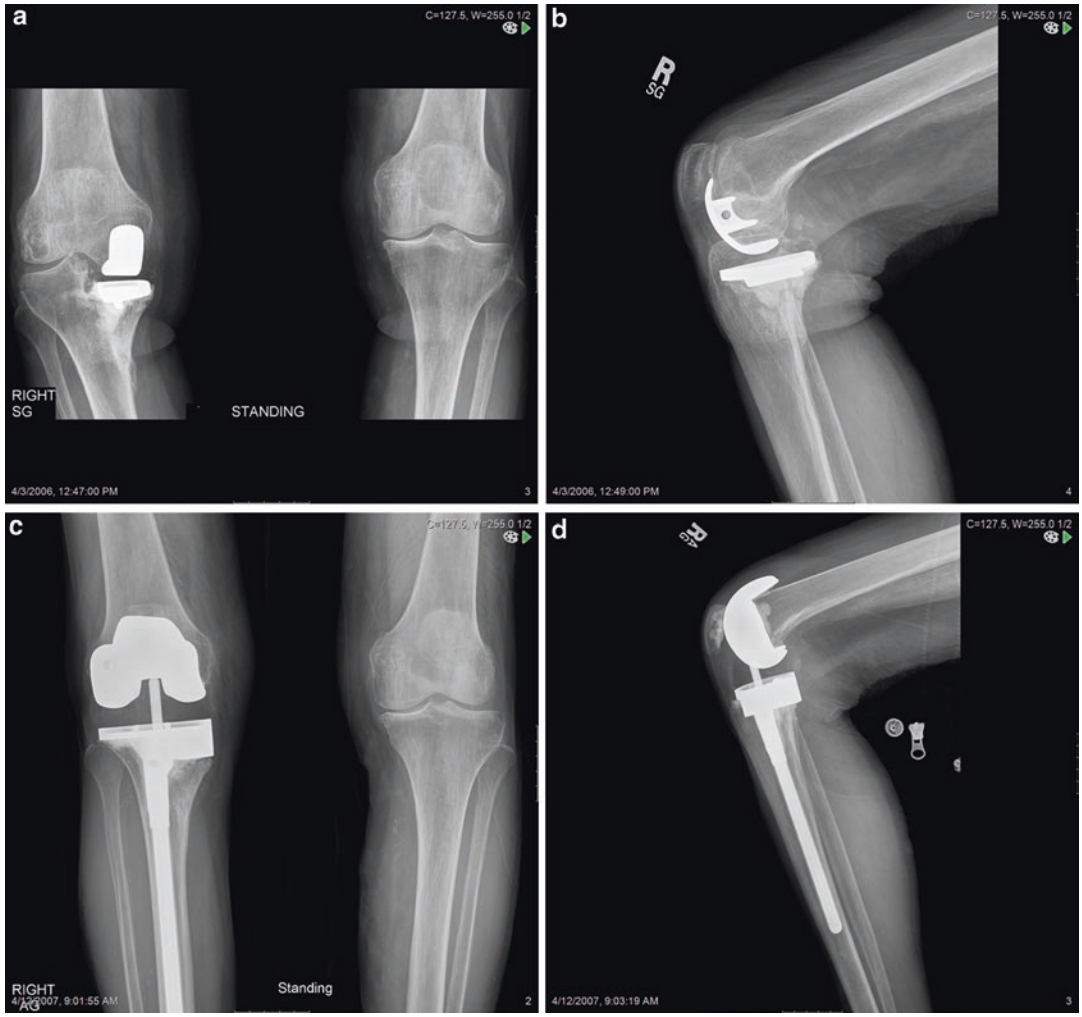

Fig. 21.9 (**a**, **b**) AP and lateral X-ray of failed medial UKA with failure due to loosening and subsequent medial tibial fracture with associated subsidence. (**c**, **d**) AP and lateral X-ray after revision to TKA with metal augments for medial defect and press-fit long stem due to large defect

quality of life, complications, and survival rate after revision UKA to TKA are more comparable to revision TKA rather than primary TKA results." [51] Craik et al. reported on 546 medial mobile-bearing UKAs with a 2-year revision rate of 5.3%. Thirty-four percent of these revisions required augments, stems, or bone graft. The authors concluded outcomes of revision UKA to TKA were inferior to those for primary TKA [52]. Rancourt et al. compared to 63 failed UKA revised to TKA with a match group of 126 primary TKA in a single center. The revision group required stems, augments, and grafts in 24% of the cases. They concluded revision of UKA to TKA is technically more difficult and function is less satisfactory at a mean 3.1-year follow-up versus primary TKA [53]. Pearse et al. obtained data from the New Zealand Joint Registry and reported on 205 failed UKA revised to TKA and compared these to 34,369 primary TKAs. In the revision UKA group, 28% required stems or augments. Forty-one percent reported poor results after failed UKA converted to TKA and had inferior survivorship when compared to primary TKA [46]. Robertson et al., using Swedish Registry data through 2012, identified 902 failed

UKAs converted to TKA and compared them to 118,229 primary TKAs. Risk of revision was 2.8 times higher for the UKA versus the TKA, and stems or revision implants were required in 17% of the failed UKA group [51].

Summary

The majority of failed UKAs are revised to TKA. If appropriate indications are met, liner exchange or revision to another UKA are possible, but in general, these procedures have poor longevity and a higher failure rate. Revision of failed UKA to TKA appears to have a slightly inferior outcome when compared to primary TKA, but better outcome than revision TKA. The mechanism of failure and the potential challenges at revision are influenced by the type of implant used, the surgical technique at the time of primary UKA, and patient-related factors. Most revisions can be accomplished using primary TKA systems. However, a system that allows the use of augments, stems, and/or metaphyseal sleeves or cones should be available.

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Hinge Implants

22

Rami Madanat, Steven J. Schroder, and Andrew A. Freiberg

The origin of knee arthroplasty can be traced to 1863 and Vernuil's attempt to relieve arthritic knee pain through the surgical interposition of joint capsule [1]. Soft tissue substrates such as muscle, fat, fascia, and pig bladder were later used. However, the outcomes of each were equally as unsatisfactory as Vernuil's original procedure. Eventually *biologic* or *tissue* arthroplasty substrates were abandoned in favor of acrylics and metal alloys in the form of a hinge [1]. The constraint to motion inherent in the hinge design was thought necessary to allow a stable physiologic range of motion and prevent dislocation of the prosthetic joint [2]. Like soft tissue arthroplasty, the clinical results of early, hinged prosthesis were poor. Prosthetic loosening, fracture, and deep infection were common [1–17]. Newer generations of the hinge design were developed to combat perceived design flaws but met with little success. Continued poor results led to disfavor of the hinge design and the adoption of newer, more successful, unlinked arthroplasty designs. As total knee arthroplasty has expanded, specific indications for both an unconstrained and a highly constrained arthroplasty design have become apparent, and the development and evolution of the linked hinge prosthesis have continued. Further design modifications include multiple sizing, component modularity, hinge rotation, ingrowth surfaces, polyethylene bearings, and the manufacture of fracture-resistant superalloys. The resultant generation of linked, rotating, hinged prostheses combined with the use of porous metal cones holds promise for improved survivorship in complex knee reconstruction.

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History

The first hinged total knee prosthesis was made from acrylic resin and introduced by Walldius in 1951 [1]. The same design was later produced from stainless steel. Other designs soon followed, such as Shier's metallic hinge in 1953, Young's Vitallium valgus hinge in 1958, and the Stanmore

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and Guepar hinges in 1969 [1–18]. These prostheses, among others, are termed the *first generation.* The first-generation prostheses were highly constrained, allowing only simple flexion and extension. These highly constrained designs transferred high stresses to the implant-cement-bone interfaces, producing early prosthetic loosening. In addition, the majority of first-generation hinges consisted of metal-to-metal articulations and resulted in fretting, fatigue, fracture, and sometimes, dramatic particulate wear debris. Overall, these prostheses were found to have unacceptable complications and early failure rates.

A *second generation* of hinged prostheses followed with design modifications that decreased prosthetic constraint by including axial rotation and varus/valgus motion of the hinge [17, 19–32]. These less constrained designs include the Sheehan, Herbert, Attenborough, Spherocentric, Noiles, and Kinematic rotating hinge prostheses. Like their first-generation counterparts, some early second-generation prostheses suffered unacceptable complication rates and early failure. The Herbert total knee is one such example. Catastrophic failure within 1 year of implantation forced the implant to be pulled from the market soon after its introduction [21]. However, most second-generation rotating hinged knees enjoyed early promising results. The mid- to late-term outcomes were more disappointing [17, 22–32]. As a whole, the second generation of hinged knee designs were a clinical improvement over the first generation, but unacceptably high failure rates and numerous complications continued [33].

In general, these second-generation implants are no longer used. Design evolution has resulted in the marketing of a *third generation* of implants such as the Finn, S-ROM, and NexGen RHK prostheses [34–40]. In one instance, a second-generation implant, the Noiles hinge, is the direct predecessor to the newer, third-generation, S-ROM modular, mobile-bearing hinge prosthesis [38, 39]. Specific third-generation modifications include prosthetic modularity, deepening of the anterior femoral groove to improve patellar tracking, the manufacture and utilization of *superalloys*, broad polished tibial components, congruent polyethylene bearings, multiple sizing for better metaphyseal fit and fill, long stem extensions, bony ingrowth collars, and distal augments that restore the joint line. These third-generation modular, mobile-bearing, hinged prostheses have produced good results in the short- and midterm [34, 38, 39]. However, additional follow-up is necessary to evaluate the long-term success of these third-generation implants.

First-Generation Implants

Walldius

Borge Walldius is credited with the first attempt at knee arthroplasty using an endoprosthesis. The Vitallium hinged prosthesis was introduced in 1951 and intended for use in patients with rheumatoid arthritis [1]. The design of this prosthesis underwent several modifications and subsequently produced four types of designs known as Mark I through Mark IV (Fig. 22.1). The four designs differed in length, angulation, and stem construction. The Mark I and II were implanted without the use of methyl methacrylate, whereas the Mark III and IV were designed to be secured with methyl methacrylate. The Mark IV differed

Fig. 22.1 Walldius Mark IV prosthesis (From Jones GB. Total knee replacement-the Walldius hinge. Clinical Orthopedics and Related Research. 1973 Jul-Aug(94):50–7, with permission)

further in that stem fenestrations were provided to improve cement fixation. Neutral and 7° valgus designs allowed for a range of motion from 5° of hyperextension to 110° of flexion. The uniaxial hinge consisted of a central cylinder fixed with a washer and locking screw. A single 28-mm hinge width was available. Rotation along the longitudinal axis was prevented by both the anterior femoral and posterior tibial lips. In addition, the femoral lip provided an articular surface for the patella [1–7].

The long-term clinical results with the Walldius hinge were poor. At the time, constraint was thought necessary to provide stability. Axial rotation, a normal part of knee kinematics, was not perceived to be important [2]. However, these design concepts led to excessive stress concentration at the implant-cement-bone interfaces, which in turn led to early loosening. The prosthesis also suffered from significant subsidence in both femoral and tibial bone. Nevertheless, there are several reports in the literature using this prosthesis in rheumatoid patients with short-term follow-up (1–3 years) and good results with regard to pain relief, stability, and range of motion [1–7]. These reports, however, also highlight a high rate of complications such as infection, fracture, loosening, subsidence, and peroneal nerve palsy [1–7]. Despite the clinical failure of the Walldius experience, it represents the original foundation for prosthetic hinge knee design evolution.

Shiers

The Shiers hinged knee prosthesis (Fig. 22.2) was first implanted in 1953 [8, 9]. The hinge was made of a molybdenum bearing and stainless steel. The actual hinge consisted of a femoral female surface and a tibial male surface united by a main bearing, which was prevented from unwinding by a reverse-threaded locking screw. In addition, triflanged stems of varying lengths, accommodating differing femur and tibia lengths, were screwed onto the hinged surfaces. The design concept allowed uniaxial flexion via the hinge, limited extension to 180°, and preserved lateral stability via the large bearing surfaces [6, 8–12].

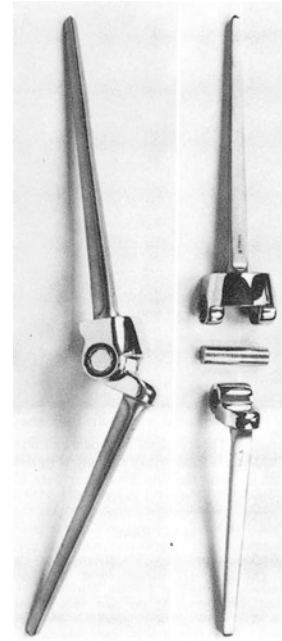

Fig. 22.2 The uniaxial Shiers total knee arthroplasty (From Arden GP. Total knee replacement. Clinical Orthopedics and Related Research. 1973 Jul-Aug(94): 92–103, with permission)

The operative technique consisted of a lateral parapatellar approach to expose the knee joint. A patellectomy was performed with care to maintain the continuity of the extensor mechanism. Approximately 0.75 in. of distal femoral condyle was removed with a saw, and the posterior aspects of the condyles were removed with an osteotome. The proximal 0.25 in. of the tibial plateau was resected while preserving the collateral ligaments. The stems of both the female and male components were gently hammered into the medullary cavities of the femur and tibia, respectively. The components were then linked and locked with the main bearing and locking screw. Patients were placed in a cylindrical cast for 10 days, after which full weight-bearing was allowed to impact the hinge. The cast was removed on day 12, and formal physical therapy was initiated [8, 9].

A common complication with this early design of the Shiers hinged knee was stem fracture from metal fatigue [8, 9]. In Shiers' original series of 17 patients, there were 8 stem fractures

in 6 patients. All fractures occurred at the threaded junction of the stem and hinged surface. The fractures occurred at varying intervals ranging from 4 months to 4 years [9]. This complication led to modifications including the elimination of stem modularity. The hinge halves were machined out of a single block of steel, thereby eliminating the easily fatigued stem-hinge modular interface. In addition, the hinges were made a shorter standard length. Finally, the locking screw was made more robust by increasing the diameter [8, 9].

Shiers reported his short-term clinical results in 1961 [10]. After modifications to the hinge, Shiers reported no more prosthetic fatigue fractures and concluded that a short-term successful result was possible in three cases out of four. This report was complicated by multiple cases of skin necrosis, deep infection, loosening, and foot drop. Later reports on the Shiers hinged knee also demonstrated short-term improvements in knee pain. However, many authors noted more severe complications, such as skin necrosis and deep infection necessitating amputation, bolt extrusion, extensor lag and tendon rupture, tibia fracture, hematoma, fat embolism, deep vein thrombosis (DVT), and even four cases of death within 48 h. As with the Walldius hinged knee, the Shiers showed degrading results over time with regard to pain and function [8–12].

Stanmore

The Stanmore hinged knee prosthesis was introduced in 1969 [13]. The early designs were constructed of either titanium 160 with Vitallium bearings or entirely of CoCr. The latest designs were made from CoCr with bushings of ultrahigh molecular weight polyethylene (UHMWPE), in which a stationary metal axle was retained by a titanium 318 clip. The prosthesis had long, oval, tapered medullary stems that were cemented into place and at a fixed angle of 8° of valgus [13, 14].

The clinical results, as with all the first-generation prostheses, were poor in the long term because of the highly constrained design. However, inconsistent short-term results were reported. In 1978, Lettin reported pain relief in 94% of patients at an average follow-up of 2.5 years [13]. On the other hand, Karpinski in 1987 had good results in only 23% of his patients at an average follow-up of 44.7 months [14]. The experience with the Stanmore prosthesis was also associated with an unacceptable rate of major complications [13, 14].

Guepar

The Guepar prosthesis, introduced in 1969, had several specific design goals and represents the first real attempt to improve on previous design shortcomings [15]. These goals included minimal bone resection, joint stability, valgus alignment, preservation of motion, preservation of patellar tracking, and a dampening effect in extension. The prosthesis had an offset hinge of CoCr that provided 5° of recurvatum and 180° of flexion. There was a choice of either a 7° valgus or modified straight femur, both with 13-cm stems. A trochlear plate provided for patellofemoral articulation. Finally, a silicone rubber bumper was present on the anterior-superior tibia to dampen the femoral-tibial contact by 25% in extension [15].

The clinical results, as with all the highly constrained first-generation prostheses, were poor in the long term. Le Nobel in 1981 reported on 113 knees in 97 patients with an average follow-up of 19 months [16]. Seventy-four of ninety-seven patients reported little or no pain, and 79 patients believed that surgery was worthwhile. Fifty-five results were graded as excellent or good, but 30 were poor [15]. In addition, the complications associated with this prosthesis, like the other first-generation prostheses, were both numerous and severe [7, 15–17].

Second-Generation Implants

In the early 1970s, it became apparent that mid-term results with the first-generation hinged prostheses were poor and that early results with unlinked prostheses were promising. As such, designers began attempting to meld the concepts

of linked and unlinked knee arthroplasty [18]. The successive design changes throughout the second generation document a newer, more scientific approach to prosthesis design, outcomes analysis, and knee arthroplasty. The newer prostheses were a clear attempt by investigators to decrease joint constraint, decrease bone cement-prosthesis stress, and improve longevity. As a whole, the design modifications associated with the second generation of hinged knee implants may be summarized as the inclusion of varus/valgus motion and modest axial rotation to a linked design [17, 19–32].

Sheehan

The Sheehan hinged knee was introduced in 1971 [19]. This design was both constrained and unconstrained depending on the degree of flexion and extension of the knee. The prosthesis was made up of femoral and tibial components with intramedullary stems, which were mirror images for the left and right knees. The external surface of the femoral component was designed to have a curvature simulating a normal knee, thus allowing for a constantly changing instant center of rotation. The tibial component had a high-density polyethylene surface mounted on an intramedullary stem. The tibial polyethylene had an expanded intracondylar stud shaped like a rugby football. This polyethylene stud interlocked between the femoral bearing surfaces and engaged the inner radius of the femoral component. When the knee was fully extended, the tibial stud engaged the notch of the femoral component and prevented axial rotation and allowed 2–3° of side-to-side motion. With 30° of flexion, the gradual widening of the femoral notch allowed approximately 20° of rotation and 6–7° of side-to-side motion. Beyond 90° of flexion, there was no direct linkage between the tibial stud and the femoral component. This allowed femoral rollback and reduced tensile and distraction forces on the components. The prosthesis did not have an accommodating patellar surface; nevertheless, the patella made contact with the prosthesis after 50° of flexion [19].

Sheehan reported his short-term results in 1978 with 157 knees and an average follow-up of 34 months. He reported good results with regard to pain relief and had no cases of clinical or radiological loosening. However, there were four cases of the plastic-metal interface detaching on the tibial component and two cases of fracturing of the tibial stud [19]. Furthermore, long-term results deteriorated, like the rest of the first- and second-generation hinged knees. Rickhuss et al. reported in 1994 the 5- to 10-year follow-up for the Sheehan hinged knee [20]. Using the Hospital for Special Surgery Scoring System, only 15.6% had good results, while 40% had poor results. At review, 31% of the patients had undergone revision surgery or were awaiting such surgery. Therefore, the authors thought that the Sheehan knee replacement should be considered obsolete [20].

Herbert

One of the earliest second-generation prostheses was described in 1973 by Herbert [21] (Fig. 22.3). The ball-in-socket Herbert design consisted of a polyethylene femoral socket and a CoCr tibial sphere on a shank. While providing unrestrained flexion and extension, the ball-in-socket also allowed 10° of varus and valgus and some limited rotation. The surgical technique called for a limited notch resection, posterior femoral condylar resection, and cementing of left or right fixed valgus femoral stems [21].

Original laboratory testing showed significant shank wear from metal-on-metal gliding between the femoral housing and the tibial shank (Fig. 22.4). Shank wear created increased varus/valgus motion at 500,000 flexion/extension cycles. It was assumed that 1 million cycles represented 1 year of expected in vivo use. Medial condylar and shank fractures were also observed [21] (Fig. 22.3). Clinical experience with 23 prostheses in 22 patients implanted at the Cleveland Clinic from 1973 to 1974 was disastrous. Three dislocations and four medial housing fractures occurred between 5 and 23 months postoperatively. [21].

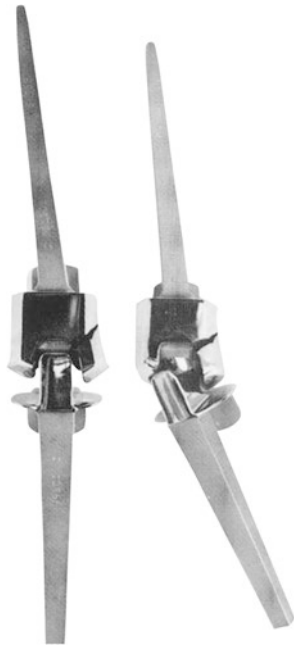

Fig. 22.3 The Herbert total knee arthroplasty prosthesis. Pictured are prosthetic medial condylar fractures that resulted in the prosthesis being pulled from market soon after its release (From Murray DG, Wilde AH, Werner F, Foster D. Herbert total knee prosthesis: combined laboratory and clinical assessment. The Journal of Bone and Joint Surgery American volume. 1977 Dec;59(8):1026–32, with permission)

The prosthesis was modified in late 1974 to add metal to the femoral housing and narrow the notch. The ultimate strength of the prosthesis was increased while decreasing varus/valgus and rotatory motion. Laboratory testing showed significant shank wear at 2 million cycles. Medial housing fracture was noted at 2.8 million cycles. Clinically, one medial housing fracture occurred at 13 months postoperatively in 12 knees. In total, the Herbert prosthesis was found to have a 15% failure by prosthetic fracture within 2 years. The prosthesis was discontinued in April 1976 [21]. Although a clinical failure, the Herbert prosthesis experience emphasized the relevance of laboratory assessment in new prosthetic designs.

Spherocentric

The Spherocentric knee was first introduced in 1973 near the same time as the Herbert prosthesis [22]. As in the design of the Herbert knee, the Spherocentric knee was designed to address specific problems experienced with earlier designs. The designers identified three main problems with earlier designs: (1) metal-on-metal contact generates extensive wear and fatigue of the implant; (2) uniaxial rotation creates high-torsional loads that are transferred from the prosthesis linkage to the prosthesis-cement or bone interfaces, thus producing early loosening; and (3) mechanical extension stops produce high-impact loads that are also transferred to the prosthesis-bone or cement interfaces, creating early loosening [22]. The design of the Spherocentric knee included free motion in all rotational axes through a ball-in-socket articulation but provided for load sharing with condylar outriggers and tracks. A cam mechanism that provided controlled deceleration reduced end loading in extension. All metal-on-metal contact was eliminated by incorporating replaceable polyethylene-bearing surfaces. All prostheses were cemented, and all polyethylene surfaces were loaded in compression. These design features provided for multiaxial motion with decreased prosthesis-cement interface stress, thereby theoretically improving longevity [22, 23].

Before clinical experience with the Spherocentric knee, mechanical testing was performed in extension, flexion, varus and valgus, and compression on implants in cadaveric knees. The investigators maintain that the testing documented not only the stability and strength of the assembly but also of the prosthesis-cement-bone interfaces. The tests also demonstrated satisfactory range of motion, kinematics, and deceleration cam mechanism function [22]. The early failure of the Herbert prosthesis led the investigators to perform fatigue investigations of the linkage and housing. Early results identified several areas of considerable surface strain where fatigue failure could occur. Multiple design revisions resulted in the thickening of all prosthetic surface intersections as well as reinforcing of the anterior notch housing. At the conclusion of these mechanical investigations and subsequent design modifications, the institutional review board at the University of Michigan approved clinical use of the Spherocentric knee in 1973 [22].

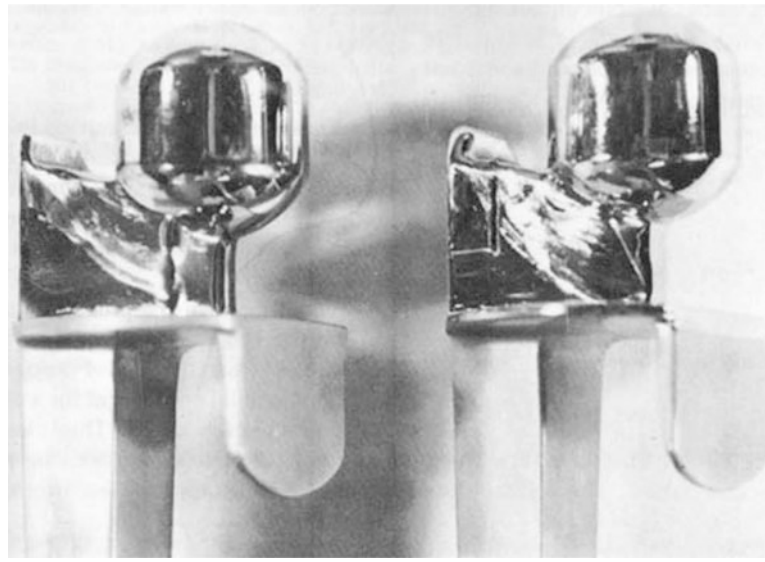

Fig. 22.4 Shank etching from metal-metal wear at 1 million cycles (From Murray DG, Wilde AH, Werner F, Foster D. Herbert total knee prosthesis: combined laboratory and clinical assessment. The Journal of Bone and Joint Surgery American volume. 1977 Dec;59(8):1026–32, with permission)

Matthews et al. reported a midterm result of 58 of the first 81 Spherocentric knees in 1982 [22]. The specific indications for using the Spherocentric knee were fixed varus or valgus greater than 20°, flexion contracture greater than 30°, instability greater than a 20° arc, and severe metaphyseal bone loss. Duration of follow-up averaged 48 months, with a range of 24–73 months. All implants were cemented in the first-generation technique. No patellae were resurfaced. The majority of patients experienced markedly improved range of motion, stability, ambulatory capacity, and pain. In comparison with reports with other devices, the complication rate was quite low. The deep infection rate was 3.5% (3 of 84 knees). Only 7 knees (8.3%) required reoperation for infection, instability, or pain [22]. Early clinical enthusiasm was dampened when it was reported that 52% of radiographically followed patients displayed some radiolucency at the prosthesis-cement or cement-bone interface. Longer-term follow-up displayed only modest deterioration of the results but was limited to only 21 patients [23]. Nevertheless, the basic principles for the design of modern linked prostheses and the methodology for investigating the devices, both in the laboratory and in the clinical setting, are grounded in the Spherocentric experience.

Attenborough

The Attenborough hinged knee was introduced in 1974 and was one of the first prostheses to compromise between the highly constrained first-generation hinged knees and the unconstrained condylar prosthesis [24]. The Attenborough hinged knee was comprised of a polyethylene tibial component, which was cemented in place. The metal femoral component consisted of the femoral articular surface and a short stem, which was also cemented in place. The original knee prosthesis had a stabilizing rod, which was contained in the femoral component. This rod fits inside the tibial component and allowed some lateral and rotational laxity. In the newer modified models, the stabilizing rod is separated from the femoral component and is locked into the femoral component with a polyethylene circlip. This separation of the rod from the femoral component allowed for greater ease in insertion of the prosthesis and facilitated the removal of cement. The femoral-tibial articulation of this prosthesis is similar to the knees used today. The difference lies with the stabilizing rod. The stabilizing rod provides the linkage of the prosthesis but allows for some lateral and rotational laxity. When the lateral and rotational movements occur, the joint opens and tightens the soft

tissues, which produce a gradual deceleration of movements instead of a sudden block to movement [24]. This was the conceptual advantage over other second-generation hinged knees that limited movement with a hard block, which may lead to early loosening.

Early clinical results were promising. Attenborough short-term results of 245 knees showed only two cases of tibial loosening [24]. Vanhegan also presented his short-term results with 100 knees at 2.5 years of follow-up. He found 85% good results with only two knees having loosened [25]. However, as with the early generation hinged knees, long-term results deteriorated. Kershaw et al. in 1988 reported on 132 arthroplasties with a 77-month average follow-up (49–120 months). He found a 30% loosening rate and a 19% wound-healing complication rate. The survivorship analysis using revision as the end point showed survivorship to be 77% at both 6 and 10 years. However, if pain and radiographic loosening were used, then survivorship declined to 65% at 6 years and 52% at 10 years [26].

Noiles

The Noiles total knee (Fig. 22.5) was introduced in the late 1970s by Joint Medical Products (Stamford, CT) [27]. The prosthesis consisted of a modified constrained hinge that allowed 20° of varus/valgus as well as axial rotation. The cemented femur and uncemented tibial components were linked via a cemented poly sleeve and a hinge pin. Knee simulator data showed torque similar to that of an unconstrained design and less than that of a semiconstrained design total knee prosthesis [27].

The clinical adaptation of the Noiles design was intended for patients with anticipated heavy use and severe varus/valgus instability as well as revision surgery [27, 28]. The late 1970s and early 1980s clinical experience was very positive. However, poor results were reported by Shindell in 1986 [28]. Twenty-three knees in nineteen patients with an average age of 61 years were followed for up to 75 months. HSS scores improved from 41.3 to 76.8 at 6 months, but 10 knees failed at an average of 32 months. The majority of failures were in heavy patients (>200 lb) and in patients with large tibial metaphyses. A significant rate of subsidence of the tibial prostheses occurred (5.1 mm) even in well-functioning knees. Subsidence of greater than 10 mm was reported in rheumatoid patients [28]. Despite the clinical failure of the original Noiles hinge design, the device further advanced hinge technology by coupling decreased constraint with decreased mechanical failure of the link.

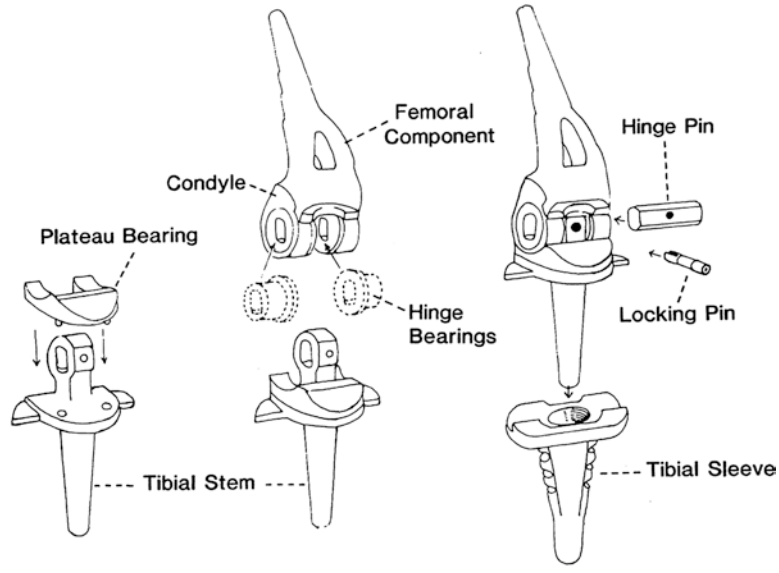

Fig. 22.5 Schematic of exploded Noiles total knee arthroplasty prosthesis. Note the link modularity and metal on polyethylene articulating surfaces (From Kester MA, Cook SD, Harding AF, Rodriguez RP, Pipkin CS. An evaluation of the mechanical failure modalities of a rotating hinge knee prosthesis. Clinical Orthopedics and Related Research. 1988 Mar(228):156–63, with permission)

Kinematic

In 1978, the Kinematic rotating hinge device was introduced for clinical use [17]. Like the Noiles and Spherocentric prostheses, the Kinematic rotating hinge prosthesis was designed to decrease the clinical and mechanical failure mechanisms of earlier designs. Several fundamental principles required for a well-functioning linked prosthesis were identified, and extensive mechanical and wear testing of the design was performed before clinical release.

The design team proposed five primary questions: (1) How is hyperextension limited and what is the range of flexion before impingement? (2) Is the prosthesis unrestricted in axial rotation? (3) How is varus/valgus alignment restricted? (4) Is there provision for patellar replacement/resurfacing? (5) How much bone is resected from the intercondylar area? [17] The resultant design was a cast cobalt chrome femoral component with condylar replacement and intramedullary stems for use with cement. Removable, condylar, polyethylene bushings prevent metal-on-metal contact between the femoral component and a snap-in axle that provides flexion and extension. A cobalt chrome tibial bearing component articulates between the femoral snap-in axle and an all-polyethylene tibial component. The all-polyethylene tibial component is cemented to the tibia and has a central cylinder to receive the rotational axle of the cobalt chrome tibial bearing component [17].

The prosthetic linkage controls 2 of 3° of linear freedom, while the soft tissue sleeve limits distraction [17, 29]. The prosthesis also controls varus/valgus motion while allowing flexion-extension and axial rotation. The limits of flexion are related more to soft tissue restraints than to prosthetic design. Extension is limited by the posterior soft tissues and also by a polyethylene bumper on the tibial bearing component that engages the femoral axle at 3° of hyperextension. Posterior placement of the axle in the condyles helps facilitate unlimited flexion and lockout in hyperextension. Axial rotation of the prosthesis is limited to 12° internal and external rotation by the incongruent curvatures of the all-polyethylene tibia and the base plate of the cobalt chrome tibial bearing component.

Wear analysis of the polyethylene bushings was performed through a 30° arc of motion in a simulator loaded to approximately three times standard body weight, at 37° C, with distilled water as a lubricant, for up to 5 million cycles [29]. Most flexion-extension rotation occurred between the axle and the polyethylene bushings, creating a maximum wear of 0.23 mm at 5 million cycles. No significant changes were noted in any other component. However, when an off-center load was applied in a similar experiment, permanent deformation of both the bushing and polyethylene tibial component were noted [29]. Despite the authors' claim that the deformation was mild in both components, the results indicate that reconstruction of a neutral mechanical axis of the lower extremity is crucial to the longevity of this design.

Finite element analysis of the relationship between the cobalt chrome tibial bearing component and both the condylar portion of the femoral component and the all-polyethylene tibial component concluded that the majority of weight-bearing force in a normally aligned knee reconstruction passes from the tibia to the femur via the condyles [29]. The risk of fatigue fracture of the rotational axle is extremely low. Mechanical testing of the rotational axle confirmed the fatigue limit of the metal to be slightly higher than the expectant forces as calculated by finite element analysis [29]. These results also indicate that neutral axis reconstruction with the Kinematic rotating hinge prosthesis is critical to the longevity of the prosthesis. Excessive varus or valgus produces moments greater than those predicted and could result in fatigue failure of the polyethylene bushings, the all-polyethylene tibial component, or the rotational axis of the cobalt chrome tibial bearing component. Five of the first 200 devices implanted suffered fatigue fracture of the rotational axle at its junction with the base plate. Subsequently, the design was modified to thicken the rotational axle and improve the tolerance between the femoral condyles and the cobalt chrome tibial bearing component [29]. The Kinematic rotating hinge experience furthered

the scientific approach to introducing a new prosthesis, and many of the design principles are preserved in newer design-linked prostheses.

The first clinical results with the Kinematic rotating hinge were published in 1982 [29]. Twenty-two knees were followed for an average of 12 months with a range of 5–24 months. The indications for a constrained prosthesis were a combination of marked collateral ligament deficiency and bone loss, in which a condylar-type replacement was considered unsuitable. All but one case was a revision procedure. All patients without prior patellectomy underwent patella resurfacing. Half of the extensor mechanisms required lateral release for patellar stabilization. The short duration of follow-up in this series prevented the authors from reporting radiographic or clinical results of mechanical failure. However, 17 of 22 knees reported trivial or no pain, 16 of 22 patients had the same or improved range of motion, there were no cases of postoperative sepsis, and no re-revisions were performed [17].

Good early clinical results using the Kinematic rotating hinge prosthesis were also reported independently by Shaw and Rand [17, 30]. Follow-up periods ranged from 25 to 79 months and averaged approximately 4.0 years. Satisfaction rates in the primary setting range from 80 to 90%. Satisfaction rates after revision surgery to the Kinematic rotating hinge were worse, however, ranging from 74 to 83%. Patellar instability, the most frequently reported complication by both investigators, was reported as high as 36%. More serious complications reported by Rand included sepsis in three cases and implant breakage in one. Of greatest concern was the report by both authors that, despite the short-term follow-up period, progressive radiolucent lines were present in as many as 25% of cases [17, 30, 31].

Unlike the experience with many hinged devices, midterm follow-up with the Kinematic rotating hinge has recently been reported by Springer et al. [32] Sixty-nine knees were followed for an average of 75 months with a range of 24–199 months. The indications for implanting a linked device were (1) severe bone loss combined with ligamentous instability, (2) periprosthetic fracture, (3) severe collateral ligament instability, (4) congenital dislocation of the knee, and (5) reimplantation after sepsis. The average range of motion was from 1° shy of full extension to 94° of flexion. At final follow-up, Knee Society Scores had improved an average of nearly 40 points. However, complications were frequent and often severe. Thirty-two percent of patients experienced at least one complication. Postoperative infection was greater than 14%, and component fatigue failure was 10%. Patellar pain was reported as severe in 13% of patients, the majority of whom had an unresurfaced patella. Radiographic analysis of the surviving components revealed that 13% of patients had definite loosening of either or both the femoral and tibial components [32]. Although unreported, failure for any reason can be interpreted as high as 40% at an average of approximately 6 years in this patient population. The authors concluded that linked prosthetic reconstruction with the Kinematic rotating hinge should be reserved for salvage situations [32].

Overview of First- and Second-Generation Implants

In 1986, the Swedish Orthopaedic Society published the survivorship analysis of over 8000 knee arthroplasties enrolled in the Swedish Knee Arthroplasty Project between 1975 and 1983 [33]. Included in the report, subdivided by primary diagnosis of osteoarthritis and rheumatoid arthritis, was an independent survivorship analysis of four first-generation and three second-generation hinged knee arthroplasty designs. Arthroplasties were designated as failures if one or more prosthetic components had been added, removed, or replaced during the observation period. At 6 years, 140 first-generation hinges implanted for primary diagnosis of osteoarthritis had a survivorship of only 65%. One hundred two second-generation hinges implanted for the same diagnosis had a survivorship of 83% at the same follow-up duration. The majority of failures in both first- and second-generation designs were secondary to infection and mechanical loosening [33]. The Swedish experience clearly linked

improved prosthetic design and surgical technique to improved prosthetic longevity. Nevertheless, the fundamental problems with linked prosthetic designs were also highlighted. Despite improved survivorship, unacceptable rates of loosening and major complications such as deep infection persisted. Survivorship of both first- and second-generation hinges was notably inferior to that of both unicompartmental and tricompartmental unlinked designs. In rheumatoid arthritis, survivorship was similar in all hinged designs but inferior to the survivorship of unlinked tricompartmental arthroplasty [33]. This report accurately encapsulated the unsatisfactory clinical performance of hinge knee arthroplasty designs up to that point; however, it also provided promise that continued design evolution could improve longevity.

Third-Generation Hinges

Finn

The Finn rotating hinged knee (Biomet, Inc., Warsaw, IN), introduced in 1990, is a modular CoCr implant [34, 35]. The prosthesis functions via an axle and yoke construct and approximates the anatomic profile of the knee. The link is not significantly weight-bearing as contact between the femoral and tibial components is maintained throughout the range of motion. The design improves the distribution of weight-bearing forces and patellofemoral kinematics by several specific design modifications. Anatomically sized femoral components have a deep patellar tracking groove and an anatomic axis of motion with a posterior center of rotation.

Preservation of the joint line is made possible through different sizing of the femoral component and selecting different thickness of the modular polyethylene bearing. Lastly, femoral and tibial geometry is congruent with a broad ultrahigh molecular weight polyethylene (UHMWPE) surface contact throughout the range of motion. The net result is a prosthesis with improved stress distribution, 135° of flexion, 20° of internal rotation, and 20° of external rotation. The design further includes both modular cemented and uncemented femoral and tibial stem extensions, as well as distal femoral and proximal tibial replacement [34, 35].

The clinical results have been good in the short-term follow-up. In 1991, Finn reported no cases of failed fixation, instability, or patellofemoral maltracking in 23 knees at 9 months follow-up [35]. Later follow-up of 42 knees revealed a 25% incidence of overall complications in tumor reconstruction and suggested that mechanical failure was still an issue [36]. Westrich et al. in 2000 reported on 24 Finn prostheses with an average of 33 months of follow-up [34]. All the patients had significant improvement in the Knee Society Scores (average preoperative score 44, average postoperative 83). One patient (two knees) had progressive femoral radiolucent lines no greater than 2 mm. Five patients had patellar subluxation, but none were symptomatic [34]. Currently, there are no long-term series in the literature to report mechanical loosening rates with this implant. Of note, the Finn knee reports showed decreased rates of infection when compared with most first- and second-generation designs [34–36]. This was likely related to improvements in surgical technique.

The Finn knee designers' greatest contribution to the evolution of the hinge knee design was a formal kinematic analysis of gait and stair-stepping published in 1999 [37]. Young (average 29.7 years) and older (average 56.2 years) patients with Finn rotating hinge knee prostheses were evaluated with regard to gait and stair-stepping ability. Results were compared with both normal controls and patients with unlinked, posterior cruciate ligament (PCL)-retaining prostheses. The younger patients were as capable as younger controls and differed only in stride length and the external rotatory moment about the knee. Many of the younger patients had proximal tibia and soft tissue resected for tumor along with compromised extensor mechanisms reconstructed with rotation of the medial gastrocnemius. Decreased stride length was thought to be related to weakened calf musculature and push-off strength [37].

Older patients were also noted to be equally as functional with regard to the activities of daily living tested in this study. The cadence and velocity of gait was similar to both the unlinked, PCL-retaining arthroplasty patients, and the controls. However, stride length was significantly short when compared with controls despite the lack of confounding soft tissue procedures. Older patients with Finn knee prostheses ambulated with an externally rotated, stiff-legged gait. The patients locked their knees in full extension at heel strike and maintained their knees in that position during early and midstance. Flexion of the torso placed the center of mass forward and reduced the demand on the extensor mechanism by creating an extension moment at the knee. Reliance on external moments to facilitate extension must increase prosthesis-cement and cement-bone stresses and may have a detrimental effect on prosthetic longevity. In contradistinction, rotatory moments on the knee were lessened. Without collateral ligaments, rotation of the prosthesis is checked predominantly by the lines of action of the knee flexors and extensors. The resultant moment in patients with the Finn prosthesis produced increased external rotation of the tibia during both stance phase and stair-stepping. Older patients with Finn rotating hinge knees were observed to externally rotate their torsos in the direction of the externally rotated foot during stair-stepping, thereby reducing normal internal rotatory forces about the knee. It was concluded that reduction in torque would reduce prosthesis-cement and cement-bone stresses and the potential for loosening [37]. This reduction would not be possible in first-generation, uniaxial hinge designs.

The kinematic data parallel the clinical experience of the Swedish Knee Arthroplasty Project [33, 37]. Increased prosthesis-cement and cement-bone stresses associated with a stiff-legged gait result in early mechanical loosening when compared with unlinked prostheses. However, axial rotation, a second-generation design modification, decreases prosthesis-cement and cement-bone stresses, thereby improving longevity.

S-ROM

The S-ROM rotating hinged total knee (Fig. 22.6) is a third-generation hinge that was developed from its precursor the Noiles hinged knee [38]. As discussed previously, the Noiles was an axle yoke system that allowed 20° of rotation as well as flexion and extension. However, several problems with the Noiles such as failure at 32 months, single size, subsidence, and poly wear led to its abandonment [27, 28]. The S-ROM is a modification of the Noiles that has addressed these problems. The prosthesis is CoCr, and the femoral component has a deepened groove for improved patellar tracking. The tibial component is broad with a polished finish. These femoral and tibial components are augmented with press-fit diaphyseal stems with slots or flutes. These are modular and have several sizes to obtain the best fit and fill and optimal load transmission. In addition to the stems, augments are available to

Fig. 22.6 Exploded S-ROM modular, mobile-bearing hinge knee prosthesis. Note modular stem extensions and modular metaphyseal filling components (From Jones RE, Barrack RL, Skedros J. Modular, mobile-bearing hinge total knee arthroplasty. Clinical Orthopedics and Related Research. 2001 Nov(392):306–14, with permission)

restore the joint line. The polyethylene is congruent with the femoral component and allowed to rotate on the tibial component [38, 39].

The clinical results of this and other third-generation rotating hinged prostheses are encouraging. In a combined series of 2 surgeons, 30 knees with a mean follow-up of 49 months showed excellent results [38]. These midterm results were obtained using press-fit diaphyseal stems with metaphyseal filling sleeves and cemented components. The Knee Society Scores improved from 52 preoperatively to 134 postoperatively. The visual analog pain scales for walking showed significant improvement from 6.6 preoperative to 2.8 postoperative. The visual analog pain scales for stair-climbing ability also improved from 7.6 preoperatively to 3.9 postoperatively. Finally, no mechanical failures of the implants have been seen in the midterm follow-up [38].

Several other third-generation prostheses are commercially available. The MOST, the Kotz, the LINK, and others are modular prostheses with capabilities for managing severe bone loss. These systems have predominantly been applied after bone tumor resection about the knee, and little is known about survivorship. Data in the revision arthroplasty setting are also lacking. However, each design is an axle yoke system with polyethylene-bearing surfaces that transfer the majority of weight-bearing force through the femoral condyles. It is reasonable to expect clinical performance to parallel that of other third-generation prostheses.

NexGen RHK

The Zimmer (Warsaw, IN) NexGen rotating hinge knee is a CoCr resurfacing prosthesis, is the latest of the modern hinged devices, and may represent a new generation of prostheses [40]. The prosthesis, like most modern unlinked revision prostheses, is designed as a resurfacing prosthesis. A slightly larger, intercondylar box cut accommodates the link, and flexibility is achieved through standard revision stem and augment modularity [40].

This hinged device is not linked in the same manner as traditional hinges. The hinge consists of a CoCr hinge post that is preassembled to the intercondylar box of the femoral component. Metal-on-metal contact is prevented by a polyethylene box liner and bushing. A hinge pin secures the mechanism. After the components have been implanted, a CoCr hinge post extension is threaded into the preassembled hinge post and inserted into a polyethylene bushing located inside the tibial base plate stem. Like the Finn knee, the link is unloaded, and the majority of weight-bearing forces (95%) are transmitted from the tibia to the femur via a highly conforming polyethylene bearing. The device allows 25° of internal and external rotation about the post extension but prevents dislocation with a jump distance of 4 cm. Flexion and extension are permitted from 0 to 120° with 2 modes of dampening the terminal extension load [40]. Two studies have reported good to excellent outcomes and survivorship in revision arthroplasty at 56–60 months [41, 42].

Endo-Model

The Endo-Model rotational hinge prosthesis was developed in 1979 and has been used especially in Europe for more than 30 years. Based on data from the UK National Joint Registry, this prosthesis was used in nearly a third of all primary and revision knee procedures in which hinged knees were used in 2012. The Endo-Model rotational hinge achieves flexion and rotatory motion through a component cross joint. A tibial guide pin loosely connects within the femoral bushing and allows for even distribution of load across the joint throughout the entire range of motion and the design features as anti-dislocation device. The resection required on the tibiofemoral joint plane is 14 mm, and the size of the intracondylar portion is between 28 and 34 mm. The prosthesis is available in four implant sizes (left and right) and is available in a cemented and non-cemented version with several femoral and tibial stem options. The femoral component has a physiologic valgus of 6°, overextension amounts to 3°,

and the prosthesis allows flexion of up to 165°. Rotation of the prosthesis ends in extension by form closure, increases continuously with flexion, and is limited primarily by the capsule and ligament structures.

Several studies have assessed the outcomes and survivorship of the Endo-Model hinged prosthesis [43–48]. Already in 1997, Lombardi et al. demonstrated a survival of 85% in a series of 109 patients (113 TKAs) with a mean 25-month follow-up [43]. The most recent publication by Sanguineti et al. evaluated 20 knees at a mean time of 42 months and reported a survival of 95% [48]. As with other hinged implants, the most commonly reported complications have been aseptic loosening and deep infection, but a few studies have reported cases of tibiofemoral dislocation as a consequence of trauma, polyethylene malposition, or flexion-extension gap mismatch [45, 48].

Modular Rotating Hinge (MRH)

In 2003, Stryker introduced their third-generation hinged knee, the modular rotating hinge (MRH). This design was developed from the original 1979 precursor Kinematic rotating hinge and, as a result of its success, the MRH has been incorporated into Stryker's Global Modular Replacement System (GMRS). The GMRS is an all-in-one modular system designed to address situations requiring radical bone resection in trauma, oncologic, and adult reconstructive cases which the MRH design is an integral component. The femoral and tibial base plate implants are constructed of CoCr and offer a wide variety of block and angle wedge augments. Not only are the MRH stems interchangeable between the femoral and tibial components but also are available in fluted, press-fit titanium and in cemented or press-fit CoCr. Furthermore, the MRH is designed to allow for unimpeded rotation about the tibial axis thereby eliminating hard, abrupt stops leading to a reduction in stress transfer to the bone-cement interface. The system also offers a neutral and 3° anterior bumper insert that functions to prohibit hyperextension.

A recent series of 12 primary knee patients implanted with the Stryker MHK demonstrated significant improvement in function, pain, and range of motion when compared to preoperative values [49]. However, it should be noted that although objective functional scores increased, they were lower than those seen in typical primary knee replacement patients. Furthermore at a minimum follow-up of 10 years, no patient underwent revision of the prosthesis, and no implant demonstrated radiographic evidence of loosening. A similar retrospective review clinically and radiographically analyzed 26 patients (21 revision cases and 5 complex primary cases) undergoing implantation of the Stryker MHK for collateral ligamentous deficiency [50]. On average at a mean 2 years follow-up, both functional scores and ROM improved, while no patient's pain or function declined. Although radiographic small, nonprogressive radiolucent lines (<2 mm) were observed in three patients, these findings remained stable throughout the study period, and no implant loosening or subsidence was observed. These short- and midterm results are encouraging; however, larger and more longitudinal studies should be pursued.

Legion HK Hinged Knee System

Smith and Nephew's Legion HK is a third-generation rotating hinge designed for ease in transitioning from mid-level to hinged constraint during revision surgery. The Legion HK uses the same tibial footprint and femoral positioning as the other Legion revision products and only minor adjustments, while using the same cutting instruments, are required to progress through the product line. As opposed to an axial loading device, the Legion HK was designed as a condylar loading implant that has been shown to transfer an average of 96% of stress from the linkage promoting increased life of the hinge components. Furthermore, the Legion HK has an asymmetrical, anatomic base plate that accepts five different insert heights. These "guided-motion" inserts are marketed as a fixed-bearing design as they are doubly locked

onto the tibial tray to minimize the motion between the tray surface and backside of the insert. However, this unique design feature allows for a more natural "screw-home" motion with medial pivot and lateral rollback through the flexion arc. By modeling natural knee kinematics, the "guided-motion" design attempts to optimize the Q-angle, thereby improving patellar tracking and reducing potential patellar subluxation and dislocation events. Through condylar loading and improved kinematics, the Legion HK may provide similar wear characteristics as primary total knee replacements.

Indications for Hinged Implants

A review of the literature indicates that hinged prostheses represent fewer than 1% of all knee arthroplasties performed in the United States [31]. In our practice as well, linked prostheses are infrequently required. Most are performed in association with large bone deficits encountered during revision arthroplasty or after tumor resection. However, as the number and complexity of revision surgeries increase, we anticipate the increased need for hinged total knee arthroplasty.

We believe that uniaxial hinge prostheses have no role in modern arthroplasty. Instead, all linked reconstructions should be performed with a prosthesis that allows some degree of axial rotation and varus/valgus motion. It is also preferable for the condylar reconstruction to dissipate forces through load sharing. In this manner, the axle and link are protected from fatigue fracture as the weight-bearing forces are partially dissipated through host bone. Decreased constraint and condylar load sharing also decrease stresses at the prosthesis-cement and prosthesis-bone interfaces and potentially increase prosthesis longevity.

The absolute indications for rotating hinge reconstruction in our practice are (1) femoral and/or tibial tumor resections that sacrifice the origins or insertions of the collateral ligaments, (2) gross ligamentous incompetence defined as the clinical absence of all four major knee ligaments, and (3) severe bone loss from osteolysis, sepsis debridement, or component removal that has eliminated the origin or insertion of the collateral ligaments [41–43].

In revision knee arthroplasty, we grade bone loss intraoperatively, after primary component removal, using the AORI classification (Tables 22.1 and 22.2). Bone loss is graded separately for the femur and tibia on a progressive scale from 1 to 3 [51]. The implication is that grade F3 and T3 bone loss is frequently associated with compromised collateral ligaments. Hinged total knee arthroplasty substitutes for the collateral ligaments and often is the optimal reconstruction choice for grade F3 and T3 bone loss.

Relative indications for rotating hinge reconstruction in our practice include (1) severe valgus/varus deformity combined with severe flexion contracture that necessitates complete release of both collaterals, (2) severe uncorrectable flexion-extension gap imbalance that may result in cam dissociation of an unlinked design, (3) primary or revision arthroplasty in patients with neuromuscular diseases such as polio, (4) compromised extensor mechanism, and (5) severe recurvatum [52–54]. The author's algorithm for selecting an appropriate prosthesis with regard to ligament competence and bone loss is represented by Fig. 22.7.

Technique

Surgical exposure of the knee and subsequent removal of implants are difficult in revision surgery. Several modifications to the standard medial parapatellar approach have been suggested to improve exposure in difficult cases. These include the quadriceps snip, V-Y quadricepsplasty, quadriceps turndown, tibial tubercle osteotomy, and medial epicondylar osteotomy, which are discussed in Chap. 6. Our preferred technique is the quadriceps snip because the technique is simple to perform, provides excellent improvement in exposure, and may be performed without alteration in postoperative therapy protocols. The tibial tubercle osteotomy may be combined with the quadriceps snip to provide increased exposure; however, postoperative protocols must be

Table 22.1 AORI femoral bone loss classification

AORI femur grade	Deficit	MCL/LCL	Bone reconstruction
F1	Intact metaphyseal bone	Intact	Cement or particulate graft
F2a	Metaphyseal loss single condyle	Intact	Cement or metal augment
F2b	Metaphyseal loss both condyles	Intact	Cement, metal augment, or structural graft
F3	Deficient metaphysis	Compromised	Structural allograft or segmental replacement

Table 22.2 AORI tibial bone loss classification

AORI tibial grade	Deficit	MCL/LCL	Bone reconstruction
T1	Intact metaphyseal bone	Intact	Cement or particulate graft
T2a	Metaphyseal loss med or lat plateau	Intact	Cement or metal augment
T2b	Metaphyseal loss med and lat plateau	Intact	Cement, metal augment, or structural graft
T3[a]	Deficient metaphysis	Compromised	Structural allograft or segmental replacement

[a]Possible extensor mechanism compromise

altered to include cast or brace immobilization in extension for several weeks followed by passive range of motion. Active extension is delayed 4–6 weeks, and full weight-bearing is delayed 6 weeks when a tibial tubercle osteotomy is needed.

Once the knee has been exposed, the soft tissue envelope is assessed. The medial and lateral gutters, the suprapatellar pouch, and potential space between the patellar tendon and the anterior tibia proximal to the tubercle are reestablished through scar excision. Medial and lateral collateral ligament competence can now be assessed through palpation and manual testing. Full extension and several positions of flexion should be assessed because contracted tissues such as the posterior capsule may provide apparent stability in extension despite incompetent collateral ligaments.

The components to be revised are next assessed for positioning prior to removal. Frequently, component malposition and/or improper sizing can be determined as the source of patellar maltracking/dislocation, stiffness, and instability. These clues can be used to help guide the proper reconstruction. After component removal with thin osteotomes and/or a Gigli saw, bone loss is assessed and graded using the AORI classification (Tables 22.1 and 22.2). Rotating hinge reconstruction is performed only when less constraining prostheses are unlikely to provide adequate stability, or severe bone loss (F3 and/or T3) exists.

The first step is to provide the ultimate reconstruction with a stable tibial platform and a correct joint line. Minimal proximal tibia is osteotomized perpendicular to its anatomic axis, and the platform is leveled or raised by block or segmental augmentation as necessary. Preoperative planning and even contralateral radiographs are helpful in reestablishing the joint line. Frequently used landmarks for reestablishing the joint line when working on the tibia are the inferior pole of the patella and the head of the fibula. Elevating the joint line may create patellar baja, cause anterior impingement of the extensor mechanism in flexion, alter the kinetics of the patellofemoral joint, and limit the range of motion. Most current hinged devices combat this issue by placing a cutout in the anterior polyethylene and providing the ability to manipulate the joint line through the use of various sized

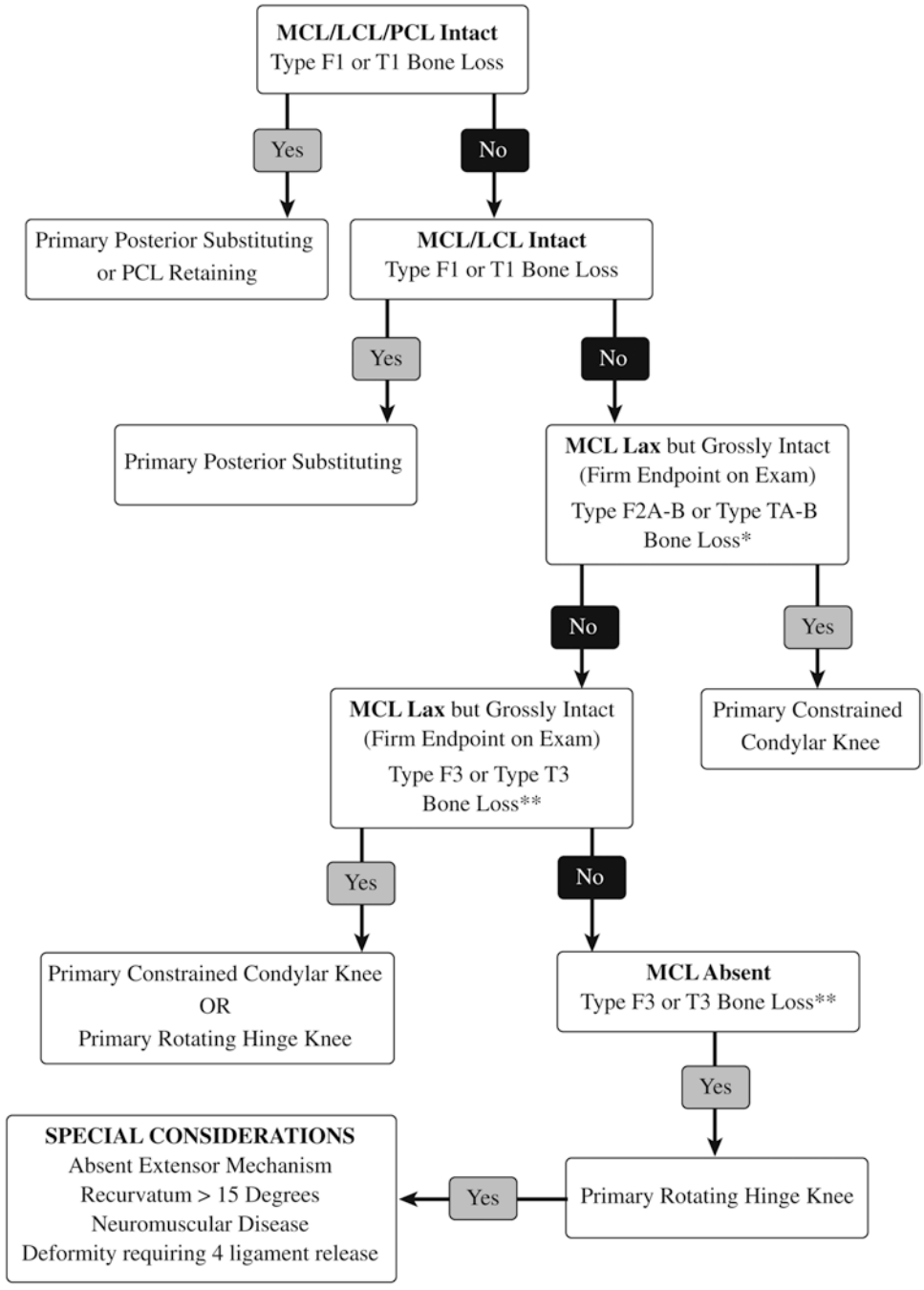

Fig. 22.7 Algorithm for ligament competence and bone loss. (*Asterisk*) Bone loss made up with augments and cement, stem tibia, and/or femur. (*Double asterisk*) Bone loss cannot be made up by augments and cement and must use structural graft or segment replacement

modular wedge and segment options. The tibia is next machined to accept appropriate stem sizes and then oriented in rotation based on the position of the tibial tubercle. If the tubercle is absent, we base rotation off an extramedullary guide rod positioned parallel to the lateral tibial crest and located distally just lateral to the anterior aspect of the medial malleolus. Most rotating hinge

prostheses do not require a posterior tibial slope (no rollback in linked prosthesis), and it is usually recommended that the proximal tibia be cut perpendicular to the long axis. The perpendicular cut also helps prevent flexion instability and prosthesis dissociation.

The femur is first reconstructed with respect to rotation. Three degrees of external rotation of the femoral component is optimal for proper patellar tracking. The easiest landmark to assess rotation is the epicondylar axis. If the epicondyles are absent, then Whiteside's line can be used. Posterior referencing is often less useful in the assessment of femoral rotation because in the revision setting the condyles are deficient. The posterior condyles are helpful, however, in assessing the position of the implant that is to be revised. If the primary component appears internally rotated, then one must be prepared to perform a new anterior reference cut in the proper rotation. Once rotation is established, the femur is sized in the AP plane and cut to fit a trial component. Revision knee systems provide 5° and/or 7° valgus femoral stems, and the distal femoral resection must be made appropriately. Bone deficiency and the need for augmentation are easily assessed by examining the unsupported portions of the femoral trial. Great care is taken at this point to establish the proper joint line from the femoral side. Distal augments or segments should be trialed until the medial joint line is 25–30 mm distal to the medial epicondyle and 20–25 mm distal to the lateral epicondyle. This joint line should match the joint line established via tibial reconstruction, including 10–16 mm of polyethylene tibial insert. If the epicondyles are absent (F3 bone loss), then the femoral reconstruction is simply brought down to the joint line established by tibial reconstruction. Keep in mind that the joint line may be elevated pre-revision due to femoral collapse and the routine use of *plus cuts* on the distal femur during primary arthroplasty. This slight elevation of the joint line on the femoral side is commonly required during revision reconstruction to ensure full extension. Once the joint line is confirmed, the femur is machined for the appropriate size augments and stem.

Balance of the flexion and extension gap at the appropriate joint line is easily accomplished with modern instrumentation and modular hinge designs. The trial reduction should be balanced much the same as a primary arthroplasty. Care must be taken to eliminate gross flexion instability, as this may lead to dissociation of the hinge post from the tibial polyethylene-bearing surface in some *unlinked* rotating hinge prostheses. The modern hinge device typically provides a 3–4-cm *jump distance.* Soft tissue releases are frequently needed to balance the flexion and extension gaps, but most work should be done on the bony side by a combination of resection and augmentation. Range of motion should be from full extension to beyond 90° flexion. Mild joint line elevation with respect to femoral positioning is best tolerated when trial reduction does not achieve full extension.

The trial reduction is then inspected with regard to patellofemoral function. Mild patella baja associated with patellar tendon fibrosis and contracture is well tolerated if the joint line has been properly restored. If the extensor mechanism impinges on the anterior tibial reconstruction despite an appropriately recessed polyethylene design, then mild joint line lowering with respect to the tibial reconstruction is appropriate. Care should also be taken to ensure that the femoral trial component is not oversized. The AP size increase of the femoral component varies per design but is approximately 4 mm per size. Downsizing the femoral component decreases extensor mechanism tension during flexion. Tibial and femoral component rotation should be rechecked and corrected if patellofemoral tracking is poor. Lateral releases are required more commonly in the revision setting than in the primary setting, but the underlying causes for maltracking are the same. Component position should be addressed before performing a lateral release. We routinely release the tourniquet before performing a lateral release to prevent tethering of the quadriceps musculature and to help in maintaining strict hemostasis. Persistent genicular bleeding after lateral retinacular release may result in postoperative hemarthrosis, stiffness, and wound compromise.

Once satisfactory trial reconstruction is achieved, the bony surfaces are prepared for cementing. The authors routinely cement the tibial and femoral components and stems. We com-

monly use cement restrictors to limit the extent of cementing but do not routinely pressurize the medullary spaces. Concern exists in both linked and unlinked reconstructions regarding the longevity of *hybrid* techniques, in which the components are cemented and the stems are not. In the future, newer cementless techniques and design modifications may become available and obviate the need for cement.

Outcomes of Hinged Implants in Revision

The reported outcomes of hinged devices in revision surgery at short- to midterm have been good. In 2009, Berend and Lombardi reviewed the published results on rotating hinge devices in nontumor use [55]. They reported the outcomes of 17 studies published between 1986 and 2008. In all, the studies assessed seven different hinged devices at a mean time of 24–132 months. The postoperative Hospital for Special Surgery (HSS) scores ranged from 71 to 73, the Knee Society Scores (KSS) from 95 to 137, and the range of motion from 88° to 120°. Survival free of open reoperation for any reason ranged from 44 to 96% with most studies reporting survival of greater than 70%. Nine studies published after 2010 have assessed the outcomes of revision arthroplasty using hinged devices with a follow-up time ranging from 46 to 106 months [41, 42, 47, 48, 50, 56–59] (Table 22.3). These studies also reported on seven hinged devices. The mean HSS and KSS scores ranged from 67 to 88 and 114 to 176, respectively. In these studies, the reported survival after reoperation for any reason has ranged from 71 to 96%. The most commonly reported complications were aseptic loosening and deep infection.

Use of Porous Metal Cones with Hinged Implants

Principles

Severe bone loss remains a major challenge in revision knee arthroplasty. Interest in porous metals has grown due to the limitations of using structural allografts and to address existing deficiencies in adult reconstructive surgery. The main advantages compared to allograft include simplified surgical technique, immediate weight-bearing, no disease transmission, and lack of late collapse [60]. Although these porous metal augments provide structural support, they are expensive, need to be cemented to the prosthesis, will not reconstitute bone stock, and are potentially difficult to remove in cases of infection [61].

Porous metals are relatively new biomaterials that can help in achieving improved implant stability in patients with large bone defects [62]. Porous tantalum has several properties that make it suitable for this purpose. It has a low stiffness, high coefficient of friction, and high volumetric porosity [63]. Porous tantalum exhibits scaffolding abilities for osteoblast activity and has demonstrated predictable bony ingrowth [64]. In canine models, tissue ingrowth into porous tantalum begins as early as 4 weeks and extends up to 80% by 52 weeks [65]. The high frictional characteristics combined with early bone ingrowth provide early implant stability and enable early weight-bearing [66]. It has already been used effectively to manage severe bone deficiencies in the acetabulum during revision THA [67]. Porous tantalum cones are commercially available in multiple sizes and shapes and can be contoured with a burr, cut, or drilled. They are also compatible with most revision knee systems.

In cases of revision knee arthroplasty where hinged implants are deemed necessary, it is not uncommon to encounter severe metaphyseal and meta-diaphyseal bone loss. The use of porous metal cones in association with hinged implants has several advantages. The ability to obtain proximal fixation translates into durable fixation of the entire construct. As constrained implants require the use of stems, the porous metal cone converts a "tube within a tube" into a rotationally stable construct. As the stem is cemented and "unitized" to the cone, this construct provides an initial frictional scratch fit of the hinged implant to the bone, which later becomes biologically stable through bony ingrowth [68]. This technique may enable the use of shorter stems due to improved proximal biological fixation and less reliance on distal diaphyseal engagement. It has

Table 22.3 Outcomes of revision total knee replacement using hinged devices

Study, year	No. knees	Type of devices	Mean follow-up, months (range)	Reimplant for infection (%)	Hospital for Special Surgery score (0–100)	Knee Society score (0–200)	Range of motion (degrees)	Survival, after reoperation for any reason (%)	Complications reported (%)
Hernandez-Vaquero and Sandoval Garcia 2010	26[a]	Kinematic	46 (24–107)[a]	0 (0)	NR	128[a]	NR	88[a]	Extensor mechanism (19%), deep infection (8%)
Mortazavi et al., 2010	22	Kinematic, Finn, Maxim, S-ROM	59 (24–115)	0 (0)	NR	123	NR	78	Periprosthetic fracture (14%), hematoma (9%)
Hossain et al., 2010	74	SMILES, MRH, S-ROM	58 (12–120)	(33)[b]	NR	84 (clinical score)	112	93	Aseptic loosening (3%), deep infection (3%)
Gudnason et al., 2011	42	Endo-model	106 (72–216)	0 (0)	67	114	108	71	Aseptic loosening (9.5%), deep infection (4.8%)
Bistolfi et al., 2012	31	RHK	60 (32–100)	4 (13)	88	NR	114	79	Deep infection (6.5%), aseptic loosening (6.5%)
Neumann et al., 2012	24	RHK	56 (36–60)	0 (0)	NR	176	116	96	Patella subluxation (4%)
Weiss et al. 2014	18	S-ROM	60 (24–108)	NR	NR	NR	100	83[c]	Deep infection (14.6)[c]
Sanguineti et al., 2014	20	Endo-model	42 (20–128)	5 (25)	NR	170	102	95	Deep infection (5%), dislocation (5%)
Deehan et al., 2014	33	S-ROM	96 (62–112)	8 (24)	NR	NR	105	86	Implant failure (3%), deep infection (3%)

Adapted from Berend KR, Lombardi AV. Distal Femoral replacement in nontumor cases with severe bone loss and instability. Clin Orthop Relat Res. 2009;467:485–492, with permission

NR not reported

[a]Includes five complex primary cases

[b]Combined data for 126 PS, 149 CCK and 74 rotating hinges

[c]Combined data for 18 rotating hinge and 23 constrained condylar implants

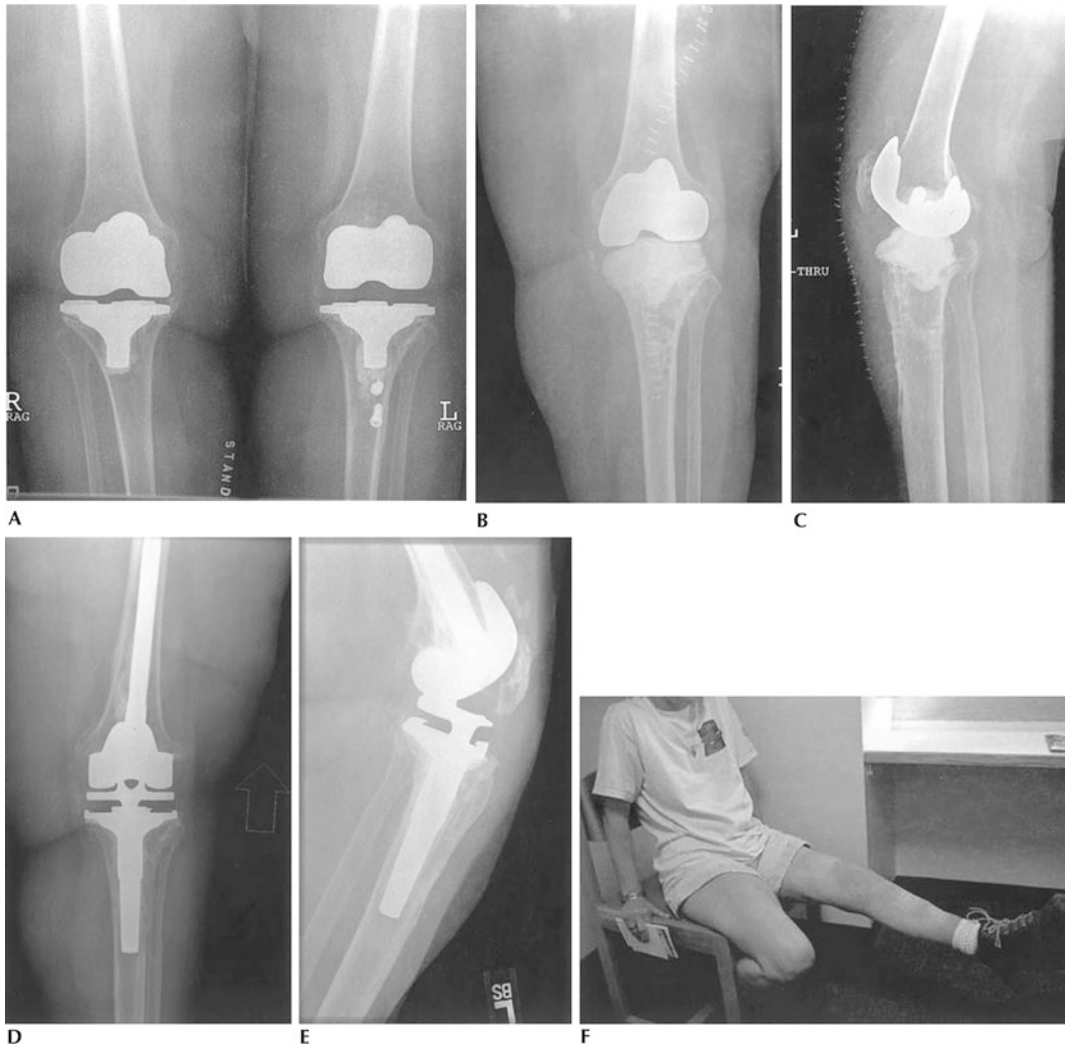

Fig. 22.8 (**a**) Failed infected arthroplasty. (**b**, **c**) AP and lateral views of the first stage of revision. (**d**, **e**) AP and lateral views of rotating hinge prosthetic implant reconstruction. (**f**) Two-year postoperative range of motion

also been proposed that successful proximal ingrowth of the tibial cone may off-load stresses on the tibial stem thereby producing a long-term protective effect [69].

Technique

Once adequate surgical exposure and implant removal have been achieved, as previously outlined, the underlying tibial and femoral bone should be adequately debrided and the remaining defect graded according to the AORI standard. The debridement should remove fibrous and nonviable tissue as well as any remaining cement, especially in the diaphyseal and meta-diaphyseal regions. In these areas, retained cement may deflect reamers during medullary canal preparation and broaching for cone placement resulting in potential fracture, malalignment, and imperfect mating of the cone augment with host bone. However, aggressive removal of cancellous bone should be avoided, as this is the preferred interface for seating of the cone augment and ultimately bony ingrowth.

After the bony surfaces have been prepared, provisional cone trials are used to gauge the appropriately sized and shaped augment needed

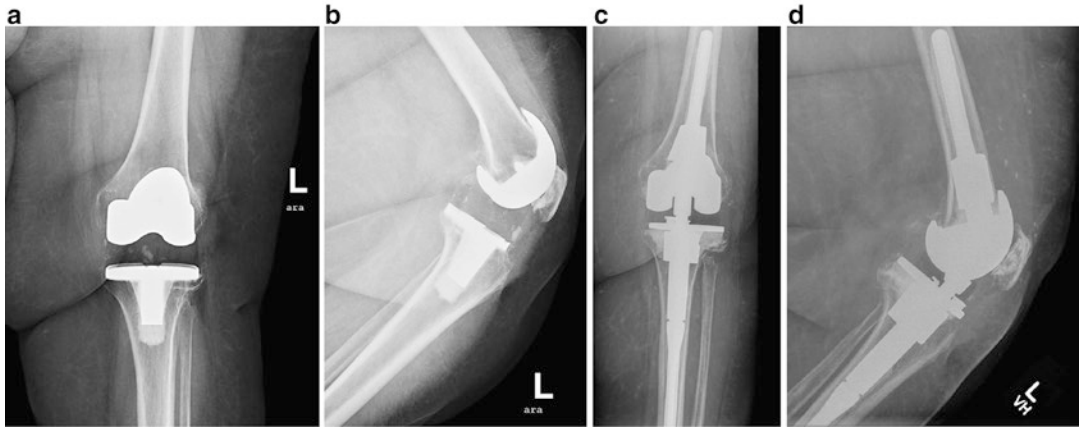

Fig. 22.9 (**a**, **b**) AP and lateral views of the failed primary posterior-stabilized total knee arthroplasty. (**c**, **d**) AP and lateral views of porous cone augmentation and rotating hinge prosthetic implant reconstruction

to address the defect. During this process, reversing the orientation of the trial on the bone surface improves visualization and aids in assessment. Moreover once satisfactory sizing is achieved, the trial may be outlined for more precise bone contouring. When smaller cone augments are chosen, manufacturer technique guides outline preparatory steps with cone reamers and broaches that use the intramedullary reamer as a guide. However, this process may require unnecessary increased host bone removal especially with larger, asymmetric defects. Alternatively with the meticulous use of a high-speed burr, the cone augment can be oriented irrespective of reamer alignment to best fit the bony defect and achieve the desired frictional, scratch fit. Furthermore, porous metal augments may be cut or custom contoured with a burr to match the host bone architecture or to receive the hinged implant construct. If possible, it is recommended that the provisional augment and components be placed during final trialing to verify fit and orientation.

After final trialing, the provisional components are removed, and the bony surfaces undergo final debridement with pulsatile lavage to clear residual debris. The porous metal cone is then taken by hand and placed in the previously determined orientation within the defect. Although the trial and final implant have the same dimensions, the porous surface of the cone augment has higher frictional coefficient than the trial, which will commonly prevent full seating of the implant manually. Therefore, terminal seating of the augment requires controlled impaction with the manufacturer-supplied impactors and small bone tamps for fine-tuning. During this step, it is imperative great care be taken to avoid excessive force which may result in iatrogenic fracture. If voids exist between host bone and the augment after impaction, the surgeon may choose to graft these defects to promote bony ingrowth and potentially prevent cement extrusion during hinge implantation.

Prior to final hinge component cementation, repeat trialing with the provisional hinge components with the final cone augment verifies the proper terminal seating of the cone and the orientation of the stemmed components. Once the cement has been prepared, small amounts may be applied to the porous inner surfaces of the cone and "thumb-pressurized" to ensure cement interdigitation of roughly a few millimeters. At this point, the hinged implants are cemented into place according to previously described techniques.

Outcomes of Porous Metal Cones in Revision

Although there are only a limited number of studies that have assessed the use of porous metal cones in revision knee arthroplasty, the results are

Example Case 1

A 45-year-old woman has an infected total knee arthroplasty and history of patellar tendon avulsion (Fig. 22.8a). Components were removed, and radical debridement was undertaken. The tibia was reconstructed originally with an antibiotic-impregnated cement tibial spacer and recementing of the autoclaved original femoral component with an antibiotic-impregnated cement (Fig. 22.8b, c). Repeat debridement was undertaken before permanent reconstruction. After 6 weeks of intravenous antibiotic and 3 months of oral antibiotic, the knee was aspirated and documented free of infection. At the time of reconstruction, the extensor mechanism was compromised, the medial collateral ligament (MCL) was absent, and the bone stock was graded as F3 and T2. Reconstruction with a rotating hinge prosthesis was undertaken with reconstruction of the extensor mechanism (Fig. 22.8d, e). Nearly 2 years postoperatively, the patient ambulates without assistive device, has flexion to 95°, and has only a 5° extensor lag (Fig. 22.8f).

Example Case 2

A 68-year-old woman presented 15 years after undergoing left-sided posterior-stabilized total knee arthroplasty for evaluation of progressive pain and instability. Physical examination revealed limited range of motion from 5° lack of full extension to 90° of painful flexion. The patient's knee demonstrated significant laxity to both varus and valgus stress throughout range of motion and valgus thrust with weight-bearing (Fig. 22.9a, b). At surgery, the lateral collateral ligament (LCL) was absent, and the MCL was incompetent. The patient had moderate to severe osteolysis, and the bone loss was graded as F2b and T3. The boney defects were reconstructed with porous cone augments on both the femoral and tibial sides, and the joint was reconstructed with a rotating hinge prosthesis (Fig. 22.9c, d). At 1 year postoperatively, the patient ambulates with a walker and has a range of motion from 0 to 100°.

encouraging [62]. To our knowledge there are only nine studies that have assessed the use of porous metal cones in revision knee arthroplasty using hinges. [60, 68–75] Most of these studies have included a combination of implants with various degrees of constraint including hinged devices, constrained condylar devices, and posterior-stabilized implants. The mean follow-up time has ranged from 24 to 84 months, and cones have been used to address AORI type 2 and 3 bone defects in both the tibia and femur. In most of these studies, no loosening of the cones was reported, but three studies reported a loosening rate of 3–4% [69, 71, 74]. The reported reoperation rate for any reason varied from 5 to 27%. Osseointegration of porous metal cones has been shown to occur reliably in both cases revised for aseptic loosening and in cases of two-stage reimplantation for infection. The main reason for failure or reoperations after two-stage revision was not related to cone loosening but recurrent infections. Highly porous metal cones are a valuable addition to the armamentarium when reconstructing large contained and uncontained bone defects in revision knee arthroplasty. Longer-term follow-up is needed to show the durability of these constructs especially in the presence of constrained devices.

Conclusion

In conclusion, hinged total knee arthroplasty has undergone a unique design evolution, from single-size, uniaxial devices with poor fixation methods to current designs with multiple sizes, modularity, multiple modes of fixation, and decreasing constraint. The evolution parallels

the scientific evolution of orthopaedics and knee surgery in general. Increasing laboratory testing and engineering have been part of each new advance. Clinical reports and kinematic testing support the notion that these design modifications can affect prosthetic longevity and improve outcomes. Nevertheless, no hinged prosthesis has midterm clinical results comparable with those of unlinked designs. Long-term data have not been reported with any linked device. As such, hinged prostheses should be reserved for specific indications. Porous metal cones show promising results in conjunction with hinged prostheses in the setting of severe bone loss and may lead to further improvements in hinged implant survival in this setting. Despite design advances and future promise, hinged devices serve predominantly as a salvage option in cases of tumor reconstruction, severe bone loss, severe ligamentous instability, severe deformity, and extensor mechanism dysfunction.

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Total Knee Arthroplasty After Fractures About the Knee

23

Alexander S. McLawhorn and Russell E. Windsor

Gonarthrosis in a patient who has had a fracture about the knee may result from direct injury to the articular surface at the time of fracture, or it may result secondarily from altered mechanics across the knee with associated ligament injuries and bony deformities. It may be incidental to the fracture that has occurred in the metaphyseal or diaphyseal region of the knee. Also, secondary arthritic deterioration may develop from hardware penetrating into the joint.

Total knee arthroplasty in these patients presents an array of technical challenges to the surgeon, and patient outcomes are worse than they are for routine primary knee arthroplasty patients [1]. Damage to the soft tissue envelope of the knee and multiple surgical scars complicate the surgical exposure and may lead to healing problems and stiffness due to the associated scarring that may develop from the fracture itself or from the extent of surgery required to initially fix the fracture [2, 3]. There is a greater risk of infection due to soft tissue envelope compromise and possible bacterial colonization of bone or hardware [3–6]. Bone loss, malunion deformity, and fracture nonunion can present problems that may require augments, long-stemmed implants, or even a corrective osteotomy to solve (Fig. 23.1) [1, 7]. Advanced technologies can assist preoperative planning and intraoperative realignment of the lower extremity [8–14]. Issues relating to the patella present their own challenges [3, 15]. Finally, soft tissue balancing of the knee can be difficult, particularly if the collateral ligaments have been damaged.

Although primary total knee replacement is not infrequently performed for posttraumatic osteoarthritis secondary to fracture, the technical challenges to these clinical cases present demand techniques that are more frequently required during revision total knee replacement. The only significant difference between primary total knee replacement for arthritis involving an intra-articular or extra-articular fracture and revision surgery is that the surgeon may have more bone stock at his or her disposal when performing the reconstruction. Only in severe intra-articular tibial plateau or femoral condylar fractures could there be extenuating circumstances in which there is extraordinary bone loss secondary to the severity of the fracture.

Epidemiology

It has been estimated that posttraumatic arthritis accounts for over $3 billion in annual health-care costs in the United States and that posttraumatic arthritis comprises approximately 9.8% of all cases of knee arthritis [16]. Patients who have undergone previous knee surgery receive total knee replacement at a significantly younger age than patients with primary osteoarthritis [17]. Yet, nearly one half of periarticular knee fractures occur in the patients older than 50 years [18,

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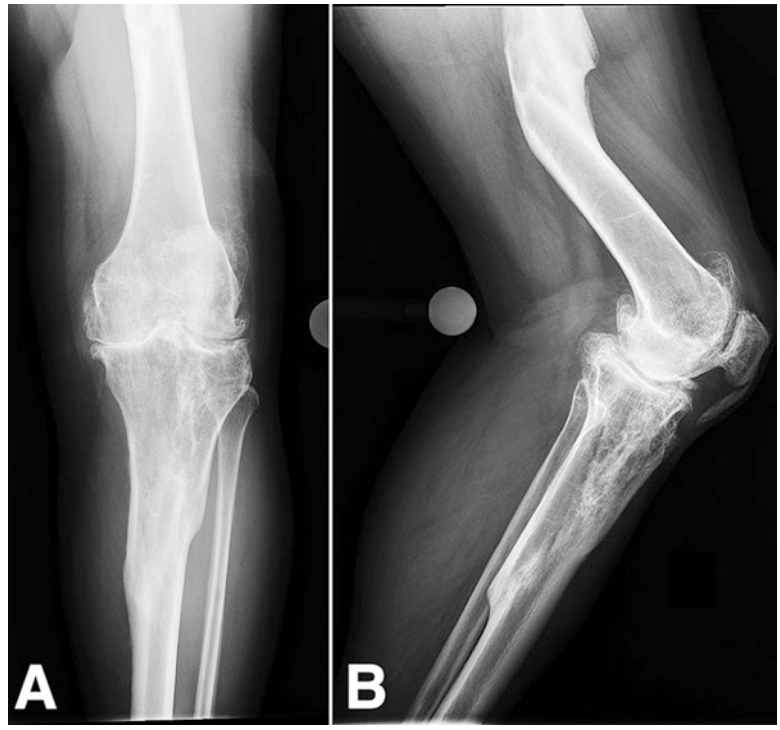

Fig. 23.1 (**a**) Anteroposterior and (**b**) lateral radiographs showing extra-articular tibial and femoral fractures resulting in coronal and sagittal plane deformities

19]. In particular, distal femoral fractures are more common in the older patients than in younger patients [18], with an annual incidence of approximately 20 cases per 100,000 persons over 50 years old [19].

The frequency of conversion from prior internal fixation to arthroplasty is less than 10%, although progression of preexisting arthritis occurs in up to 60% of cases [1, 18, 20, 21]. Lower extremity malalignment after fracture fixation increases the likelihood of arthroplasty [22]. Approximately 7% of patients requiring operative management of tibial plateau fractures will require total knee replacement within 10 years of fracture fixation, which corresponds to a 5.3 times increased risk of requiring total knee replacement compared to patients having not suffered an operative tibial plateau fracture [20]. Older patients, patients with bicondylar fractures, and those patients with more comorbidities are also more likely to require total knee replacement after open reduction and fixation of tibial plateau fractures [20]. Yet, it is noteworthy that only 11% of bicondylar fractures will require total knee replacement within 10 years [20]. The majority of conversion knee arthroplasty patients have suffered a split-depression fracture of the lateral plateau, probably reflecting the frequency of this fracture pattern, and the commonest modes of failure necessitating arthroplasty are valgus collapse and nonunion [23]. Less is known about the frequency of conversion from open reduction and internal fixation of distal femur fractures and patella fractures to arthroplasty.

Preoperative Considerations

A careful preoperative assessment is necessary for all patients presenting with persistent complaints after fracture treatment about the knee. A detailed history and physical exam should focus on the location and quality of pain, presence of instability and collateral ligament incompetency, extensor mechanism function, presence of prior surgical scars, skin grafts and flaps, magnitude of associated deformities, and range of motion [1]. Preoperative range of motion should guide patient expectations regarding postoperative range of motion, since they are closely

correlated, and preoperative stiffness is common in the posttraumatic knee [24].

Infection Risk

Knee arthroplasty after fracture about the knee has been shown to carry a higher risk of infection [3–5, 25–27]. This may be due to a damaged soft tissue envelope resulting from the original injury and/or open reduction and internal fixation exposure or to colonization of hardware, especially in the case of external fixators. Knee arthroplasty patients who have had prior infections following tibial plateau fixation are four times more likely to require additional procedures compared to patients who did not have a prior infection [27].

The preoperative work-up should include laboratory tests for markers of infection (complete blood count, C-reactive protein, and erythrocyte sedimentation rate) [1]. An aspiration of the knee should be obtained and the specimen sent for Gram stain, culture, and sensitivities [28]. During the total knee replacement operation itself, intraoperative Gram stain, intraoperative frozen section, and culture may also be useful. If there is a high index of suspicion for infection at the time of surgery, it may be appropriate to perform a staged primary total knee replacement with the first stage consisting of a thorough debridement of the knee, including making the definitive bone resections for the arthroplasty. The implantation of the prosthesis is delayed until the presence of infection in the knee tissue is resolved. During the first stage, the initial distal, anterior, and posterior femoral bone resections are performed. The proximal tibial resection and posterior patellar resection are also done, and an antibiotic-impregnated acrylic spacer block is inserted. This procedure serves as an aggressive debridement since the articular surfaces are resected at this stage. Finishing resections such as femoral chamfers and tibial stem preparation are completed during the second stage when the prostheses themselves are implanted with antibiotic-impregnated cement. In the authors' experience, considerable success has been achieved in treating patients at high risk in this way. Implantation of the knee prostheses may be done as early as 1 week after this first stage if the intraoperative culture results are negative. However, if they are positive, implantation is delayed for 6 weeks or more, while the infection is treated with an organism-specific course of parenteral antibiotics. This scenario is similar to the two-stage treatment of an infected total knee replacement. Antibiotic impregnated cement is advised for the second stage, even if there was no evidence found of an active infection.

Imaging

In addition to a routine series of radiographs of the knee, it may be necessary to obtain additional imaging such as a full-length standing anteroposterior radiograph or CT scan to clearly define any deformity resulting from the fracture [7]. A technetium diphosphonate bone scan, gallium scan, or magnetic resonance imaging (MRI) may be useful for localizing infection if there is a high suspicion for its presence. These scans are particularly suggested in cases in which numerous operative procedures were performed or cases in which the patient had a prolonged, complicated course of treatment. The value of preoperative MRI is controversial. However, metal artifact reduction sequences can minimize the effects of retained hardware on image quality. MRI scans can evaluate the extent of intra-articular injury for acute fractures, and they can assess both acute and chronic injuries to periarticular ligaments [1, 29]. CT scans are useful in the setting of acute fracture to define the degree of intra-articular comminution and to assist making the decision between internal fixation and immediate arthroplasty.

Full-length standing radiographs are important for preoperative planning to determine the possible need for corrective osteotomy [7]. This is particularly important if there is a significant malunion present that may affect the overall alignment of the knee, and the deformity can be multiplanar (Fig. 23.1). Cross-sectional imaging may best define the deformity in all three planes and identify nonunions. Biplanar slot radiogra-

phy is a new imaging modality that produces simultaneous orthogonal radiographs. Compared to CT, the images are acquired with the patient standing, the radiation dose is significantly reduced, and three-dimensional surface models (versus volumetric rendering) of bony anatomy can be created [30, 31].

Exposure

Soft Tissue Envelope

The soft tissue envelope may be compromised either as a result of the initial injury or as a result of subsequent surgeries. An effort should be made to incorporate old incisions and to avoid large subcutaneous tissue flaps, if possible. If tissue flaps must be created, they should be thick and deep to the fascial plane. In the case of multiple incisions, the most lateral incision that is practical should be used [3], since the vascular supply to the skin anterior to the knee is primarily derived from the medial side [1]. If there are old incisions that cannot be used practically, then it may be necessary to adjust the incision medially or laterally to increase the width of the skin bridge; the minimum recommended skin bridge is 6 cm. Hockey stick incisions and transverse incisions may present a particular concern. In general, an incision can be crossed at right angles but should not be crossed acutely ($\leq 60°$). Incisions older than 10 years probably can be ignored.

If there are particular concerns about the soft tissue envelope, the surgeon may perform a *delay* procedure, in which only the skin incision and soft tissue dissection is performed, and the wound is closed. The healing of this incision is then monitored for 2 weeks to determine the presence of eschar formation and to permit neovascularization of the soft tissue flaps. If skin necrosis develops, then separate vascularized soft tissue coverage grafts would be needed prior to or at the time of the knee replacement stage [3, 32]. Similarly, if the soft tissue envelope over the tibial tubercle or patellar tendon appears tenuous, preemptive flap coverage may be considered, and total knee arthroplasty can be performed after flap maturation and recovery of knee range of motion [1]. A gastrocnemius muscle flap or vascularized free myocutaneous flap may be used in this situation to obtain healthy soft tissue coverage [4]. If a patient has received prior soft tissue coverage procedures (e.g., skin grafting or muscle flap transfer) or vascular repair, respective consultations with a plastic surgeon or vascular surgeon may be prudent [1]. Intraoperative angiography can be used to plan the surgical incision and to assess wound closure, which may help mitigate the risk of wound necrosis and other wound-related complication [33].

In situations in which the skin is adherent to the underlying extensor mechanism, tissue expanders may be inserted to stretch the skin and create neovascularized environment before the primary total knee replacement [34]. As in revision situations, it may be necessary to extend the original incision proximally and distally to more clearly define the subcutaneous tissue planes. This enables the surgeon to find the proper depth of the plane between the extensor mechanism and subcutaneous adipose tissue or scar.

Scar tissue and bone deformity or overgrowth may make exposure of the knee quite difficult. In general, the surgical approach should protect the patellar tendon and collateral ligaments. Adhesions in the suprapatellar pouch, medial and lateral gutters, and around the extensor mechanism are excised first. A standard medial soft tissue peel is performed off the proximal medial tibia, extending posteriorly past the mid-coronal plane. The patella does not need to be everted but can be retracted laterally. Knee flexion, cruciate ligament release, release of the anterior horns of both menisci, and external rotation of the tibia should be attempted next. If these steps do not provide adequate exposure, the surgeon may need to consider techniques such as a quadriceps snip, lateral retinacular release, V-Y quadriceps turndown, or tibial tubercle osteotomy to facilitate exposure [1, 25, 35]. The quadriceps snip is generally the preferred choice due to its relative simplicity and ability to be extended. Furthermore, it does not alter postoperative

rehabilitation. It is performed by extending proximally and laterally at a 45-degree angle from the standard medial arthrotomy that is performed during most primary replacement surgeries. Early lateral retinacular release is performed when there is difficulty with lateral exposure or in cases in which there is considerable scarring from a previous lateral incision or adherent scar along the lateral femoral gutter. A V-Y turndown can be created by extending the lateral retinacular release proximally into the medial parapatellar arthrotomy. A turndown risks patella and patellar tendon devascularization and a postoperative extensor lag. Thus, it should be employed judiciously, if ever, and tibial tubercle osteotomy is typically preferred over a V-Y turndown [36]. This technique is particularly recommended if a previous tibial tubercle osteotomy was used during the initial approach for open reduction and internal fixation of a tibial plateau fracture. The osteotomy should include the entire patellar tendon insertion, and the fragment is typically 8–9 cm long, 2 cm wide, and 5–10 mm deep. A lateral soft tissue "hinge" should be preserved to protect the blood supply to the fragment, and fixation can be performed with screws or wires [1].

In rare situations, skeletonization of the distal femur may be required if there is substantial preoperative ankylosis. In these latter situations, the surgeon should be prepared to use prostheses with further built-in constraint, such as a constrained condylar knee, or total condylar III implant. In extraordinary cases of severe distal femoral malunion or severe proximal tibial condyle disruption and bone loss, constrained rotating hinge designs may be required.

Intraoperatively, careful attention should be paid to implant sizing, since oversized implants can lead to pressure necrosis of the overlying skin. If soft tissue coverage seems marginal during surgery, postoperative range of motion should be delayed several days in order to monitor the wound. At-risk wounds with persistent drainage or marginal necrosis may require early operative debridement and possible myocutaneous flap coverage [1].

Fixed flexion and valgus deformities place the peroneal nerve at risk for neuropraxia postoperatively, and at least one large study has confirmed that posttraumatic arthritis patients are at increased risk for peroneal nerve palsy after knee arthroplasty [37]. Maintaining the knee in slight flexion postoperatively may mitigate the risk for peroneal palsy in these cases. For severe, chronic deformities, primary peroneal neurolysis may be considered [1].

Removing Hardware

Removal of hardware is not mandatory unless the presence of the hardware interferes with instrumentation, placement, or function of the arthroplasty (Fig. 23.2). A longer incision and greater exposure are usually required to remove hardware. It is only necessary to use the original medial or lateral incision if it is clear that the implant is not reachable by the standard midline incision that will be used during the replacement. Often, buttress plates affixed to the lateral tibial plateau may be simply removed by entering the anterolateral muscle compartment through an extended midline incision. The soft tissue envelope should be assessed preoperatively to determine the likelihood of success. Obese patients may have enough adipose tissue coverage to permit easy access to the lateral side of the joint by further lateral dissection through the midline incision. A separate incision may be necessary, if instrumentation cannot be easily applied to the implants through the midline incision. The use of a single midline incision simplifies the exposure and decreases the risk of skin flap necrosis that may arise as a result of the presence of two freshly made incisions.

Nevertheless, as a general rule, only hardware that is symptomatic or that interferes with the knee reconstruction should be removed. Otherwise unnecessary hardware removal places the operative site in danger of necrosis or additional bone loss if implant extraction is difficult. Hardware removal can usually be performed at the time of joint reconstruction. A separate removal stage is generally reserved for

Fig. 23.2 (**a**) Anteroposterior and (**b**) lateral radiographs of a left knee with intramedullary femoral implant and medial plate that will interfere with the total knee replacement. Femoral screws could be removed through percutaneous lateral incisions, and the rest of the hardware could be removed through the midline incision used at the time of total knee replacement. Alternatively, these implants could be removed as a separate procedure

large implants that may extend far away from the knee joint itself. This strategy allows for the soft tissues to heal prior to definitive reconstruction. When there are large implants, such as long tibial plates, it may be preferred to selectively remove only part of the hardware preventing implantation of a knee arthroplasty. This obviates extensive soft tissue damage and the need to bypass potential stress risers either proximal or distal to the knee joint [1]. However, if there is a suspicion of infection, the hardware should be removed as part of a staged treatment plan, and a sample of deep tissue should be obtained and sent for frozen section, routine pathology, culture, and sensitivity.

Proximal intramedullary femoral nails that extend to the distal metaphysis interfere with the use of intramedullary alignment instrumentation. In this case, extramedullary alignment instruments or advanced technologies, such as patient-specific cutting guides, should be considered. The nail should only be removed if there is little risk of disrupting the proximal aspect of the femur.

Advanced Technology

Several advanced technologies purport improved component alignment for total knee arthroplasty. All systems require some type of signaling technology, whether infrared, electromagnetic, or gyroscopic, that directs the placement of surgical instrumentation intraoperatively to perform accurate bone resections. Image-guided systems require preoperative axial imaging or intraoperative fluoroscopy, while imageless systems rely on registration of bony landmarks intraoperatively. Patient-specific instrumentation uses preoperative CT or MR imaging to create single-use custom cutting blocks that conform to the unique topography of a patient's articular surfaces and set the alignment and resection depth of the bone cuts based on a virtual, preoperative plan. All of these technologies may be particularly useful in the setting of posttraumatic arthritis with concomitant deformity. Additionally, instrumentation of the intramedullary canal can often be avoided, which is particularly useful if there is

intramedullary hardware and/or deformities affecting the femoral diaphysis, making access difficult and resections based off intramedullary cutting guides unreliable.

Arguably, the most appropriate use for these tools are posttraumatic knees with substantial deformity, and they have been used successfully in several series to achieve neutral mechanical alignment in total knee replacements performed in patients with post-fracture malunion. These techniques can be used for acute [8] and chronic fracture deformities [9–13, 38]. They permit the surgeon to plan and execute bone cuts precisely, and previously implanted hardware can often be retained. However, the learning curve associated with these technologies requires the surgeon to become proficient with them during routine knee arthroplasty prior to applying them to complex cases. If patient-specific instrumentation is used, a system that utilizes axial imaging and long-leg radiographs may be more accurate than those that rely on axial imaging of the knee alone [39].

Bone Loss

Bone loss in the posttraumatic knee is addressed similarly to bone loss during revision total knee arthroplasty. Contained defects of the tibial plateau or femoral condyles can be filled with morsellized bone graft that can usually be obtained from autogenous resected bone [3]. Frequently, it may be necessary to combine grafting with the use of metal augmentation. Large metaphyseal deficiencies can be managed with sleeves, cones, or impaction grafting. However, it may be necessary to add a stem to the component to add stability to the construct if there is still proximal discontinuity that mandates additional fixation [40]. If there is an uncontained tibial or femoral defect, then augments and an intramedullary stem extension should be added to the component. Hybrid fixation, with long uncemented stems and cement around the tibial baseplate or femoral resurfacing component, is preferred. Short, uncemented stems have demonstrated a higher risk for failure. Therefore, short stems, if used, should be fully cemented.

Larger defects may require the use of a distal femoral or proximal tibial replacement that is used for the treatment of tumor excisions in this area. Bulk allografts may be also used in these situations, and the surgeon must weigh the risk and benefits of allograft incorporation, stability, and long-term survivorship. This decision-making process is somewhat age dependent, as allograft usage would be considered in the younger patient with better bone stock and large constrained, distal femoral or proximal tibial replacements are better suited for the older patient with more compromised bone stock.

Bone Deformity

Malunion or nonunion may result in deformity of either the tibia or the femur (Fig. 23.3). This may be in the coronal plane (varus/valgus), the sagittal plane (flexion/extension), the axial plane (rotation), or any combination of these. If the deformity is not corrected, the altered mechanics that may have caused the arthritis could also lead to early failure of the device [9, 10]. For example, sagittal plane malunions may cause the femoral component to be placed in hyperextension. If this occurs, particularly with a posterior stabilized total knee replacement, excessive cam-post impingement can occur, leading to early failure. Despite known complications associated with implant malposition and residual deformity, optimal component position is achieved in fewer than 50% of patients in some series [41]. Further, preoperative malunion and nonunion increase the risk of postoperative complications after knee arthroplasty [37].

Intra-articular deformity (deformity within the collateral ligaments) may be corrected with the bone cuts or may require augments; however, extra-articular deformity (deformity proximal to the femoral origin of the collateral ligaments or distal to the tibial insertion) may need to be corrected by osteotomy [7, 42]. A good rule for handling malunion situations is to mark out a line on the standing radiograph of the planned resection that would provide the correct mechanical axis. If there is the risk of violating the collateral

ligament insertions on the femur, then a corrective osteotomy should be contemplated. If osteotomy is required, it is usually performed at the site of the original malunion. Otherwise, a swan-neck or curved bow deformity would be obtained due to the malunion site and osteotomy site being too close together.

As a general guide, if extra-articular deformities are <10° in the coronal plane and <20° in the sagittal plane, they can be addressed using modified bone cuts at the level of the joint, along with selective soft tissue releases, as long as neither the osteotomies or soft tissue releases compromise the collateral ligaments (Fig. 23.4). The closer the center of the deformity is to the joint, the more it contributes to the overall bone prosthesis configuration. Compared to tibial deformities, femoral deformities are more challenging to correct with intra-articular resections [43]. Larger deformities may require extra-articular osteotomies that can be performed simultaneously with the total knee replacement or in staged fashion [1, 43–46].

Malunion may make it difficult or impossible to use intramedullary instrumentation to gain appropriate alignment of the distal femoral or proximal tibial resection. Hence, extramedullary alignment guides or advanced technology, such as computer-assisted surgical techniques, should be used to obtain correctly aligned resections. If osteotomies are performed simultaneously with arthroplasty, care should be taken to avoid intrusion of cement into the osteotomy site, and osteotomies should be bridged with intramedullary stems [46]. Large axial plane deformities affecting the femur should be corrected with a derotational osteotomy, since proper rotational alignment is critical for total knee longevity and proper patellofemoral mechanics. A derotational osteotomy fixed with a retrograde intramedullary nail allows visualization of the epicondylar axis during the correction and facilitates hardware removal at the time of total knee replacement [1]. When there is translational deformity, offset stems can be used to prevent implant malposition. Multilevel lower limb deformities may require osteotomies and arthrodesis of other joints in addition to knee arthroplasty [44]. The surgeon should have constrained implant designs available, if needed to provide intrinsic stability in cases were ligament balancing is difficult to achieve by conventional methods.

Nonunion

Distal femoral nonunions occur more frequently than proximal tibial nonunions. Revision open reduction and internal fixation of nonunited fragments with bone graft may be possible at the time of arthroplasty [3]. If implant stability is compromised, a stem may be added to a femoral or tibial component. Long-stemmed prosthesis may be appropriate to span a transverse nonunion. Uncemented, press-fit, diaphyseal-engaging stems are preferred to bypass the nonunion site and provide implant stability. Alternatively, intramedullary nail fixation can be performed simultaneously with total knee replacement. Autogenous bone graft obtained from the normally resected bone, allogeneic bone graft, bone graft substitutes, and adjuvants should be considered to augment local biology and promote fracture union.

The initial resection of bone may be significant enough that the nonunited segment is almost completely excised. In these cases, simple metal augments may be used. The resected bone, however, serves as an excellent source for autogenous graft material and is packed around any persistent nonunion sites. The combination of stem extensions, fixation of the nonunited fracture fragments, and autologous bone graft is quite successful in bringing about union of the fracture site and handling of the arthritic condition. Distal femoral replacement may provide more predictable results in elderly or osteoporotic patients with nonunions, permitting immediate weightbearing and avoiding the need for fracture union. In these patients, cemented fixation may be preferred.

Protected weightbearing may be necessary based on the overall stability of the reconstruction. However, in most cases, the postoperative rehabilitation course progresses uneventfully.

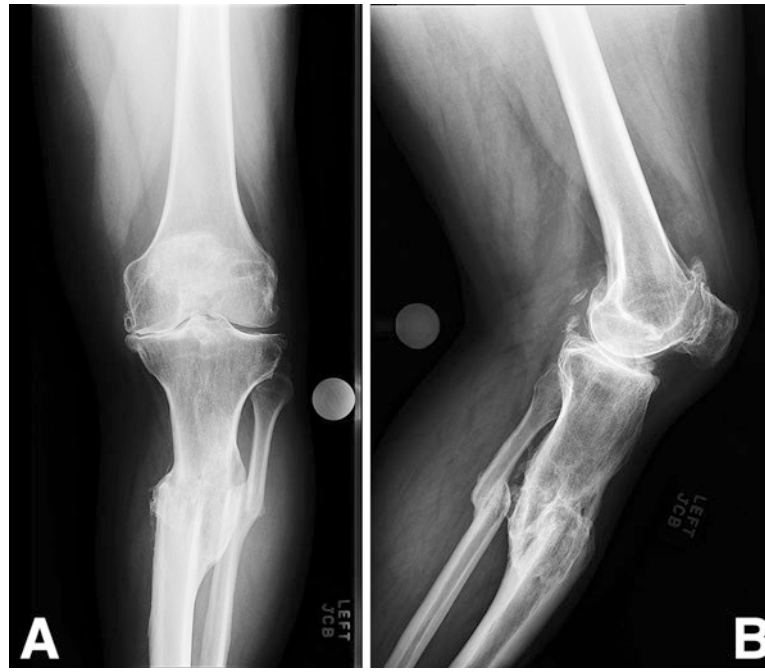

Fig. 23.3 (**a**) Anteroposterior and (**b**) lateral X-ray of a proximal tibial malunion

Acute Fracture

In the majority of cases, a fracture about the knee should be treated by open reduction and internal fixation as appropriate. Arthroplasty can be performed later after the fracture fragments have healed, if and when arthritis develops. However, if there is poor prospect for normal joint function (in the case of preexisting arthritis or significant chondral injury), particularly in an elderly or frail patient, arthroplasty with or without retention and fixation of fracture fragments may be appropriate at the time of the acute fracture [18, 47–49].

Certainly, open reduction and internal fixation should be considered first, as every attempt should be made to preserve bone stock. If posttraumatic arthritis occurs after the fracture has healed, total knee replacement can be performed. However, in elderly patients, open reduction and internal fixation may require partial or nonweightbearing or prolonged bedrest that impede early mobilization and may increase the risk of venous thromboembolic disease or pulmonary embolism. Thus, the rationale for arthroplasty for acute periarticular fractures of the knee is similar to the rationale for treating femoral neck fractures with endoprosthetic replacement. Furthermore, osteosynthesis in elderly patients can be exceedingly complex, particularly when there is substantial intra-articular fracture comminution. Their risks for loss of fixation, malunion, and nonunion are elevated [18]. In such cases, it may be more prudent to consider primary knee replacement. The benefits include quick rehabilitation and early mobilization without the need for prolonged protected weightbearing. In general, all attempts should be made to preserve the natural knee anatomy. However, there may be extenuating circumstances when total knee replacement is the more prudent option.

Managing distal femoral fractures acutely with arthroplasty begins with the decision to resect or retain the distal femur. Technically, resection is typically the more practical option, although it requires a collateral-substituting hinged prosthesis. Provisional reduction of the fracture fragments before resection can assist achieving accurate restoration of the joint line and femoral rotation. Retention and fixation may be most appropriate for partial articular fractures

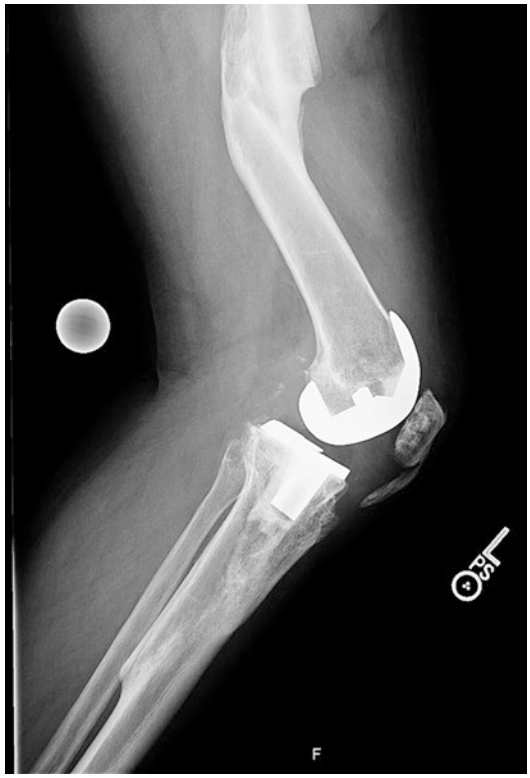

Fig. 23.4 Lateral X-ray of a total knee replacement in the setting of distal femoral and proximal tibial fracture malunions

(e.g., AO type B fractures affecting a single condyle) [50], depending on bone quality. A stemmed revision component should be used, and cement fixation is typically preferred over uncemented diaphyseal fixation, because the diaphysis is frequently ectatic and osteoporotic.

Acute management of proximal tibia fractures requires both stable fixation of fracture fragments and the use of stemmed tibial components to facilitate unrestricted, early weightbearing [51]. Resection of fracture fragment is not advised, since critical extensor and flexor tendons insert on the proximal tibia. Reconstruction options can be guided by the Schatzker type of the fracture [18]. Schatzker types I, II, and IV are characterized by unicondylar split fractures of the plateau, Schatzker type III is pure depressions of the plateau, and Schatzker types V and VI are bicondylar fractures without or with metaphyseal involvement, respectively [52]. Unicondylar fractures with fragments that are large enough for internal fixation should be stably reduced, fixed, and bypassed with a stemmed tibial component. Treatment of type III fractures depends on whether the depression is contained or not. Small (<1 cm), contained defects can be filled with bone graft or cement, whereas uncontained depressions without circumferential cortical support may require tibial augments. Type V and VI fractures require stable plate fixation and stemmed components. Nonunions of tibial tubercle fracture fragments are difficult to treat. Thus, fractures involving the tubercle may represent a contraindication to total knee arthroplasty [18].

A non-compromised soft tissue envelope is a prerequisite for knee reconstruction with an endoprosthesis. An anterior midline incision allows for fracture fixation and arthroplasty reconstruction. Since stems are usually required, intramedullary cutting guides can be used for the femoral and tibial resections. The articular insert which ensures knee stability with the least constraint is preferred, to reduce stresses across implant, cement, and bony interfaces. However, hinged implants must be used when there is collateral ligament incompetence. Resurfacing the patella may reduce the risk of reoperation in this patient population [18].

Patella Considerations

Care should be taken to avoid rupture of patella tendon at the time of surgery by using techniques previously mentioned to facilitate the exposure without putting undue tension on the patella tendon [3]. If the exposure is difficult, it may be necessary to secure the patella tendon to the tibial tubercle with a bone pin. Alternatively, the patella can be retracted laterally without eversion during femoral and tibial bone preparation. There is a higher risk of delayed rupture of the extensor mechanism in this patient group that may occur during extensor mechanism eversion and flexion of the knee, particularly in patients who have diabetes or are taking oral steroids [3, 4].

Fractures of the proximal tibia can result in scarring of the patella tendon and patella baja.

Mild cases may require fashioning of a recess in the anterior portion of the tibial polyethylene, but more severe cases may require tibial tubercle osteotomy or even an extensor mechanism allograft.

In cases in which a tibial tubercle osteotomy was performed to expose a tibial fracture for reduction and internal fixation, the tibial tubercle may progress to nonunion. In addition to fixation with screws, this may require bone grafting and bone graft adjuvants and perhaps also reinforcement with a cable or wires. It may be necessary to splint the limb in extension postoperatively and may compromise overall rehabilitation of the arthroplasty.

There are very few studies examining total knee replacement in patients with prior patella fractures [15]. A patella fracture if unhealed and not amenable to fixation may be treated by simple debridement of prominent bone or by complete patellectomy keeping in mind that extensor strength will be compromised. Nonunion, partial patellectomy, and complete patellectomy do not appear to influence subsequent need for reoperation or revision surgery [15].

Soft Tissue Balancing

Stiffness

Preoperative range of motion may be less than normal in which case the surgeon should expect poorer postoperative range of motion, particularly in the case of distal femoral fracture. Some cases require manipulation of the knee in the first 6–12 weeks postoperatively [3]. Extensor mechanism scarring is difficult to release. Extensor mechanism lengthening is not recommended as secondary quadriceps mechanism weakness may develop despite the possibility of improved flexion. Scar tissue may be excised in the medial and lateral gutters. But, flexion may only be increased marginally if interstitial scarring of the quadriceps muscle is present. The vastus intermedius may be lifted off and dissected free from the anterior aspect of the femur. A lateral release is frequently required because of extensor mechanism scarring and contracture.

Stiffness is less of a secondary problem after tibial plateau or shaft fractures. The stiffness that is created is generally intra-articular rather than extra-articular, which is the case in supracondylar femur or femoral shaft fractures.

Ligament Balancing

If extra-articular deformity is corrected by intra-articular compensatory angular resection, balancing may not be possible. These particular deformities may be more appropriately treated by an extra-articular osteotomy. Extensive soft tissue release may be necessary at the time of surgery either to correct deformity or for stiffness. Substantial soft tissue release may compromise stability of the knee. Also, ligament injuries, which may result from the original trauma or are secondary to the subsequent abnormal mechanics, may also compromise knee stability. The least constrained implant needed for well-balanced flexion and extension gaps should be used. When the medial collateral ligament is damaged, advancement of the native ligament or ligament reconstruction can be considered, and excessive valgus alignment should be avoided. If a more constrained device is needed, addition of stems to strengthen fixation may be required. In the most significant cases of severe bone loss and soft tissue scarring, rotating hinged prostheses may be required.

Outcomes

Few high-quality studies report outcomes for conversion knee arthroplasty after fracture fixation, and many are limited by short clinical follow-up (Fig. 23.5). In general, there are more complications, and revision operations are required frequently. Deep infection, limited flexion, extensor mechanism compromise, residual instability, peroneal nerve palsy, and persistent pain are common [1, 5, 6, 37, 53, 54]. Quality of life parameters after knee arthroplasty are lower in patients with posttraumatic arthritis when compared to those with primary osteoarthritis

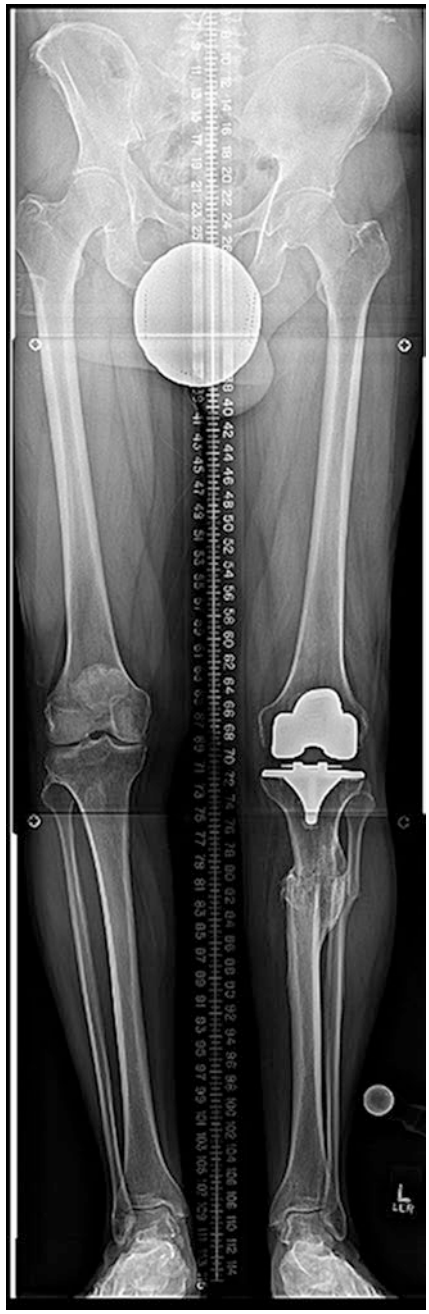

Fig. 23.5 Postoperative anteroposterior long-leg standing alignment radiograph of a patient who received a left total knee replacement after malunion of a proximal tibial fracture

[55]. Patients with defects and deformities in both the femur and tibia are at risk of achieving less comparative postoperative knee function to their preoperative knee state, although pain is likely to improve [56]. Large database studies found that the odds of revision total knee replacement were 66% higher in patients with a diagnosis of posttraumatic arthritis [53], and the risk of deep surgical site infection was at least two to three times higher in these patients [5, 26]. The prevalence of deep infection is approximately 4% after knee replacement for posttraumatic arthritis [5].

In a large, single institutional study, 11% of posttraumatic knee arthritis patients treated with arthroplasty required revision surgery at a mean of 4 years, and 20% required additional procedures [37]. The most common reason for revision was deep infection, and manipulation under anesthesia was the commonest additional procedure. At 20 years, the revision-free survival was 67%, procedure-free survival was 55%, and complication-free survival was only 23%. There was no difference in the revision-free survivorship of knee replacements performed after proximal tibia fractures versus those performed after distal femur fractures, but patients with prior distal femur fractures appear to be at increased risk of postoperative complications compared to patient with prior proximal tibia fractures [37]. Younger patient age also increases the risk of postoperative complications, revision, and need for additional procedures [37]. Patients requiring staged or simultaneous osteotomies may be at increased risk for complications, as well [46].

Older series have demonstrated that the prevalence of revision surgery after conversions for tibial plateau fractures range from 8 to 20%, and the prevalence of complications is 24–48%, with good clinical outcomes reported in approximately 75% of patients [18]. Contemporary series evaluating total knee replacement after tibial plateau fracture have reported that up to 86% of patients have good to excellent outcomes [57], a 13–34% prevalence of postoperative complications [23, 57, 58], 90% survivorship at 7 years [57], and approximately 82% survivorship between 10 and 15 years [23, 58]. Lateral unicondylar knee arthroplasty has been performed infrequently for posttraumatic arthritis isolated to the lateral compartment with valgus

deformity less than 15° and intact ligaments [59]. Complications in these patients are reportedly low, and survivorship at 10 and 15 years are 100% and 80%, respectively [59]. Thus, unicondylar knee arthroplasty might be a consideration for younger patients with posttraumatic lateral compartment arthritis. The frequencies of revision surgery, complications, and good outcomes after conversion arthroplasty following distal femoral fracture fixation are 8%, 15%, and 52%, respectively [41]. The 15-year revision-free survival in patients receiving total knee replacement after patella fracture is 86% and has been found to be similar to patients without prior fracture, although functional outcomes are inferior and manipulation under anesthesia is more commonly required [15].

Arthroplasty in the setting of acute, comminuted, intra-articular fracture may be an attractive option, particularly for elderly patients with preexisting arthritis, and those for whom postoperative compliance with weightbearing restrictions will be difficult. Only a few heterogeneous case series have reported results of total knee arthroplasty performed for acute fracture [18, 51, 60–65]. In general, these studies show good functional outcomes, early weightbearing, and low incidence of revision surgery. However, the frequency of complications ranges from 8% to 42% [18]. Twenty-year survivorship of primary hinged implants for acute fracture can exceed 94% [18]. However, the risk for deep infection may be over six times higher in these patients compared to other primary total knee replacement patients [26], and the presence of a preexisting ipsilateral hip implant is associated with an increased risk of future periprosthetic femur fracture when acute distal femoral fractures are treated with arthroplasty [64]. Furthermore, as with fractures of the proximal femur, 1-year mortality is high following arthroplasty for acute periarticular knee fractures in the elderly, with rates reported up to 40% [64].

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Management of the Stiff Total Knee Arthroplasty

24

Van P. Stamos, Kevin S. Borchard, and James V. Bono

The ultimate goal of total knee arthroplasty is to achieve a stable, painless knee with an excellent range of motion allowing for maximum function. A normal knee should have a range of motion from 0° to approximately 140°, although functional demands for most activities of daily living such as walking, sitting, driving, and climbing stairs can be easily accomplished with motion from 10° to 95°. The uncomplicated total knee arthroplasty usually results in a range of motion of 0–5° to 115–120°, which, although not as full as a normal knee, allows greater motion than is needed for basic function [1, 2]. Recalling this basic information is critical when evaluating a knee with a limited range of motion.

Stiffness following total knee arthroplasty can be extremely disappointing to both patient and surgeon. It can also be one of the most difficult complications to remedy. When faced with a stiff knee, the surgeon must remember that the best predictors of postoperative motion are preoperative motion and the passive motion achieved at surgery with the patella reduced and the joint capsule closed [2–7]. This fact is particularly important when evaluating a patient who has been operated by another surgeon; if only 60° of flexion was achieved at surgery and the patient has 60° 2 weeks postoperatively, he is doing quite well. However, if 125° of flexion was achieved at surgery and 2 weeks later the patient has only 60° of flexion, he is doing quite poorly. The treating surgeon must consider the passive range of motion at the time of surgery when assessing the stiff knee; one should not be influenced by arbitrarily defined numbers.

Knee stiffness can be the result of myriad causes, with some being more easily remedied than others. It is imperative that the surgeon fully evaluates the stiff knee and properly identifies the cause so that appropriate treatment can be administered. Differentiating the stiff painful knee from the stiff painless knee can be particularly helpful.

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Causes

Infection

Infection following total knee arthroplasty may present in many ways. Fortunately, it is the rare patient who presents with systemic signs of sepsis such as fever, chills, and/or shock. Far more common is the patient who is slow to progress following total knee arthroplasty despite aggressive physical therapy and other modalities. Flexion goals are not met, and the knee is insidiously painful and stiff. Constitutional symptoms as well as local wound problems are often absent, leaving pain and stiffness as the only signs of infection. It is therefore imperative that sepsis be excluded when presented with the stiff knee. The evaluation and treatment of infected total knee arthroplasties is fully discussed in Chap. 5.

Associated Conditions

Knee stiffness may not be directly attributable to the knee itself. Disorders of the hip and spine may present as pain in the knee. Evaluation of both areas should be performed when assessing the stiff knee to exclude hip or spine pathology [8]. A flexion contracture of the hip may contribute to a flexion contracture of the knee. Ideally, hip abnormalities should be corrected before addressing disorders of the knee.

A wide array of nerve or muscular disorders must also be considered when evaluating the stiff knee. Diseases of the central nervous system that result in spasticity markedly affect motion and impede physical therapy. As revision surgery is rarely helpful in this patient group, they must be identified to prevent the surgeon from proceeding with surgery that will almost certainly not achieve its intended goals.

Complex Regional Pain Syndrome

Complex regional pain syndrome (CRPS) is a particularly troublesome disorder that results in knee pain and stiffness. It is often difficult to diagnose and may be extremely difficult to treat. Any additional insult such as trauma or surgery to a limb exhibiting this condition usually aggravates symptoms. Therefore, it is critical that the surgeon identifies this disorder before any surgical intervention.

Because CRPS is commonly described as a disorder of the upper extremity, lower extremity involvement is often overlooked. The incidence following total knee arthroplasty has been reported as 0.8% [9], so the surgeon must have a high index of suspicion to make the appropriate diagnosis. Diagnostic tests are seldom useful; the diagnosis is made on clinical grounds. Pain out of proportion to objective findings on physical examination is the classic sign, but the patient usually also exhibits delayed functional recovery, vasomotor disturbances, and trophic changes [9–11]. Physical examination may reveal skin hypersensitivity, decreased temperature, edema, and hyperhidrosis. In late stages, atrophy of the skin may be present. Limitation of motion affects flexion more commonly than extension, and the patellofemoral joint is often quite sensitive.

Treatment should be instituted immediately once the diagnosis is made. If symptoms have been present for less than 6 weeks, nonsteroidal anti-inflammatory medication and physical therapy for range of motion and desensitization are the mainstays of treatment [10]. The patient should be encouraged to bear weight and use the limb as much as possible. Patients with clinical symptoms dominated by sympathetically mediated pain may improve with a lumbar sympathetic block [12]. Blockade of the sympathetic nervous system to the lower extremities is both therapeutic and diagnostic, and it should alleviate symptoms, at least initially. Critical to success is the institution of aggressive physical therapy immediately following blockade. Some authors have reported success rates of as high as 80% with this regimen [13].

The key factors for a positive outcome are early recognition, aggressive treatment, and the avoidance of additional surgery or trauma to the extremity [10]. In addition, multidisciplinary teams, which include pain specialists, rheumatologists, physical and occupational therapists,

and psychologists experienced in managing this condition, should be involved with these patients [12].

Heterotopic Ossification

Occasionally, heterotopic ossification can be identified following total knee arthroplasty (Fig. 24.1). Most commonly it is seen in the quadriceps muscle or anterior supracondylar region of the femur, but other locations have also been reported. Historically, its incidence following knee arthroplasty was considered low [14]. It was also considered a rare cause of knee stiffness. Two separate case reports describe patients who developed severe myositis ossificans following knee replacement with porous ingrowth prostheses [15, 16]. In one, the diagnosis of hypertrophic osteoarthritis was thought to be a predisposing factor when combined with extensive surgical exposure of the distal femur at the time of surgery and postoperative manipulation of the knee. In addition, the authors noted difficulty managing the dosage of Coumadin in the postoperative period in this patient.

However, a more recent retrospective review of 98 primary knee arthroplasties in 70 patients demonstrated an incidence of heterotopic ossification of 26% [17]. The authors identified significantly elevated lumbar spine mineral bone density in those patients who developed heterotopic ossification as compared with a matched control group of patients who did not develop ectopic bone. Based on these findings, they identified increased lumbar spine bone mineral density as an indicator of patients at risk for the development of postoperative heterotopic ossification.

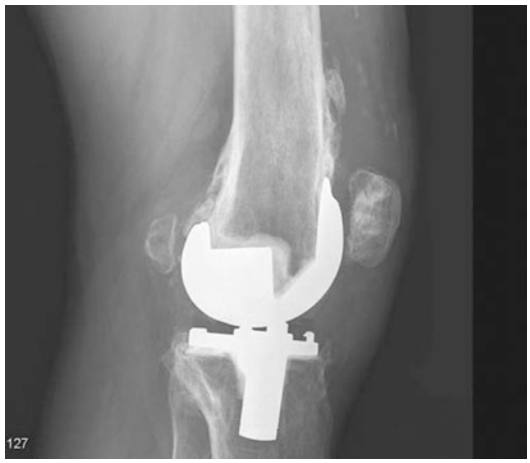

Fig. 24.1. Heterotopic ossification is seen in the extensor mechanism and can limit flexion of the knee. Limited surgical dissection in the suprapatellar pouch may potentially avoid this complication

Treatment consists of excision of ectopic bone followed by prevention of recurrence with either radiotherapy or pharmacologic means. The response to this treatment is not entirely predictable so it should be reserved for cases in which there is severe limitation of motion and extensive heterotopic ossification.

Arthrofibrosis

Arthrofibrosis is probably the most common cause of knee stiffness in patients with mechanically sound reconstructions [4, 18]. These patients develop adhesions or dense scar within the joint or extensor mechanism that either act to tether or mechanically impede full joint motion. Fibrous nodules may also form on the undersurface of the quadriceps tendon leading to patellar clunk syndrome, particularly in posterior-stabilized designs. Although this syndrome responds well to arthroscopic resection of the fibrous nodules, it is not commonly associated with diminished range of motion [19]. Attempts to identify predisposing factors for the development of arthrofibrosis have been largely unsuccessful. Thus, preventive measures are limited. A prolonged period of immobilization is certainly a causative factor. Currently, most joint surgeons implement aggressive rehabilitation in the postoperative period in an attempt to decrease the incidence of this complication. At many institutions, this often includes the use of continuous passive motion, the efficacy of which is uncertain. Several studies have concluded that continuous passive motion has no effect on range of motion when measured at 3 months and 1 year [5, 7, 20]. These studies do, however, demonstrate

significantly greater flexion in the early postoperative period for patients who were treated with continuous passive motion.

Posterior Cruciate Ligament Tightness

In patients with stiffness following implantation of posterior cruciate retaining devices, several authors have suggested tightness or contracture of the posterior cruciate ligament as the etiology [17, 21, 22]. Significant improvement in range of motion following open or arthroscopic release of the posterior cruciate ligament was achieved in the majority of these patients.

Technical Considerations

The etiology of stiffness following knee arthroplasty is often technique related, which often can be elucidated on radiography or by physical examination. These patients can be distinguished from patients with arthrofibrosis by comparing their postoperative motion with that achieved at surgery. Limitation of motion, if technique related, will be present at the time of surgery. Prior to attributing these imperfections to surgical error, one must consider a few points. While it should be the goal of every surgeon to implant prosthetic components in anatomic position and perfect alignment to allow full range of motion, this is not achievable in all cases due to variations in anatomy and technical limitations available. Because there are limits to the sizes and configurations of implants used and the variations in anatomy are infinite, compromises are often necessary after considering the alternatives.

Five broad categories of technical imperfections can lead to knee stiffness. These are retained bone or osteophytes of the posterior femoral condyles, malalignment, imbalance of the extension gap and flexion gap, improperly sized components, and improper reconstruction of the patellofemoral joint.

At the time of primary knee arthroplasty, bone or osteophytes along the posterior femoral condyles and femur should be removed, if possible. This is best accomplished in the following fashion: With a trial femoral component in position, a curved osteotome is used to resect any excess posterior bone. The trial component is used as a template so the surgeon can precisely remove the correct amount of bone and often includes the removal of a small portion of normal posterior femoral condyle. If resection of posterior bone is incomplete, the remaining bone can impinge on the posterior edge of the tibial component or tibia, resulting in a mechanical impediment to full flexion. Residual posterior bone can be identified on a lateral radiograph and should be looked for when a patient presents with a stiff knee (Fig. 24.2).

Restoration of proper mechanical alignment is critical to ensure both proper function and longevity of a knee implant [23]. This includes alignment in sagittal, coronal, and rotational planes. Significant malalignment in any of these planes can result in decreased range of motion. Standing 3 foot anteroposterior and lateral radiographs are most helpful in assessing alignment and should be obtained for any patient in whom revision surgery is being considered. In the coronal plane, it is not uncommon to see errors of up to 3° on either the femoral or tibial component [1]. It would be highly unusual for this amount of malalignment to result in motion limitation [1, 23]. However, when measurements exceed 5°, the likelihood of resultant loss of motion increases dramatically. In the sagittal plane, excessive flexion or extension of the femoral component can lead to limitation of motion, but the degree of error must be quite large and is rarely seen as the cause. This is not the case with the tibial component, in which a relatively small degree of malalignment in this plane can significantly affect motion. The slope of the tibial prosthesis relative to the long axis of the tibia should be carefully evaluated. Excessive posterior slope may result in lack of full extension and instability in flexion. Anterior slope (i.e., hyperextension of the tibial component) is likely to lead to recurvatum deformity and lack of full flexion. Of course, the amount of posterior slope designed into the particular component implanted must be taken

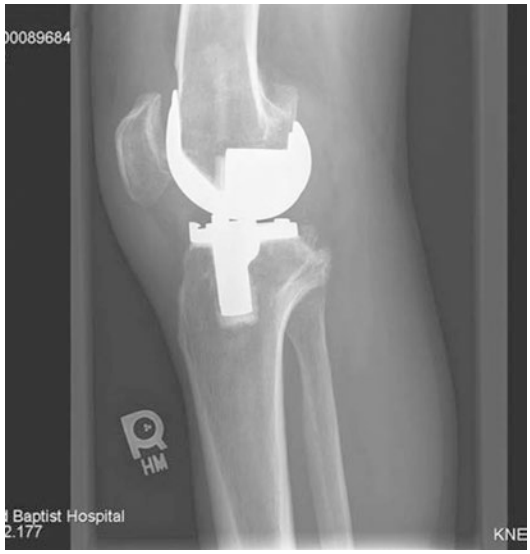

Fig. 24.2. Incomplete resection of posterior osteophyte. The remaining bone can impinge on the posterior edge of the tibia, resulting in a mechanical impediment to full flexion, and can tent the posterior capsule resulting in incomplete extension

into account when evaluating the radiograph. When possible, comparison of the patient's preoperative anatomic tibial slope to that achieved postoperatively can be enlightening.

Improper balance of the extension and flexion gaps can clearly lead to stiffness following knee arthroplasty. This includes both asymmetry of the individual gap and mismatch between gaps. If the extension gap is tight relative to an appropriate flexion gap, lack of full extension is the result. Conversely, if the flexion gap is tight relative to an appropriate extension gap, limited flexion is observed.

Incorrect sizing of the implant affects knee motion. For both the femoral and tibial components, appropriate anteroposterior dimension is most important for restoration of knee mechanics. Oversizing of the femoral component results in tightening of the collateral ligaments in flexion. The resultant flexion/extension gap mismatch leads to incomplete flexion. Undersizing of the tibial tray, when combined with excessive anterior placement on the tibia, also affects motion. In this situation, the uncovered posterior cortex of the tibia leads to a mechanical block from contact between the posterior femur and tibia as the knee is flexed. Finally, oversizing of the composite thickness of the tibial component and liner results in a knee that is globally too tight, limiting both flexion and extension.

Complications associated with reconstruction of the patellofemoral joint can result in decreased flexion [18, 24]. Maltracking or tilting of the patella can have an effect on motion by both mechanical and pain-mediated pathways. Patients with these findings often demonstrate an unwillingness to fully flex their knees. If the reconstructed patella is too thick, increased forces across the patellofemoral joint may impede flexion.

Excessive internal of the femoral and tibial components has also been associated with postoperative stiffness, either individually or summed [25]. Internal rotation of either component may contribute to patellar maltracking giving patients the sense that the patella is going to subluxate or dislocate with deep flexion. Patients will avoid deeper flexion to prevent this sensation. In addition, internal rotation of the components contributes to alterations in the flexion gap. Whereas, internal rotation of the femur may cause an excessively tight medial flexion gap, tibial internal rotation can limit the amount of femoral rollback possible. Both mechanisms may limit flexion.

Elevation of the joint line, which can occur with over-resection of the distal femur, underresection of the tibia or excessive soft tissue release, can also contribute to loss of flexion [26, 27]. This condition, often termed "pseudopatellar baja," can also contribute to extensor lag, impingement of the patella against the tibial polyethylene or tibial plate, anterior knee pain, increased energy expenditure, and rupture of the patellar or quadriceps tendons [28].

Identification of technical imperfections when presented with the stiff knee is relatively straightforward. The difficulty lies in whether those findings are the actual cause of stiffness. The surgeon must remember that technical imperfections can be identified in many well-functioning total knee replacements.

Metal Hypersensitivity

Delayed hypersensitivity reactions after total knee arthroplasty are rare and poorly understood. However, these patients may present with knees that are painful and stiff. Current literature on metal hypersensitivity causing stiffness is limited to small case series and case reports so the incidence is unclear. In these reports, patients underwent extensive preoperative workups, which ruled out infection. Intraoperative histopathology revealed a thickened synovium and adhesions with either a predominantly lymphocytic or histiocytic monocellular response, consistent with a type IV allergic reaction. Symptoms resolved in each of these reports after revision to ceramic or zirconium femoral components and titanium tibial components [29–31].

Miscellaneous

Anecdotal cases of loose bodies within the joint have been described. In one case report, an intra-articular fragment of methyl methacrylate was identified [32]. Knee motion was restored after arthrotomy and removal of the offending loose body. Fracture of the polyethylene should also be considered when determining the cause of knee stiffness.

Treatment

General

Treatment should be directed at the causative factor. The previous section addressed the treatment of infection, reflex sympathetic dystrophy, and heterotopic ossification. The remainder of this section discusses treatments for stiffness related to arthrofibrosis, posterior cruciate ligament tightness, metal hypersensitivity, or technical errors. Included are some associated with significant complications of which the surgeon and patient must be aware before embarking on these courses of action. Manipulation and arthroscopy are directed toward the treatment of arthrofibrosis. These modalities should be reserved for patients who originally had adequate motion but have lost it over time. The patient who never had adequate motion is unlikely to benefit from arthroscopy or manipulation.

Manipulation Under Anesthesia

Although its use and effectiveness were once controversial, manipulation under anesthesia of the stiff total knee arthroplasty has been shown to be a useful treatment. Patients who fail to attain intraoperative range of motion during postoperative rehabilitation may benefit from the disruption of adhesions that occurs during manipulation. The most effective time to perform a manipulation is within 12 weeks of surgery, so patients need to be identified and treated early if one is to be successful. A recent review found that no difference was seen in final range of motion for patients that underwent MUA at less than 6 weeks or between 6 weeks and 3 months [33]. However, patients who underwent manipulation at greater than 3 months and demonstrated significantly lower range of motion compared with patients manipulated before 3 months [14].

Earlier studies noted that, despite early gain in range of motion, patients would eventually worsen, and manipulation did not affect ultimate range of motion after knee arthroplasty [3, 14, 18]. More recent studies have shown that the early gains seen in range motion appear to be maintained at up to 5 and 10 year follow-up [34, 35]. Complications following manipulation are rare with the incidence of periprosthetic fractures and fatal pulmonary embolism in a recent review at 0.2% and 0.1%, respectively [33]. Considering the low risks and good long-term outcomes that are possible, a successful manipulation can have for the patient, therapist, and surgeon.

In order to be effective, manipulation, like any procedure, needs to be performed correctly. General or regional anesthesia is mandatory to provide adequate muscle relaxation and control of pain, thereby decreasing the risk of fracture or extensor mechanism rupture. Once the patient is under anesthesia, passive range of motion should

be measured with the patient supine. Extension is assessed by supporting the heel with the hip slightly flexed. The amount of extension is recorded. Flexion is measured by supporting the lower extremity from the thigh with the hip flexed to 90°. The knee is allowed to bend passively to maximum flexion with gravity. Once the arc of motion has been determined, manipulation is performed. With the patient's leg supported by both hands around the calf and the ankle in the surgeon's axilla, a gentle steady flexion force is applied. As the adhesions are torn, the surgeon will feel a sensation of crepitus, and flexion of the knee will gradually increase. Alternatively, the leg may be allowed to freely fall from full extension into flexion. This maneuver is repeated several times; the weight of the limb itself is used to disrupt adhesions. With the knee in extension, an attempt at mobilization of the patella should be performed by applying inferior and medially directed forces, which assist in lysis of adhesions in the suprapatellar pouch. These maneuvers should be repeated until the motion attained at surgery is reproduced or no further progress is made. Postmanipulation motion is then measured in the fashion described previously. Continuous passive motion should be instituted immediately and set to the maximum extension and flexion achieved with manipulation. Following the procedure, adequate analgesia must be given so the patient does not experience pain and resist the motion that has been achieved. An epidural catheter maintained for 24–48 h following the manipulation is often beneficial. An aggressive physical therapy program is then instituted to avoid losing the motion gained with manipulation.

Arthroscopy

Arthroscopic treatment of disorders of the knee is the most common procedure in orthopaedic practice. Its use in the treatment of problematic knee arthroplasty, however, has historically been relatively uncommon [36, 37]. As experience with this technique has increased, its utility and safety have grown [38]. When contemplating the use of arthroscopy for the stiff knee, the indications and prerequisites are similar to those for manipulation; that is, the motion of the knee is less than that attained at surgery, rehabilitation is slow to progress, and the etiology is thought to be arthrofibrosis or tightness of the posterior cruciate ligament. Arthroscopy can be attempted for the patient who has failed non-operative management, including manipulation. Earlier studies showed limited success in significantly improving range of motion after total knee arthroplasty [38–41]. However, a more recent review demonstrated improvements similar to manipulation, with increases in range of motion from 18° to 60°. Unlike manipulation, the improvement in range of motion following arthroscopy can be seen even after 1 year following surgery [42]. In addition, arthroscopy allows direct visualization and removal of adhesions. This allows the surgeon to resect scar tissue that correlates with the patient's motion restrictions. Removing scar tissue in the suprapatellar pouch, anterior interval/pretibial recess, and intercondylar notch or releasing a tight PCL can improve flexion. Releasing a tight posterior capsule or posterior adhesions and removing posterior osteophytes can improve knee extension [43]. Fibrous bands of secondary scar isolated to the patellofemoral joint can result in tethered patella syndrome or patella clunk syndrome. These patients have a reproducible pattern of symptoms characterized by painful patellar grinding and crunching when actively extending the knee and some limitation of motion. There is a consistent pattern of fibrous band formation with the most common occurring at the superior border of the patellar component. Arthroscopic removal of these adhesions and fibrous tissue has been shown to give excellent results [44–46].

In patients with cruciate-retaining designs, arthroscopic release of the posterior cruciate ligament has been shown to increase range of motion and result in increased patient satisfaction [21].

One might also reasonably consider the use of the arthroscope for the removal of a foreign body that is impeding motion. Although no series have been reported, one would expect a positive outcome if used to treat the case described earlier of an intra-articular fragment of methyl methacrylate limiting joint motion.

Revision Surgery

Ultimately, the surgeon must address the stiff knee that is the result of technical imperfections or rarely, metal hypersensitivity. Attempts to improve motion in these patients require revision knee arthroplasty and the potential complications associated with such an undertaking. Therefore, before embarking on such a potentially hazardous course, the potential benefit must be clearly demonstrated. This benefit should be determined in the context of the functional range of knee motion described in the introductory section of this chapter and the true functional requirements of the patient. When contemplating revision surgery for knee stiffness, the surgeon and patient must have reasonable expectations and goals. The surgeon must have experience in revision surgery and have a clear surgical plan. The patient must understand that the ultimate outcome with revision surgery may not be improved and may in fact be worsened. Both must be prepared for complete revision of all components. As the saying goes: "Hope for the best, prepare for the worst."

Techniques used for revision of total knee replacements are described in detail in Chap. 6. What follows is merely an overview of revision surgery as it pertains to treatment of the stiff knee.

Revision of the stiff knee arthroplasty requires attention to detail that begins with the skin incision and surgical approach. Previous incisions should be used whenever possible. Because the skin is often contracted and tenuous in this group of patients, excision of hypertrophic scar is strongly discouraged as it may not allow a tension-free closure at the completion of the procedure. In addition, closure may require rotational flaps or grafts, so the surgeon must be prepared by using appropriate incisions and handling all tissues carefully. Nearly all cases require an extensile approach to avoid the disastrous complication of avulsion of the patellar tendon. Favored approaches include the quadriceps snip, V-Y quadriceps turndown, and tibial tubercle osteotomy, all of which are thoroughly described in Chap. 6.

Next, the suprapatellar pouch and medial and lateral gutters are examined. All scar and fibrous tissue in these areas is excised, and the undersurface of the quadriceps tendon is debrided. The knee is then flexed, and the components are examined for evidence of loosening or abnormal polyethylene wear. Patellar tracking and function of the extensor mechanism are assessed. If the patella has been resurfaced, the composite thickness should be measured with a caliper. Measurements greater than 26 mm in men and 24 mm in women may indicate inadequate resection at time of patellar reconstruction [24]. As described earlier in this chapter, the resultant overly thick patella can be a cause of limited flexion. Range of motion is then assessed once thorough debridement of scar and mobilization of the extensor mechanism are complete. Occasionally, adequate motion will have been restored. More commonly, however, further evaluation is required.

Overall static alignment and symmetry of the extension and flexion gaps are then assessed. If abnormalities are observed, one must determine if correction can be achieved with exchange of the polyethylene and soft tissue releases. Custom designed angled bearing inserts have been described for use in these situations [47]. If present, the modular tibial insert is then removed, and attention is directed posteriorly. Dense scar and residual bone along the posterior femur are excised. Adequacy of removal is assessed by finger palpation. Subsequently, range of motion is checked after replacement of the tibial insert. If it is considered inadequate, revision of the femoral and/or tibial components is performed if a technical imperfection has been identified.

Flexion of the knee is evaluated both with the patella everted and with the patella reduced. Diminished flexion with the patella reduced compared with the patella everted indicates extrinsic tightness of the extensor mechanism due to scarring and fibrosis. In this setting, lengthening of the quadriceps mechanism may be accomplished by creating several relaxing incisions in the tendon with a No. 11 knife blade.

Prior to closure, patellar tracking is reevaluated carefully. Lateral release and/or revision of

the patellar component to decrease its thickness may be required. The surgical wound is then closed using meticulous surgical technique and cautious handling of the tissues.

Conclusion

The knee that is stiff following total knee arthroplasty presents a difficult problem to the surgeon [48–51]. Prior to embarking on a treatment regimen that may include revision surgery, which is fraught with complications, one must be certain the benefits to the individual patient outweigh the risks. Knee motion from 10° to 95° may be perfectly adequate for some and unacceptable for others. Similarly, the cause of limitation of knee motion and corrective treatment with acceptable risk must be identified. Revision surgery should be pursued only after these factors are considered.

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Aseptic Synovitis

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Knee joint effusions commonly occur immediately after total knee arthroplasty (TKA), gradually disappear within 6 months, and generally pose no significant risk to the longevity of the total knee arthroplasty. Joint effusions are likely the direct result of perioperative changes, with surgical disruption in blood flow and lymphatic return as well as repeated tissue inflammation from postoperative physical therapy sessions. However, joint effusions that initiate after a period of joint quiescence or do not resolve after TKA are much more concerning and require a thorough workup and accurate diagnosis. Although there are many potential causes for knee synovitis, a periprosthetic infection must be ruled out due to the severe consequences that can result from a delayed or missed diagnosis of a periprosthetic joint infection. In addition, although less acutely alarming, aseptic causes of synovitis may also indicate joint pathology requiring revision surgery.

Indications for revision total knee arthroplasty have shifted over the last decade due to improvements in implant technology and surgical technique. With the advent of new machination, sterilization, and storage practices for polyethylene inserts, the rate of revision due to polyethylene wear has decreased [1–5]. Similarly, an increased understanding of knee arthroplasty biomechanics and alignment, including rotational correction to improve patellar tracking and tibial coronal and sagittal plane balancing to yield a neutral joint line, has led to a decrease in the revision rate due to component malalignment [1, 2, 5]. As seen in two recent studies, the most common causes of revision TKA are now aseptic loosening, periprosthetic joint infection, and joint instability [1, 2]. Polyethylene wear, joint malalignment, and arthrofibrosis are much less frequent causes for TKA revision but still represent a considerable percentage of the overall TKA revision rate [1, 2]. Importantly, many of these failure mechanisms can cause knee effusions but are not categorized as true aseptic synovitis in the setting of a TKA. Differentiating between the multiple pathologies is important because treatment options may vary significantly, from conservative pain control to joint explantation and revision TKA. The goal of this chapter is to identify and describe several unique sources of

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aseptic synovitis and highlight diagnostic and treatment principles.

Low-Grade Infection

Periprosthetic joint infection must be included in any differential when a patient has new-onset or unresolved synovitis or knee pain due to potential joint pathology. Recently, an international consensus has been obtained about the definition and diagnosis of periprosthetic joint infection, but the authors directly mention that in certain low-grade infections, several of the criteria may not be met despite a true periprosthetic joint infection present [6]. Atypical organisms, such as *Actinomyces*, *Propionibacterium*, and *Candida*, have all been cultured after total knee arthroplasty and may not present with the same symptoms as seen with a typical periprosthetic joint infection [7–9]. As such, every effort must be made to rule out periprosthetic joint infection as a cause of synovitis before looking to an alternate aseptic synovitis etiology.

Clinically, patients with a low-grade infection may not have classic symptoms of fever, severe pain, and joint erythema but instead may have only moderate pain and knee stiffness [10]. Radiographs may not show any pathological changes aside from osteolysis in cases of long-standing chronic infections. Traditional infection and inflammatory markers, such as erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP), may only be slightly elevated and have a low sensitivity [10]. Alternate markers, such as interleukin-6 and alpha-defensin, may provide a higher accuracy in diagnosis of periprosthetic joint infections [11, 12]. The results of joint aspiration may be confounded by a low bacterial load and should be repeated several times as warranted if clinical suspicion is high [10]. Molecular testing, such as with polymerase chain reaction (PCR) studies, may be helpful when bacterial counts are low and can detect non-culturable organisms [10].

Treatment options for low-grade periprosthetic joint infections include irrigation and debridement with modular implant exchange as well as single- and double-stage reimplantation. Because these indolent infections may be hard to detect and thus have a higher likelihood of being chronic, irrigation, and debridement may not be sufficient [10]. Single-stage reimplantation potentially lowers operative cost and patient morbidity but may result in a higher reinfection rate; as such, two-stage reimplantation remains the current standard for treatment of these infections especially in cases with negative preoperative cultures [10].

Polyethylene Wear

Polyethylene wear in total knee arthroplasty is the result of patient, implant, and surgical factors that may lead to a painless or painful aseptic effusion [13]. If the wear rate is excessive, osteolysis, implant loosening, and aseptic failure may occur leading to TKA failure and necessitating a revision procedure. Although the prevalence of polyethylene wear has decreased as a cause for revision total knee arthroplasty, it still is a problem that requires close evaluation and serial follow-up to ensure the integrity of the knee arthroplasty.

Osteolysis is a macrophage-mediated inflammatory response to polythene debris after total joint arthroplasty. The release of inflammatory cytokines from synovial macrophages may yield an inflammatory reaction, effusion, and bone resorption. As a result of the rolling and sliding mechanism of the knee joint during motion, wear mechanisms such as delamination, pitting, and fatigue failure result in the shedding of relatively larger polyethylene debris particles [14–16]. In contrast, the relative constraint of total hip arthroplasty leads to adhesive and abrasive wear with smaller polyethylene debris particles [14–16]. A small polyethylene particulate size has been implicated in osteolysis, which may partially explain why this mechanism of failure is not as prevalent in total knee arthroplasty compared to total hip arthroplasty [16, 17]. However, backside wear from micromotion at the interface of the polyethylene insert and the tibial tray may lead to smaller debris and be a major cause of particulate wear osteolysis [13].

Patient age, gender, activity level, and body mass index have all been proposed as factors that can affect the rate of polyethylene wear [18–21]. However, the current literature is not conclusive about any single patient variable due to the difficulty in isolating the influence of each feature [13]. For instance, patients with a higher body mass index may have a lower activity level because of their weight thus lowering the wear rate. Similarly, younger arthroplasty patients may have a lower activity level due to limitations caused by their pathology, such as rheumatoid arthritis. These patient variables are difficult to modify but still must be accounted for as a cause of premature polyethylene wear.

Polyethylene design, sterilization, and storage can greatly influence the rate of wear. Polyethylene inserts are made by machining, where the insert is milled from a sheet or bar, or compression molding, where polyethylene powder is melted into a mold. Machining may cause a region of polyethylene chain stretching leading to oxidation and delamination of the insert subsurface, typically seen 1–2 mm below the articular surface [22, 23]. Inserts that are less than 6 mm thick may have higher contact stresses, and the recommended polyethylene thickness has been suggested at a minimum of 8 mm [24, 25]. The failure rate of inserts sterilized by gamma radiation in the presence of oxygen has been well described, with free radicals leading to oxidization and increased susceptibility to implant failure [26, 27]. Similarly, a prolonged shelf life prior to implantation may also result in increased *in vitro* oxidization and failure [28, 29].

Cross-linking of polyethylene by moderate- or high-dose gamma and electron beam irradiation promotes covalent bond formation and decreases wear rates, at the cost of increased polyethylene fatigue failure. This treatment method has been adopted in total hip arthroplasty with great success. However, highly cross-linked polyethylene has not been as widely adopted in total knee arthroplasty. Multiple *in vitro* studies have shown a decrease in wear when compared to conventional polyethylene [30–32]. In contrast, *in vivo* short- and mid-term TKA studies are conflicting about the benefits of cross-linking, with one study showing a benefit in reducing the revision rate and others showing no significant difference [33–36]. Although there may be a decrease in wear rates, particles shed from highly cross-linked polyethylene may be smaller and more biologically reactive [32]. Given the increased cost, potential for catastrophic failure, and lack of conclusive benefits, judicious use of cross-linked polyethylene is warranted in TKA.

Wear from the tibial insert can be generated at the articular surface or between the insert and the tibial tray. Articular surface wear is caused by normal and abnormal contact forces from the femoral component contact onto the tibial insert. Moderately or fully congruent (conforming) inserts, as seen with posterior-stabilized knees, maximize the femoral surface contact area and theoretically decrease focal contact stress but may increase stress at the component-bone interface. In addition, the tibial post in posterior-stabilized knees may provide an additional source of contact and wear [37]. Flat inserts, as seen with cruciate-retaining knees, distribute force over a smaller area and theoretically increase focal contact stress but may provide a more physiologic knee motion [13]. In practice, multiple studies have not shown a conclusive advantage for either design in regard to patient satisfaction and postoperative outcomes although one recent large international registry analysis suggested advantages for cruciate-retaining TKA [38–41].

Adoption of metal tibial trays allows modularity of the polyethylene insert. However, this can result in backside wear from micromotion at the locking mechanism interface between the polyethylene insert and the tibial tray. Backside wear can be a source of joint debris and can lead to increased rates of osteolysis [42, 43]. The effect of backside wear can be modulated by using polished trays and limiting the conformity at the articular surface [44–46]. Another potential solution to backside wear is with rotating platform mobile-bearing components, which allow for a smooth gliding surface and may reduce wear compared to fixed-bearing knees [45]. However, recent studies have shown that wear rates for mobile-bearing knees may be higher than

expected due to an increased surface area of articulation [47, 48].

Appropriate surgical alignment of the femoral and tibial components is an important factor in limiting excessive contact stress and reducing wear rates. Traditionally, a neutral postoperative coronal alignment (from 2.5° to 7.4° of valgus) has been considered crucial to limit the rate of failure [49, 50]. Recently, short- and mid-term studies showing kinematic alignment with patient-specific implants have shown promising results in regard to function and survivorship [51, 52]. Ensuring proper axial rotation of the femoral and tibial components is extremely important to ensure proper patellar tracking and limit the mechanical stress on the polyethylene patellar button [53, 54].

Significant polyethylene wear can be visualized on plain radiographs, with evidence of thinning or asymmetry of the inserts being one of the indicators (Fig. 25.1). Osteolysis can also be seen on radiographs as lucencies around or underneath the components (Fig. 25.2). Severe osteolysis may require a preoperative CT to determine the quantity and quality of the bone available for revision surgery planning. Infection should always be ruled out with the help of inflammatory markers and a knee joint aspiration when clinically indicated. An elevated mononuclear cell count in the face of a normal polymorphonuclear cell count may suggest aseptic polyethylene wear [55]. During surgery, bone graft, augments, sleeves, cones, and stems should be available to fill large defects and provide additional stability. A thinned polyethylene insert may be visible during revision for aseptic polyethylene wear (Fig. 25.3).

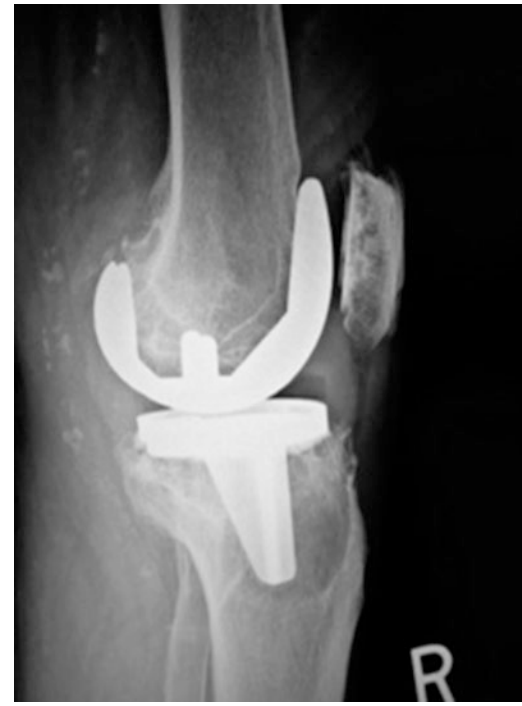

Fig. 25.1. Thinning of the polyethylene tibial insert is evident with visible joint space narrowing. Significant osteolysis is seen in the tibial, most prominently anteriorly and inferiorly to the tibial keel

Metallosis and Metal Hypersensitivity

Metallosis is the result of soft tissue, synovium, and bone infiltration by metal debris that is shed from the prosthesis. Typically, this is caused by mechanically induced abrasion between metal and polyethylene components [56]. The resulting inflammatory reaction can lead to recurrent knee pain and effusion and potentially cause severe osteolysis, implant loosening, and arthroplasty failure. There are multiple causes of metallosis, with the most common being with metal-backed polyethylene patellar components where high stress forces on the small surface lead to increased creep and particle formation [57, 58]. Other reported causes include abrasive two-body wear from modified implants as well as joint instability leading to continuous focal impingement [56, 59].

Diagnostic workup for metallosis includes an analysis of inflammatory markers to rule out an underlying infection. Joint aspiration should have negative cultures, with a low leukocyte count and PMN percentage, but may be black-tinged with visible metallic particles (Fig. 25.4) [60]. Radiographs may show several distinct findings from the deposition of the metal debris in the soft tissue (Figs. 25.5 and 25.6). The “bubble sign” is a distinct curvilinear radiodensity resulting from

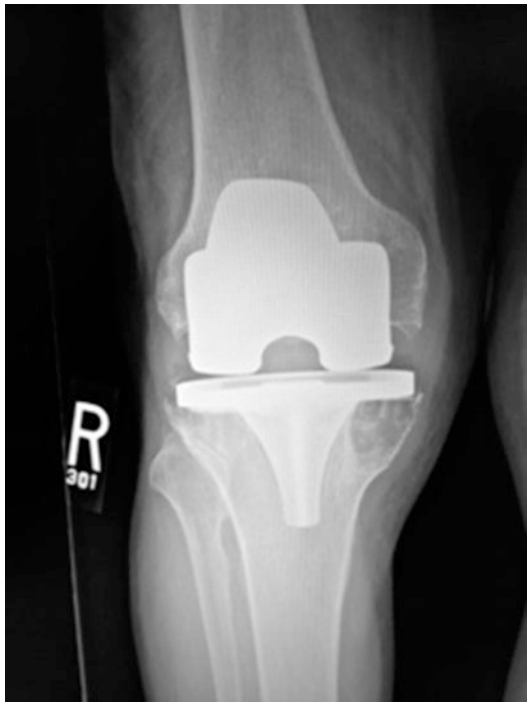

Fig. 25.2. Osteolysis is seen, at the femoral condyles and tibial plateau, with a large cavitary lesion under the medial tibial baseplate

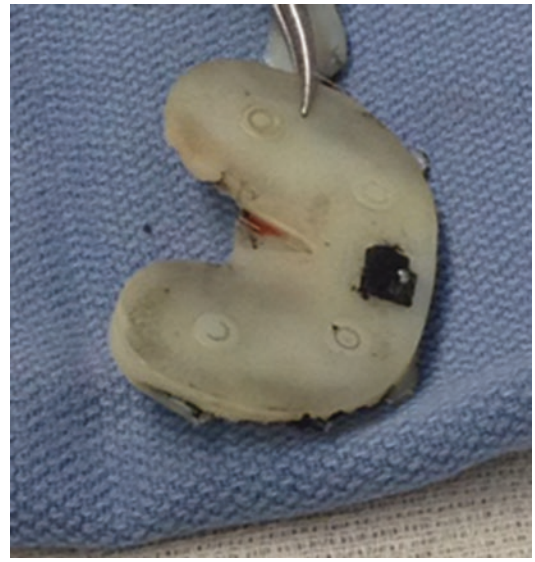

Fig. 25.3. Thinning of the polyethylene insert is seen with backside wear at the posterior locking mechanism

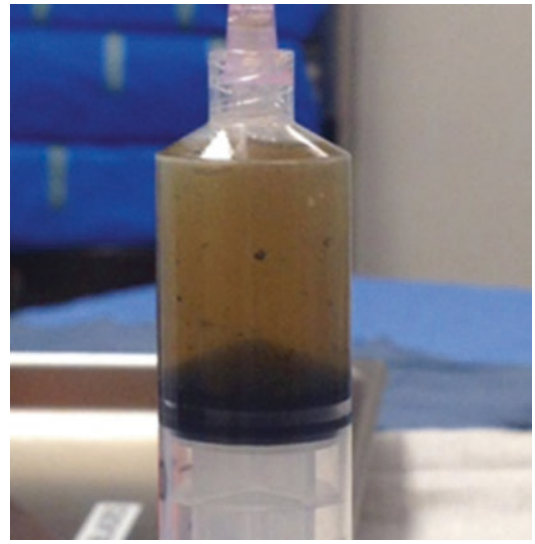

Fig. 25.4. Joint aspiration showing visible black particles of metallic debris. No purulence is seen in the synovial fluid

metal outlining the joint capsule. The "cloud sign" is more fluffy and amorphous and represents general metal deposition. The "metal-line sign" is a thin rim of linear increased density normally seen in the suprapatellar region [61]. During revision surgery, the joint synovium may have visible metal deposits (Fig. 25.7), and soft tissue histology may show infiltration by giant cells, histiocytes, and black metal particles (Fig. 25.8) [56, 60–62].

Like metallosis, metal hypersensitivity is the result of a physiologic reaction to metal debris from the prosthesis. However, it manifests as a type IV delayed hypersensitivity allergy with lymphocyte activation and cytokine release mediated by the immune system [63]. Metal hypersensitivity can lead to knee pain, effusion, stiffness, and more uniquely also to localized or diffuse dermatitis, eczema, and hair loss [64, 65]. The underlying cause of metal hypersensitivity has not been well established, and a history of cutaneous metal allergy is not strongly correlated with an increased rate of revision arthroplasty; however, some authors advocate preoperative testing for patients with a history of cutaneous metal allergy [63, 66, 67].

Metal hypersensitivity will result in negative infectious markers and an aseptic joint aspiration.

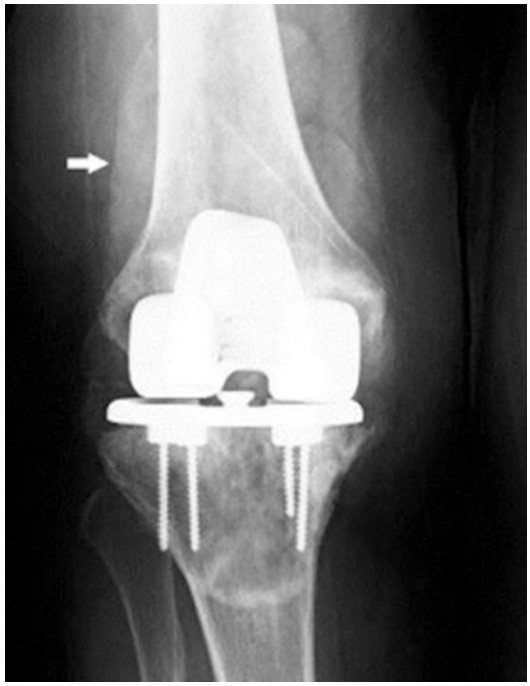

Fig. 25.5. Osteolysis, polyethylene wear, and metallic debris accumulation are seen. A "bubble sign" is visible at the superior joint capsule, indicated by the small *white arrow*

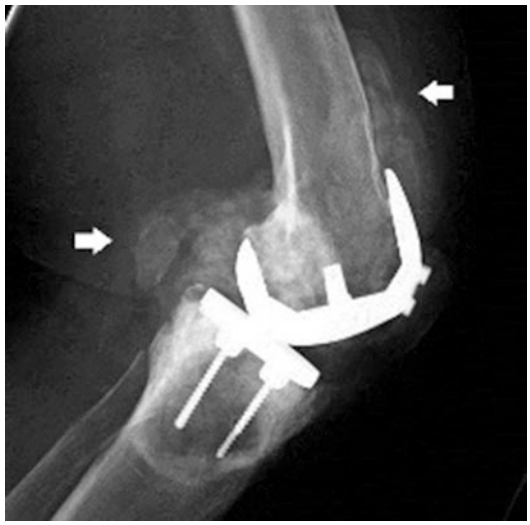

Fig. 25.6. A "cloud sign" is visible at the posterior knee joint and the suprapatellar region, indicated by the small *white arrows*

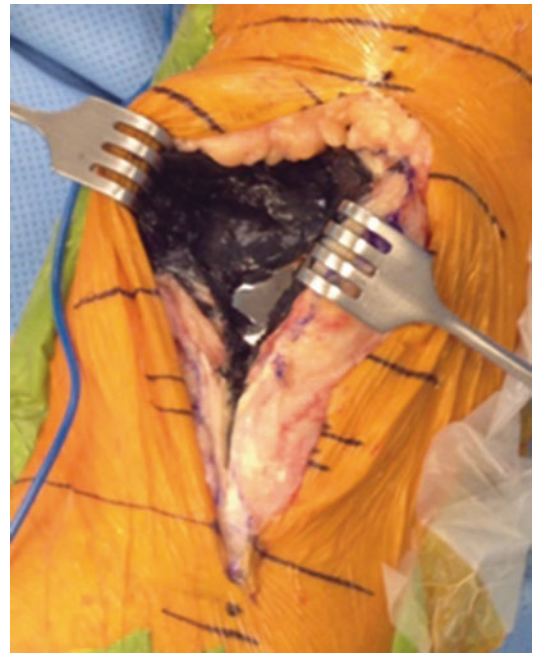

Fig. 25.7. Upon joint arthrotomy, a significant amount of metallic debris is seen overlying the synovium and implants

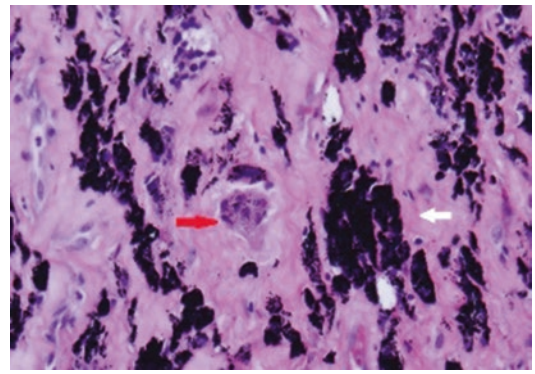

Fig. 25.8. Histological examination showing infiltration of metallic debris, indicated by the small *white arrow*, as well as a giant cell, indicated by the small *red arrow*, in the synovial tissue

Radiographs may not necessarily show any significant osseous or soft tissue changes, unless osteolysis is severe and thus visible on radiographic imaging (Figs. 25.9 and 25.10). The two most commonly used diagnostic tests for metal

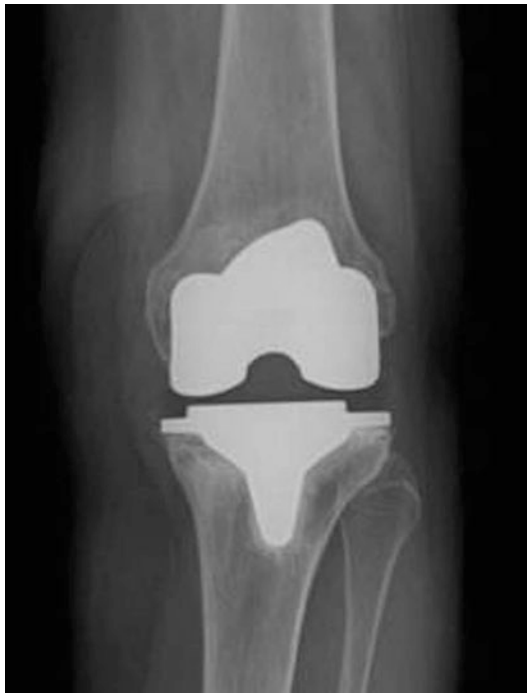

Fig. 25.9. Osteolysis is seen with subsidence of the medial tibial baseplate leading to a varus angulation

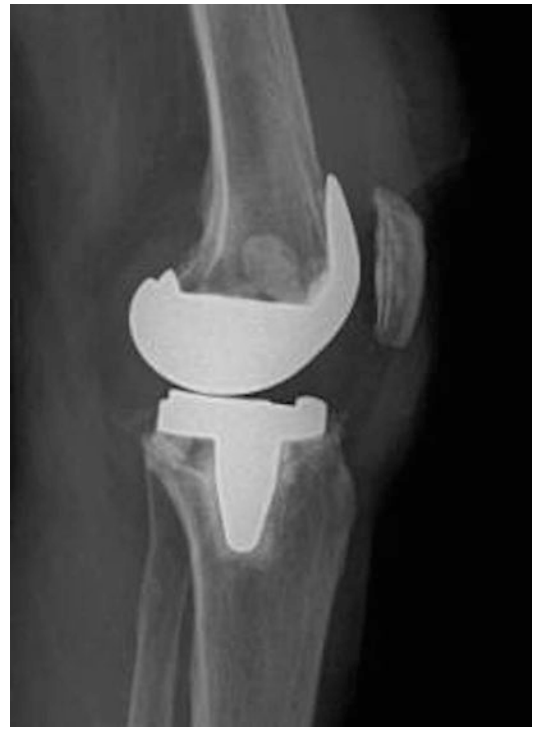

Fig. 25.10. Osteolysis is seen with subsidence of the anterior tibial baseplate leading to an anterior tibial slope

hypersensitivity are skin patch testing and lymphocyte transformation testing. However, both of these tests have shortcomings: skin patch testing is subjective and may not correlate to deep reactivity around artificial implants, while lymphocyte transformation testing is not readily available and may not correlate with patch test results [68]. Because there is not a definitive diagnostic test available, metal hypersensitivity is currently a diagnosis of exclusion.

In cases of severe metallosis or hypersensitivity, treatment may include revision total knee arthroplasty and complete synovectomy. During revision, one indication of hypersensitivity is significant synovial hypertrophy (Figs. 25.11 and 25.12). A thorough and extensive debridement should be performed, especially for metallosis, to remove any particles that could lead to abrasive third-body wear and continued synovitis. Revision components composed of oxidized zirconium, ceramic, or titanium that limit the amount of cobalt-chrome should preferentially be used, both to limit the rate of metal wear and to lower the amount of metal ion allergens [61, 64, 69]. Continued clinical follow-up for these patients is required to ensure that the revision TKA components do not deteriorate or cause an allergic response.

Crystalline Arthropathy

Gout attacks can occur after total knee arthroplasty and cause acute pain and effusion similar to that seen in a native knee. It is important to distinguish between gout arthropathy and infection, especially because gout can present with constitutional symptoms such as fevers, chills, and generalized malaise [70, 71]. Gout arthritis results from abnormal purine metabolism with increased uric acid production and monosodium urate crystal deposition in the synovium and soft tissue. This pathologic process can still occur after total knee arthroplasty and cause significant problems.

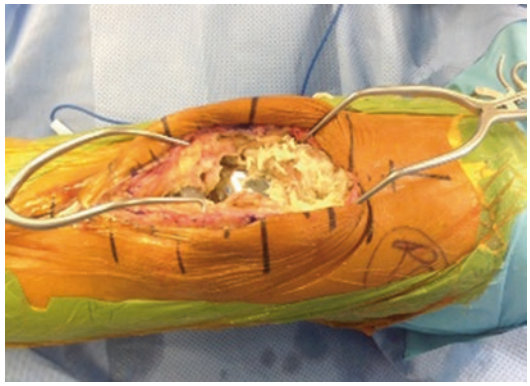

Fig. 25.11. Significant synovial reaction and hypertrophy are seen surrounding the implants

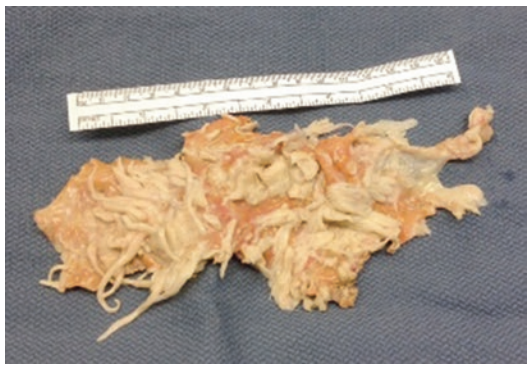

Fig. 25.12. En bloc excision of the synovium is recommended for visualization during revision surgery as well as decreasing the synovitis and removing any debris retained in the synovium

Diagnosis of gout involves analyzing multiple markers; however, not all are specific and sensitive to gout. For instance, CRP and ESR levels may be abnormally high and not be helpful in ruling out infection [70, 72]. Elevated serum uric acid levels only suggest, and do not confirm, a gout attack [72]. Joint aspiration may yield leukocyte counts from 2000 to 20,000, which is well within or higher than the range seen in periprosthetic joint infections [73, 74]. Fluid analysis under microscopy normally shows negatively birefringent urate crystals, and this likely is the most important criteria for the diagnosis of gout arthropathy [70, 71]. However, there are cases of gout attacks without crystals seen in the joint aspiration [74].

Pseudogout is another type of crystalline arthropathy resulting from calcium pyrophosphate dihydrate deposition that can manifest after total knee arthroplasty, both in the acute postoperative period and many years after a successful TKA [75–78]. As with gout, pseudogout may present with symptoms of fever, swelling, and joint pain similar to that seen with periprosthetic joint infections [78]. CRP and ESR levels may be elevated, and joint aspiration may yield an elevated white blood cell (WBC) count [75, 77, 78]. Fluid analysis normally shows positively birefringent calcium crystals which aid in the diagnosis [77, 78].

With both types of crystalline arthropathy, accurate diagnosis is essential, mainly to exclude periprosthetic joint infection as the source of the symptoms. Joint aspiration with fluid analysis showing crystals normally is diagnostic and can help limit the rate of unnecessary invasive treatment [73]. Treatment of crystalline arthropathy after total knee arthroplasty can be managed medically until symptoms resolve; however, with extensive bone loss and implant loosening, a revision TKA surgery may still be required [70].

Inflammatory Arthropathy

Rheumatoid arthritis is an autoimmune disorder resulting in an inflammatory cascade that can affect knee joint synovium, capsule, ligaments, and bone. Medical treatment utilizing disease-modifying antirheumatic drugs has been adopted as the mainstay of treatment and tremendously decreased the need for early surgery, but those with severe, uncontrolled disease may still require total joint arthroplasty [79]. After surgery, patients can present with recurrent rheumatoid synovitis and present with knee pain, effusion, and stiffness.

Ruling out a periprosthetic infection is critically important when evaluating the swollen knee in the rheumatoid patient. Multiple studies have shown an increased rate of infection after total knee arthroplasty for treatment of rheumatoid arthritic patients as compared to osteoarthritis patients [80–83]. This may be due to several

factors including soft tissue and wound concerns due to chronic synovitis as well as attenuation of the immune system from medications such as corticosteroids [84]. Interestingly, the use of biologic and nonbiologic medications is not as well established, with some studies showing only limited correlation with infection after orthopaedic procedures and others suggesting an increased rate of periprosthetic joint infections [81, 85–87]. Serum analysis may show an elevated ESR and CRP, and joint aspiration can have elevated leukocyte counts from 5000 to 25,000 [88]. However, as opposed to infection, joint fluid aspiration will not be grossly purulent, and joint fluid cultures will be negative [88].

Other inflammatory arthropathies, such as ankylosing spondylitis and psoriatic arthritis, can present in a comparable fashion to that of rheumatoid arthritis [89]. In general, diagnosis is similar with an emphasis on ruling out periprosthetic joint infection. Patients who are on disease-modifying drugs or have soft tissue concerns must be carefully examined [89]. Revision knee arthroplasty for any patient with an inflammatory arthropathy is difficult, and a higher rate of complications must be anticipated [90].

Spontaneous Hemarthrosis

Spontaneous, atraumatic hemarthrosis after total knee arthroplasty is uncommon with a reported incidence from 0.5 to 1.6% [91, 92]. The cause of hemarthrosis is still debated, with several authors suggesting entrapped synovium and soft tissue between articulating surfaces leading to recurrent bleeding [91, 93]. Other factors that have been identified include pseudoaneurysms, pigmented and nonpigmented villonodular synovitis, hemophilia, and chronic anticoagulation [94–98]. Diagnosis of hemarthrosis includes inflammatory markers and aspiration to rule out periprosthetic joint infection, blood profile and coagulation panel to evaluate the clotting cascade, and angiography or ultrasound to evaluate the vasculature. Anticoagulation medications should be stopped and conservative treatment with immobilization started. Operative treatments include embolization and arthroscopic or open synovectomy [99].

Summary

There are multiple causes of recurrent aseptic synovitis after total knee arthroplasty. Diagnostic options for evaluation include radiographs, laboratory studies, and joint aspiration. Imaging may show polyethylene wear, metal wear, and bone osteolysis but also may be normal. Laboratory blood studies should include WBC, ESR, and CRP, as well as other specific markers such as uric acid and metal ion levels. Joint aspiration with a leukocyte count, polymorphonuclear cell percentage, and cultures should always be performed. In addition, aspirate analysis may reveal crystals, metallic debris, or hematoma. Critically, a high degree of suspicion must be held for periprosthetic joint infection as the cause of synovitis, especially because low-grade infections may closely resemble many of the aseptic pathologies. Treatment options for aseptic synovitis will differ based on the underlying etiology. Medical management is the mainstay for some causes, such as crystalline and inflammatory arthropathy, while severe polyethylene wear or implant metallosis will likely require revision arthroplasty. Aseptic synovitis is a common and potentially detrimental condition after total knee arthroplasty and must be closely evaluated and treated by the orthopaedic surgeon.

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Prodromes of Failure After Revision Total Knee Arthroplasty

26

Jess H. Lonner and Max Greenky

Roughly 650,000 primary total knee arthroplasties (TKA) are performed annually in the United States, and it is estimated that this number may nearly double to 1.3 million by the year 2030 [1]. While the long-term success and survivorship of primary TKA exceed 90% into the second decade [2–4], there are an inevitable risk of failure and a need for subsequent revision. In fact, the incidence of revision TKA has continued to grow at an undisturbed rate. In 2005, it was estimated that 38,300 revision knee arthroplasties were performed in the United States, with the number expected to grow to 268,200 in 2030 representing a 601% increase during that period [5].

As a growing number of primary and subsequent revisions are performed, particularly in the younger and more active sector of our population, the likelihood of requiring secondary revision looms large [6, 7]. Patients less than age 65 now account for 50% of TKA revisions in the United States [8]. Monitoring these patients is necessary. However, given the escalating costs, resource burden, and time constraints of managing the ever-growing volume of arthroplasty patients necessitating care, developing an alternative strategy for following patients is necessary. One potential method is to follow patients remotely, with periodic surveys or telemedicine portals, which allow patients to stay connected by reporting signs and symptoms that may portend a failing arthroplasty and prompt formal evaluation by the healthcare providers.

Results After Revision Total Knee Arthroplasty

Functional improvement after a well-performed revision total knee arthroplasty, at least in the short term, can be expected [9]. A meta-analysis of 37 studies found that while the results of revision TKA were clearly inferior to those of primary total knee replacement, significant improvements in the mean knee society function scores and clinical scores can be expected, improving from 30.4 points to 57.4 points ($p < 0.0001$) and from 32.8 points to 74.9 points ($p < 0.0001$), respectively [10]. Unfortunately, despite these functional improvements, revision TKAs will statistically fail more frequently and earlier than primary TKAs, regardless of contemporary

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advancements in implant design, stems and augments, surgical technique, and quality and sterilization techniques of the polyethylene. Clearly, a great deal of variability exists in the success and survivorship of revision TKA, complication rates, and patient satisfaction.

The results of revision TKA are impacted by the quality of bone stock, integrity of the collateral ligaments, function of the extensor mechanism, surgical proficiency, and implant selection. Often, it is the former (i.e., quality of bone support) that deteriorates progressively in the failing revision arthroplasty, as a result of component motion and subsidence. This problem is compounded in the presence of osteolysis from particulate debris that is generated from polyethylene wear, metallosis, or other sources. Once a revision total knee arthroplasty has failed, the complexity, need for bone graft or augments, degree of implant constraint, and eventual success of further revision procedures can be affected by the timeliness of detection of that failure and subsequent intervention. The majority of reports have been relatively short term with survivorship ranging from 66% to 87% at 3.5–6.0 years [6, 7, 11–15].

The modes of failure of revision TKA differ nominally from the failure of primary TKA [16]; however, compared to patients with primary TKA, those with revision TKA are nearly six times more likely to require an additional revision TKA [7]. Suarez et al. reviewed 566 revision TKAs and found that 12% failed at an average of 40.1 months. Predominant revision failure modes included infection (46%), aseptic loosening (19%), and instability (13%). Revisions for infection are 4 times more likely to fail than revisions for aseptic loosening. Only 4.3% of knees revised for aseptic loosening required re-revision as compared to 21% of knees revised for infection, of which 61.5% were due to another infection. Revision knee arthroplasty was more likely to fail in younger patients and in those who underwent polyethylene exchanges. Furthermore, these failures often occurred within 2 years of the initial revision. Patients who required index revision for infection had only a 71% survivorship at 12 years compared to those with aseptic diagnoses who had 85% survivorship at 12 years [15]. Mortazavi et al. found that 18.3% of 499 revision TKAs failed at an average follow-up of 64.8 months (range, 24.1–111.6). Failures of 83% occurred within 2 years. Infection was the predominant cause of failure (44.1%) followed by stiffness (22.6%), patellar or extensor mechanism problems (12.8%), periprosthetic fracture (5.9%), loosening (4.9%), hematoma formation (3.9%), malalignment (2.9%), and instability (2.9%) [11].

There may be a difference in failure mechanisms in older (ages 60–70) compared to younger (age 50 or younger) patients. Aggarwal reported that infection accounted for 32% and 50% of revision TKA failures in younger and older patients, respectively. Aseptic loosening of revision TKA was the mechanism of failure in 28% and 15% of younger and older patients, respectively, highlighting the greater tendency for mechanical complications and wear in the younger patients, who represent a growing cohort of recipients undergoing revision TKA [6]. In their review of 2637 knee revisions in the Finnish Arthroplasty Registry, Sheng et al. reported a survivorship of 89% at 5 years and 79% at 10 years, using repeat revision as the end point. Younger patients, earlier revisions, longer time in situ of the primary implants, and revisions performed for patellofemoral problems failed at higher rates [15].

Revision TKAs are challenging cases, fraught with high rates of secondary surgeries, despite improvements in comprehension of failure mechanisms, implant designs, surgical techniques, and prevention of infection [12]. In a retrospective review of 1814 index knee revisions by Sierra et al., 373 (20%) required subsequent reoperation one or more times. The average time from index revision total knee arthroplasty to the first reoperation was 3.5 years (range, 1 day–19 years). The cumulative risks of first reoperation at 5, 10, and 15 years were 16.1% (95% CI, 14.2, 17.9), 26% (95% CI, 23.4, 28.6), and 31.4% (95% CI, 30.2, 39), respectively. There was no difference in risk to first reoperation when comparing the decades in which the index revisions were done (1970–1980, 1981–1990, and 1991–2000). The

authors concluded that despite substantial improvements during the past three decades in component design, surgical technique, and prevention of infection, patients who have a revision total knee arthroplasty are at substantial risk of having one or more subsequent problems that result in a reoperation [12].

Surveillance After Revision Total Knee Arthroplasty

These points highlight the need for routine surveillance after revision total knee arthroplasty and early intervention once failure is detected. Looking at contemporary series, primary TKA failure modes include polyethylene wear, aseptic loosening, instability, infection, arthrofibrosis, malalignment or malpositioning, extensor mechanism deficiency, avascular necrosis of the patella, and periprosthetic fracture [16, 17]. Documented failure mechanisms after revision TKA have subtle differences than in primary TKA, but for all intents and purposes, the main distinction is in the different incidences of these complications [11–15]. Again, clearly the most common reasons for failure after revision knee arthroplasty are related to the failure of structural support or infection, which can compromise further revision surgery if treatment is delayed. The need for reoperation after revision arthroplasty is approximately [4, 12, 14, 15] 12–20%, of which nearly 44% may require two or more additional surgeries, highlighting the importance of timely identification and treatment of problems [12].

Routine Follow-Up

As in failures of primary knee replacements, identifying the mode of failure of the revision total knee arthroplasty is important to ensure that the intricacies of the problem are addressed at the time of subsequent reoperations. Further, routine surveillance is critical for even the well-functioning revision total knee arthroplasty to identify mechanical failures early, before the cascade of bone loss and component subsidence. Early diagnosis of and intervention for the failed revision TKA enhance the facility with which further revision knee replacement can be performed and potentially optimize the results of treatment. Despite the importance of routine surveillance, practically speaking it may be difficult to follow routinely all patients over an extended period of time because of a variety of barriers, some of which are self-imposed, but others that have either a geographic, economic, or procedural basis [18–24]. The obstacles to routine assessment are occasionally physician-imposed, in that we arbitrarily assign follow-up intervals. These intervals may be too infrequent to capture a failing arthroplasty early in the process [25]. Alternatively, patients who live far away from the treating surgeon may opt not to return for periodic assessment, or they may choose to follow up with a more locally accessible orthopedist. This problem may be hastened if regional centers are developed to care for patients with failed total knee replacements. Some patients may simply opt to discontinue routine follow-up visits because of their inconvenience. In one study, 45% of patients preferred not to return to the orthopaedic office for an evaluation because of concerns regarding lost wages and expenditure of time [26]. Capitated care is another potential obstacle to routine surveillance after revision total joint replacement. While the trend common to the early and mid-1990s is less prevalent now, in which maintenance care, even after surgical interventions, was often relegated to the primary care physician, the future structure of healthcare delivery in the United States is uncertain. It is clear, though that on some level our ability to routinely follow patients after revision total knee replacement surgery is being impacted. In light of these obstacles, an alternative method of surveillance of patients after revision total knee arthroplasty may be practical if it is proven effective at identifying those patients at risk for or actively undergoing implant failure. Surveillance should not be delayed, since more than 50% of revision surgeries may be necessary within the first 2 years after arthroplasty [12, 16].

Internet-Based Follow-Up, Telemedicine, and Follow-Up Radiography

The use of mailed questionnaires or Internet-based follow-up has been proposed to circumvent or complement direct patient follow-up [27–37]. While there is a paucity of literature to evaluate the effectiveness of Internet-based follow-up, this may in fact be an effective vehicle for following patients after revision arthroplasty. Several studies have shown Internet-based rehabilitation to be efficacious in quality and satisfaction of follow-up [30, 37]. Given that the incidence of some problems like wound drainage, thromboembolic complications, instability, and stiffness occurs early in the postoperative period and that most other signs and symptoms of failure occur later, ongoing surveillance is important after the first year after revision TKA, when the majority of symptoms have stabilized [31].

Several studies have detailed a variety of prodromal symptoms and signs that are most commonly associated with mechanical failure after total knee arthroplasty. These signals of failure may be identified by email-based questionnaires, telephone conversations, or live video conversations [24, 32, 33]. The presence of these prodromal symptoms or signs that develop in the setting of implant *failure* should prompt radiographs and further direct hands-on evaluation [24, 30]. In a series of failed total knee arthroplasties with polyethylene wear, Tsao et al. noted the presence of pain in 75%, effusion in 63%, clicking in 28%, and stiffness in 6% [32]. A series by Knight et al. found that swelling was evident in 89%, stiffness in 72%, pain in 67%, clicking in 38%, and instability in 22% [33]. Comparable symptoms of mechanical failures after total knee arthroplasty were reported in a series by Lonner et al., including pain (84%), swelling (76%), progressive coronal plane deformity (19%), instability (17%), stiffness (17%), new onset of clicking or grinding (7%), catching (4%), and patellar pain, subluxation, or clicking (4%) [16]. In the latter series, the average duration of symptoms before presentation was 13 months (range, 1 week to 5 years), suggesting that an annual symptom-based questionnaire (Table 26.1) and series of weightbearing radiographs of the knee can be an effective means of alternative surveillance after knee arthroplasty [24]. In that series, particularly in the absence of clinical symptoms, standing radiographs were considered an important supplement

Table 26.1. Sample symptom-based questionnaire

Symptom	Yes	No
1. Pain	–	–
2. Swelling	–	–
3. Instability	–	–
4. Stiffness	–	–
5. Clicking	–	–
6. Progressive deformity	–	–
7. Grinding	–	–
8. Catching	–	–
9. Redness	–	–
10. Drainage	–	–
11. Fevers	–	–
For each positive response, address the following: Was it associated with an injury?_____ Was the onset of symptoms acute or insidious?_____ Is it present both with activity and at rest?_____ With what activities are the symptoms associated?_____ Has it resolved or is it continuing?_____		

Over the last 12 months, have you experienced the following new symptoms that you had not previously noted?
From Lonner JH, Siliski JM, Scott RD. Prodromes of failure in total knee arthroplasty. *J Arthroplasty.* 1999;14:488–492, with permission

to the questionnaires for identifying failures. The dilemma with this means of surveillance (i.e., remote reporting of symptoms) is that it would not be pertinent for those patients who never recovered from the initial postoperative pain, stiffness, or swelling that usually resolves within the first year after revision surgery or those with other uncommon causes of early dysfunction, such as instability from imbalance or patellar dysfunction not addressed at the time of revision surgery, reflex sympathetic dystrophy, arthrofibrosis, or infection. This method of alternative surveillance does not distinguish between aseptic and septic failure; suspicion for infection should always be high, and subsequent evaluation should include an appropriate workup for infection.

The potential for response bias in the reporting of patient satisfaction, function, and knee scores when using email or telephone surveys is a legitimate concern [26, 27, 34, 35]. But while there are potential inaccuracies of the questionnaires that are used for assessing clinical outcome and patient satisfaction, as well as a variety of other objective measurements, questionnaires can be a valuable vehicle for identifying symptoms of failure of knee arthroplasties that have previously been functioning well [24, 30]. While these clues to failure should theoretically be easily gleaned from a questionnaire, there is an element of diminished efficacy of email-based surveys. One recent survey of 472 surviving patients after total knee arthroplasty found that the response to questionnaires tends to diminish with time from the index surgery, such that the response rate to a standard questionnaire fell from 75% at 2 years to 54% at 10 years ($p = 0.0016$) [28]. In that series, "nonresponders" tended to be those with inferior results; however, the study did not identify whether those who had new signs of problems were more or less likely to respond to the questionnaire than those who were faring well or those who had never done well after the surgery [27].

Nonetheless, as an alternative to office-based follow-up visits after the first postoperative year, web-based follow-up of knee and hip arthroplasty is cost-effective, time efficient, and a safe method of follow-up inasmuch as identifying problems or concerns that should prompt an in-person physician visit. While 14% of patients may prefer to see the surgeon in person, others prefer the convenience and lower costs associated with web-based follow-up [30]. In a study by Marsh et al., while moderate to high satisfaction levels with a web-based follow-up assessment have been reported, patients who completed the usual method of in-person follow-up assessment reported greater satisfaction (82% vs. 76%). However, the small difference in satisfaction may not outweigh the additional cost and time-saving benefits of the web-based follow-up method [29]. Additionally, Marsh et al. reported substantial cost savings from a societal and healthcare payer perspective with web-based follow-up, making its use particularly germane given cost pressures in contemporary healthcare [28].

Conclusion

While comparison of failure mechanisms and rates in revision TKA is confounded by variability in implant designs (old versus new prostheses), technical complexity (extent of bone and ligament loss), integrity of the extensor mechanism, presence of overt or occult sepsis, and outcomes measures, there is one certainty. That certainty is that a percentage of revision TKAs will fail. Identifying the prodromal signs and symptoms that suggest a problem is important to prompt early intervention which may optimize outcomes of additional surgery that may be necessary after revision TKA.

The potential value of Internet-based follow-up coupled with standing radiographs for identifying symptoms of mechanical failure cannot be overstated. A number of patients whose implants are failing may deny knee symptoms that are reflective of implant failure, and this can only be reconciled by obtaining concurrent weightbearing radiographs of the knee. Complementing the questionnaire with standing radiographs will effectively identify the *occult* failures. The administration of periodic questionnaires and standing radiographs at intervals of 12–24 months can be an effective method of surveillance after

revision total knee arthroplasty, particularly when there are obstacles to direct annual follow-up. The possibility that the presence of acute pain or swelling can be indicative of deep infection should not be overlooked, and patients with new symptoms should always be scrutinized and evaluated for sepsis or mechanical failure.

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27 Assessing the High-Risk Patient for Revision Total Knee Replacement

Andrew H. Glassman, Nicole T. Meschbach, and Joshua S. Everhart

The number of total knee arthroplasty procedures performed in the United States is anticipated to increase exponentially in the next decade and beyond, and consequently, the need for revision TKA is expected to double between the years 2007 and 2030 [1, 2]. With rare exception, revision total knee arthroplasty (TKA) is an elective procedure. As such, orthopedists have the opportunity and obligation to ensure medical optimization prior to surgery. Doing so maximizes the likelihood of a successful reconstruction and minimizes the risk of complications.

Inherently, revision surgery carries increased risks of both systemic and local complications as compared to primary arthroplasty, even in the ideal host. While "high risk" in the specific context of revision total knee replacement has not been defined, two principals are helpful. Firstly, medical comorbidities recognized as risk factors for systemic complications following primary TKA are equal, if not more important in the revision setting, where the operative duration tends to be longer. Secondly, bone stock damage, ligament deficiency or absence, vascular compromise, scarring, and prior skin incisions all increase the risk of local complications.

While the patient's well-being is always our foremost consideration, there are now institutional incentives for careful preoperative risk assessment and management. CMS initiatives now provide costly penalties for unplanned readmissions, hospital-acquired conditions, and patient safety indicator (PSI) violations [3].

Candidates for revision TKA have frequently suffered from chronic disability, may be frustrated by ineffective nonoperative treatments, and are understandably eager to proceed with surgery. It is important for surgeons to engage these patients in a therapeutic partnership wherein they understand and embrace the merits of preoperative risk assessment, management, and optimization and the possible need to postpone the procedure [4].

The technical aspects of revision total knee arthroplasty for various failure modes are covered in other chapters. It must be emphasized that definitive identification of the failure mode underlying the need for revision TKA is the first step in the preoperative evaluation. As Vince has aptly stated, "Revision of the inexplicably painful knee arthroplasty will yield miserable results" [5]. Revision without a definitive diagnosis and operative plan places the patient at high risk for an unfavorable outcome. Infection accounts for the most common short-term mode of failure,

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while prosthetic loosening is more common in the long term [6]. Overall, aseptic loosening is the most common etiology [6]. Pain, instability, periprosthetic fracture, arthrofibrosis, patella resurfacing, PE wear, patella loosening, malalignment of components, and extensor mechanism deficiencies account for similar instances of short- and long-term failure [6]. Identification of these failure modes is presented in those portions of this book dedicated to each.

Risk Factors

Obesity

The World Health Organization defines obesity as BMI ≥30 kg/m^2. This is further subclassified into class I (BMI = 30.00–34.99 kg/m^2), class II (BMI = 35.00–39.99 kg/m^2), and class III (BMI ≥40 kg/m^2) or morbid obesity [7]. Nearly 32% of the population in the United States is categorized as obese, and this percentage continues to increase [8]. As the number of TKA's performed yearly continues to grow, the number of patients categorized as obese undergoing TKA simultaneously continues to increase [9].

Almost 50% of patients undergoing TKA are obese [10]. Multiple studies have shown that obesity has been correlated with higher complications after both primary and revision TKA. The rate of obesity in patients undergoing revision total knee arthroplasty in the United States has more than doubled from 2002 to 2012 [9]. Both obese and morbidly obese patients have a four- to tenfold increase in the prevalence of periprosthetic joint infection (PJI) postoperatively [11]. Patients categorized as super obese (BMI > 50 kg/m^2) have a risk of infection twentyfold higher than nonobese patients and >50% complication rate. Morbid obesity is associated with increased rates of re-revision, worse implant survivorship, reoperation, and PJI after aseptic revision TKA [12]. Obesity is associated with other comorbidities including type 2 diabetes mellitus, hypertension, dyslipidemia, cardiovascular disease, stroke, sleep apnea, gallbladder disease, hyperuricemia, and gout, all of which may further contribute to higher complication rates [13]. Diabetes mellitus may heighten the complications associated with obesity [14].

Morbid obesity is associated with higher risk of immediate inhospital postoperative period complications including wound dehiscence, genitourinary complications, and inhospital death [15]. In the critical postoperative 90-day period, hospital readmission rate can increase from 8.1% for a normal weight patient to 9.9% for an obese patient with 40 < BMI < 50 and to 12.3% for the super obese patient with BMI >50 [16]. Total hospital costs, length of stay, and rate of discharge to a facility are all significantly higher in morbidly obese patients [15]. In the first 12 months after the index procedure, obese patients are at higher risk for failure requiring early revision [8]. As BMI increases, a higher load is enforced across the bone-cement interface potentially leading to aseptic loosening [17], although some studies dispute this relationship [18].

Total knee arthroplasty can improve functional outcomes and patient satisfaction in obese patients; however, obesity remains a risk for inferior results compared to nonobese patients [19]. Morbidly obese and super obese patients achieve significantly lower functional outcomes [20].

Paradoxical malnutrition in obese patients also warrants close attention. Malnutrition is defined by the following laboratory values: serum transferrin <200 mg/dL, serum albumin <3.5 g/dL, serum prealbumin <22.5 mg/dL, and total lymphocyte count <1200–1500 cell/mm [3, 4]. Malnutrition is associated with infection, longer hospital stays, and a fivefold to sevenfold greater risk of developing major wound complications after total joint arthroplasty [21]. In the preoperative risk assessment, obese patients screening positive for malnutrition are referred to a nutritionist.

Weight loss following TKA failure and prior to revision is challenging at best. Rapid weight loss under medical supervision or even bariatric surgery should be considered. In the setting of catastrophic failure requiring more urgent intervention

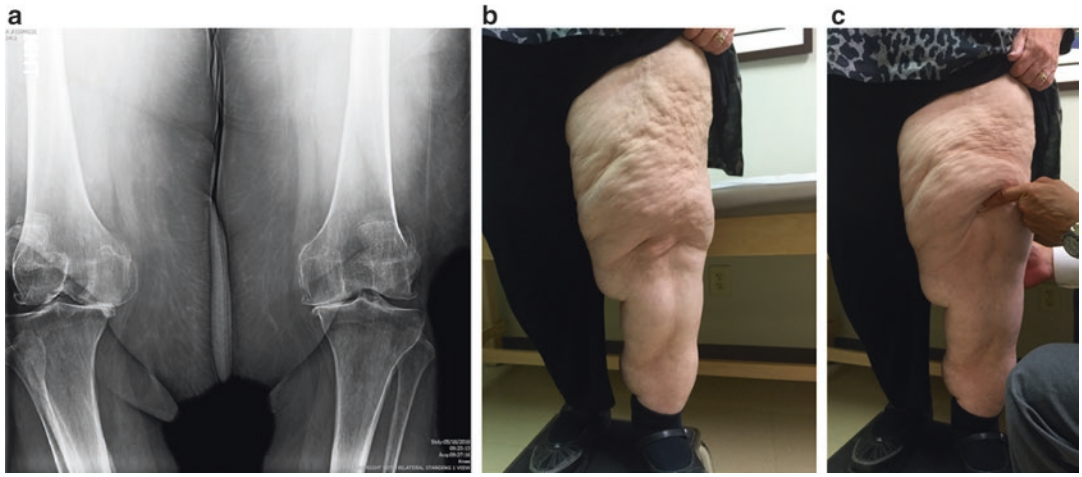

Fig. 27.1 (**a**) Standing anterior-posterior radiograph of an obese patient with a pendulous fatty panniculus following massive weight loss. (**b** and **c**) Photographs demonstrating redundant skin overhanging the patella

(e.g., periprosthetic fracture or infection), patient expectations should be managed realistically, using the above information.

Finally, patients having experienced significant weight loss following massive weight loss through diet or bariatric surgery may have pendulous, redundant skin over the knee that complicates wound closure and healing. Such patients should be referred to plastic surgery for consideration of panniculectomy (Fig. 27.1).

Tobacco Use

There are well-established associations between tobacco use and early wound-healing complications, postoperative medical complications, and implant failure due to infection or aseptic loosening. In a large case series, Møller et al. demonstrated that active smokers had a twofold risk of wound complications following primary knee or hip arthroplasty as well as increased risk of postoperative medical complication, increased length of stay, or postoperative admission to an intensive care unit [22]. In a case-control study by Kapadia et al., compared to nonsmokers, active tobacco users had a higher rate of failure of primary TKA (90% survivorship over 4 years compared to 99%) and had a higher rate of postoperative medical complications [23]. Nwachakwu reported a similarly elevated TKA revision rate among smokers (Odds Ratio 2.87) with the most common failure modes being infection (30%) followed by aseptic loosening (18%) and stiffness (18%) [24]. Additionally, a significantly higher rate of deep infection was noted among active tobacco users (Hazard Ratio 2.37) after primary TKA or THA in a large cohort study by Singh et al. [25] Tobacco use is a modifiable risk factor, and in our opinion, smoking cessation should be mandatory prior to revision knee arthroplasty; we recommend requiring a negative urine or serum cotinine as confirmation of smoking cessation prior to surgery.

Dental Caries

Dental clearance prior to total joint arthroplasty has historically been common practice, although recent data suggest it may be of limited efficacy in the primary arthroplasty population. In several recent studies, the incidence of dental pathology noted on screening varies from 8 to 23% [26–28]. In a prospective study by Lampley et al., 8.8% of elective arthroplasty patients had dental pathology noted on dental screening though there was no significant reduction in infection rates compared to a control group of hip fractures treated with arthroplasty who did not receive dental screening [28].

Nonetheless, an appropriate dental history (history of recent dental procedures) should be a part of the evaluation of any patient in whom revision TKA is contemplated. Waldman et al., noted that 11% of knee arthroplasties presenting with late infections were later attributed to hematogenous seeding from a dental procedure [29]; Kaar et al. also report on a late infection in an arthroplasty patient after a simple teeth cleaning [30].

Diabetes

More than 8% of patients undergoing primary and revision TKA have been diagnosed with diabetes mellitus [31]. The 2007 American Diabetes Association position statement recommends that adult patients with diabetes mellitus have a hemoglobin A1c level of <7% (normal, 4–7%), a preprandial capillary plasma glucose level of 90–130 mg/dL, and a peak postprandial capillary plasma glucose level of <180 mg/dL [32]. Diabetes is frequently associated with obesity and other comorbidities that may contribute to the increased risk of complications after TKA.

Patients with diabetes mellitus are at increased risk for perioperative complications including myocardial infarction, CVA, ileus, UTI, pneumonia, need for transfusion, and mortality [32]. They have increased likelihood of postoperative infections, wound complications, and revisions [14]. Wound complications including bulla formation, erythema with drainage, and skin necrosis are all associated with diabetes [14]. Diabetic patients may also experience nonroutine or delayed discharge and higher hospital charges [33]. Diabetes has been found to be independently associated with poorer functional outcome after TKA, significantly decreased subjective outcome scores and limitations in activities of daily living compared to nondiabetic patients [13].

Glycemic markers are important risk assessment tools in the preoperative evaluation prior to TKA. While glycemic control is important in preventing the short- and long-term complications of diabetes, it is unclear what ideal perioperative glucose range or maximum hemoglobin A1c level should be employed to optimize patients prior to TKA [34]. There have been positive correlations between certain markers including HbA1c $\geq$ 8 and/or fasting blood glucose $\geq$200 mg/dL and surgical site infection [14].

It is noteworthy that elevated preoperative glucose levels in patients *without* a prior diagnosis of diabetes are also associated with increased risk for PJI [35]. Glycemic variability may be more important than hemoglobin A1c or actual blood glucose values [34]. Other studies have found, however, when comparing patients to those without diabetes undergoing TKA that there was no increased risk of revision arthroplasty, deep infection, or deep venous thrombosis [36]. Consultation with an endocrinologist should be pursued for preoperative blood glucose control that is difficult to manage or outside the established limits of ADA guidelines.

Cardiovascular Disease

Cardiovascular comorbidities are a significant risk factor for major systemic adverse events and deaths following total joint arthroplasty [4]. Cardiovascular complications comprise 42–75% of adverse events following total joint arthroplasty [37, 38]. Independent predictors of cardiac complications after TJA include revision TKA, a history of coronary artery disease, myocardial infarction, congestive heart failure, valvular heart disease, and arrhythmia [39]. Cardiovascular complications including pulmonary embolism, fatal arrhythmias, acute coronary syndrome, and cardiopulmonary arrest are the most common causes of death after TJA [37]. Thirty-day cardiac-related mortality has been reported in 0.18% of patients after TKA [40]. Ninety-day cardiac complication rates after TKA are increased in patients >65 years old, with and without known cardiac disease, and higher ASA class [41]. Patients who have had a previous acute myocardial infarction (AMI) with and without stent placement are at increased risk of having another AMI after TKA within 1 year [40, 42]. These events may extend the length of

hospital stay by an average of 11 days [40]. Elective TKA should be performed at least 1 year after an episode of AMI or stent placement [40].

The American Heart Association and the American College of Cardiology have published guidelines for perioperative cardiovascular evaluation [43]. Any patient with active cardiac conditions should undergo specialist evaluation and treatment before consideration of total joint arthroplasty (Table 27.1) [43]. Expert recommendations should be obtained for thrombotic prophylaxis and cardiac medications both pre- and postoperatively [43].

Table 27.1 Cardiovascular screening recommendations prior to revision knee arthroplasty

• Any patient with the following active cardiac conditions should undergo specialist evaluation and treatment before consideration of revision total joint arthroplasty:
– Unstable coronary syndromes Unstable or severe angina Recent myocardial infarction (within 4–6 weeks)
– Decompensated heart failure Inability to carry out any physical activity without discomfort Symptoms of cardiac insufficiency at rest, such as fatigue, palpitation, or dyspnea Discomfort that is increased with physical activity Worsening or new-onset heart failure
– Substantial arrhythmias High-grade, Mobitz type-II or tertiary atrioventricular block Symptomatic ventricular arrhythmias Supraventricular arrhythmias (including atrial fibrillation) with heart rate of >100 beats/min at rest Symptomatic bradycardia Newly recognized ventricular tachycardia
– Severe valvular disease Severe or symptomatic aortic stenosis Symptomatic mitral stenosis (progressive dyspnea on exertion, exertional presyncope, heart failure)
• Electrocardiogram evaluation should be performed in all patients >50 years old and within 30 days of revision surgery. Stress cardiac imaging should be strongly considered in those with an abnormal "strain" pattern
• Functional capacity should be assessed with the use of a metabolic equivalent (MET) scale. Patients with adequate functional capacity to perform activities involving >4 METs without experiencing symptoms can typically be cleared for surgery from a cardiovascular standpoint
• If poor functional capacity is present, patients with clinical risk factors should be evaluated by a specialist for clearance or potential additional noninvasive testing. Clinical risk factors may include type 2 diabetes mellitus, cerebrovascular disease, and ischemic heart disease. Patients with no risk factors are likely to receive cardiovascular clearance
• In patients with stable coronary disease, coronary revascularization prior to a noncardiac surgery has limited value and is not recommended. Those who may benefit from such intervention would likely have preexisting active coronary disease, and the procedure would be indicated independent of the planned revision [65]

Data from [4, 43, 65]

Prior Infection

In the initial evaluation of a patient presenting for possible revision TKA one should (1) assume there is an infection until proven otherwise, and (2) once convinced there is no current infection, evaluate the patient's risk for future infection. It is prudent to obtain serum inflammatory markers on all patients presenting for revision arthroplasty and investigate the cause of any elevated results (ESR greater than 30 mm/h and CRP greater than 10 mg/L) [44]. If there is clinical suspicion for infection, synovial aspiration is indicated. Synovial fluid culture is worthwhile but is not sufficiently sensitive to rule out infection as clinically infected cases can have negative cultures due to prior antibiotic use, the presence of a slow-growing organism, or the presence of biofilms [45]. Synovial alpha-defensin (part of the commercially available Synovasure assay, CD Diagnostics) has shown good sensitivity and specificity [46]. Normal laboratory results may in the immunocompromised patient and are critically evaluated in the patient with a highly suspicious clinical history, exam, or radiographic findings. Further imaging such as MRI with the use of a metal artifact reduction sequence (MARS) [47] or alternatively a tagged white blood cell scan can be utilized [48]. Finally, in a patient in whom all previous testing is negative but there is lingering suspicion for infection, an open biopsy can be performed; in this circumstance we recommend

adhering to Musculoskeletal Infection Society (MSIS) guidelines and obtaining multiple synovial tissue samples (3–5 in total) for frozen section with positive result defined as greater than five neutrophils in five high-power fields at 400× magnification [49].

Vascular Complications

Vascular complications following total knee arthroplasty are rare, but the sequelae may be dire and threaten both life and limb. The reported incidence of vascular complications in patients undergoing TKA ranges from 0.03 to 0.17% [50, 51]. However, the majority of acute perioperative vascular complications occur in patients with preexistent, chronic arterial insufficiency, and these patients can, with some effort, be identified preoperatively as being at increased risk. In an analysis of 1182 consecutive TKA's, 24 cases or 2% were found preoperatively to have chronic lower extremity ischemia based upon a careful history, physical, and ancillary studies including ankle-brachial indices and ankle pulse volume recordings [50]. In the same series, ischemic complications following TKA occurred in 6 knees or 0.5% of the entire cohort (6/1182). However, all complications occurred in the group with preexistent ischemia, representing an incidence of 25% (6/24) in these patients, who were all identified as high risk preoperatively.

Screening for patients at risk for vascular complications begins with a thorough, focused history. The likelihood of vascular compromise increases with age. Thus, a high index of suspicion is maintained for the elderly and those with other known risk factors. Those factors include a history of any prior vascular reconstruction, including lower extremity reconstruction, coronary artery bypass grafting, carotid endarterectomy, or resection of an abdominal aortic aneurysm [50]. Other risk factors are smoking, diabetes mellitus, and hypertension [50]. Patients are queried for symptoms of claudication, ischemic rest pain, or a history of vascular ulcers.

The physical examination begins with inspection for telltale signs of skin discoloration, hairlessness, or dystrophic nails. Pulses are palpated for the presence and strength as well as asymmetry. Popliteal fullness warrants evaluation for the presence of popliteal aneurysm. Routine preoperative radiographs are evaluated for calcification of the femoral/popliteal arterial tree. Based upon the information described above, noninvasive vascular studies such as ankle-brachial indexes and pulse volume recordings are ordered. At the author's institute, we have an extremely low threshold for referring at-risk patients to vascular medicine/surgery to direct such studies, which may include arteriography.

Post-Arterial Bypass Patients

Patients with a history of prior arterial reconstruction/bypass ipsilateral to an arthritic knee for which TKA is contemplated represent a small but distinct group. In a Mayo Clinic Registry study [52], 10 such limbs in 9 patients were identified out of 19,808 TKA's performed over a 27-year period (0.05%). Ischemic complications occurred in two of these knees. Whereas arterial complications have been reported in 0.03–0.17% of all patients undergoing TKA [50, 51], the incidence in the post-bypass group was 2/10 (20%). A tourniquet was used in only one of these patients. Although the limb was preserved, an infection developed and resection arthroplasty was required. In the second patient, no tourniquet was used, yet arterial occlusion occurred, eventuating in below-knee amputation. Thus, avoidance of tourniquet use alone is not protective in such patients. Various protocols have been proposed for the management of this select group of patients, including the use of intraoperative heparin therapy [52]. We believe that a prior history of ipsilateral limb arterial bypass or reconstruction is an absolute indication for preoperative vascular surgical consultation and individualized comanagement.

Tourniquets should always be used at the lowest effective pressure and for the shortest duration necessary [53]. In the face of known peripheral arterial disease, it may be advisable to avoid tourniquet use altogether. Ankle-brachial indexes may be useful in this decision. If the index is 0.9 or greater, and no arterial calcifications are noted

on plain radiographs, tourniquet use is generally felt to be safe. Lower indexes should prompt referral to vascular surgery. Calcifications on plain films suggest the risk of plaque fracture and embolization with tourniquet use [53]. A tourniquet is never used in patients who are status post-ipsilateral arterial revascularization [50, 54].

Despite thorough preoperative screening and patient optimization, vascular complications do occur. The most common complication is acute thrombosis of the superficial femoral or popliteal artery [55]. For those patients at high risk of such an event, provisions for the immediate availability of vascular surgical intervention must be made preoperatively. Likewise, arrangements are made for continuous postoperative monitoring. If a problem does arise and revascularization is indicated, intervention must be immediate. Appropriate preoperative preparations enhance possibility of a favorable outcome. In a series of 11 patients with acute arterial insufficiency, 7/11 patients (63%) had full restoration of function with appropriate, timely intervention [55]. As previously mentioned, our threshold for preoperative referral to vascular surgery is quite low. In summary, our indications include a prior history of ipsilateral vascular reconstruction, absent or asymmetric pulses, ankle-brachial indexes below 0.9, suspicion or documentation of a popliteal aneurysm, and arterial calcification on plain radiographs (Fig. 27.2) in patients with symptoms of arterial insufficiency [54].

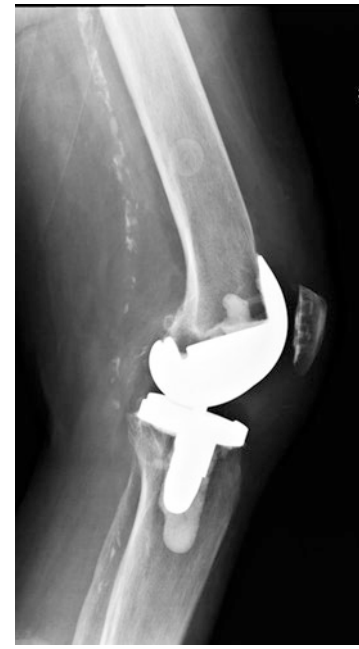

Fig. 27.2 Preoperative lateral radiograph of a patient to be revised for flexion instability, demonstrating extensive calcification of the femoral-popliteal arterial tree

Poor Bone Quality

The incidence of osteoarthritis of the knee increases with age. Concomitantly, bone health tends to decline. In one study [56] 199 patients awaiting total hip or knee arthroplasty were evaluated with DEXA scan. Osteoporosis was found in 23%, and an additional 43% of patients met World Health Organization criteria for osteopenia. Thus, poor bone quality should always be suspected in patients undergoing revision TKA. This is in addition to actual bone loss secondary to osteolysis and possibly during implant removal. Osteopenia is a known risk factor for periprosthetic fracture following total knee arthroplasty [57–59] and should be suspected in patients revised for that reason.

Risk factors for osteopenia include rheumatoid arthritis, corticosteroid use, smoking, increasing age, and female sex. The role of poor bone quality in aseptic loosening has not been firmly established. A relationship may be inferred from the observation that the incidence of aseptic loosening after TKA has been shown to be lowered by the perioperative administration of bisphosphonates [59, 60]. As such, we recommend the use of long-stemmed revision components in patients with significant osteopenia. Likewise, patients with both osteopenia and obesity are, in the authors' experience, prone to insufficiency fractures (Fig. 27.3). Long-stem prostheses are recommended to enhance the stability of revision constructs in these patients as well.

The routine initiation of bisphosphonate therapy must await further study. Continuation of previously prescribed bisphosphonates for patients undergoing revision TKA is under-

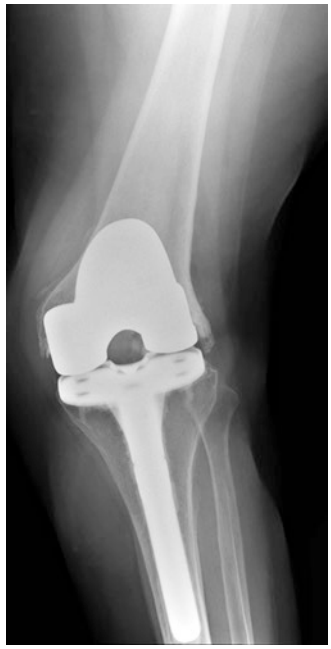

Fig. 27.3 Anterior-posterior radiograph of an osteoporotic postmenopausal female with a supracondylar insufficiency fracture

taken only with the collaboration of the prescribing physician or upon advice of the orthopedist's customary bone health consultant, usually an endocrinologist.

Social Assessment

Satisfactory postoperative care and rehabilitation following revision total knee arthroplasty can often be costly and require substantial care coordination. It is important particularly in complex or high-risk cases to assess whether a patient has the resources necessary to follow a postoperative discharge and rehabilitation plan. For example, a 4-week supply of low-molecular-weight heparin for home DVT chemoprophylaxis may be prohibitively expensive for some patients even if it is partially covered by insurance; in this case a less expensive but acceptable therapy such as warfarin or factor X inhibitor selected preoperatively may prevent last minute changes at the time of hospital discharge. Discharge expectations must be managed proactively and preoperatively in patients likely to require extended care placement after revision TKA. The use of a simple preoperative screening tool such as RAPT developed by Oldmeadow et al. can facilitate discussion of a discharge plan in the office at the time surgery is scheduled (Table 27.2) [61].

Table 27.2 Risk Assessment and Prediction Tool (RAPT) for prediction of discharge disposition

Item	Value	Score
Age group (years)	50–65 66–75 >75	2 1 0
Sex	Male Female	2 1
Walking distance	Two blocks or more 1–2 blocks Housebound	2 1 0
Use of a gait aid	None Single-point stick Crutches/frame	2 1 0
Use of community supports	None or one per week Two or more per week	1 0
Caregiver at home	Yes No	3 0

Total score > 9: low risk of discharge to a nursing facility. Score 6–9: intermediate risk. Score < 6: high risk of discharge to a nursing facility

Patients presenting for revision surgery with chronic pain are at increased risk for depressive symptoms [62] or chronic reliance on oral narcotics for analgesia [63]. A recent review conducted within our department emphasizes that while revision arthroplasty patients with depression can still experience substantial improvement of orthopaedic symptoms, they are prone to mild or moderate residual symptoms after surgery and should be counseled that they likely will not become symptom-free [64]. Untreated clinical depression is not an absolute contraindication to revision surgery unless there are concerns for patient safety. If so, preoperative mental health assessment should be considered [64].

Summary

Revision total knee arthroplasty poses risks of various local and systemic complications. Certain comorbidities are known to increase the

likelihood of complications and/or a poor outcome. A concerted effort should be made to identify the presence and severity of these risk factors. Modifiable risks should be mitigated or eliminated if possible. If practical, revision should be delayed until the patient can be medically optimized.

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Salvage Knee Surgery: Arthrodesis

28

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Primary arthrodesis or fusion of the knee is an uncommon procedure performed in the twenty-first century. It is rarely performed primarily for arthritis. The main role of knee arthrodesis is as a salvage procedure for an unrevisable failed total knee arthroplasty (TKA) [1]. Arthrodesis of the knee, in the face of grossly deficient bone stock and ligamentous instability, is difficult to achieve [2–5]. In limb salvage surgery for malignant and potentially malignant lesions about the knee, resection arthrodesis using an intramedullary rod and local bone graft has been reported as a successful primary procedure [6]. When performed as a primary procedure after trauma, arthritis, or instability, solid fusion may not always occur, with rates of union reported between 80 and 98% by various methods. Fibrous nonunion after attempted fusion frequently is painful [3, 7–10], and rigid internal fixation promotes bony union. Using strict patient selection criteria, knee arthrodesis should be reserved as a salvage procedure for chronic infection, posttraumatic arthritis, periarticular tumor, or instability primarily following failed TKA.

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Indications

Failed Total Knee Arthroplasty

Currently, the most frequent indication for knee fusion, as well as the most difficult circumstance in which to achieve union, is the failed, unrevisable TKA. This failure may be due to persistent infection, massive bone or soft tissue loss, or irreparable damage to the extensor mechanism [11]. Mechanical failure of an arthroplasty can nearly always be better managed by revision. Two-stage reimplantation may be the best choice when the failure is caused by sepsis. However, some cases of failed TKA with bone loss and infection can only be managed by resection arthroplasty and staged arthrodesis.

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Arthrodesis as a salvage procedure for a failed septic knee replacement is indicated in the following circumstances: (A) persistent infection recalcitrant to repeated debridement and antibiotic regimen; (B) disruption of the extensor mechanism; (C) an infectious organism that is only sensitive to severely toxic antibiotic agents, such as *Candida albicans* or other fungi [12–14]; or (D) a young patient or a disillusioned older one who does not wish to face possible future revision arthroplasties. Occasionally, fusion may be the best choice for a very heavy patient with a septic TKA failure. Although certain patients insist on TKA reimplantation following septic TKA, some do not want to risk recurrent infection and choose arthrodesis as definitive treatment.

Deficiency of the extensor mechanism is a compelling indication for arthrodesis when it occurs in the setting of an infected knee arthroplasty. The patient generally displays a profound extensor lag with poor results if reimplantation TKA is performed. Despite various reconstructive techniques, disruption of the extensor mechanism often yields a compromised result [15]. The patient will never be able to adequately extend the knee and will generally display a profound extensor lag if reimplantation TKA is attempted. Repair of the extensor mechanism is often impossible because of extensive tissue destruction that occurs secondary to the infection. An extensor mechanism allograft may be needed to reconstruct the extensor deficit but is relatively contraindicated in the setting of previous sepsis.

Unilateral Posttraumatic Osteoarthritis in a Young Patient

In a healthy young male laborer with an isolated, severely damaged knee, an arthrodesis is occasionally indicated [16]. Historically, a successful fusion was felt to be more durable over time than any other reconstructive option. However, with improved implants and techniques that have increased the longevity of TKA's, arthroplasty is currently considered a more appropriate option for younger patients [17–20]. Yet, in the younger individual, a knee replacement is unlikely to endure a lifetime of hard use and will potentially require future revision. The patient's decision to undergo arthrodesis should be made carefully, since conversion of a knee arthrodesis to successful arthroplasty is not easily performed at a later date [21]. Fortunately, disabling unilateral, posttraumatic osteoarthritis in a young person is rare, and each case must be judged individually. Occasionally, joint debridement or realignment by osteotomy provides temporary symptomatic relief. Extensive preoperative discussion, including the risks, benefits, expectations, and alternatives to surgery help the patient decide whether to have surgery, postpone it, or avoid it altogether. Despite the long-term durability of fusion, the patient may still insist on TKA, and the patient should understand that the success of arthrodesis following unsuccessful arthroplasty might be less predictable.

Malignant and Potentially Malignant Knee Lesions

Certain potentially malignant and low-grade malignant tumors about the knee, such as aggressive giant cell tumor, chondrosarcoma, recurrent chondroblastoma, and carefully selected higher-grade malignant lesions, may be satisfactorily controlled by adequate local resection of the lesion. Reconstruction of the defect created by such resection may be accomplished by (A) extremity shortening and arthrodesis, (B) arthrodesis with large intercalary bone grafts to preserve length, (C) arthroplasty with custom-made prosthetic replacements, and (D) allotransplantation of joints [22–33]. Local resection and arthrodesis for tumors about the knee was first described in 1907 by Lexer and others [23, 25, 29, 33, 34]. Success in controlling the tumor was frequently complicated by infection, nonunion, and late fatigue fracture. Enneking reported 20 patients with malignant or potentially malignant tumors (osteogenic sarcoma, giant cell tumor, synovial cell sarcoma, chondrosarcoma, and chondroblastoma) in the proximal tibia or distal femur [6]. These patients were treated by local resection and arthrodesis using a customized fluted

intramedullary rod and autogenous segmental cortical grafts obtained from the same extremity. While fusion is useful in the setting of malignancy when other reconstructive options are not appropriate, it is most commonly used after tumor resection when the extensor mechanism is lost or in the presence of infection [35].

Multiple Operated Knee

Occasionally, there are patients who, despite or because of multiple operations, complain of a diffusely painful and usually unstable knee. The original insult may have been a ligament injury or patellar dislocation resulting in reflex sympathetic dystrophy with or without subsequent operative intervention. Underlying emotional and psychiatric problems may be present. These patients are challenging to treat, and additional knee surgery of any kind may be unwarranted and inadvisable secondary to its poor outcome. Management should consist of simple conservative care, bracing, physical therapy, evaluation by a pain service, and perhaps, psychiatric consultation. For a select few, arthrodesis may be the correct approach. In this situation, a preoperative trial of a cylinder cast is important to convey the functional limitations of knee arthrodesis to the patient.

Painful Ankylosis

Ankylosis of the knee is defined as a range of motion of no more than 10–20°. Patients who develop stiffness from severe rheumatoid arthritis or osteoarthritis may be successfully treated by total knee arthroplasty using quadriceps turndown or tibial tubercle osteotomy techniques, *skeletonization* of the femur, and reestablishment of the medial and lateral gutters by scar excision [36]. However, even in these cases, the likelihood of obtaining normal motion is small, with the final outcome often being less than 90° of motion. In the ankylosed knee following sepsis or remote trauma, an arthroplasty may be either contraindicated or likely to produce a suboptimal result, particularly in terms of functional motion. Therefore, a painful ankylosis of the knee may benefit from an arthrodesis.

Neuropathic/Paralytic Conditions

In the setting of a neuropathic joint, a total knee may fail due to aseptic loosening and resultant bone loss may necessitate fusion as a salvage procedure [37]. Arthrodesis of a neuropathic knee joint, however, has resulted in limited success and frequent nonunion. Thorough debridement of all bone detritus and complete synovectomy have been demonstrated to increase the rate of bony union [38]. Drennan reported ten cases of arthrodesis of a Charcot knee in nine patients [38]. The best results were obtained after complete removal of the thickened, edematous synovium in these knees. When the Charcot knee is painless, bracing and conservative management is the treatment of choice. However, some Charcot knees are painful and should be carefully selected for knee arthroplasty or arthrodesis. Variable results of TKA in Charcot joints have been reported [39, 40]. However, if TKA is performed, bone defects should be treated by implants with metal augments rather than by bone grafting, and constrained posterior stabilized knee replacement designs are recommended.

Currently, poliomyelitis is rare in the United States and Western Europe, where vaccination is widespread. Muscle weakness can usually be managed successfully by bracing, as these patients often have little pain. However, when associated with genu recurvatum, bracing is difficult and may not be successful. In this setting, arthroplasty is technically demanding [41]. In paralytic conditions, arthrodesis adequately addresses the quadriceps weakness and angular deformity.

Contraindications

Contraindications to arthrodesis include a contralateral amputation, pathology in bilateral knees, and ipsilateral hip arthrodesis [42]. These associated conditions could make a functionally limited patient even less so if a knee arthrodesis

was performed. Furthermore, it is important to consider that a fused knee transfers greater stress to the hip, ankle, and lumbar spine; thus, a patient with pre-existing arthritis or limitations at these joints may not tolerate a knee fusion as well. Overall, it is important to individualize the decision to proceed with knee arthrodesis and assure that the patient understands preoperatively the functional limitations they will encounter [43].

Arthrodesis Techniques

Arthrodesis of the knee may be accomplished by one of the four techniques: (A) compression arthrodesis with external fixation, (B) compression arthrodesis with compression plating [44, 45], (C) intramedullary rod fixation, and (D) a combination of intramedullary rod fixation and compression plating [46].

A suitable cancellous surface on both the femoral and tibial surfaces optimizes fusion. Bone shortening relaxes the hamstrings and increases flexibility at the hip joint, which is desirable if both knees have to be fused [7]. Charnley reported that patients considered limb shortening advantageous for dressing and foot care [7]. The desired alignment is 0–5° of valgus, with the knee flexed 10–15°. Less flexion can be accepted in the presence of marked bone loss. The patella can be left alone or used to augment the fusion mass.

When arthrodesis is indicated after failed total knee arthroplasty with bone loss, further host bone should not be resected; the surfaces must be thoroughly debrided and their irregular surfaces opposed to give the best possible contact. Intramedullary reamings as well as the patella can be used as graft to fill large defects. It should also be noted that fusion rates are improved with application of AO principles, notably adequate reduction and contact of the bony surfaces, stable fixation, and preservation of the bony and soft tissue blood supply [47].

Preoperative Considerations

In addition to a thorough history that examines the etiology of the patient's knee pathology, consideration should be given to systemic issues, such as diabetes mellitus, rheumatoid arthritis, chronic renal failure, peripheral vascular disease, and long-term corticosteroid use due to their effects on wound healing and fusion success. Similarly, an examination of existing scars should be performed to plan the surgical approach and to avoid skin flap compromise. Historically, as the blood supply to the anterior knee is derived medially, the lateralmost incision should be utilized in the setting of pre-existing scars. An examination of the patient's preoperative range of motion and alignment should be performed, as well as radiographs obtained which help assess alignment and any preexisting hardware. Furthermore, it may be useful to allow the patient a preoperative trial period in a cylinder cast or knee immobilizer, so as to simulate life with a knee fusion [43].

Compression Arthrodesis

Compression arthrodesis using an external pin and frame technique was first popularized by Key and Charnley [7, 8, 48–50]. Multiple transfixation pins are now used. Half-pins (6.5 mm Schantz screws) at right angles to the transfixation pins augment stability. Other configurations, such as triangular frames with half-pin fixation, result in a high degree of anteroposterior and mediolateral stability [9, 51]. Furthermore, success with Ilizarov external fixation systems has been achieved.

The advantages of external fixation include stable compression across the fusion site with ability to dynamize and align appropriately [9, 51], technical ease of application and removal with limited exposure and decreased blood loss, ability to more easily manage soft tissue defects, and avoidance of deep, permanent hardware. In the presence of a deep or polymicrobial infection, external fixation may be preferred to internal fixation for arthrodesis so as to avoid implanted hardware. Disadvantages of external fixation include external pin tract problems and loosening, poor patient compliance, slower advancement of weight bearing, frequent need for premature removal and cast immobilization, nonrigid fixation in cases of severe bone loss, and

potentially a lower fusion rate when compared to intramedullary fixation [52].

Success has been achieved with external fixation compression arthrodesis [7, 8, 48–51]. Fusion rates of 50% occurred in series that included large numbers of failed hinged prostheses. In this situation, external fixation does not always provide the stability necessary for bone healing. Knutson and colleagues reported 91 attempted fusions for failed knee arthroplasty. Fusions after surface replacement arthroplasties were much more successful than those after hinged prostheses. They believed that both intramedullary rod and external fixation methods were successful and that repeated attempts at fusion were worthwhile [53]. External fixator devices must be in place for approximately 3 months; then cast immobilization is necessary until the arthrodesis is healed. One advantage of external fixation for treatment of septic knee replacements is that the device may be removed, leaving no retained hardware in the knee.

The use of compression plate fixation to achieve knee fusion has been frequently described [44, 45]. Dual plate fixation has been recommended to achieve rigid biplanar fixation, and Nichols achieved solid fusion of 11 knees after failed TKA at an average of 5.6 months [53]. A more extensive dissection is required, and the technique is demanding, especially in severely osteoporotic patients with significant bone loss where screw purchase may be compromised.

Surgical Technique

External Fixation Compression Arthrodesis

Existing midline incisions are used, and joint surfaces are prepared with a saw, parallel to each other and perpendicular to the longitudinal axis of the limb. Cutting jigs from a total knee arthroplasty tray may be used to make accurate resections and obtain the correct alignment. Transfixation pins are passed through the distal femur and the upper tibia. The pins are then connected to the frame and compression is applied. More specifically, however, external fixators can be uniplanar, biplanar, or circular. Uniplanar external fixators are typically applied anteromedially or anterolaterally to improve rigidity yet avoid the midline incision. They are easiest to apply, however may lack appropriate medial to lateral stability. Biplanar external fixators attempt to improve stability in the medial to lateral direction, but the increased pin number escalates the risk of neurovascular injury, pin tract infection, and stress fracture [43, 54]. Circular frames provide excellent stability, allow for fine-tuning of alignment, and early weight bearing. They can, however, be somewhat difficult to apply, are expensive, and can be cumbersome for the patient.

Intramedullary Rod Arthrodesis

Intramedullary rod fixation has been reported to achieve union in a high percentage of patients (Fig. 28.1) [55–64]. Knutson obtained fusion in 9 out of 10 knees treated with this method [61]. Donley et al. obtained an 85% fusion rate in 20 knees using intramedullary rod fixation and arthrodesis for the treatment of giant cell tumor, nonunion of a distal femur or proximal tibia fracture, aseptic loosening of a total knee replacement, and septic total knee replacement [55]. In addition, Griend [58], Harris [59], and Mazet [62] have reported successful results using this technique. Wilde, however, successfully fused only six of nine knees using an intramedullary rod technique [64].

Advantages of the intramedullary rod technique include immediate weight bearing and easier rehabilitation, avoidance of external transfixation pins and frames, high fusion rates, the potential for dynamization and load sharing, and increased stability in the bone weakened by atrophy or osteopenia in which screws or pins may pull out. The disadvantages include the risk of proximal rod migration requiring removal, difficulty achieving accurate alignment, intramedullary dissemination of infection, risk of fat embolism, and potential incompatibility with ipsilateral total hip arthroplasty.

After failure of a hinged arthroplasty, the femur and tibia may resemble hollow cones with little or no remaining cancellous bone. In this setting, external fixation devices cannot provide the stability required for arthrodesis (Fig. 28.2), but intramedullary fixation may be appropriate. Cortical bone is often irregular, partially

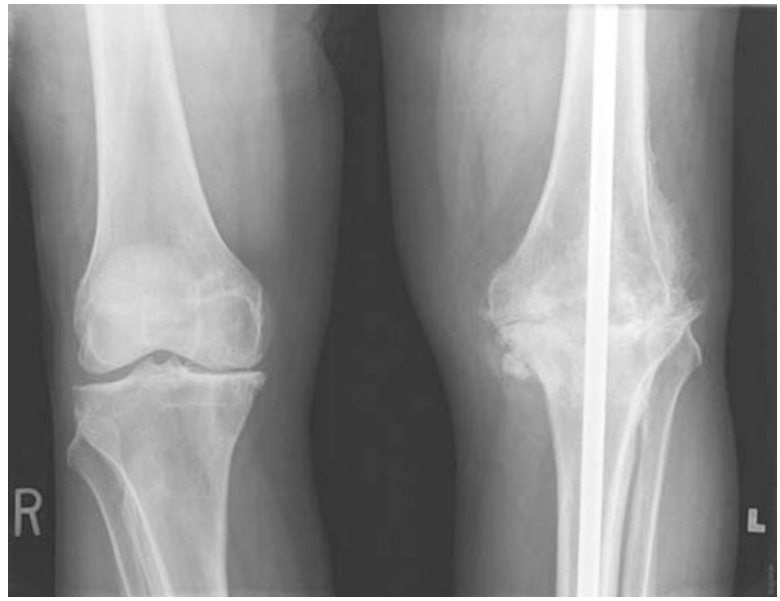

Fig. 28.1 A 70-year-old man with successful arthrodesis following failed two-stage reimplantation

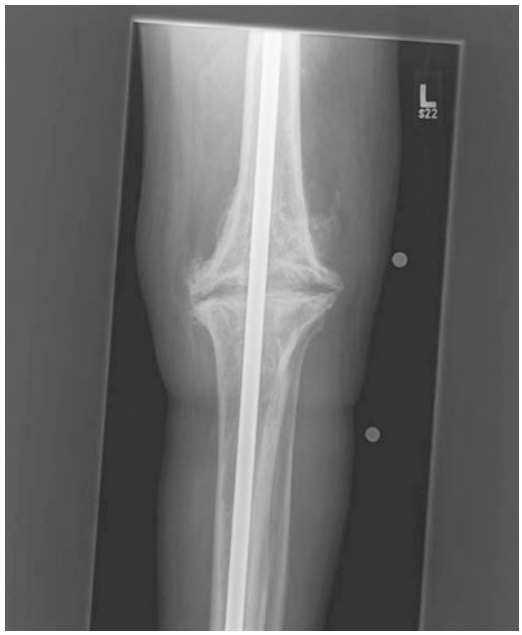

Fig. 28.2 Extensive bone loss precludes the use of extramedullary fixation. An intramedullary rod approximates remaining cortical bone, which is supplemented with autologous bone graft, and if necessary, morsellized allograft

devascularized, or impregnated with metallic debris. Kaufer et al. recommended an initial period of prolonged immobilization [60]. If this results in a stable, painless, fibrous ankylosis, then no further treatment is indicated [65]. After removal of the prosthetic components, a period of up to 1 year is allowed to pass before performing formal arthrodesis by intramedullary rod fixation.

Intramedullary arthrodesis has gained widespread favor for the salvage of severely infected knee replacements. Most authors recommend performing the procedure in two stages, although Puranen has reported single-stage arthrodesis in a few patients who were infected with organisms exquisitely sensitive to antibiotics [63]. However, the best results occurred with a staged arthrodesis after administration of 4–6 weeks of intravenous antibiotic therapy between prosthetic removal and arthrodesis [63]. Kaufer recommended a curved, nonmodular Kuntscher rod that was cut down to an appropriate length during the procedure [55, 59]. In severe infections in which a two-stage reimplantation of a new total knee replacement is less likely to succeed, e.g., *Clostridium perfringens* [13] and *Candida albicans* [66], successful arthrodesis has been achieved. New, safer, fungal-specific antimicrobial drugs may make salvage of the latter infection possible in the future. In our series, we reported the results of intramedullary arthrodesis

of the knee after failed septic TKA [67]. Union occurred in 16 out of 17 patients (94%) at an average of 16 weeks.

Stiehl has reported eight cases of knee arthrodesis using combined intramedullary rodding and plate fixation [46]. By adding a compression plate, intramedullary nail arthrodesis can be extended to situations in which bone loss requires a segmental allograft.

Nonmodular Intramedullary Rod

Our technique of intramedullary arthrodesis of the knee has been previously described [68]. The original longitudinal incision is used whenever possible. The knee joint is exposed in a manner similar to that used in revision arthroplasty, and all scar tissue is resected. Cancellous bone is completely exposed on the distal femur and proximal tibia. An intramedullary ball-tip guidewire is introduced into the tibial shaft to the plafond of the ankle (Fig. 28.3). The canal is sequentially reamed until the cortex is engaged at the tibial isthmus. This canal width determines the intramedullary rod diameter. The tibial length is measured using the guide rod as a reference.

The ball-tip guidewire is removed from the tibial canal and inserted into the femoral shaft until it contacts the piriformis recess (Fig. 28.4). The femoral canal is reamed until it matches the size of the tibial reamer. The femoral length is measured using the guide rod at the piriformis fossa as a reference. Subtracting 1 cm from the combined length of the femur and tibial measurements determines the appropriate rod length. The guidewire is tapped proximally through the piriformis recess with a mallet (Fig. 28.5). The guidewire is advanced until it can be easily palpated under the skin of the thigh, with the leg in an adducted position. An incision is made over the guidewire, and dissection is carried down through the gluteal musculature to the piriformis recess. The recess is reamed progressively to a size 1 mm larger than the tibial and femoral reamer size (Fig. 28.6). After reaming, an arthrodesis nail of the appropriate length is inserted (Fig. 28.7). Compression is applied to

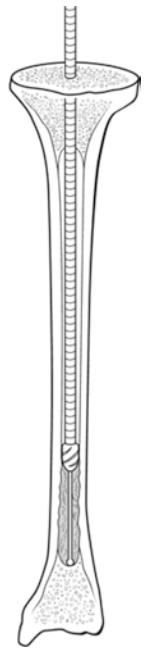

Fig. 28.3 An intramedullary ball-tipped guidewire is introduced into the tibial shaft to the plafond of the ankle. The canal is sequentially reamed until the cortex is engaged at the tibial isthmus. This canal width determines the intramedullary rod diameter. The tibial length is measured using the guide rod as a reference

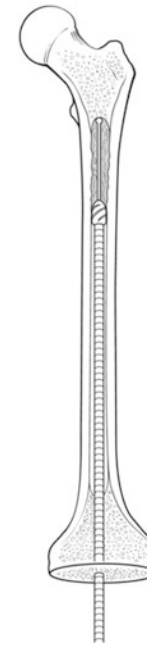

Fig. 28.4 The ball-tipped guidewire is removed from the tibial canal and inserted into the femoral shaft until it contacts the piriformis recess. The femoral canal is reamed until it matches the size of the tibial reamer. The femoral length is measured using the guide rod at the piriformis fossa as a reference

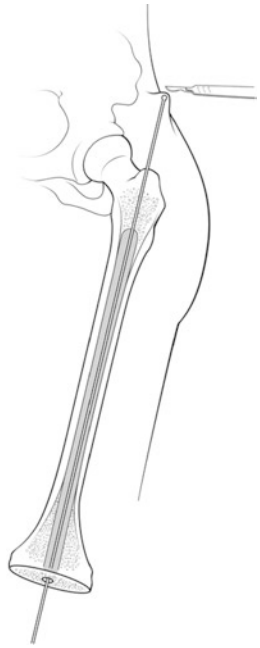

Fig. 28.5 The guidewire is tapped proximally through the piriformis recess with a mallet. The guidewire is advanced until it can be easily palpated under the skin of the thigh, with the leg in an adducted position. An incision is made over the guidewire, and dissection is carried down through the gluteal musculature to the piriformis recess

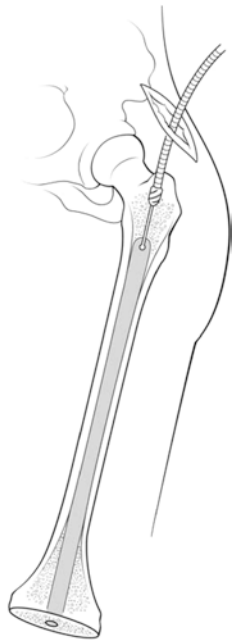

Fig. 28.6 The recess is reamed progressively to a size 1 mm larger than the tibial and femoral reamer size

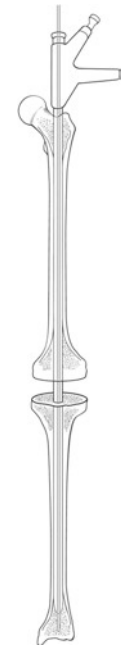

Fig. 28.7 After reaming, an arthrodesis nail of the appropriate length is inserted

the arthrodesis site by applying a retrograde force to the tibia by striking the heel (Fig. 28.8). The patella may be used to augment the fusion by using two 6.5 mm cancellous screws for fixation at the level of the resection.

In the treatment of traumatic femoral shaft fractures, an intramedullary nail is inserted with its curve following the anterolateral bow of the femur. However, in intramedullary knee arthrodesis, if the rod follows the anterolateral bow of the femur, it creates varus alignment with slight hyperextension. For this reason, the rod is inserted with the curve positioned anteromedially down the femoral shaft. The rod then comes through the tibia in valgus and slight flexion at the knee, which is a preferred position of arthrodesis. An axial load is placed on the proximal tibia against the distal end of the femur during rod insertion. Sometimes the rod forces the anterior tibial flare forward, making closure of the arthrotomy difficult. If this occurs, the surgeon may modify the anterior flare with a reciprocating saw. Resected bone and intramedullary reamings should be used as autograft, although some authors consider this unnecessary [55].

Fig. 28.8 Compression is applied to the arthrodesis site by applying a retrograde force to the tibia by striking the heel

Interlocking screws or wiring of the proximal portion of the rod has been recommended to prevent proximal migration [55, 59].

Modular Intramedullary Nail

Alternatively, intramedullary rodding may be accomplished using the Neff femorotibial nail (Zimmer, Inc., Warsaw, IN) or the Wichita nail (Stryker, Allendale, NJ), which is comprised of independent femoral and tibial rods coupled at the knee joint (Fig. 28.9a, b). Advantages of this technique include independent sizing of the femoral and tibial diaphysis, the elimination of proximal or distal rod migration, the elimination of a surgical incision about the hip, and the ability to accommodate a future ipsilateral total hip arthroplasty.

The intramedullary canal is sequentially reamed until the cortex is engaged at the tibial and femoral isthmus. This canal width of the tibia and femur determines the size of the tibial and femoral portions of the nail. The bony surfaces of the tibia and femur are prepared to maximize bony contact. The tibial and femoral lengths are measured using fluoroscopy. The appropriately sized tibial and femoral components are selected. As the components are of a fixed length, any shortening of the components is accomplished with a Midas Rex diamond-tipped cutting wheel. After preparing the femoral and tibial metaphyses to accept the articulated portion of the nail, the actual components are inserted into the tibia and femur, respectively. The male and female portions of the nail are coupled. Several blows to the heel secure compression of the Morse taper, which is then reinforced with two set screws. Autologous bone from the intramedullary reamings is then packed about the fusion site. The patella may be used as an additional source of autologous graft and is secured using two 6.5 mm cancellous screws.

Plate Fixation

Rigid fixation for arthrodesis can be achieved with internal plate fixation. This technique involves plate osteosynthesis, either in a tension band fashion anteriorly, or dual plating medially and laterally, to compress the distal femur and proximal tibia and achieve rigid fixation. Several studies have evaluated plate fixation for knee arthrodesis with good results [45, 69]. Following arthrodesis with plate fixation, patients may bear partial weight on the operative extremity. While results of plating for knee arthrodesis are promising, one particular downside of this technique is that in the presence of an infection, an internal device may necessitate its removal to eradicate the infection, while compromising the fusion.

Resection Arthroplasty

Resection arthroplasty is accomplished by excising the opposing articular surfaces of the distal femur and proximal tibia (Fig. 28.10). Complete removal of scar tissue, synovium, and all foreign material, including metallic hardware, knee replacement components, and acrylic cement is mandatory [65, 70]. This option is generally reserved for medically fragile patients who cannot tolerate a two-stage reimplantation protocol. It may also serve as an intermediate step for the patient who has reservations about arthrodesis.

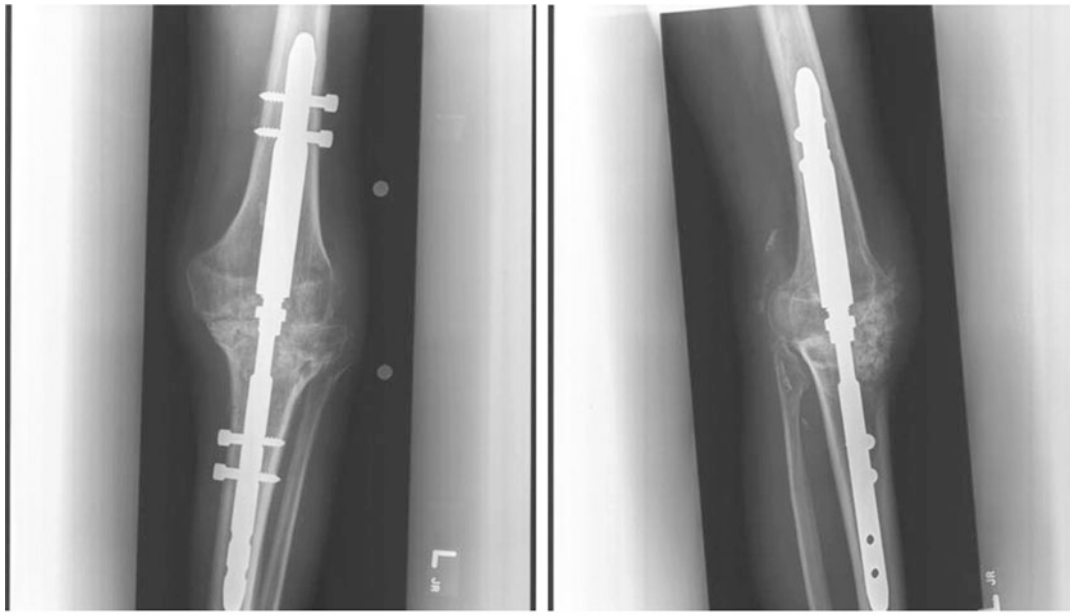

Fig. 28.9 (**a** and **b**) Successful intramedullary arthrodesis using the modular Wichita nail

Fallahee et al. reported 28 knees that underwent resection arthroplasty for infected total knee arthroplasty [65]. Six patients with prior monarticular osteoarthritis found the resection arthroplasty unacceptable and underwent successful arthrodesis. In three patients, spontaneous bony fusion developed after the resection, with the knee in satisfactory alignment. Patients with more severe disability before the original knee arthroplasty were more likely to be satisfied with the functional results of the resection arthroplasty. Conversely, patients with less disability originally were more likely to find the resection arthroplasty unacceptable. Fifteen patients walked independently. Five of those patients were able to stand and walk without external limb support. The other ten patients used either a knee-ankle-foot orthosis or a universal knee splint. All 15 patients, however, required either a cane or walker and remained either moderately or severely restricted in their overall walking capacity.

Definitive resection arthroplasty is useful for the severely disabled sedentary patient. The procedure is least suitable for patients with relatively minor disability before their original total joint replacement. In the latter group, arthrodesis or reimplantation of a total knee replacement is recommended, if possible, depending on the sensitivity of the organism and adequacy of the antibiotic treatment. The advantage of the resection arthroplasty is that some motion is preserved for sitting and transferring into and out of automobiles. The disadvantages are persistent pain and instability with walking.

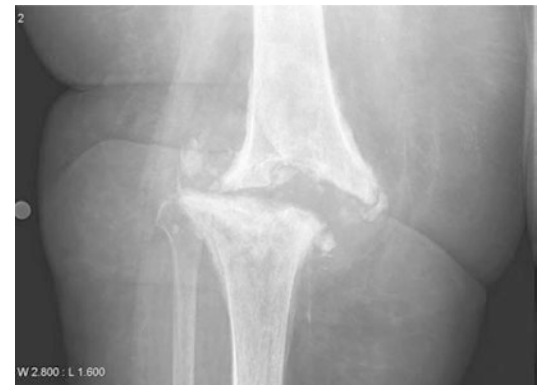

Fig. 28.10 Resection arthroplasty in an obese elderly woman following failed septic TKA with recurrent sepsis

A modified resection arthroplasty has been presented for problem cases with sepsis or excessive loss of bone stock, in which exchange arthroplasty or arthrodesis is inadvisable or impossible [71]. The space between the femur and tibia is filled with a bolus of antibiotic-impregnated polymethylmethacrylate after implant removal. The cement spacer improves initial stability and diminishes functional limb length discrepancy. Furthermore, the spacer maintains a potential space for easier reimplantation of a TKA after spacer removal in the future [72–74].

Complications of Arthrodesis

Notable complications of knee arthrodesis include nonunion, fracture, thromboembolism, infection, and neurovascular injury. Patients with insufficient bone stock, infection, or inadequate fixation are prone to nonunion, which can be a source of persistent pain. Regardless of the technique, union may not occur. In our report of 17 intramedullary knee arthrodeses for the treatment of failed septic TKA, complications occurred in ten patients, including recurrent infection, nonunion with subsequent nail breakage, proximal migration of the nail, and perforation of the ankle joint [67]. If the resulting pseudarthrosis is painful, the arthrodesis should be revised to enhance stability at the nonunion site. Failed intramedullary fusion with pseudarthrosis may eventually cause breakage of the rod. Fatigue fracture of the rod occurs at or near the pseudarthrosis site. Arthrodesis may be revised using a larger intramedullary nail supplemented by autologous bone grafting. Other sources of pain can include hip pain from proximal migration of an intramedullary nail, especially if no interlocking screws are used. Femoral or tibial fractures can occur after successful arthrodesis secondary to increased forces generated from a large single bone moment arm.

A successful arthrodesis may remain actively infected, particularly if foreign material or necrotic tissue remains. With external fixation, pin tract infections may require premature removal of the apparatus and can seed the intramedullary canal if followed by intramedullary rod fixation.

As mentioned previously, knee arthrodesis can have a profound effect on the hip, ankle, and spine due to altered mechanics. Back pain has been reported, and patient satisfaction is modest, even with the best arthrodesis. Shortening of the lower extremity is common with an average of 3 cm and needs to be discussed with the patient thoroughly preoperatively. A stiff limb, although painless and functional, can be socially unacceptable. Arthritis and functional limitations in these areas should be evaluated prior to performing a knee fusion. Furthermore, a patient considering knee arthrodesis may benefit from a trial in a cylinder cast to understand the permanent disadvantages of a stiff limb.

Conversion of a solid knee arthrodesis to TKA has been reported [16]. This procedure is relatively contraindicated for the following reasons: (A) collateral ligament integrity is compromised; (B) long-standing fusion may result in permanent contracture and scarring of surrounding musculature, limiting knee flexion after conversion; (C) muscle atrophy may not be irreversible and leaves a residual extension lag; (D) the new arthroplasty is at greater risk of infection or mechanical problems than are routine knee replacements; and (E) if subsequent septic or aseptic failure occurs, there is probably a decreased chance of successful fusion.

Outcomes of Arthrodesis

Fusion rates in knee arthrodesis have been shown to range from 38 to 100% depending on the technique utilized [43]. Overall, intramedullary nail fixation appears to have a higher fusion rate, especially following a failed TKA. Notably, Knutson et al. found that while intramedullary nails were effective in arthrodesis, external fixation for failed TKA had a failure rate of >50% [53]. Factors that appear to result in a lower fusion rate include infected knees, rheumatoid arthritis, and knees that are status-post failed TKA. However, when comparing arthrodesis techniques including external fixation, internal fixation, and intramedullary nailing, none have definitively been shown to be superior in all situations, and each has its own benefits and drawbacks [75].

While knee arthrodesis is functionally limiting and associated with a certain stigma of failure of reconstructive options, for the appropriate patient with realistic expectations, a knee arthrodesis may be of benefit in that it can relieve pain and, in a sense, be a definitive procedure without extensive postoperative rehabilitation.

Summary

Arthrodesis as a salvage procedure remains a durable, time-proven technique for treatment of sepsis, tumor, failed arthroplasty, and the flail limb [76, 77]. It should be performed selectively, especially in light of modern arthroplasty and the increasingly favorable results of two-stage reimplantation. Arthrodesis of the knee can be performed via various techniques [78–80]. Each technique has a role in these difficult salvage knee cases.

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