Partial Knee Arthroplasty

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Preface

Partial knee replacements have a long history in the treatment of knee disease. Initially described in the early 1970s as an alternative to total knee replacement, the concept of a resurfacing option limited to one of the three compartments of the knee continues to play a role managing knee disease.

Partial knees have delivered on their promise of a less invasive procedure with earlier recoveries and increased patient outcome and satisfaction compared to total knee replacement. They do represent some of the so-called forgotten knees every surgeon and patient is dreaming to achieve following surgery.

As we enter into the fourth decade of use, multiple authors have reported on long-term outcomes that rival and in many cases outperform total knee replacements.

The purpose of our book was to collect an international faculty of experts in the field who will review the North American, European, and Asian perspectives on the state of the art in partial knee replacement. It was our intention, as editors of this book, to deliberately for the first time on a routine basis create international binomials in order to deliver in each chapter a consensual international perspective on partial knee replacement. From indications to surgical technique and through results, the reader will have access to the latest thoughts and opinions of the world's leading unicompartmental knee arthroplasty surgeons.

We hope that this book will be a valuable addition to those interested in partial knee surgery all around the world.

Marseille, France — Jean-Noël A. Argenson
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Contents

Introduction

It is a well-known fact that history repeats itself. In the world of knee arthroplasty, this is certainly true. The Gunston polycentric knee, which is considered the original predecessor to modern day total knee arthroplasty, was merely two partial knee replacements – one for the medial compartment and one for the lateral compartment. As in many of the early designs which followed this implant, the patellofemoral articulation was ignored. With subsequent failure of these designs, the current tri-compartmental condylar design was introduced. It was met with great enthusiasm and large marketing budgets. The short, intermediate, and ultimately long-term results were excellent. Despite this, a number of centers throughout the world continued to be proponents of partial knee arthroplasty. While there have been significant advancements in total knee arthroplasty, there has also been an increased demand from more sophisticated customers. As in the hip, knee patients are looking for the forgotten knee. It is a well-known fact that removing the anterior cruciate ligament changes the entire kinematics of the knee. Therefore, there has been a paradigm shift. Surgeons are approaching the knee based on the compartmental anatomy. Specific compartment replacement has been showed to alleviate the patient's symptoms and offer a more normal functioning knee, hence the value of this textbook. We are truly a global society. In order to deliver the best care to our patients, we must appreciate the perspectives of everyone involved in our specialty. Only then can we call ourselves a well-rounded, well-educated orthopedic surgeon prepared to deliver the best that the world has to offer to our patients.

Columbus, OH, USA — Adolph V. Lombardi
Oxford, UK — Christopher A. Dodd

1 Indications of Partial Knee Arthroplasty: Consensus Statement

Keith R. Berend and Christopher A. Dodd

Introduction

Unicompartmental knee arthroplasty (UKA) has been advocated as a conservative alternative to total knee arthroplasty (TKA) in specific patients with osteoarthritis isolated to one compartment of the knee [1, 2]. Survivorship of various implant designs of UKA ranges between 91% at 20 years and 98% at 10 years [3, 4]. UKA is associated with a faster recovery [5–7], better range of motion [8], a higher activity level [4, 9], and fewer perioperative complications [10] when compared to TKA. Perhaps the most significant issue detracting from the utilization of UKA, however, is that most reports in national registries demonstrate a 3 times higher revision rate following UKA compared with TKA [11, 12] with many of these revisions occurring early compared with TKA [13]. In 1989, indications and contraindications for UKA by Kozinn and Scott were published. Over time these became accepted as the classic selection criteria [14]. Over the past three decades, the indications and contraindications for and against UKA have been widely reported and debated. Most recently a consensus statement on the modern indications and contraindications for medial UKA was published detailing the clinical evidence for increased utilization of UKA [15]. The consensus indications broadly detail the variables that surgeons may be concerned with when deciding between UKA and TKA.

The indications described below are based mainly on the mobile-bearing UKA, which are well-defined and evidence-based. The indications for the fixed-bearing UKA were originally based on Kozinn and Scott as previously stated. Many surgeons now base the fixed-bearing UKA indications on the mobile-bearing UKA, and we await evidence to show whether this is correct or not.

This chapter paraphrases and summarizes the conclusions of that recent publication. These indications and contraindications, unless otherwise noted, apply to all forms of unicompartmental arthroplasty: medial, lateral, and patellofemoral.

The primary indication for medial UKA is anteromedial osteoarthritis (AMOA; Fig. 1.1) [1–3, 15–17]. AMOA is defined as bone-on-bone, Grade IV disease, or eburnated bone on the femoral condyle and tibial plateau. The severity of disease can be identified on standing anterior-posterior radiographs or 30–45° flexed posterior/anterior views (Rosenberg views) and/or patellofemoral disease with axial or sunrise views of the

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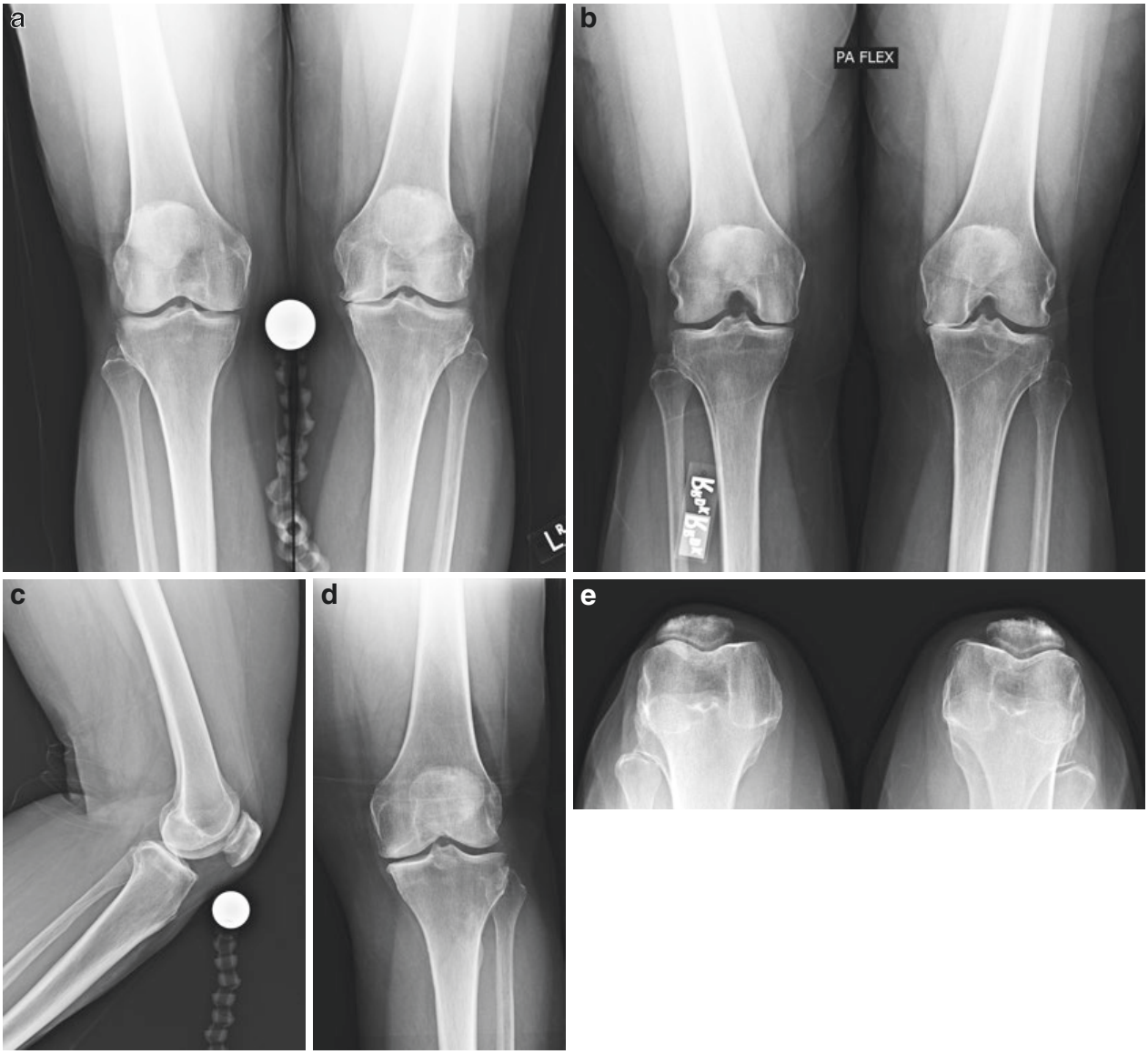


Fig. 1.1 Anteromedial osteoarthritis – a 68-year-old female patient with moderate to severe left knee pain was diagnosed with anteromedial osteoarthritis of the left knee and recommended for medial UKA based on clinical examination and radiographic evaluation that included (**a**) standing weight-bearing anterior-posterior, (**b**) 30–45° posterior-anterior flexed, (**c**) lateral, (**d**) valgus stress, and (**e**) axial or sunrise patellofemoral views

patellofemoral joint. If bone-on-bone arthritis is suspected but not shown on these views, then varus stress view radiograph is performed to confirm Grade IV disease.

In isolated disease, AMOA represents a functionally and ligamentously normal knee with intact anterior cruciate ligament, correctable varus deformity, and functionally intact lateral compartment. Functionally intact lateral compartment is defined as normal joint space preservation on stress radiographs, and visual exam of articular cartilage appears normal following medial arthrotomy. Radiographic evidence of lateral compartment spurring is not a contraindication. AMOA presents with intra-articular varus deformity that is fully correctible with maintenance of the lateral joint space, on valgus stress radiograph. The overall limb alignment is irrelevant if the intra-articular deformity (genu varum) is correctable on stress radiograph or is correctable intraoperatively following osteophyte removal. It is suggested that AMOA and the correctable deformity are present when the mechanical knee alignment is 10° of varus or less and when there is less than a 15° flexion contracture. While the magnitude of deformity

is not in itself an absolute contraindication, deformity greater than 10° in the coronal plane and 15° of fixed flexion will routinely be associated with ACL deficiency and is, by definition, not AMOA. Magnetic resonance imaging (MRI) and arthroscopic evaluation have not been validated as accurate methods for determining candidacy.

Isolated bone-on-bone lateral disease is confirmed in much the same way with stress radiographs, PA flexion views, and correctable deformity. These same views can confirm normal tibiofemoral joint in isolated patellofemoral disease.

An additional widely accepted indication for medial UKA is avascular necrosis (AVN; Fig. 1.2) [18, 19]. AVN involving and isolated to the medial compartment is another excellent indication for medial UKA whether spontaneous or following previous surgical intervention. MRI may be beneficial in defining disease as isolated to the medial compartment. However, MRI can be misleading as to the severity of disease with extensive edema is evident, while adequate bone support is almost always still be present for successful UKA.

Since the initial publication by Kozinn and Scott [14], obesity or high body mass index

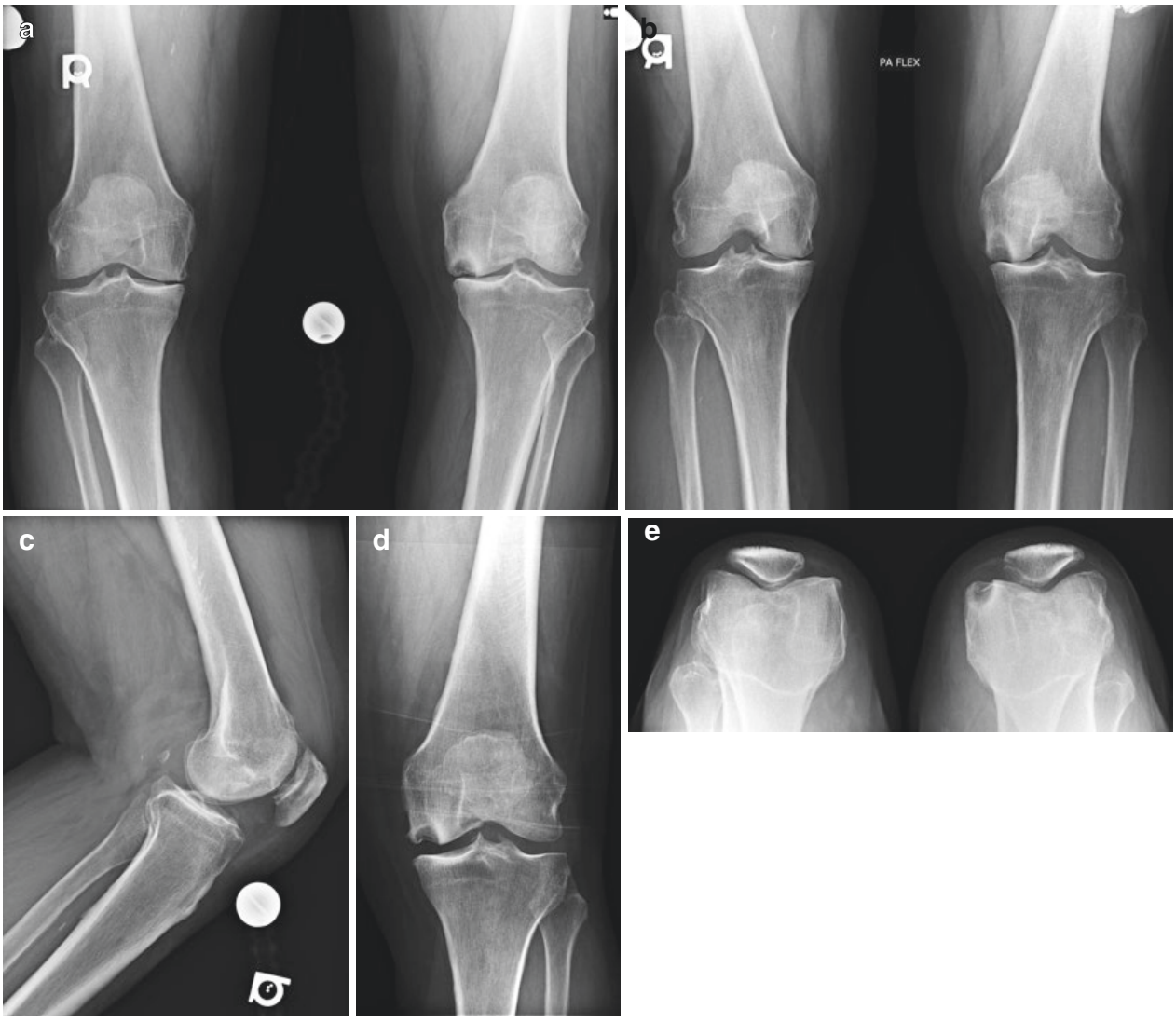


Fig. 1.2 Avascular necrosis of the medial femoral condyle – A 72-year-old male patient with severe left knee pain was diagnosed with avascular necrosis of the left medial femoral condyle and recommended for medial UKA based on clinical examination and radiographic evaluation that included (**a**) standing weight-bearing anterior-posterior, (**b**) 30–45° posterior-anterior flexed, (**c**) lateral, (**d**) valgus stress, and (**e**) axial or sunrise patellofemoral views

(BMI) has been considered a contraindication. The concern regarding BMI and obesity is in the longevity and survival of medial UKA [20–23]. Previously published reports have noted poor survival in obese patients with BMI over 32 kg/m^2 using fixed-bearing, all-polyethylene implants, and thus they are a concern. More recent series with modern metal-backed designs have shown excellent survivorship in obese patients. This survival may be equivalent or higher than in patients of more normal weight. Furthermore, a higher improvement in knee scores may be obtained with UKA in the more obese patients. Recently, Lum et al. published a large comparative series in which severely obese patients who underwent medial UKA demonstrated equal survivorship with substantially fewer reoperations, reduced deep infection, and fewer perioperative complications than TKA [24]. Severely obese patients had improved Knee Society functional scores and maintenance of range of motion after UKA compared with TKA [24]. With a metal-backed UKA, obesity or increasing BMI is not considered a contraindication.

Historically, younger age has been a concern for UKA survival. However, in patients with AMOA, age is no longer considered as a contraindication to UKA [20, 25, 26]. The same may be true for lateral and PFR, but limited specific data related to age exist. Berend et al. noted, "In registry studies younger age is associated with increased risk of revision; however, these types of studies do not address severity of disease. There exists a bias towards performing UKA in younger patients with less severe disease and higher expectations. Revisions in this population, while higher, are not correlated to activity or age. Instead, younger patients are more frequently revised for unexplained pain, or failure to meet expectations. Nevertheless, UKA is an attractive alternative in the younger patient as a conservative first arthroplasty in this age group. It is important that an initial conservative tibial resection is planned to make any future revision equivalent to a primary TKA" [15].

There continue to be debate and disagreement regarding the status of the patellofemoral joint (PFJ) and indications for medial UKA. In the consensus statement, the three mobile-bearing UKA surgeons stated that the status of the PFJ was irrelevant and not a contraindication unless there was severe lateral facet patellofemoral joint osteoarthritis (PFJOA). The three fixed-bearing UKA surgeons were much more concerned about the influence of PFJOA on the results. Full-thickness cartilage loss within the lateral facet of the patella and/or lateral trochlea, with or without lateral patellar subluxation, is a contraindication to medial UKA for many surgeons. For mobile-bearing UKA, only bone loss and grooving in the lateral patellofemoral joint is considered a contraindication. This occurs in 1% of patients with AMOA. Other degenerative findings within the patellofemoral joint have been shown to be acceptable and not to be considered as contraindications [20, 27, 28]. Preoperative spurring, disease of the medial facet and/or trochlear disease on axial radiographs, intraoperative evidence of medial facet degeneration or trochlear disease, and the presence of so-called anterior knee pain on physical examination are not an absolute contraindication in the knee with AMOA [29]. Most recently, these data were supported by a midterm study published by an independent, non-designer surgeon [30]. One hundred UKA were evaluated, and the presence of patellofemoral disease was not associated with higher failure. However, the authors did note that while all patients demonstrated improvements in pain and function, those with central or lateral Grade III patellofemoral disease had lower scores. Medial patellofemoral disease did not affect outcomes in any fashion [30].

Finally, surgeons have historically been concerned with chondrocalcinosis. Certainly, the presence of clinically relevant inflammatory disease (calcium pyrophosphate deposition or crystalline arthropathy) with a history of synovitis, effusion, and/or popliteal cyst is a contraindication. However, chondrocalcinosis or radiographic evidence of calcium within the cartilage or meniscus is not a contraindication to UKA [20, 31, 32].

There are several absolute contraindications to UKA including obvious joint infection or inflammatory disease [33]. Additionally, the authors of this chapter believe that previous high tibial osteotomy should also be considered a contraindication [34, 35]. The previous extra-articular alignment procedures create significant overcorrection when the intra-articular varus deformity is treated with UKA. This may lead to premature failure of the lateral compartment. While one study suggests that previous HTO may not be a contraindication [35], given the complex nature of this clinical scenario, the authors believe that previous HTO remains a contraindication.

The presence of a functionally intact anterior cruciate ligament (ACL) is one of the hallmarks of AMOA. However, there are certain cases in which ACL deficiency may be safely ignored or concomitant ACLR may be performed with medial UKA [36–40]. No data exist on the results of lateral or patellofemoral UKA in ACL deficiency, so it is recommended that this be avoided. UKA may still be considered in medial disease if the deformity remains fully correctable and the disease has not progressed to a posterior medial wear pattern. Recommendations for slight variance in surgical technique have been proposed, with reduction in posterior slope in these cases [41]. Interestingly, there is consensus that in sedentary or elderly patients, ACL laxity/deficiency is not a contraindication when all other indications are met.

Anteromedial osteoarthritis is the primary indication for medial UKA, and it is strongly recommended that the procedure be reserved for patients in whom severe bone-on-bone disease has been documented clinically and radiographically. Several studies have demonstrated poorer outcomes and survival when medial UKA is used in patients with milder presentation of disease with partial-thickness cartilage loss [42–44]. In one study, the reoperation rate was 6 times higher when preoperative thickness of the medial joint space was greater than 2 mm versus 2 mm or less on standard weight-bearing radiographs in extension [43]. In another more recent study, patients with partial thickness cartilage loss in their knees had significantly worse outcomes at 1, 2, and 5 years after UKA compared with those with full-thickness cartilage loss and a threefold greater rate of reoperation – mainly arthroscopy for persistent pain [42].

The indications and contraindications for UKA have been debated and researched for decades. In recent years many of the classic criteria have been questioned and challenged with a recent consensus statement being produced [15]. In the most basic terms, UKA is indicated when osteoarthritis or avascular necrosis is isolated to a single compartment in a ligamentously normal knee. To make this decision easier for the surgeon and patient, a recent study has provided a radiographic decision aid that proved to be 93% sensitive and 96% specific for indicating UKA. In those patients who met the radiographic criteria for UKA, there was 99% 5-year survival of medial UKA (Fig. 1.3) [45]. Utilizing these simplistic criteria, up to 50% of knees may be candidates for UKA and survivorship.

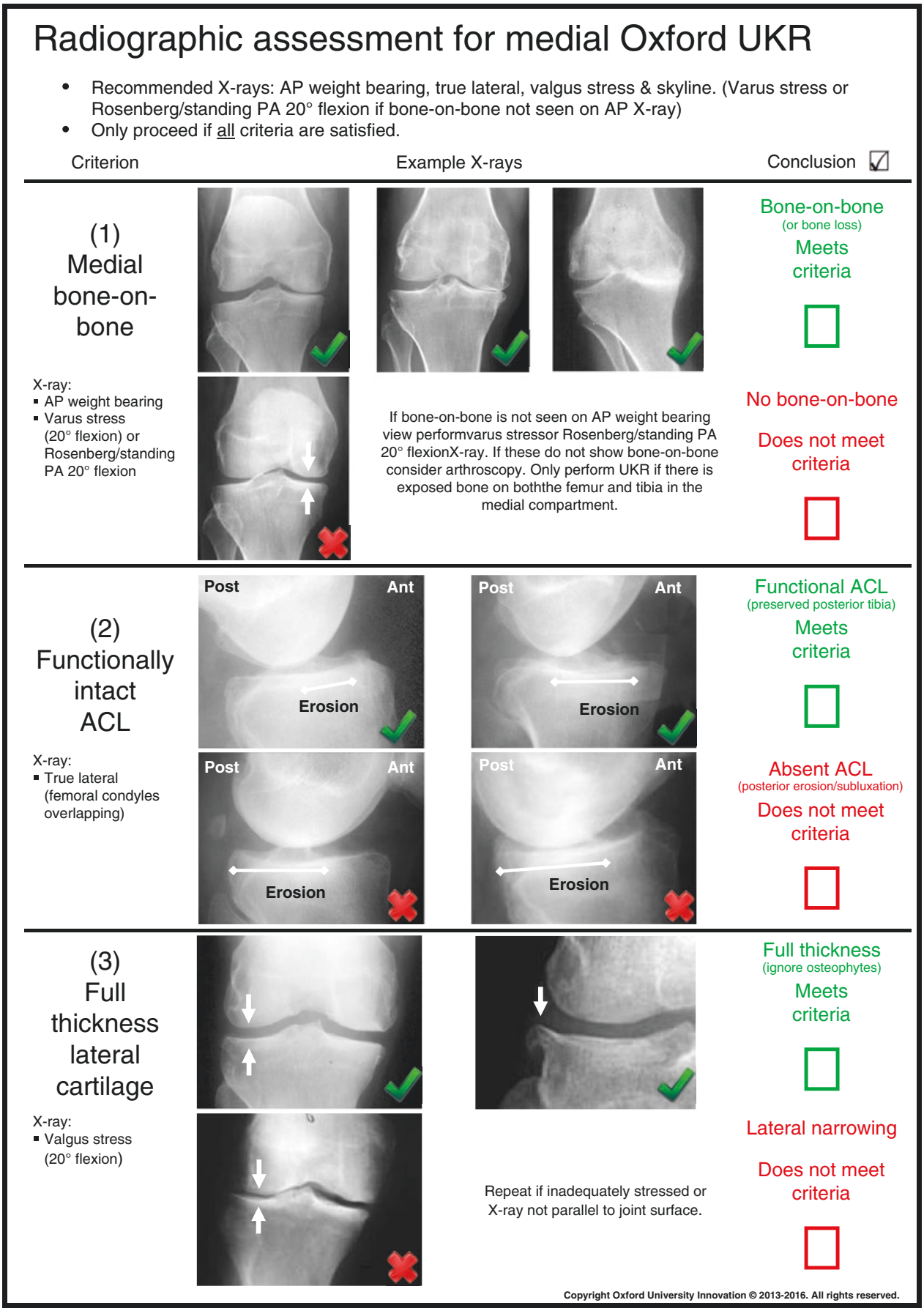
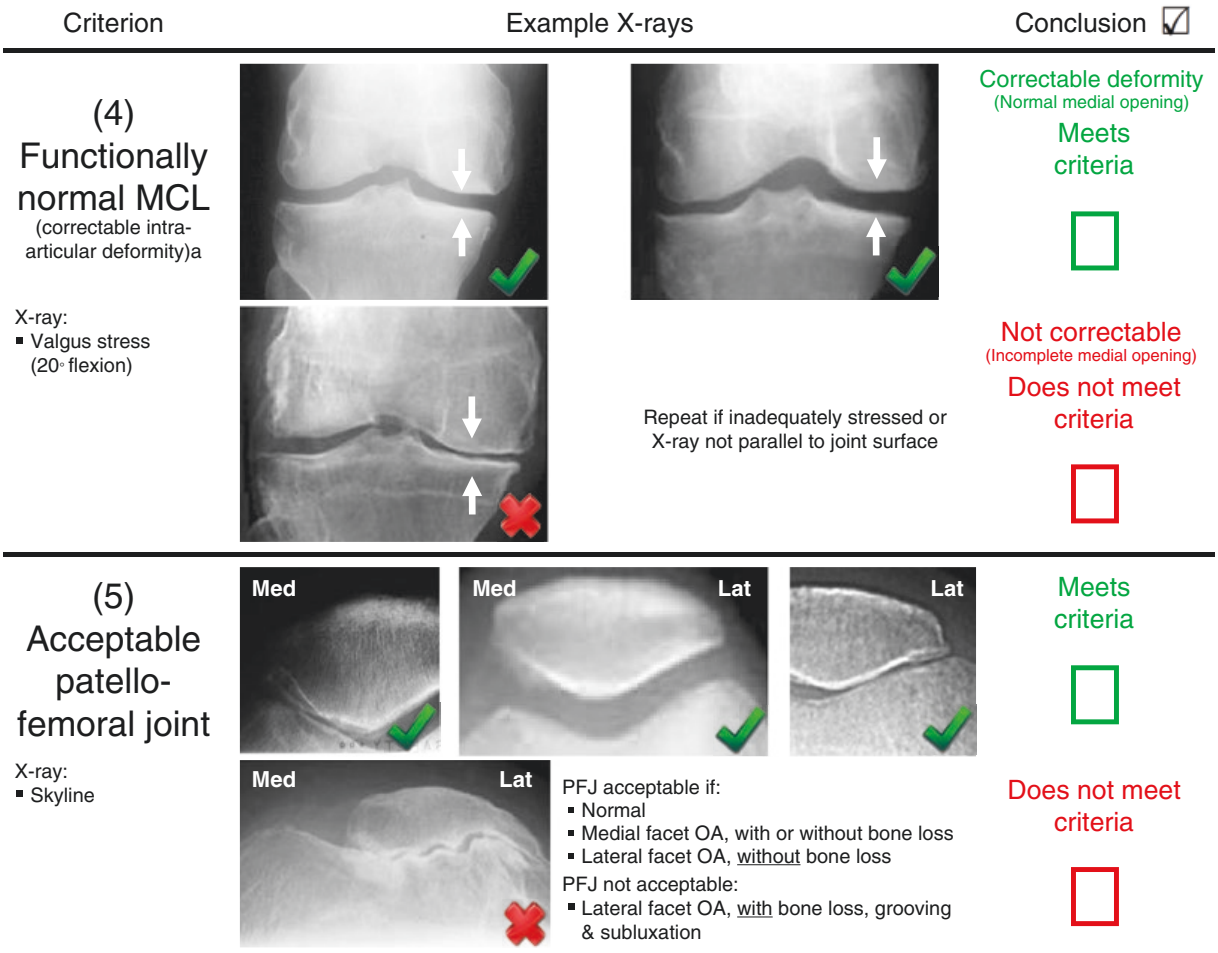


Fig. 1.3 A radiological assessment tool for medial mobile-bearing unicompartmental knee arthroplasty (UKA) has been shown to be 93% sensitive and 96% specific for indicating UKA. (Reproduced with permission from Hamilton et al. [45])

Radiographic assessment for medial Oxford UKR



The primary indication for the Oxford UKR is anteromedial OA. The diagnosis of anteromedial OA is based on the radiographic criteria shown above [1]. Medial avascular necrosis is also an indication.

The following factors do not preclude Oxford UKR if all other criteria are met:

- Isolated medial pain is not a requirement. Pre-operative anterior knee painhas been reported to not compromise the outcome [2,3].
- Patient's age, weight and activity level [4-6].
- Chondrocalcinosis (cartilage calcification on X-ray), lateral marginal osteophytes ormedial tibial subluxation (which should correct when the UKR is implanted if the ACL is intact) [6-8].

The final decision on whether to perform UKR is made when the knee has been opened and directly inspected. The following factors do not preclude Oxford UKR if all other criteria are met:

- Full thickness cartilage loss on the non-weight bearing medial side of the lateral femoral [9].
- Full thickness cartilage loss in the patellofemoral joint

[1] Hamilton TW et al. Validation of a Radiological Decision Aid to Determine Suitability for Medial Mobile-bearing Unicompartmental Knee Replacement. NIHR Doctoral Research Training Camp Poster. July 2015.
[2] Berend K et al. Does Preoperative Patellofemoral Joint State Affect Medial Unicompartmental Knee Arthroplasty Survival? AAOS Poster No. P204. February 2011.
[3] Liddle AD et al.Preoperative pain location is a poor predictor of outcome after Oxford unicompartmental knee arthroplasty at 1 and 5 years. KSSTA 21:2421-6, 2013.
[4] BerendK. et al. Obesity, Young Age, Patellofemoral Disease and Anterior Knee Pain: Identifying the Unicondylar Arthroplasty Patient in the United States. Orthopedics. 30:19–23, 2007.
[5] Kang, S. et al. Pre-operative Patellofemoral Degenerative Changes Do Not Affect the Outcome After Medial Oxford Unicompartmental Knee Replacement. JBJS Br. 93-B:476–8, 2010.
[6] Pandit H. et al. Unnecessary Contraindications for Mobile-bearing Unicompartmental Knee Replacement. JBJS Br.93-B:622–8, 2011.
[7] Goodfellow JW, O'Connor J, Pandit H, Dodd C, Murray D. Unicompartmental Arthroplasty with the Oxford Knee (2nd Edition), Goodfellow Publishers, Oxford, UK, 2015. [8] Kumar V et al.Comparison of Outcomes after UKA in Patients With and Without Chondrocalcinosis: A Matched Cohort Study. KSSTA 2015 *online* 19 March 2015.
[9] KendrickBJ et al. The implications of damage to the lateral femoral condyle on medial unicompartmental knee replacement. JBJS Br 92(3)374-9, 2010.

Fig. 1.3 (continued)

References

1. Berend KR, Lombardi AV. Liberal indications for minimally invasive Oxford unicondylar arthroplasty provide rapid functional recovery and pain relief. Surg Technol Int. 2007;16:193–7.
2. White SH, Ludkowski PF, Goodfellow JW. Anteromedial osteoarthritis of the knee. J Bone Joint Surg Br. 1991;73-B(4):582–6.
3. Murray DW, Goodfellow JW, O'Connor JJ. The Oxford medial unicompartmental arthroplasty. J Bone Joint Surg Br. 1998;80-B(6):983–9.
4. Price AJ, Svard U. A second decade lifetable survival analysis of the Oxford unicompartmental knee arthroplasty. Clin Orthop Relat Res. 2011;469:174–9.
5. Newman JH, Ackroyd CE, Shah NA. Unicompartmental or total knee replacement? Five-year results of a prospective, randomised trial of 102 osteoarthritic knees with unicompartmental arthritis. J Bone Joint Surg Br. 1998;80-B(5):862–5.
6. Reilly KA, Beard DJ, Barker KL, Dodd CA, Price AJ, Murray DW. Efficacy of an accelerated recovery protocol for Oxford unicompartmental knee arthroplasty – a randomised controlled trial. Knee. 2005;12(5):351–7.
7. Svärd UC, Price AJ. Oxford medial unicompartmental knee arthroplasty: a survival analysis of an independent series. J Bone Joint Surg Br. 2001;83-B(2):191–4.
8. Laurencin CT, Zelicof SB, Scott RD, Ewald FC. Unicompartmental versus total knee arthroplasty in the same patient. Clin Orthop Relat Res. 1991;273:151–6.
9. Fisher N, Agarwal M, Reuben SF, Johnson DS, Turner PG. Sporting and physical activity following Oxford medial unicompartmental knee arthroplasty. Knee. 2006;13(4):296–300.
10. Berend KR, Morris MJ, Lombardi AV. Unicompartmental knee arthroplasty: incidence of transfusion and symptomatic thromboembolic disease. Orthopedics. 2010;33(9 Supple):8–10.
11. Furnes O, Espehaug B, Lie SA, Vollset SE, Engesaeter LB, Havelin LI. Failure mechanisms after unicompartmental and tricompartmental primary knee replacement with cement. J Bone Joint Surg Am. 2007;89(3):519–25.
12. Koskinen E, Paavolainen P, Eskelinen A, Pulkkinen P, Remes V. Unicondylar knee replacement for primary osteoarthritis: a prospective follow-up study of 1,819 patients from the Finnish Arthroplasty Register. Acta Orthop. 2007;78(1):128–35.
13. Lewold S, Goodman S, Knutson K, Robertsson O, Lidgren L. Oxford meniscal bearing knee versus the Marmor knee in unicompartmental arthroplasty for arthrosis: a Swedish multicenter survival study. J Arthroplast. 1995;10(6):722–31.
14. Kozinn SC, Scott RD. Unicondylar knee arthroplasty. J Bone Joint Surg Am. 1989;71A(1):145–50.
15. Berend KR, Berend ME, Dalury DF, Argenson JN, Dodd CA, Scott RD. Consensus statement on indications and contraindications for medial unicompartmental knee arthroplasty. J Surg Orthop Adv. 2015;24(4):252–6.
16. Cartier P, Sanouiller JL, Grelsamer RP. Unicompartmental knee arthroplasty surgery. 10-year minimum follow-up period. J Arthroplast. 1996;11(7):782–8.
17. Gibson PH, Goodfellow JW. Stress radiography in degenerative arthritis of the knee. J Bone Joint Surg Br. 1986;68(4):608–9.
18. Radke S, Wollmerstedt N, Bischoff A, Eulert J. Knee arthroplasty for spontaneous osteonecrosis of the knee: unicompartmental vs bicompartmental knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2005;13(3):158–62.
19. Langdown AJ, Pandit H, Price AJ, Dodd CA, Murray DW, Svärd UC, Gibbons CL. Oxford medial unicompartmental arthroplasty for focal spontaneous osteonecrosis of the knee. Acta Orthop. 2005;76(5):688–92.
20. Pandit H, Jenkins C, Gill HS, Smith G, Price AJ, Dodd CA, Murray DW. Unnecessary contraindications for mobile-bearing unicompartmental replacement. J Bone Joint Surg Br. 2011;93(5):622–8.
21. Murray DW, Pandit H, Weston-Simons JS, Jenkins C, Gill HS, Lombardi AV, Dodd CA, Berend KR. Does body mass index affect the outcome of unicompartmental knee replacement? Knee. 2013;20(6):461–5.
22. Palumbo BT, Scott RD. Diagnosis and indications for treatment of unicompartmental arthritis. Clin Sports Med. 2014;33(1):11–21.
23. Cavaignac E, Lafontan V, Reina N, Pailhé R, Wargny M, Laffosse JM, Chiron P. Obesity has no adverse effect on the outcomes of unicompartmental knee replacement at a minimum follow-up of seven years. Bone Joint J. 2013;95-B(8):1064–8.
24. Lum ZC, Crawford DA, Lombardi AV Jr, Hurst JM, Morris MJ, Adams JB, Berend KR. Early comparative outcomes of unicompartmental and total knee arthroplasty in severely obese patients. Knee. 2018;25(1):161–6.
25. Price AJ, Dodd CA, Svard UG, Murray DW. Oxford medial unicompartmental knee arthroplasty in patients younger and older than 60 years of age. J Bone Joint Surg Br. 2005;87(11):1488–92.
26. Parratte S, Argenson JN, Pearce O, Pauly V, Auquier P, Aubaniac JM. Medial unicompartmental knee replacement in the under-50s. J Bone Joint Surg Br. 2009;91(3):351–6.
27. Berend KR, Lombardi AV Jr, Morris MJ, Hurst JM, Kavolus JJ. Does preoperative patellofemoral joint state affect medial unicompartmental arthroplasty survival? Orthopedics. 2001;34(9):e494–6.
28. Munk S, Odgaard A, Madsen F, Dalsgaard J, Jorn LP, Langhoff O, Jepsen CF, Hansen TB. Preoperative lateral subluxation of the patella is a predictor of poor early outcome of Oxford phase-III medial unicompartmental knee arthroplasty. Acta Orthop. 2001;82(5):582–8.
29. Liddle AD, Pandit H, Jenkins C, Price AJ, Dodd CA, Gill HS, Murray DW. Preoperative pain location is a

poor predictor of outcome after Oxford unicompartmental knee arthroplasty at 1 and 5 years. Knee Surg Sports Traumatol Arthosc. 2013;21(11):2421–6.
30. Konan S, Haddad FS. Does location of patellofemoral chondral lesion influence outcome after Oxford medial compartmental knee arthroplasty? Bone Joint J. 2016;98-B(10 sup B):11–5.
31. Berger RA, Della Valle CJ. Unicompartmental knee arthroplasty: indications, techniques, and results. Instr Course Lect. 2010;59:47–56.
32. Hernigou P, Pascale W, Pascale V, Homma Y, Poignard A. Does primary or secondary chondrocalcinosis influence long-term survivorship of unicompartmental arthroplasty? Clin Orthop Relat Res. 2012;470(7):1973–9.
33. Schindler OS, Scott WN, Scuderi GR. The practice of unicompartmental knee arthroplasty in the United Kingdom. J Orthop Surg (Hong Kong). 2010;18(3):312–9.
34. Rees JL, Price AJ, Lynskey TG, Svard UC, Dodd CA, Murray DW. Medial unicompartmental arthroplasty after failed high tibial osteotomy. J Bone Joint Surg Br. 2001;83(7):1034–6.
35. Valenzuela GA, Jacobson NA, Buzas D, Koreckij TD, Valenzuela RG, Teitge RA. Unicompartmental knee replacement after high tibial osteotomy: Invalidating a contraindication. Bone Joint J. 2013;95-B(10):1348–53.
36. Boissonneault A, Pandit H, Pegg E, Jenkins C, Gill HS, Dodd CA, Gibbons CL, Murray DW. No difference in survivorship after unicompartmental knee arthroplasty with or without an intact anterior cruciate ligament. Knee Surg Sports Traumatol Arthrosc. 2013;21(11):2480–6.
37. Mancuso F, Hamilton TW, Kumar V, Murray DW, Pandit H. Clinical outcome after UKA and HTO in ACL deficiency: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2016;24(1):112–22.
38. Weston-Simons JS, Pandit H, Jenkins C, Jackson WF, Price AJ, Gill HS, Dodd CA, Murray DW. Outcome of combined unicompartmental knee replacement and combined or sequential anterior cruciate ligament reconstruction: a study of 52 cases with mean follow-up of five years. J Bone Joint Surg Br. 2012;94(9):1216–20.
39. Dervin GF, Conway AF, Thurston P. Combined anterior cruciate ligament reconstruction and unicompartmental knee arthroplasty: surgical technique. Orthopedics. 2007;30(5 suppl):39–41.
40. Engh GA, Ammeen DJ. Unicondylar arthroplasty in knees with deficient anterior cruciate ligaments. Clin Orthop Relat Res. 2014;472(1):73–7.
41. Suero EM, Citak M, Cross MB, Bosscher MR, Ranawat AS, Pearle AD. Effects of tibial slope changes in the stability of fixed bearing medial unicompartmental arthroplasty in anterior cruciate ligament deficient knees. Knee. 2012;19(4):365–9.
42. Hamilton TW, Pandit HG, Inabathula A, Ostlere SJ, Jenkins C, Mellon SJ, Dodd CA, Murray DW. Unsatisfactory outcomes following unicompartmental knee arthroplasty in patients with partial thickness cartilage loss: a medium-term follow-up. Bone Joint J. 2017;99-B(4):475–82.
43. Niinimaki TT, Murray DW, Partanen J, Pajala A, Leppilahti JI. Unicompartmental knee arthroplasties implanted for osteoarthritis with partial loss of joint space have high re-operation rates. Knee. 2011;18(6):432–5.
44. Pandit H, Gulati A, Jenkins C, Barker K, Price AJ, Dodd CA, Murray DW. Unicompartmental knee replacement for patients with partial thickness cartilage loss in the affected compartment. Knee. 2011;18(3):168–71.
45. Hamilton TW, Pandit HG, Lombardi AV, Adams JB, Oosthuizen CR, Clavé A, Dodd CA, Berend KR, Murray DW. Radiological decision aid to determine suitability for medial unicompartmental knee arthroplasty: development and preliminary validation. Bone Joint J. 2016;98-B(10 Suppl B):3–10.

2 The Perioperative Management of Partial Knee Arthroplasty: Anesthesia, Pain Management, and Blood Loss

Samy Ftaita, Mark Pagnano, and Emmanuel Thienpont

Introduction

Pain is the body's physiological reaction to tissue injury and involves nociceptive, inflammatory, and ischemic phenomena [1]. The inflammation caused by surgical lesions leads to the release of inflammatory mediators (e.g., serotonin, histamin, lactic acid, bradykinin, prostaglandins, etc.) capable of inducing peripheral sensitization [2]. This inflammatory response, induced by the inflammatory soup, varies according to the extent of the surgical trauma and therefore invites for less traumatic surgery, as offered by unicompartmental knee arthroplasty [3, 4].

The peripheral sensitization can proceed to a central sensitization phenomenon. It is induced, on the one hand, by the release of prostaglandin and on the other hand by the stimulation of excitatory neurotransmitter production in the spinal cord [5, 6] which reduces inhibitory neurotransmitter activity in the dorsal horn. This phenomenon is caused by a central inflammatory reaction induced by the parallel release of pro-inflammatory cytokines [1, 7].

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Both peripheral and central sensitization will lead to postsurgical pain. The extent of this pain depends on many variables and is influenced both by phenotype and genotype of the individual patient. Pain can be modulated at different levels. In this chapter we explain how to optimize pain management and blood management protocols for those patients undergoing unicompartmental knee arthroplasty [1].

Pain Management

Preemptive and Preventive Pain Management

Substantial unrelieved postoperative pain is associated with an increased length of hospital stay, delayed recovery, and persistent postsurgical pain (PPSP) [8]. To tackle postoperative pain, antinociceptive intervention might be more effective if started before surgery rather than after. This is the concept of preemptive analgesia [9]. Based on diverging results in the literature, however, others would argue it is not the timing of pain prevention but rather analgesic duration and effectiveness that are most important when treating pain. The concept of preemptive analgesia has evolved in favor of the concept of preventive analgesia [10].

With a perioperative analgesic intervention, preventive analgesia aims to reduce the risk of

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central and peripheral sensitization [11]. It seems that when started before the incision, this treatment blocks some of the neuroendocrine response to surgical stress and is beneficial [1].

Sensitization phenomena are responsible for hyperalgesia, allodynia, and persistent postsurgical pain [12, 13]. Hyperalgesia is an exaggerated perception of painful stimuli in the operated area or remote [2]. Allodynia is the painful perception of normally banal sensations. PPSP is defined as persistent knee pain beyond 3 months after surgery [1].

Preventive analgesia combines analgesic and anti-hyperalgesic treatments. NSAIDs, pregabalin, gabapentin, and acetaminophen are commonly used in this context. This leads us to the concept of multimodal pain management.

Multimodal Pain Management

Multimodal analgesia (MA) aims to tackle postoperative pain by combining drugs and anesthetic techniques (e.g., nerve blocks or local infiltration analgesia) with different mechanisms of action, simultaneously or sequentially [11]. The principle is to obtain a synergistic and complementary action in order to produce the best analgesia possible with the lowest doses possible [14]. The main objective is to reduce the use of opioids which limits the patient's rapid mobilization and has multiple adverse effects (e.g., drowsiness, nausea, vomiting, ileus, respiratory depression, etc.) [15]. In addition, opioids can induce hyperalgesia by a phenomenon called opioid-induced hyperalgesia [1].

Multimodal pain management is part of the broader task of global patient care that enables recovery as quickly as possible. This is the concept of fast-track surgery [16]. Most multimodal protocols rely on the use of oral analgesics (acetaminophen, NSAIDs) combined with lower-dose opioids [1, 11]. Today other approaches, such as the use of gabapentinoid, ketamine, or glucocorticoid, are being researched, and some appear promising for the prevention of persistent postsurgical pain [17–19].

The use of locoregional anesthesia has long been considered an important pillar of multimodal pain treatment. Initially, femoral nerve blocks were used with great success in regard to pain control but subsequently criticized because they impeded rapid rehabilitation and caused some falls [16]. This leads to other more specific techniques such as adductor canal nerve blocks either solely or combined with periarticular infiltration techniques such as local infiltration analgesia (LIA) [20].

A good multimodal pain protocol must therefore allow for early mobilization, promote rapid rehabilitation, and prevent the onset of PPSP.

Local Infiltration Analgesia

Until the arrival of local infiltration analgesia or LIA, the two most popular analgesic techniques in knee surgery were epidural analgesia and continuous peripheral nerve blocks [14]. LIA has the advantage of avoiding complications related to the epidural technique or prolonged bedrest and does not require any special technical skills. The principle of LIA is to inject a mixture of ropivacaine (often combined variously with ketorolac, epinephrine, glucocorticoid, and antibiotic) into the area to be operated on [14, 15]. Most often it is carried out with one single injection but can be delivered continuously via a catheter into the articulation. In the case of a single injection, the analgesic effect is limited in duration (though perhaps extended by combination with ketorolac or glucocorticoid) and hence the importance of an integrated multimodal approach. In a double-blind study, a periarticular analgesic injection after unicompartmental knee arthroplasty was shown to significantly reduce postoperative pain at rest and in motion compared with the control group [16]. This shortened the hospital stay by 2 days on average. The difference could be explained by the effective analgesia which allows a quicker mobilization and the reduced use of morphine, as well as its side effects. Some studies focus on ways of increasing the analgesic power of local injections by targeting nerve structures instead of a local anesthesia randomly in the

operated area [20]. Often LIA is applied at the end of the surgery just before closure; however we believe LIA should be part of preventive pain control. If well executed and with its first injections at the start of the surgery, peripheral sensitization might be reduced. In general, we start the surgery with an adductor canal blockade performed by the surgeon. Immediately after canal blockade, the different anatomical areas of femur and tibia are infiltrated methodically from anterior to posterior following the bony landmarks. Even though there's no doubt that LIA is effective after knee arthroplasty, many questions remain such as the following: What is the best mixture? Do we need to add adrenaline for a longer action or less resorption? Should we add an anti-inflammatory drug like ketorolac or steroids? Is there a place to add antibiotics or tranexamic acid? Which dosage for which area of the knee? When is the best moment during surgery to inject [13]? In a combination with nerve blocks, LIA may play a protective role against the onset of central and peripheral sensitization and the development of PPSP [17, 18].

Locoregional Anesthesia

Knee innervation is complex because of its several nervous origins. The saphenous nerve; the nerves of the vastus lateralis, vastus medialis, and vastus intermedius muscles; and branches of the posterior obturator nerve originate from the lumbar plexus. The sciatic plexus is connected to the branches arising from the tibial nerve and the common peroneal nerve [21].

The femoral nerve block (FNB) and the adductor canal blockade (ACB) are two popular techniques used in postoperative knee analgesia. They are included in a multimodal approach and have both been shown to be effective in pain management after TKA [11, 22]. There are many studies in the literature comparing the effectiveness of one technique with the other. However, according to a recently published meta-analysis of TKA, there is no significant difference in pain after 8, 24, and 48 h postoperation [23]. The authors' second conclusion is that none of these techniques reduce the consumption of opioids within 48 h postoperation. However, the ACB allows a faster mobilization of patients.

The femoral nerve block is performed at the upper part of the thigh, in an area limited by the inguinal ligament, the sartorius and the adductor longus muscles. This is the historical technique in knee surgery [24, 25]. Yet it has the disadvantage of producing a motor blockade. The resultant loss of quadriceps strength is responsible for an alteration of rapid rehabilitation and increases the risk of falling [26]. A debate is still at hand on whether to use a single block or a continuous block and as to the need of performing a sciatic block in parallel [27].

The adductor canal block is done at the level of Hunter's canal, located on the mid-distal side of the femur. This area contains several nerves innervating the knee with the distinction of being located at a distance from the motor branches of the quadriceps muscle [21, 28, 29]. The saphenous nerve and the vastus medialis nerve are found here. This option retains much of the quadriceps muscle's function but requires technical knowledge from the anesthetist [25]. An experimental study showed a reduction in quadriceps muscle strength of 8% versus 49%, following adductor canal block and femoral nerve block, respectively [30].

Some authors have worked on the feasibility of direct infiltration of the distal saphenous nerve by the surgeon during surgery of the knee [20]. The remaining problem for all these techniques is the lack of posterior nerve blockade, and thus substantial posterior knee pain may remain [31]. Therefore, supplemental LIA may be useful to reduce the posterior pain [1].

General Anesthesia vs Spinal Anesthesia

Lower limb surgery gives patients the choice of either general anesthesia (GA) or spinal anesthesia (SA). It is therefore up to the anesthesiologist to explain to the patient the pros and cons of each specific technique while taking into account the wishes of the patient.

General anesthesia is the most commonly used technique historically. It has the disadvantage of being associated with nausea, vomiting, and delirium. When spinal anesthesia was introduced, it was thought to be responsible for less comorbidity and mortality than GA, which increased its popularity [32–36]. According to some authors, spinal anesthesia allows better pain management along with a reduction in opioid use, as well as a shorter hospital stay [34, 37, 38]. But in the light of the different meta-analyses and systematic reviews with divergent conclusions, no consensus seems to be really emerging [37, 39–41]. Moreover, it appears that spinal anesthesia costs less, potentially explained by an earlier return home [42]. However, spinal anesthesia also has complications. Nerve damage, infections, urinary retention, and hematomas are just some of them [43]. Technical skill is required to limit the risk of complications [11].

Well-performed general anesthesia, for example, by target controlled infusion anesthesia (TCIA) or total intravenous anesthesia (TIVA), seems to be a good alternative to spinal anesthesia in hospitals that cannot offer high-quality locoregional anesthesia. This was highlighted in a comparative study by Harsten et al., which showed better recovery and pain management when comparing a well-performed general anesthesia to a simple spinal anesthesia [35, 44].

Blood Management

Blood loss is a major challenge in any type of surgery, especially in joint replacement. Some of the blood loss accumulates in the joint capsule after surgery and causes hematomas, swelling, and stiffness that slow rehabilitation. In addition, blood loss with a significant drop in hemoglobin levels might increase morbidity and mortality, as well as the need for blood transfusion with the risks it entails [45]. However, blood loss is lower in UKA than in TKA [46]. In a retrospective study of 210 patients, Schwab et al. showed a significant reduction in hemoglobin loss, depending on whether the knee arthroplasty was partial or total. They showed a difference on day 2 (12.9 g/dl vs 12.1 g/dl, $p < 0.05$), on day 4 (12.7 g/dl vs 11.5 g/dl, $p < 0.05$), and on day 21 post-surgery (13.2 g/dl vs 12.7 g/dl, $p < 0.05$) between UKA and TKA, respectively [4]. No patients from the UKA group required blood transfusion compared with 2% in the TKA group. The authors concluded that there was less hidden blood loss in UKA than in TKA, potentially because of the less invasive aspect of the surgery [46]. This reduction in hemoglobin loss was already shown in 2003 by Yang et al., prospectively comparing 50 UKA operated by minimally invasive surgery with 50 TKA [47]. They found a drop of 14% vs 20% (1.8 g/dl vs 2.6 g/dl, $p < 0.05$) between UKA and TKA groups, respectively. Six percent of patients in the TKA group required blood transfusion compared to 0% in the UKA group. In another study, Lombardi et al. compared 115 mobile-bearing UKA with 115 cruciate-retaining TKA and saw higher hemoglobin at exit in the UKA group compared to the TKA group (12.1 vs 11.3, $p < 0.05$). Two patients (1.7%) of the TKA group required a transfusion versus 0 in the UKA group.

Preoperative Hemoglobin Optimization

This difference in blood loss observed can be explained by a dual strategy that uses a multimodal protocol for reduction of blood loss and a minimally invasive surgery that is available when partial knee arthroplasty is possible [4]. The surgical approach is less important since only one compartment of the knee needs to be exposed. The central medullary canal is not opened with many UKA techniques, and the necessary bone cuts are of smaller surfaces [46].

The risks of bleeding and blood transfusion should be considered before, during, and after the operation. Preoperative hemoglobin (Hb) dosage is part of an approach to prevent surgical risks associated with bleeding [48]. Anemia is defined as a hemoglobin level of less than 130 g/L in men and 120 g/L in women [49]. According to the World Health Organization, it is present in 11% of cases for men and 10.2% of cases for women

[50]. Pre-surgery is a risk factor for allogeneic blood transfusion, infection, increased length of stay by 5 days, and a return to hospital within 90 days and postoperative morbidity/mortality [48, 51, 52]. Different causes can be found and some corrected to improve the situation before surgery. Iron, vitamin B12, and folate deficiency are the main etiologies. Chronic inflammatory diseases, chronic renal diseases, and unknown causes are less common [53]. There are international guidelines to correct anemia that have as a key therapeutic element iron and EPO supplementation [53–55]. A period of 28 days before surgery should be sufficient to correct most anemias [53]. But no ideal preoperative Hb cutoff level has been established. A consensus about the minimal preoperative Hb level should be obtained. Partial knee arthroplasty is less bloody than total knee replacement, and studies should be carried out to decide the preoperative Hb limit for each type of knee arthroplasty.

Another aspect of blood loss prevention is the management of antiplatelet agents such as aspirin or ADP receptor antagonists (clopidogrel, prasugrel, etc.) [56]. Aspirin can be used either for primary prevention or for secondary prevention of atherothrombosis. The decision to stop aspirin before surgery reduces the risk of bleeding but exposes the patient to vascular occlusions and inflammation-related thromboembolic events. Through a multidisciplinary approach, the healthcare team should weigh the pros and cons and identify for each patient's risk for bleeding [56]. Among these are patients with a history of perioperative bleeding of undetermined origin, hemorrhagic diseases (e.g., von Willebrand disease, Leiden factor deficiency) or medical treatments (anti-vitamin K bridging), antiplatelet agents, NOAC, and NSAIDs [57]. Patient stratification is crucial. Fortunately, knee arthroplasty is by definition an elective surgery and can thus be prepared. In case of excessive bleeding, solutions such as platelet or plasma transfusion exist. The current anti-aggregating agents have a long duration of half-life, but new molecules (glycoprotein IIb/IIIa inhibitors) offer shorter half-lives and allow an effective bridging [56]. In primary prevention, aspirin can of course be stopped 7–10 days before surgery, if the surgical team believes this to be the best option. If it is used for secondary prevention, its cessation is associated with an increased risk of cardiovascular complications [56]. Schwab et al. showed in a recent study that, thanks to the effectiveness of current multimodal blood loss management, aspirin can be continued, both for primary and secondary prevention, without increasing the risk of bleeding [58].

Multimodal Blood Loss Protocol

Tranexamic acid (TXA) is used in surgery to reduce bleeding. When tissue damage occurs, tissue factor, notably present in endothelial cells, is exposed. This leads to the activation of the coagulation cascade which leads to a clot formation. In parallel, another pathway is activated and leads to the activation of fibrinolysis. Its role is to limit the spread of the thrombus and allow its degradation. This pathway is under the control of a proteolytic enzyme called plasmin [59]. By binding to plasminogen, tranexamic acid prevents binding of plasmin to fibrinogen and delays natural fibrinolysis and therefore bleeding [60].

TXA has a rapid action and a 2 h half-life. It only undergoes a low hepatic metabolization and is mainly eliminated through the kidneys, which requires a dose adjustment in case of renal insufficiency. It is an effective product capable of reducing blood loss in TKA by 34% and operation mortality through bleeding by 30% and, more generally, significantly reduces all causes of mortality [61, 62]. Several meta-analyses on TKA showed a reduction in transfusions without increased risk of complications [63–65].

To date and to the best of our knowledge, there is only one study that has studied the effect of TXA on unicompartmental knee arthroplasty [66]. It prospectively compared a group of patients that received partial knee arthroplasty via minimally invasive surgery to a TKA group. The authors did not observe any significant difference in terms of blood loss with the control group. However, the minimally invasive surgery

used in this study already reduces blood loss and makes hemorrhagic complications more rare [67, 68].

Although this has not been proven for tranexamic acid, it must be kept in mind that the risk of thromboembolic events is theoretically still possible [64, 69]. Another antifibrinolytic drug, aprotinin, was withdrawn from the market for its complications [70]. Important differences exist in the mechanism of action of aprotinin (a competitive serine protease or trypsin inhibitor) and tranexamic acid which is a lysine analog.

The best method of administration for tranexamic acid is still discussed. The same can be said for timing or repetition of doses and for what is the optimal dose. According to Ker's study, a dose greater than 1 g in adults is useless [61]. Controversy remains whether TXA can be as effective when it is topically applied or when intravenously applied. Furthermore, in UKA the impact of any topical product on the remaining native cartilage should be studied.

Another way to reduce perioperative bleeding after UKA is the use of LIA. Ropivacaine has an adrenergic effect on its own, but often dilute epinephrine is added to the cocktail. Anderson showed in a TKA study that an intraoperative epinephrine injection reduced the amount of blood in postoperative drains by 32% (195 mL) [71]. In another study comparing a patient-controlled analgesia (PCA) group to a LIA group, a 372 ml (28%) reduction in blood loss was observed [72]. In addition, the authors highlight a 4.3 times lower transfusion necessity in the LIA group. The preventive use of LIA at the start of the procedure might also help to reduce bleeding by avoiding incision-related hypertension straight after induction. Care should be taken to avoid subcuticular injection of cocktails that contain epinephrine in patients with diabetes mellitus or peripheral vascular disease who are already at risk for wound healing problems [73–78].

Reduced bleeding and less visible and hidden blood loss will result in a lower drop of Hb levels [46]. However, the reduction of blood transfusion is only indirectly related to this. Consensus about the Hb level triggering transfusion is important. Today's literature is stating 8 g/dL as an important level; however in the elderly with cardiac comorbidity, this might be too low.

Conclusion

Multimodal pain strategies, as well as multimodal blood management protocols have proven value after TKA. The same protocols can logically be applied to patients undergoing UKA. Patients undergoing UKA today can expect excellent pain relief, low morbidity, and rapid recovery when advanced pain and blood management protocols are employed.

References

1. Grosu I, Lavand'homme P, Thienpont E. Pain after knee arthroplasty: an unresolved issue. Knee Surg Sports Traumatol Arthrosc. 2014;22(8):1744–58.
2. Xu J, Brennan TJ. The pathophysiology of acute pain: animal models. Curr Opin Anaesthesiol. 2011;24(5):508.
3. Nicholson G, Hall GM. Effects of anaesthesia on the inflammatory response to injury. Curr Opin Anaesthesiol. 2011;24(4):370–4.
4. Schwab PE, et al. Lower blood loss after unicompartmental than total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2015;23(12):3494–500.
5. Khan AA, et al. Expression of COX-1 and COX-2 in a clinical model of acute inflammation. J Pain. 2007;8(4):349–54.
6. Buvanendran A, et al. Cerebrospinal fluid neurotransmitter changes during the perioperative period in patients undergoing total knee replacement: a randomized trial. Anesth Analg. 2012;114(2):434–41.
7. Kawasaki Y, et al. Cytokine mechanisms of central sensitization: distinct and overlapping role of interleukin-1β, interleukin-6, and tumor necrosis factor-α in regulating synaptic and neuronal activity in the superficial spinal cord. J Neurosci. 2008;28(20):5189–94.
8. Puolakka PA, et al. Persistent pain following knee arthroplasty. Eur J Anaesthesiol (EJA). 2010;27(5):455–60.
9. Kissin I. Preemptive analgesia: terminology and clinical relevance. Anesth Analg. 1994;79(4):809–10.
10. Pogatzki-Zahn EM, Zahn PK. From preemptive to preventive analgesia. Curr Opin Anaesthesiol. 2006;19(5):551–5.
11. Moucha CS, Weiser MC, Levin EJ. Current strategies in anesthesia and analgesia for total knee arthroplasty. J Am Acad Orthop Surg. 2016;24(2):60–73.
12. Woolf CJ. Central sensitization: implications for the diagnosis and treatment of pain. Pain. 2011;152(3):S2–S15.

13. Treede R, et al. Hyperalgesia and allodynia: taxonomy, assessment, and mechanisms. Hyperalgesia. 2004;30:1–15.
14. Kehlet H. Synergism between Analgesics. Ann Med. 1995;27(2):259–62.
15. McDonald D, et al. An enhanced recovery programme for primary total knee arthroplasty in the United Kingdom—follow up at one year. Knee. 2012;19(5):525–9.
16. Kehlet H, Thienpont E. Fast-track knee arthroplasty – status and future challenges. Knee. 2013;20(Suppl 1):S29–33.
17. Zhang J, Ho K-Y, Wang Y. Efficacy of pregabalin in acute postoperative pain: a meta-analysis. Br J Anaesth. 2011;106(4):454–62.
18. Lunn T, Kehlet H. Perioperative glucocorticoids in hip and knee surgery–benefit vs. harm? A review of randomized clinical trials. Acta Anaesthesiol Scand. 2013;57(7):823–34.
19. Wu CL, Raja SN. Treatment of acute postoperative pain. Lancet. 2011;377(9784):2215–25.
20. Kavolus JJ, et al. Saphenous nerve block from within the knee is feasible for TKA: MRI and cadaveric study. Clin Orthop Relat Res. 2018;476(1):30–6.
21. Horner G, Dellon AL. Innervation of the human knee joint and implications for surgery. Clin Orthop Relat Res. 1994;301:221–6.
22. Lund J, et al. Continuous adductor-canal-blockade for adjuvant post-operative analgesia after major knee surgery: preliminary results. Acta Anaesthesiol Scand. 2011;55(1):14–9.
23. Kuang M-J, et al. Is adductor canal block better than femoral nerve block in primary total knee arthroplasty? A GRADE analysis of the evidence through a systematic review and meta-analysis. J Arthroplast. 2017;32(10):3238–3248. e3.
24. Chan E-Y, et al. Femoral nerve blocks for acute postoperative pain after knee replacement surgery. Cochrane Database Syst. Rev. 2014;(5):1–198.
25. Hadzic A, et al. Femoral nerve block for analgesia in patients having knee arthroplasty. Anesthesiology. 2010;113(5):1014–5.
26. Ilfeld BM, Duke KB, Donohue MC. The association between lower extremity continuous peripheral nerve blocks and patient falls after knee and hip arthroplasty. Anesth Analg. 2010;111(6):1552.
27. Paul JE, et al. Femoral nerve block improves analgesia outcomes after total knee Arthroplasty: a meta-analysis of randomized controlled trials. Anesthesiology. 2010;113(5):1144–62.
28. Romanoff ME, et al. Saphenous nerve entrapment at the adductor canal. Am J Sports Med. 1989;17(4):478–81.
29. Laurant DB-S, et al. The nerves of the adductor canal and the innervation of the knee: an anatomic study. Reg Anesth Pain Med. 2016;41(3):321–7.
30. Jæger P, et al. Adductor canal block versus femoral nerve block and quadriceps strength: a randomized, double-blind, placebo-controlled, crossover study in healthy volunteers. Anesthesiology. 2013;118(2):409–15.
31. Thienpont E. CORR insights®: saphenous nerve block from within the knee is feasible for TKA MRI and cadaveric study. Clin Orthop Relat Res. 2018;476(1):37–9.
32. Rodgers A, et al. Reduction of postoperative mortality and morbidity with epidural or spinal anaesthesia: results from overview of randomised trials. BMJ. 2000;321(7275):1493.
33. Zywiel MG, et al. The influence of anesthesia and pain management on cognitive dysfunction after joint arthroplasty: a systematic review. Clin Orthop Relat Res. 2014;472(5):1453–66.
34. Johnson R, et al. Neuraxial vs general anaesthesia for total hip and total knee arthroplasty: a systematic review of comparative-effectiveness research. Br J Anaesth. 2016;116(2):163–76.
35. McCartney C, Choi S IV. Does anaesthetic technique really matter for total knee arthroplasty? Br J Anaesth. 2013;111(3):331–3.
36. Pugely AJ, et al. Differences in short-term complications between spinal and general anesthesia for primary total knee arthroplasty. JBJS. 2013;95(3):193–9.
37. Macfarlane AJ, et al. Does regional anesthesia improve outcome after total knee arthroplasty? Clin Orthop Relat Res. 2009;467(9):2379.
38. Williams-Russo P, et al. Randomized trial of epidural versus general anesthesia: outcomes after primary total knee replacement. Clin Orthop Relat Res. 1996;331:199–208.
39. Hu S, et al. A comparison of regional and general anaesthesia for total replacement of the hip or knee: a meta-analysis. Bone & Joint Journal. 2009;91(7):935–42.
40. Kehlet H, Aasvang EK. Regional or general anesthesia for fast-track hip and knee replacement-what is the evidence? F1000Research. 2015;4:1449.
41. Fowler S, et al. Epidural analgesia compared with peripheral nerve blockade after major knee surgery: a systematic review and meta-analysis of randomized trials. Br J Anaesth. 2008;100(2):154–64.
42. Gonano C, et al. Spinal versus general anesthesia for orthopedic surgery: anesthesia drug and supply costs. Anesth Analg. 2006;102(2):524–9.
43. Horlocker TT. Complications of regional anesthesia and acute pain management. Anesthesiol Clin. 2011;29(2):257–78.
44. Harsten A, Kehlet H, Toksvig-Larsen S. Recovery after total intravenous general anaesthesia or spinal anaesthesia for total knee arthroplasty: a randomized trial. Br J Anaesth. 2013;111(3):391–9.
45. Banerjee S, et al. Intraoperative pharmacotherapeutic blood management strategies in total knee arthroplasty. J Knee Surg. 2013;26(06):379–86.
46. Schwab P-E, et al. Lower blood loss after unicompartmental than total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2015;23(12):3494–500.
47. Yang KY, et al. Minimally invasive unicondylar versus total condylar knee arthroplasty – early results

of a matched-pair comparison. Singap Med J. 2003;44(11):559–62.
48. Jans Ø, et al. Role of preoperative anemia for risk of transfusion and postoperative morbidity in fast-track hip and knee arthroplasty. Transfusion. 2014;54(3):717–26.
49. Janz TG, Johnson RL, Rubenstein SD. Anemia in the emergency department: evaluation and treatment. Emerg Med Pract. 2013;15(11):1–15. quiz 15-6
50. Anemia WN. World Health Organization Technical Report Series No. 405. Geneva: World Health Organization; 1968.
51. Spahn DR. Anemia and patient blood management in hip and knee surgery: a systematic review of the literature. Anesthesiology. 2010;113(2):482–95.
52. Bozic KJ, et al. Patient-related risk factors for periprosthetic joint infection and postoperative mortality following total hip arthroplasty in Medicare patients. JBJS. 2012;94(9):794–800.
53. Goodnough LT, et al. Detection, evaluation, and management of preoperative anaemia in the elective orthopaedic surgical patient: NATA guidelines. Br J Anaesth. 2011;106(1):13–22.
54. Petis SM, et al. Is there a role for preoperative iron supplementation in patients preparing for a total hip or total knee arthroplasty? J Arthroplast. 2017;32(9):2688–93.
55. Bedair H, et al. Preoperative erythropoietin alpha reduces postoperative transfusions in THA and TKA but may not be cost-effective. Clin Orthop Relat Res. 2015;473(2):590–6.
56. Oprea A, Popescu W. Perioperative management of antiplatelet therapy. Br J Anaesth. 2013;111:i3–i17.
57. Slappendel R, et al. Does ibuprofen increase perioperative blood loss during hip arthroplasty? Eur J Anaesthesiol. 2002;19(11):829–31.
58. Schwab P-E, et al. Aspirin mono-therapy continuation does not result in more bleeding after knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2017;25(8):2586–93.
59. Davie EW, Fujikawa K, Kisiel W. The coagulation cascade: initiation, maintenance, and regulation. Biochemistry. 1991;30(43):10363–70.
60. Mannucci PM. Hemostatic drugs. N Engl J Med. 1998;339(4):245–53.
61. Ker K, Prieto-Merino D, Roberts I. Systematic review, meta-analysis and meta-regression of the effect of tranexamic acid on surgical blood loss. Br J Surg. 2013;100(10):1271–9.
62. Williams-Johnson J, et al. Effects of tranexamic acid on death, vascular occlusive events, and blood transfusion in trauma patients with significant haemorrhage (CRASH-2): a randomised, placebo-controlled trial. West Indian Med J. 2010;59(6):612–24.
63. Cid J, Lozano M. Tranexamic acid reduces allogeneic red cell transfusions in patients undergoing total knee arthroplasty: results of a meta-analysis of randomized controlled trials. Transfusion. 2005;45(8):1302–7.
64. Zufferey P, et al. Do antifibrinolytics reduce allogeneic blood transfusion in orthopedic surgery? Anesthesiology. 2006;105(5):1034–46.
65. Poeran J, et al. Tranexamic acid use and postoperative outcomes in patients undergoing total hip or knee arthroplasty in the United States: retrospective analysis of effectiveness and safety. BMJ. 2014;349:g4829.
66. Pongcharoen B, Ruetiwarangkoon C. Does tranexamic acid reduce blood loss and transfusion rates in unicompartmental knee arthroplasty? J Orthop Sci. 2016;21(2):211–5.
67. Jeer PJ, Cossey AJ, Keene GC. Haemoglobin levels following unicompartmental knee arthroplasty: influence of transfusion practice and surgical approach. Knee. 2005;12(5):358–61.
68. Khanna A, et al. Minimally invasive total knee arthroplasty: a systematic review. Orthop Clin. 2009;40(4):479–89.
69. Henry DA, et al. Anti-fibrinolytic use for minimising perioperative allogeneic blood transfusion. The Cochrane Library. 2011;1–208.
70. Fergusson DA, et al. A comparison of aprotinin and lysine analogues in high-risk cardiac surgery. N Engl J Med. 2008;358(22):2319–31.
71. Anderson LA, et al. Reduced blood loss after total knee arthroplasty with local injection of bupivacaine and epinephrine. J Knee Surg. 2009;22(2):130–6.
72. Bhutta MA, et al. Reduced blood loss and transfusion rates: additional benefits of local infiltration anaesthesia in knee arthroplasty patients. J Arthroplast. 2015;30(11):2034–7.
73. Röstlund T, Kehlet H. High-dose local infiltration analgesia after hip and knee replacement—what is it, why does it work, and what are the future challenges? Acta Orthop. 2007;78(2):159–61.
74. Kerr DR, Kohan L. Local infiltration analgesia: a technique for the control of acute postoperative pain following knee and hip surgery: a case study of 325 patients. Acta Orthop. 2008;79(2):174–83.
75. Essving P, et al. Reduced hospital stay, morphine consumption, and pain intensity with local infiltration analgesia after unicompartmental knee arthroplasty. Acta Orthop. 2009;80(2):213–9.
76. Nader A, et al. Single-dose adductor canal block with local infiltrative analgesia compared with local infiltrate analgesia after total knee arthroplasty: a randomized, double-blind, placebo-controlled trial. Reg Anesth Pain Med. 2016;41(6):678–84.
77. Perlas A, et al. The impact of analgesic modality on early ambulation following total knee arthroplasty. Reg Anesth Pain Med. 2013;38(4):334–9.
78. Pozek J-PJ, et al. The acute to chronic pain transition: can chronic pain be prevented? Med Clin. 2016;100(1):17–30.

3 The Outpatient Partial Knee Arthroplasty

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Introduction

Over the last several years, there has been a trend toward increasing the number of knee arthroplasty surgeries done as outpatient procedures [1], which is further fueled by increased focus on reducing healthcare costs [2, 3]. As rapid recovery protocols have become widespread, focusing on clinical and logistical optimization to reduce morbidity and mortality, shorten convalescence, and reduce length of hospital stay (LOS) [4], the feasibility of doing knee arthroplasty as an outpatient procedure has become more apparent [5, 6].

The focus is on reducing the surgical stress response by using evidence-based clinical enhancements, and rapid recovery protocols include multimodal opioid-sparing analgesia and early mobilization to fast achievement of functional discharge criteria allowing early discharge to home. Barriers to discharge that have been identified and reduced include focus on pain treatment, dizziness (orthostatic intolerance), and muscle weakness [7]. LOS following total joint arthroplasty (TJA) has been reduced in many parts of the world. As many centers had stays of just one night and experienced that some patients fulfilled discharge criteria on the same day as surgery, many surgeons have realized that outpatient arthroplasty is feasible and have called for a standardized, smooth pathway to accommodate that option. Logistically, ultrashort stays in or even bypassing the postanesthesia care unit (PACU) is facilitating discharge on the day of surgery and has been shown to be doable [8, 9].

Partial knee arthroplasty lends itself to being done in an outpatient setting for a variety of reasons. In the majority of cases, the exposure needed to complete a partial knee arthroplasty is less than for that of a total knee arthroplasty, leading to less tissue trauma [10]. This leads to patients being able to ambulate further, having better range of motion and shorter hospital stays compared with total knee arthroplasty [11]. In addition, partial knee arthroplasty has a lower associated perioperative complication rate as well as an extremely low mortality rate [12–14]. For these reasons, many surgeons who may be hesitant to do a total knee arthroplasty in the outpatient setting may be more

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comfortable with a partial knee replacement [15]. In this chapter we will discuss the various aspects of planning for and carrying out a partial knee arthroplasty in the outpatient setting and then will give an example of the authors' protocols, at both a US-based and a European center, and results of outpatient UKA done at the US facility.

Patient Evaluation and Indication for Surgery

The first step in patient selection is the clinical evaluation of the patient in the orthopedic office. The specific indications for the various types of partial knee arthroplasty are discussed in detail elsewhere in this book; however, the general evaluation of the patients is similar. During the office visit, appropriate radiographs should be obtained. These include standing anteroposterior (AP), lateral, and merchant views as well as a 30° flexed AP. A stress radiograph, either varus or valgus, should also be obtained if the patient has disease limited primarily to the medial or lateral compartment. After radiographs are obtained, the patient should have a full history taken, with special focus on the past medical history, past surgical history, and any medication or metal allergies. The surgeon should then perform a physical exam, with focus on range of motion and ligamentous examination. An important aspect of the physical examination is whether the patient with a varus or valgus deformity has a correctable deformity or whether they have a contracted collateral ligament. Physical examination findings should be corroborated by the history and radiography.

Medical Optimization

Once the patient has been indicated for partial knee arthroplasty, the next step is to determine whether they are medically fit and able to have the operation as an outpatient. Ideally, all patients should be evaluated by a general medicine physician to identify any comorbidities that could put the patient at risk during surgery, although in many hospitals, the only medical evaluation is performed by the surgeon and/or the anesthetist. One study of elective arthroplasty patients showed that pre-screening identifies a significant number of new diagnoses and 2.5% of patients were found to have unacceptably high risk for elective surgery [16]. Determining which patients qualify for outpatient surgery is an area of debate. It has been shown that coexisting cardiopulmonary, liver, and kidney diseases including chronic obstructive pulmonary disorder (COPD), congestive heart failure (CHF), coronary artery disease (CAD), and cirrhosis are those most commonly requiring intervention more than 24 h after arthroplasty [17]. A recent systematic literature-based review [18] found the following inclusion and exclusion criteria to apply for outpatient TJA: patients who are able and willing to participate, with a low ASA classification (<III), undergoing primary arthroplasty, aged 75 years or younger, and having support at home during the first postoperative days are eligible candidates for outpatient joint arthroplasty. Patients with a high ASA classification (>II), bleeding disorders, poorly controlled and/or severe cardiac disease (e.g., heart failure, arrhythmia) or pulmonary disease (e.g., embolism, respiratory failure) comorbidities, uncontrolled diabetes mellitus (DM) (type I or II), a high BMI (>30 kg/m^2), chronic opioid consumption, functional neurological impairments, dependent functional status, chronic/end-stage renal disease, and/or reduced preoperative cognitive capacity should be excluded from outpatient joint arthroplasty. A recent study in unselected patients [6], using very liberal eligibility criteria, found that 54% of an unselected patient population was eligible for outpatient surgery. However, only one-third of those patients were discharged on the day of surgery, suggesting that more strict inclusion criteria should be applied.

Some centers have developed complex algorithms to determine whether a patient is a candidate for outpatient surgery, and several tools have been proposed to preoperatively predict the patient's discharge disposition [19]. A simpler method may be to consider that any patient with major organ system failure and significant car-

Table 3.1 Relative contraindications for outpatient UKA

Relative contraindications for outpatient UKA
Congestive heart failure
Valvular disease
Severe chronic obstructive pulmonary disease
Home oxygen use
Untreated sleep apnea with BMI >40 kg/m^2
Severe renal disease
Cerebrovascular accident
Solid organ transplant

diac, pulmonary, and kidney comorbidities should not be considered a candidate for outpatient surgery (Table 3.1). In addition to identifying those patients who are not healthy enough for outpatient surgery, the medical team can help to optimize other conditions that may place the patient at higher risk when untreated but when managed properly become lower risk. For example, a patient with CAD and active angina has an unacceptably high risk. That patient may, however, fall into the acceptable risk category after intervention such as placement of a stent. Prior to scheduling the outpatient procedure, it is advisable that the logistic setup is fit for the patient to be discharged to his or her own home care and that another adult is present with the patient for at least 24 h after discharge.

Location of Surgery

In the United States, there are three major locations where the surgery may take place: a standard full-service multispecialty hospital, a musculoskeletal specialty hospital, or an ambulatory surgery center (ASC). A standard full-service multispecialty hospital has the advantage of having multiple medical specialists in-house, as well as services such as an intensive care unit (ICU), which are important in the event of major medical complications. A patient with multiple significant comorbidities that cannot be fully controlled may need to have surgery done in this type of location. A musculoskeletal specialty hospital is typically smaller than a full-service hospital, and the entire hospital is dedicated to patients undergoing some type of orthopedic or spine procedure. The ambulatory surgery center is the smallest of the three and usually consists only of operating rooms, as well as perioperative holding areas. Although it can be done, it may be more difficult to effectively develop an outpatient arthroplasty pathway in a multispecialty hospital. This type of large hospital often has multiple different stakeholders and a large deal of bureaucracy and administration that can make it difficult to establish the best practices for outpatient arthroplasty. In a musculoskeletal specialty hospital, and even more so in an ambulatory surgery center, the surgeon has more control over things such as staffing and efficiency, and the focused nature of the facility means that the entire team including nursing, anesthesia, physical therapy, and the surgeon can all be focused on attaining the goal of discharge on the day of surgery [20, 21]. Although patients planned for outpatient arthroplasty are usually successful in going home on the day of surgery, it is important that the facility has the ability for the patient to be observed overnight if needed. It is rare that a patient would have to be transferred from the ambulatory facility to a larger hospital; however, in the event of complications, there should be a protocol in place to accomplish that transfer.

In European countries like Denmark, there is less differentiation between the types of hospital as all hospitals, although variable in size, have access to PACU and ICU as well as other specialties. However, in recent years several stand-alone daycare centers performing outpatient joint replacement surgery have been established.

As studies in TJA have shown not all patients being able to leave despite being scheduled for outpatient arthroplasty, and 8–70% needed an overnight stay, it seems advisable to be able to offer an overnight stay in case the patient is not eligible for same-day discharge [6, 22, 23].

Preoperative Education and Preparation

Preoperative education is key to success in outpatient arthroplasty. Adequate education has been shown to decrease patient anxiety and improve

overall satisfaction [24, 25]. Patients should receive education regarding arthritis in general as well as the surgical procedure itself, including the risks and benefits of surgery and what to expect from a successful arthroplasty. They should also be educated on all aspects of the perioperative period, and the day of surgery should be thoroughly outlined from arrival to discharge. This should include discussion of the preoperative period, anesthesia, postoperative recovery, and physical therapy. Education should also include what to expect in the immediate postoperative period. Frequently asked questions regarding incision management, pain medications, therapy requirements, and return to work should be discussed. This information may be provided as an informational packet for the patient to read, in video form, or in a multidisciplinary patient seminar. It is important for all members of the treatment team to be on the same page regarding the answers to these questions, as conflicting information from providers will lead to a loss of confidence in the team by the patient. A preoperative physical therapy visit can be useful to go over postoperative exercises and provide instruction in the use of assistive devices such as a walker or crutches. This is also a good opportunity to obtain measures of baseline strength and range of motion for later comparison.

The mind-set of patients scheduled for outpatient unicompartmental knee arthroplasties is important, and patients should be prepared for the ultrashort stay, early discharge, and being able to cope assisted by a relative, which are mandatory for the first 24 h [26]. Also, the mind-set of the involved staff members needs to be focused on creating a smooth pathway facilitating and encouraging same-day discharge.

Postoperative Therapy and Disposition

Mobilization should begin as early as possible, preferably within 1–2 h after surgery. In-hospital physiotherapy should focus on mobilization with or without walking aid, stair climbing if required, and necessary activities of daily living (ADL). Postoperatively, physical therapy may take the form of a self-directed home exercise program, supervised home physical therapy, or outpatient physical therapy. While studies have shown no additional benefit of supervised training compared to home-based exercise [27], we prefer outpatient physical therapy because in addition to the exercises being well supervised, the act of leaving the home and getting to and from physical therapy requires the patient to perform activities that will be required for them to return to normal daily life.

Discharge criteria should combine functional discharge criteria as well as assessment of vital parameters. It is also important to discuss discharge disposition with the patient. Although patients should be able to ambulate, transfer, and ascend and descend stairs prior to discharge, they should have assistance from a friend or family member at home for at least the first 24 h postoperatively [6, 22]. Most patients will have at least one friend or family member available to assist them. However, if they do not, it may be more appropriate to perform surgery as an inpatient procedure.

Authors' Protocol: USA

Prior to surgery, patients are given an educational pamphlet and video to assure that expectations of the patient and family are aligned. The patient attends a preoperative physical therapy session during which baseline strength and range of motion are assessed and the patient is instructed in the use of walking aids and postoperative exercises. The patient is provided chlorhexidine soap and is instructed to use it to shower on the evening prior to surgery. They are instructed to be fasting after midnight but may have clear fluids until 2 h prior to surgery.

A multimodal and preventative perioperative pain management protocol is used [28]. This begins preoperatively and continues into the postoperative period with the goal of reducing the amount of narcotic medications needed by the patient, allowing them to have less side effects and to mobilize quicker postoperatively (Tables 3.2 and 3.3). Anesthetic technique consists of a

Table 3.2 Preoperative, intraoperative, and postoperative medications at White Fence Surgical Suites, New Albany, Ohio, USA

Interval	Medication	Dosing information
Preoperative		
	Celecoxib	400 mg PO
	Pregabalin or gabapentin	600 mg PO
		or 300 mg PO if >65 years old
	Acetaminophen	1 gm PO
	Dexamethasone	10 mg IV
	Metoclopramide	10 mg IV
	Scopolamine patch	Consider if no benign prostatic hypertrophy or glaucoma
	Perioperative antibiotic	
	Tranexamic acid	1 gm PO 2 h prior to incision
	Crystalloid	Start for resuscitation/hydration
Intraoperative		
	Sciatic nerve/iPack block Adductor canal block	15 ml 0.1% ropivacaine 15 ml 0.5% bupivacaine
	Propofol short-acting sedation	
	± short-acting inhalants	
	Ketamine	0.5 mg/kg IV
	Crystalloid for resuscitation/hydration	2 liters IV
	Periarticular injection	
	Ropivacaine	50 mL 0.5%
	Epinephrine	0.5 mL 1:1000
	Ketorolac	30 mg
	Ondansetron	4 mg IV
Postoperative		
	Tranexamic acid	1 gm PO 3 h after initial dose
	Urecholine	20 mg PO for benign prostatic hypertrophy/urinary retention
	Crystalloid for resuscitation/hydration	Minimum 1 additional liter
	Ondansetron	4 mg IV PRN
	Promethazine	6.25 mg IV PRN
	Oxycodone	5–10 mg PO q 4 h PRN
	Acetaminophen	1 gm PO prior to discharge
	Hydromorphone	0.5 mg IV q 10 min PRN

sciatic nerve or iPack (infiltration between popliteal artery and capsule of the knee) posterior capsular block and an adductor canal block with light general anesthesia.

Venous thromboembolic disease prevention is based upon an aspirin-based multimodal, risk-stratified approach [29]. In patients with normal perioperative risk, ambulatory calf compression devices are placed at the time of surgery and worn for 2 weeks. Patients are placed on 81 mg aspirin twice a day for 6 weeks. In patients identified as having increased risk above baseline, additional chemoprophylaxis is utilized.

Blood loss during partial knee replacement is usually not as great as during total knee replacement; however, preventing anemia is still a goal. Patients with anemia preoperatively are identified and treated. Normothermia is maintained throughout the procedure, and surgery is carried out with careful hemostasis and a minimally invasive approach. One gram PO of tranexamic acid (TXA) is given 2 h prior to incision and a second 1 gram PO dose given 3 h after the initial dose, as has been shown to be effective [30].

The postoperative period is broken down into two phases. In phase I the patient is transferred to the postanesthesia care unit and medically stabilized, while pain and nausea are managed. The goal is to manage pain and nausea with minimal narcotics or sedating medications. In phase II the

Table 3.3 Discharge medications at White Fence Surgical Suites, New Albany, Ohio, USA

Medication or therapy	Dosing information
Celecoxib	200 mg PO qd for 2 weeks
Aspirin	81 mg PO bid for 6 weeks
Antibiotics	<24 h
Acetaminophen	1000 mg PO tid for 48 h
Oxycodone	5 mg PO 1–2 q 4–6 h PRN
Hydromorphone	2 mg PO PRN breakthrough pain
Hydrocodone/acetaminophen	5 mg 1–2 q 4–6 h PRN (beginning 48 h postoperatively)
Ondansetron	10 mg PO PRN
Portable ambulatory calf pumps	
Cryotherapy motorized unit	

patient is transferred to a private room, family and friends are allowed to visit with the patient, and a small snack is given. The physical therapist will then instruct patients in the use of ambulatory aids, and they will walk, use the restroom, and be taught to negotiate stairs. The therapist will also instruct the patient in activities of daily living. Prior to discharge the nursing staff will review discharge medications and incision management instructions.

On the day following discharge, the patient begins outpatient physical therapy and continues this three times weekly until goals are met. All patients receive a nurse call within 24 h of discharge to answer any questions they may have and address any concerns. The patient is then seen for follow-up in the orthopedic office at 6 weeks postoperatively.

Authors' Protocol: Denmark

All patients scheduled for UKA are screened for eligibility in the outpatient clinic by the surgeon (Table 3.4). Patients are given standard information regarding surgery and discharge, scheduled for a visit with an anesthesiologist, and instructed by a physiotherapist prior to surgery.

Perioperative treatment is described in Table 3.5. Preoperatively on the morning of surgery, all patients receive celecoxib 400 mg and paracetamol 1 g. Before induction of anesthesia, all patients receive a single dose of methylprednisolone 125 mg IV, which has been shown to reduce pain for up to 32 h [31] and to reduce opioid consumption and swelling [32]. The surgery is performed under general anesthesia induced with IV propofol 2–3 mg/kg and remifentanil 0.5 μg/kg/min. A laryngeal mask is used for airway management, and no oxygen is given during induction. Anesthesia is maintained with an additional continuous infusion of propofol 10 mg/mL, 4–6 mg/kg/h and remifentanil 2 mg, 0.25–0.5 μg/kg/min. Normothermia is maintained with forced air warming. Intraoperative fluid replacement is 0.9% saline, 15 mL/kg/h. All UKA procedures are performed with a standard minimal incision approach with or without the use of tourniquet depending on the surgeon's preference. At the end of operation, local infiltration analgesia (LIA) is applied, which has been shown to reduce pain for 32 h [33]. Drains are not used. Postoperative radiograph is performed in the operating room (OR) and approved by the surgeon.

Table 3.4 Eligibility criteria for outpatient joint replacement surgery at Copenhagen University Hospital, Denmark

Ages 18–80 years
ASA 1–2
BMI <35
Interested in and motivated for same-day discharge
Family or relatives to be present for >24 h after discharge

Postoperatively, celecoxib 200 mg/12 h and paracetamol 1 g/6 h are administered up to and including POD6, after which the patient's general practitioner will handle further pain management. Rescue analgesics (administered if VAS > 50 mm at rest) consist of sufentanil 5–10 μg IV or oral morphine 10 mg as needed at home. Postoperative nausea/vomiting (PONV) is treated with ondansetron 4 mg. Rivaroxaban (Bayer, Denmark) is used as oral thromboprophylaxis starting 6–8 h postoperatively and given for 2 days. Mechanical thromboprophylaxis and extended oral thromboprophylaxis are not used [34].

Table 3.5 Perioperative treatment of outpatient joint replacement patients at Copenhagen University Hospital, Denmark

Interval	Medication	Dose
Preoperative		
	Celecoxib	400 mg PO
	Acetaminophen	1 gm PO
	Methylprednisolone	125 mg IV
	Perioperative antibiotic	Dicloxacillin/cefuroxime
	Tranexamic acid	1 gm IV upon induction of the anesthesia
	0.9% saline	15 mL/kg/h – start for resuscitation/hydration
Intraoperative		
	0.9% saline	15 mL/kg/h
Periarticular injection	0.2% ropivacaine	150 ml with epinephrine (10 μg/ml) in the capsule
	0.2% ropivacaine	150 ml without epinephrine in the subcutaneous tissue
Postoperative		
	Tranexamic acid	1 gm IV 3 h after initial dose
	Crystalloid or 0.9% saline	Min 1 l
	Sufentanil	5–10 μg IV PRN
	Celecoxib	200 mg PO × 2 for min 5 days
	Acetaminophen	1 gm PO × 4 for min 5 days
	Morphine	10 mg PRN
	Ondansetron	4 mg IV PRN

Table 3.6 Discharge criteria for outpatient joint replacement patients at Copenhagen University Hospital, Denmark

Steady gait with crutches, no dizziness. Stairs if required
Nausea and/or vomiting: minimal and efficiently treated with or without medications
Vital signs must be stable and consistent with age and preoperative baseline
Pain: VAS <3 at rest and VAS <5 at mobilization

Physiotherapy is started as soon as possible after surgery and continues as outpatient physiotherapy upon discharge. Patients are discharged if they fulfilled discharge criteria before 8 pm (Table 3.6).

Authors' Results: USA

Between June 2013 and December 2016, 4 surgeons in 1 group performed 4463 outpatient arthroplasty procedures at a freestanding ambulatory surgery center (ASC). These included 1344 partial knee arthroplasty procedures in 1096 patients. All patients signed our general research consent, approved and monitored by an independent institutional review board (Western IRB, Puyallup, Washington, implemented in 2005), which allows inclusion in retrospective reviews. There were 25 patellofemoral replacements (2%), 58 lateral unicompartmental knee arthroplasties (4%), and 1261 medial unicompartmental arthroplasties performed. There were 492 male patients (45%) and 604 females (55%). The mean age was 60.1 years (SD 8.0; range 32–86), and the mean BMI was 32.7 kg/m^2 (SD 6.4; range 19–62).

Of 1344 procedures, 1285 (95.6%) were discharged on the day of surgery. Of the 58 patients not discharged, 26 (1.9%) stayed overnight for reasons of convenience, 27 (2.0%) stayed overnight in the surgery center for medical reasons, and 5 (0.4%) patients required transfer to an acute care facility. The acute transfers included one patient with low oxygen saturation, two patients with cardiovascular accident (CVA), and two patients with electrocardiogram (EKG) changes, negative for myocardial infarction. The patients staying overnight at the surgery center for medical reasons included 14 with respiratory issues, 4 due to nausea/vomiting, 2 urinary

related, 2 muscle strength related, 2 with other cardiac issues, 1 with difficulty waking up, 1 wound issue, and 1 fall.

Six additional patients presented to an emergency room or acute care facility within 48 h. These included three with pain control issues, one with venous thromboembolism (VTE) symptoms with subsequent negative testing, one with allergic reaction to medication, and one with wound dehiscence.

There were 12 patients (0.9%) with unplanned care for medical reasons between 48 h and 90 days including 4 confirmed VTE, 4 allergic reactions to medication, 1 pain control issue, 1 chest pain, 1 urinary retention, and 1 constipation/ileus. There were also 16 (1.2%) patients with surgical complications requiring treatment including 10 wound revisions, 2 periprosthetic fractures, 2 arthroscopic removal of loose bodies, and 1 revision of UKA to TKA for instability and rotated bearing. Twenty-seven of 1344 knees required manipulation in the 90-day period. There was also one patient death for unknown reason in a patient who was seen at 6 weeks and was doing well at the time.

One or more significant medical comorbidities were present in 778 patients (58%). This includes previous coronary artery disease (CAD) in 87 patients (6.5%), valvular heart disease in 9 patients (0.7%), arrhythmia in 249 patients (18.5%), history of VTE in 64 patients (5%), obstructive sleep apnea (OSA) in 192 patients (14.3%), chronic obstructive pulmonary disease in 241 patients (17.9%), asthma in 146 patients (10.9%), frequent urination or benign prostatic hypertrophy (BPH) in 258 patients (19.2%), and mild chronic renal insufficiency in 40 patients (3.0%). The presence of these comorbidities was not associated with medical or surgical complications. With the low number of patients experiencing a medical complication and the vast array of medical comorbidities, we were not able to show any statistical significance. However, the presence of one or more major comorbidity was associated with a significantly increased risk of needing to stay overnight for medical observation (Table 3.7). Specific comorbidities associated with increased risk of requiring an overnight stay that were statistically significant were history of CAD and arrhythmia.

Table 3.7 Risk of overnight stay for medical reason by major comorbidity in patients undergoing partial knee arthroplasty at White Fence Surgical Suites, New Albany, Ohio, USA

Major comorbidity	Preoperative frequency	Overnight stay for medical reason	Overnight for medical reason with vs without comorbidity	Relative risk	95% CI	*P* value	Odds ratio	95% CI	*P* value
Coronary artery disease	87 (6.5%)	10	11.5% vs 1.8%	6.57	3.2–13.4	<0.0001	7.29	1.3–8.8	<0.0001
Valvular disease	9 (0.7%)	0	0.0% vs 2.4%	2.06	0.1–31.3	0.6040	2.11	0.4–28.8	0.6093
Arrhythmia	19 (18.5%)	13	5.2% vs 1.7%	3.01	1.5–6.6	0.0018	3.12	0.9–3.5	0.0019
Venous thromboembolism	64 (4.8%)	3	4.7% vs 2.3%	2.07	0.7–6.6	0.2200	2.12	0.02–7.9	0.2254
Obstructive sleep apnea	192 (14.3%)	7	3.6% vs 2.2%	1.68	0.7–3.8	0.2172	1.71	0.5–2.8	0.2195
Chronic obstructive pulmonary disease	241 (17.9%)	9	3.7% vs 2.1%	1.79	0.8–3.8	0.1318	1.82	1.4–5.7	0.1336
Asthma	146 (10.9%)	6	4.1% vs 2.2%	1.89	0.8–4.5	0.1508	1.93	1.2–5.4	0.1538
Frequent urination	258 (19.2%)	6	2.3% vs 2.4%	0.97	0.4–2.3	0.9483	0.97	1.4–4.7	0.9483
Kidney disease	40 (3.0%)	2	5.0% vs 2.3%	2.17	0.5–8.8	0.2759	2.24	0.4–22.5	02827
Any major comorbidity	778 (57.9%)	25	3.2% vs 1.2%	2.60	1.1–6.0	0.0243	2.65	1.3–4.3	0.0238

Discussion

Multiple cohort studies from various institutions (hospitals and ambulatory surgery centers) in different countries indicate that outpatient unicompartmental knee arthroplasties can be performed with low complication and readmission rates and a high degree of patient satisfaction – also compared to inpatient procedures [26, 35–37]. Additionally, similar outcomes between a hospital setting and an ambulatory center setting have been reported [38].

Evaluations of cost between in- and outpatient unicompartmental knee arthroplasties are scarce, but savings of up to 50% have been estimated for the latter [39]. Hence, reviews and editorials have concluded outpatient UKA is safe in selected patients but also have identified a need for studies assessing safety prospectively on a larger scale [40, 41].

Conclusion

This chapter describes considerations for doing UKA as outpatient surgery. Proper patient selection with a prepared and focused mind-set is key, as is creating a smooth pathway with dedicated staff members to support and facilitate the achievement of the functional milestones necessary for discharge. The evidence-based principles of fast-track surgery should be used together with multimodal pain management and logistical optimization. Current evidence obtained from cohort studies finds lower cost and no increase in complications, thus making outpatient UKA a feasible and attractive option in a correct setting.

References

1. Tingle C, Berger RA, Bolognesi MP, Della Valle CJ, Lombardi AV Jr, Scuderi GR. Same-day outpatient TJR gains popularity, but careful considerations must be made. Orthopedics Today. 2015;35(8):10–1.
2. Lovald ST, Ong KL, Malkani AL, Lau EC, Schmier JK, Kurtz SM, et al. Complications, mortality, and costs for outpatient and short-stay total knee arthroplasty patients in comparison to standard-stay patients. J Arthroplast. 2014;29(3):510–5.
3. Healy WL, Iorio R, Ko J, Appleby D, Lemos DW. Impact of cost reduction programs on short-term patient outcome and hospital cost of total knee arthroplasty. J Bone Joint Surg Am. 2002;84–A(3):348–53.
4. Husted H. Fast-track hip and knee arthroplasty: clinical and organizational aspects. Acta Orthop Suppl. 2012;83(346):1–39.
5. Berger RA, Kusuma SK, Sanders S, Thill ES, Sporer SM. The feasibility and perioperative complications of outpatient knee arthroplasty. Clin Orthop Relat Res. 2009;467:1443–9.
6. Gromov K, Kjærsgaard-Andersen P, Revald P, Kehlet H, Husted H. Feasibility of outpatient total hip and knee arthroplasty in unselected patients. Acta Orthop. 2017;88(5):516–21.
7. Husted H, Lunn TH, Troelsen A, Gaarn-Larsen L, Kristensen BB, Kehlet H. Why still in hospital after fast-track hip and knee arthroplasty? Acta Orthop. 2011;82(6):679–84.
8. Lunn TH, Kristensen BB, Gaarn-Larsen L, Husted H, Kehlet H. Post-anaesthesia care unit stay after total hip and knee arthroplasty under spinal anaesthesia. Acta Anaesthesiol Scand. 2012;56(9):1139–45.
9. Steinthorsdottir KJ, Kehlet H, Aasvang EK. The surgical stress response and the potential role of preoperative glucocorticoids on post-anesthesia care unit recovery. Minerva Anestesiol. 2017 Jun 12. [Epub ahead of print].
10. Repicci JA, Eberle RW. Minimally invasive surgical technique for unicondylar knee arthroplasty. J South Orthop Assoc. 1999;8:20–7.
11. Lombardi AV Jr, Berend KR, Walter CA, Aziz-Jacobo J, Cheney NA. Is recovery faster for mobile bearing unicompartmental than total knee arthroplasty? Clin Orthop Relat Res. 2009;467:1450–7.
12. Brown NM, Sheth NP, Davis K, Berend ME, Lombardi AV, Berend KR, et al. Total knee arthroplasty has higher postoperative morbidity and mortality than unicompartmental knee arthroplasty: a multicenter analysis. J Arthroplast. 2012;27(Suppl. 8):S86–90.
13. Berend KR, Morris MJ, Lombardi AV. Unicompartmental knee arthroplasty: incidence of transfusion and symptomatic thromboembolic disease. Orthopedics. 2010;33(Suppl. 9):8–10.
14. Morris MJ, Molli RG, Berend KR, Lombardi AV Jr. Mortality and perioperative complications after unicompartmental knee arthroplasty. Knee. 2013;20:218–20.
15. Berend ME. Oxford partial knee replacement as a gateway to outpatient arthroplasty: "lessons learned along the journey". Reconstr Rev. 2016;6(3):37–41.
16. Meding JB, Klay M, Healy A, Ritter MA, Keating EM, Berend ME. The prescreening history and physical in election total joint arthroplasty. J Arthroplasty. 2007;22(6 suppl2):21–3.
17. Courtney PM, Rozell JC, Melnic CM, Lee GC. Who should not undergo short stay hip and knee arthroplasty? Risk factors associated with major medical complications following primary total joint arthroplasty. J Arthroplast. 2015;30(9 Suppl):1–4.

18. Kort NP, Bemelmans YFL, van der Kuy PHM, Jansen J, Schotanus MGM. Patient selection criteria for outpatient joint arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2017;25(9):2668–75.
19. Hansen VJ, Gromov K, Lebrun LM, Rubash HE, Malchau H, Freiberg AA. Does the risk assessment and prediction tool predict discharge disposition after joint replacement? Clin Orthop Relat Res. 2015;473(2):597–601.
20. Cole CM. Physician-owned hospitals and self-referral. Virtual Mentor. 2013;15(2):150–5.
21. Perry JE. Physician-owned specialty hospitals and the patient protection and affordable care act: health care reform at the intersection of law and ethics. Am Bus Law. 2012;49(2):369–417.
22. Hartog YM, Mathijssen NM, Vehmeijer SB. Total hip arthroplasty in an outpatient setting in 27 selected patients. Acta Orthop. 2015;86(6):667–70.
23. Goyal N, Chen AF, Padgett SE, Tan TL, Kheir MM, Hopper RH Jr, Hamilton WG, Hozack WJ. Otto Aufranc Award: a multicenter, randomized study of outpatient versus inpatient total hip arthroplasty. Clin Orthop Relat Res. 2017;475(2):364–72.
24. McGregor AH, Rylands H, Owen A, Dore CJ, Hughes SP. Does preoperative hip rehabilitation advice improve recovery and patient satisfaction? J Arthroplast. 2004;19(4):464–8.
25. Yoon RS, Nellans KW, Geller JA, Kim AD, Jacobs MR, Macaulay W. Patient education before hip or knee arthroplasty lowers length of stay. J Arthroplast. 2010;25(4):547–51.
26. Kort NP, Bemelmans YFL, Schotanus MGM. Outpatient surgery for unicompartmental knee arthroplasty is effective and safe. Knee Surg Sports Traumatol Arthrosc. 2017;25(9):2659–67.
27. Jørgensen PB, Bogh SB, Kierkegaard S, Sørensen H, Odgaard A, Søballe K, Mechlenburg I. The efficacy of early initiated, supervised, progressive resistance training compared to unsupervised, home-based exercise after unicompartmental knee arthroplasty: a single-blinded randomized controlled trial. Clin Rehabil. 2017;31(1):61–70.
28. Jørgensen CC, Jacobsen MK, Soeballe K, Hansen TB, Husted H, Kjærsgaard-Andersen P, Hansen LT, Laursen MB, Kehlet H. Thromboprophylaxis only during hospitalisation in fast-track hip and knee arthroplasty. A prospective cohort study. BMJ Open. 2013;3(12):e003965.
29. Mallory TH, Lombardi AV, Fada RA, Dodds KL, Adams JB. Pain management for joint arthroplasty: preemptive analgesia. J Arthroplasty. 2002;17(4, Suppl 1):129–33.
30. Berend KR, Lombardi AV Jr. Multimodal venous thromboembolic disease prevention for patients undergoing primary or revision total joint arthroplasty: the role of aspirin. Am J Orthop. 2006;35(1):24–9.
31. Irwin A, Khan SK, Jameson SS, Tate RC, Copeland C, Reed MR. Oral versus intravenous tranexamic acid in enhanced-recovery primary total hip and knee replacement: results of 3000 procedures. Bone Joint J. 2013;95-B(11):1556–61.
32. Lunn TH, Kristensen BB, Andersen LØ, Husted H, Otte KS, Gaarn-Larsen L, Kehlet H. Effect of high-dose preoperative methylprednisolone on pain and recovery after total knee arthroplasty: a randomized, placebo-controlled trial. Br J Anaesth. 2011;106(2):230–8.
33. Rytter S, Stilling M, Munk S, Hansen TB. Methylprednisolone reduces pain and decreases knee swelling in the first 24 h after fast-track unicompartmental knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2017;25(1):284–90.
34. Andersen LØ, Husted H, Otte KS, Kristensen BB, Kehlet H. High-volume infiltration analgesia in total knee arthroplasty: a randomized, double-blind, placebo-controlled trial. Acta Anaesthesiol Scand. 2008;52(10):1331–5.
35. Ruiz N, Buisson X, Filippi G, Roulet M, Robert H. Ambulatory unicompartmental knee arthroplasty: short outcome of 50 first cases. Orthop Traumatol Surg Res. 2017;24 [Epub ahead of print].
36. Bradley B, Middleton S, Davis N, Williams M, Stocker M, Hockings M, Isaac DL. Discharge on the day of surgery following unicompartmental knee arthroplasty within the United Kingdom NHS. Bone Joint J. 2017;99-B(6):788–92.
37. Hoorntje A, Koenraadt KLM, Boevé MG, van Geenen RCI. Outpatient unicompartmental knee arthroplasty: who is afraid of outpatient surgery? Knee Surg Sports Traumatol Arthrosc. 2017;25(3):759–66.
38. Richter DL, Diduch DR. Cost comparison of outpatient versus inpatient unicompartmental knee arthroplasty. Orthop J Sports Med. 2017;5(3):2325967117694352.
39. Cody JP, Pfefferle KJ, Ammeen DJ, Fricka KB. Is outpatient unicompartmental knee arthroplasty safe to perform at an ambulatory surgery center? A comparative study of early post-operative complications. J Arthroplasty. 2017 Oct 10. pii: S0883-5403(17)30885-9. [Epub ahead of print].
40. Pollock M, Somerville L, Firth A, Lanting B. Outpatient total hip arthroplasty, total knee arthroplasty, and unicompartmental knee arthroplasty: a systematic review of the literature. JBJS Rev. 2016;4(12). pii: 01874474-201612000-00004.
41. Hirschmann MT, Kort N, Kopf S, Becker R. Fast track and outpatient surgery in total knee arthroplasty: beneficial for patients, doctors and hospitals. Knee Surg Sports Traumatol Arthrosc. 2017;25(9):2657–8.

Medial Fixed Bearing UKR: Technique and Tips

4

R. W. D. Pilling, C. J. Della Valle, and N. J. London

Introduction

Unicompartmental knee replacement (UKR) is an alternative to total knee replacement (TKR) in patients with end-stage knee osteoarthritis confined to one compartment [1]. UKR restores the normal kinematics of the knee compared with TKR due to the preservation of soft tissue structures leading to improved functional results. Lower morbidity, mortality, and blood loss combined with a quicker recovery are seen with UKR compared with TKR because less soft tissue dissection, bone resection, and fewer releases are required [2, 3].

Successful partial knee arthroplasty depends in part on re-establishment of appropriate lower extremity alignment, proper implant design and orientation, secure implant fixation, and restoring the tension of the soft tissue and stability.

Fixed bearing UKR has similar excellent outcomes and at least equivalent survivorship to the mobile-bearing implants without the risk of dislocation, allowing the surgeon to focus on balancing the gaps while ensuring slight under-correction. Avoiding full or especially over-correction of the varus deformity (in a medial UKR) substantially reduces the risk of progression of arthritis in the contralateral compartment. With fixed bearing UKR, a greater degree of under-correction is tolerated giving the surgeon a wider "margin of error." Correct orientation and alignment are essential however to reduce edge loading and hence contact stresses and wear. Progression of disease may be unavoidable in some patients; however it is clear that "overstuffing" the compartment with UKR leads to rapid progression of arthritis in the opposite compartments.

Five Key Principles of Fixed Bearing UKR Surgical Technique

1. Under-Correction of Limb Alignment

The key to a successful UKR is to ensure a slight under-correction of the limb alignment and have appropriate ligamentous tension restored (2–3 mm of laxity) in both flexion and extension. The mechanical axis should fall between the tibial spines and the middle of the resurfaced compartment as overloading the contralateral compartment can lead to progression of wear in the lateral compartment.

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2. Component to Component Alignment

Proper alignment of the tibial and femoral components is paramount to durable results for UKR, reducing the risk of both accelerated polyethylene wear and implant loosening. The objective is to ensure congruency between the femoral component – in both flexion and extension – on the surface of the polyethylene and tibial tray, without overhang that can lead to edge loading, especially between 20° and 60° of flexion when maximum forces occur during weight bearing.

3. Restoring the Tension of the Soft Tissues

Restoring the tension of the soft tissues allows the knee to remain stable throughout a range of motion. Many long-term UKR survivorship studies demonstrate the efficacy of employing a balanced gap technique.

4. Tibial Slope

The goal is to match the patient's native natural slope. Excessive slope may lead to excessive tension on the ACL as well as increased risk of tibial loosening, while inadequate slope may lead to limited flexion. A tibial guide set for a slope of 5° is appropriate for most patients.

5. Component Sizing

Due to the small surface area of proximal tibia that is replaced, tibial sizing and fit are generally regarded as among the most critical aspects of surgical technique. In general, the largest size that can be accommodated without overhang is desired, in order to place the component on the strongest bone of the proximal tibia, at the cortical rim.

The technique described below is intended as a general description for fixed bearing UKR but in part is specific to the Persona Partial Knee (Zimmer Biomet®) [4]. Some aspects of the technique such as setup, incision, instrument use, and tips are from the extensive experience of knee surgery by the senior authors, but are not mandatory. Appropriate implant-specific training should be sought prior to undertaking UKR with an unfamiliar implant.

Patient Setup

Supine with Tourniquet on Proximal Thigh

Foot rolls to knee position at 70° and 110–120° with a lateral support at level of tourniquet to prevent hip abduction and permit freestanding of the knee (Fig. 4.1). Ideally a minimum of 110° flexion should be achieved for unimpeded implant insertion; if this cannot be achieved, a larger incision may be necessary.

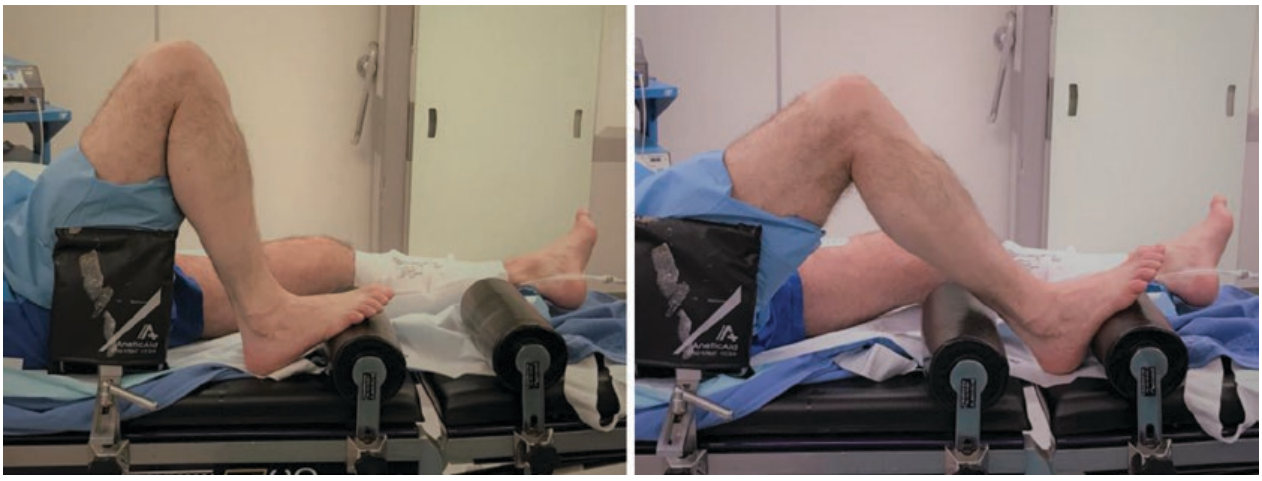

Fig. 4.1 Leg position. High thigh tourniquet with side support. Two foot rolls set for flexion of approximately 70° and 110°

Incision and Exposure

Incise skin and subcutaneous tissues over the medial compartment from superior pole of patella to tibial tuberosity (Fig. 4.2). Ensure the exposure is sufficient to allow full visualization of the surgical site and important landmarks taking care to avoid excessive tension on the skin edges. Arthrotomy is performed around the medial edge of patella and distally along the free edge of the patella tendon. Deep exposure can be carried out via medial parapatellar, mid vastus, or subvastus approach. We prefer the medial parapatellar approach (extending proximally 0.5–1 cm above the patella). A larger, more standard "TKA" incision may be preferred for surgeons as they are first learning the technique.

Expose the anteromedial tibial plateau to create enough space for the tibial cutting block, but do not release any fibers of medial collateral ligament complex. There is no need to excise significant amounts of the anterior fat pad, and merely excise tissue that blocks access to the surgical field (Fig. 4.3).

At this time, the ACL is examined as are the lateral and patellofemoral compartments. The lateral compartment should appear normal although a chondral ulcer is often seen on the medial aspect of the lateral femoral condyle in patients with greater varus deformity due to tibial spine impingement. This is not a contraindication to medial UKA; as once the deformity is reduced, the spine will no longer contact the femoral condyle. We will accept degenerative changes of the medial and central portions of the patella and femoral trochlea (unless significantly symptomatic); however full-thickness degenerative changes of the lateral facet of the patella and the lateral side of the trochlea are a relative contraindication.

Excise the anterior portion of medial meniscus, leaving a sharp free edge to facilitate excision once the posterior meniscus is exposed. Remove osteophytes from the intercondylar notch, medial femoral condyle, and tibial plateau to allow balancing and identification of the true dimensions of the compartment. Varying amounts of flexion and extension will permit visualization

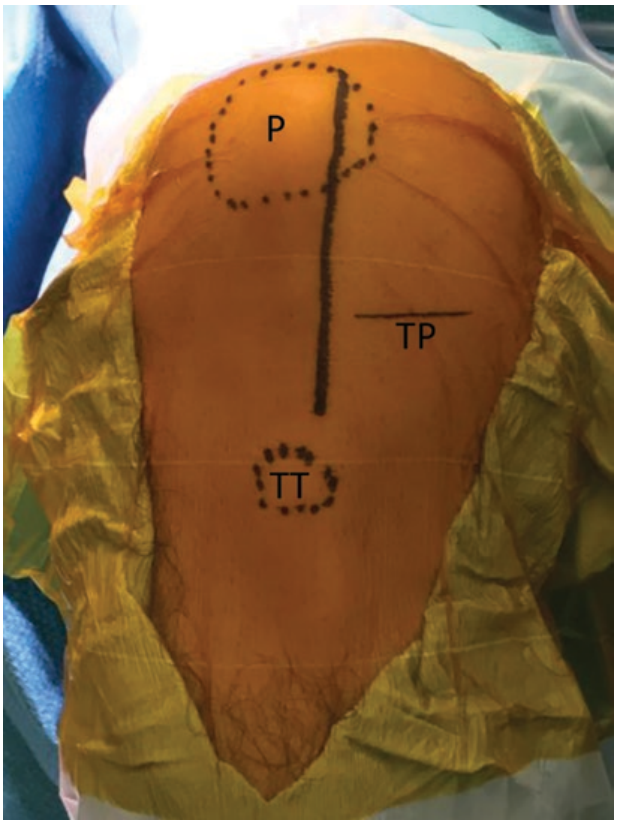

Fig. 4.2 Incision and approach. The incision marked with solid line. The dotted lines around the patella and tibial tuberosity. P patella, TT tibial tuberosity, TP tibial plateau

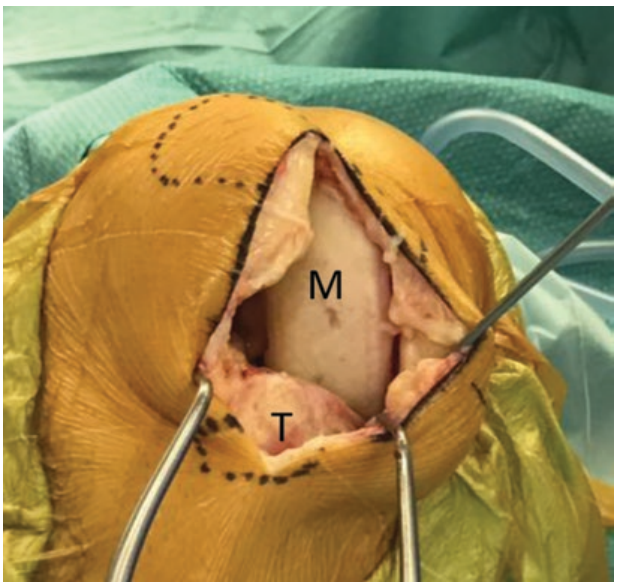

Fig. 4.3 Approach. Note the visualization of the medial and lateral walls of medial femoral condyle (M) and the notch. The limited exposure of anteromedial tibia (T) to allow close fitting of the cutting block

and ease of removal of the osteophytes. The medial notch anterior to the ACL must be cleared of osteophytes to accurately position the tibial cutting jig and to allow passage of the saw blade.

Proximal Tibial Resection

Assemble the tibial cutting block and jig. When setting the position of the tibial cutting block, the following parameters need to be accommodated:

- Axial rotation
- Coronal rotation
- Medial-lateral position (i.e., sagittal cut position)
- Posterior slope
- Depth of resection

Firstly, set rotation by aligning the long axis of the jig with the center of the talus (1 cm medial to the midpoint between malleoli) and the intersection between middle and medial third of the tibial tuberosity. The tibial tubercle and anterior tibial crest are palpable in all but the morbidly obese. Ensure the jig is not internally rotated on the tibia. Positioning the shaft of the jig parallel to the anterior tibial crest is a useful secondary guide for coronal alignment (Fig. 4.4).

Medial-lateral position: Position the block to ensure the sagittal cut will be made just lateral to the lateral border of the MFC (and hence medial to the ACL). The cutting block on the system we use has a capture to guide the saw, but many systems do not. Ensure the block is positioned (using an angel wing to assist) to cut approximately halfway up the slope of the medial tibial spine to avoid damage to the ACL (Fig. 4.5). Use an initial pin to hold the cutting block in position against the anterior cortex of the tibia. The PPK has a 12mm vertical slot for the initial pin to fix rotation but permits alterations in resection level and slope (Fig. 4.6).

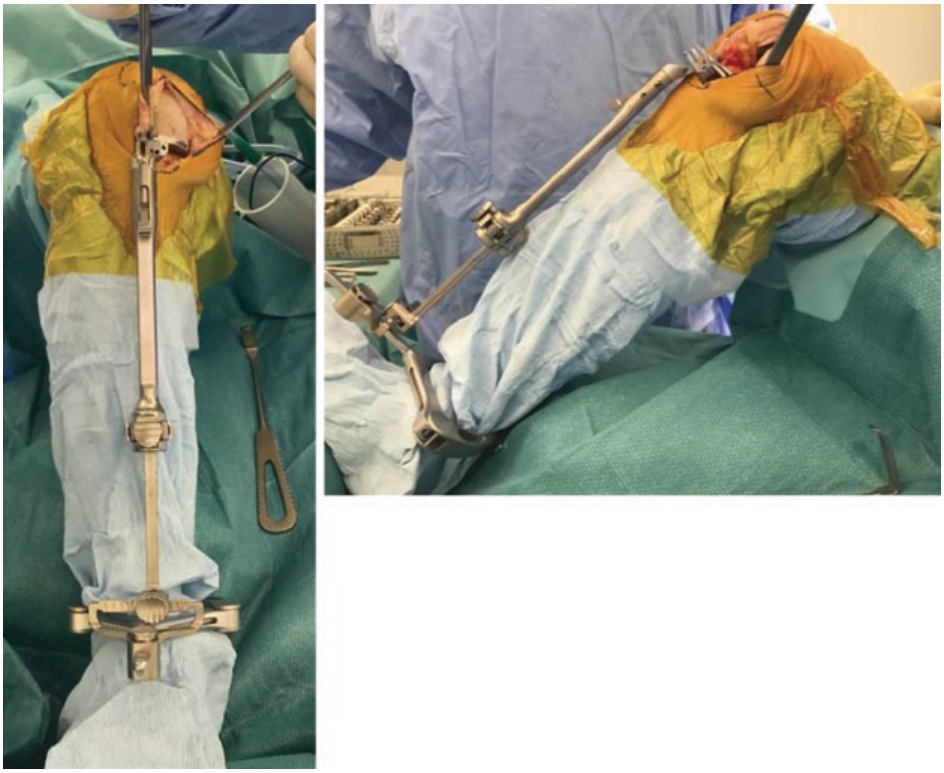

Fig. 4.4 Tibial jig alignment. Coronal alignment (left image). Parallel to the mechanical axis of the tibia – proximally the junction of middle and medial third of tibial tuberosity, distally the middle of the ankle joint (note the medial position of jig compared to malleoli). The rotation is correct (slight external rotation) when the projected sagittal cut passes posteriorly through the notch halfway up the medial tibial spine and lateral to medial femoral condyle. Sagittal alignment (right image), restored native posterior slope of tibial plateau

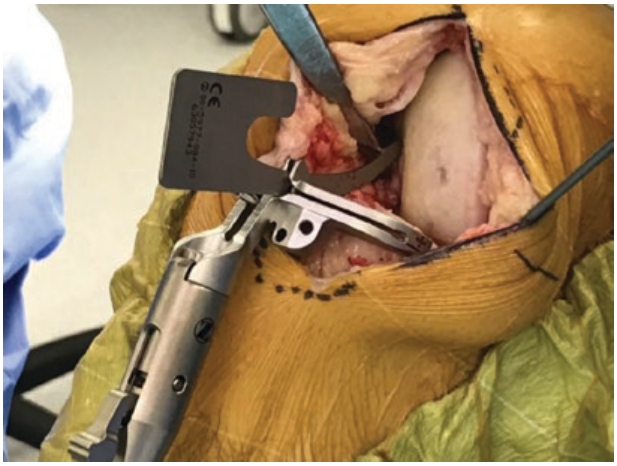

Fig. 4.5 Tibial cutting block position. Use angel wing to guide correct position of sagittal cut lateral to medial femoral condyle and halfway up tibial spine

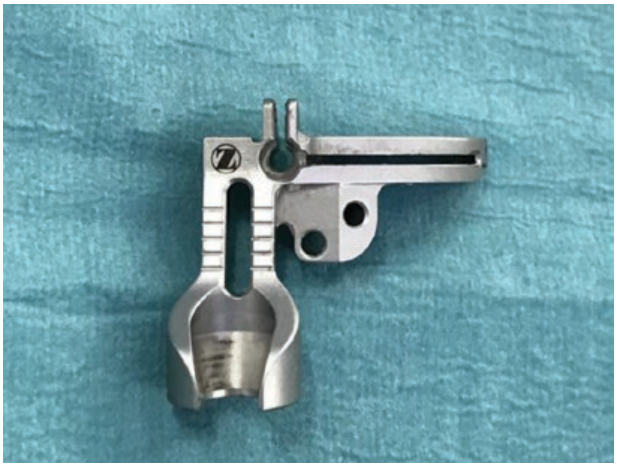

Fig. 4.6 Tibial cutting block. Long slot for initial pin. Infero-lateral corner pin with saw guides for both sagittal and transverse cuts

Posterior slope: The posterior slope can then be adjusted to match the native slope of the tibia (often 5–7° but needs consideration during preoperative planning), and the PPK uses a 5° cutting block as standard (Fig. 4.4).

In standard anteromedial osteoarthritis, a 4 mm resection (below the most worn area of the tibial plateau) is planned and the 4 mm stylus positioned on the most worn area and the jig adjusted appropriately. If there is very severe wear, the 2 mm stylus may be used. Use an angel wing to confirm amount of resection and slope.

Make the sagittal cut first using a single-sided reciprocating sagittal saw. It is critical that the saw does not dig into the plateau below the superior surface of the cutting block and thus avoid a stress riser that may increase the risk for a periprosthetic fracture of the tibial plateau. Ensure the saw blade remains parallel with the cutting block surface before moving the saw inferiorly to cut onto the cutting block. The system used by the authors is designed to allow both sagittal and transverse cuts onto a protective infero-lateral corner pin.

The transverse cut is performed next. Take great care to avoid transecting the MCL, using a retractor to protect the structures medially. Ensure the saw blade does not cut more laterally than the sagittal cut to prevent stress risers and potential tibial spine avulsion. Take care as the saw blade approaches the posterior cortex as the neurovascular structures are unprotected.

Remove the jig and block, but do not disassemble and leave pins in situ; if recutting is required, then the jig is easier to reapply if the settings are not changed. Extend the knee, use an osteotome to elevate resected bone, and remove the tibial plateau with a grasper carefully releasing any remaining soft tissue attachments. Assess the depth of the resection, and use the resected bone as a guide to begin selecting the tibial component size. Also note the distribution of wear. Anteromedial wear is typically found in the knee with a functioning ACL.

A 9 mm spacer block in extension should easily slide in and out of the space in 5–10° of flexion. It is important to hold the knee in slight flexion to relax the posterior capsule, which when under tension influences the size of the gap. The smallest insert available is the 8 mm; however the 9 mm spacer is used initially rather than the 8 mm spacer to allow a flexibility of 1 mm for the surgeon and permit the option of downsizing the final insert after components are implanted, should the need arise. The PPK uses the distal femoral cutting block as this spacer. If too loose or tight, then the next sequential size should be tried. In full extension, the overall alignment of the limb should be checked to ensure slight under-correction of the varus deformity. Alignment rods can be used, and the mechanical axis should pass medial to the midline of the knee.

If the resection is clearly too conservative, then recutting is easy at this stage as the jig setup should not have been tampered with and the pins

are in place. The order for checking rotation and alignment and performing cuts is the same as above. Depending on the system being used, either reposition the cutting block in the -2mm holes or use a 2mm "recutter" block. If alignment of the tibial cut is incorrect, then start from the beginning with the tibial jig and cutting block and pins and recut appropriately to correct.

Distal Femoral Resection

The distal femoral cutting block corresponding to the appropriate spacer identified above is inserted. The block should be advanced until flush against the anterior femur. Anterior osteophytes may require removal to seat the block correctly. Extend the knee which ensures the cutting block is supported by the cut tibial surface and contacting the distal femur. Take care not to hyperextend the knee. Secure the cutting block to the femur with a headed screw. Allow the leg to rest in near full extension to avoid compression, therefore trapping the saw blade. While protecting the MCL complex, perform the cut, and remove the screw and block. To avoid damaging the posterior popliteal area, do not extend the saw blade beyond the distal femur with the leg in extension. Use an osteotome to elevate the bone and dissect any soft tissues from the fragment as it is removed. In general, it is desired to remove approximately 5 mm of bone from the distal aspect of the femur, and measuring the resected distal femur is helpful to confirm the cut was accurate. While the implant we use is approximately 6.5 mm in thickness, the saw blade itself has some thickness or "kerf," and there is typically some wear of the articular cartilage distally. Resection of more than approximately 5 mm from the distal femur will typically lead to a tight flexion gap and resection of less a tight extension gap.

Spacer Block Technique

Select the flexion/extension gap checking block matching the previous steps. Insert the thicker "extension" end into the joint space. The block is the combined thickness of the tibial bearing and distal femoral components. Check that full extension can be achieved, and then flex 5–10 to relax the posterior structures. Test the ligamentous tension that has been restored – there should be at least 2 mm of laxity. As there is no risk of bearing dislocation in fixed bearing UKR, greater laxity can be accepted to ensure under-correction and prevent overstuffing the compartment. If there is doubt the tension is correct, confirm if the next thickest flexion/extension gap checker is too tight and the next smallest too loose. It is important that alignment demonstrates slight under-correction and that ligamentous tension permits at least 2 mm of laxity.

Check the flexion gap by flexing the knee to approximately 100°, and insert the thin end of the flexion/extension gap checker. This should be inserted with relative ease, and restore the tension as before with a minimum 2 mm of laxity. The flexion end of the gap checker is thinner because the posterior condyle is intact; the block takes account of the anticipated resection.

The correct tension sliding the blocks in and out during gap checking is not an exact science that can be described in a textbook. It is the resistance felt by the surgeon as they insert and position the gap checker, and the correct tension becomes more instinctive with experience (Fig. 4.7).

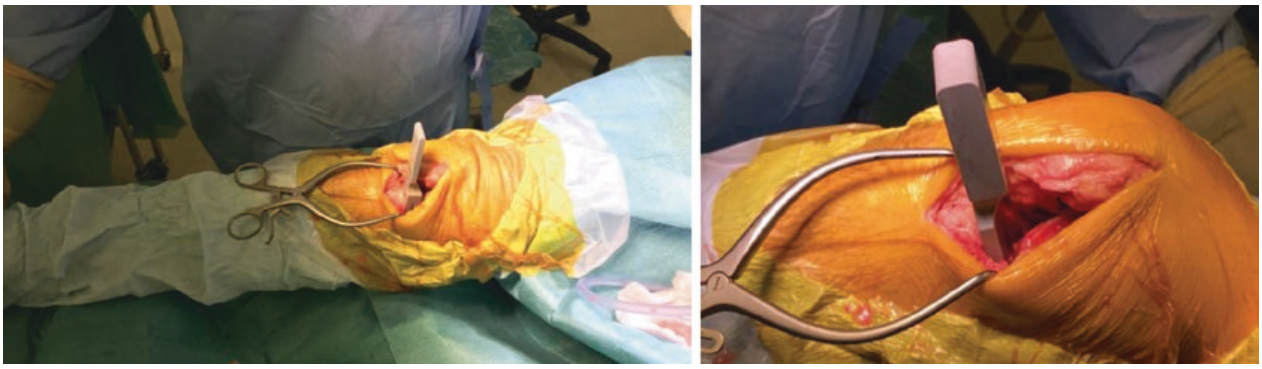

Fig. 4.7 Extension and flexion gap checking with spacer blocks

Unbalanced Flexion/Extension Gaps

If the flexion gap is correct but the extension gap tight, ensure the knee is flexed to relax the posterior capsule. If the extension gap remains tight, then consider recutting the distal femur in 1 mm increments.

If the extension gap is correct but the flexion gap tight, then rasp the articular surface of the posterior condyle, which is usually preserved. Remove 1–2 mm of cartilage, and check the flexion gap again. If the flexion gap is still tighter than extension, then review the posterior slope on the tibial cut, and assess the tension on the MCL. Recutting the tibia with increased slope may be necessary.

These issues should be relatively rare if the distal femoral resection was accurate as described above and if an appropriate amount of proximal tibia was resected.

Femoral Sizing and Cutting

The femoral finishing guide or cutting block is used to size the femur. The shape and size match the location and profile of the anterior and distal femoral component. Flex the knee to approximately 100°, and place the guide flush on the distal femoral cut and the posterior condyle. Exposure of the condyle requires the patella to be retracted. Using a trethowan bone spike or similar positioned in the notch against the lateral border of the medial femoral condyle levering the patella laterally is safe and will protect the articular surface. Ensure no soft tissue or osteophytes interfere with positioning or identification of the true dimensions of the condyle. Marking the bone with diathermy just below the anterior subchondral tidemark prior to applying the finishing block will assist in ensuring the correct size is selected (Fig. 4.8). The lateral border of the guide should be parallel to the lateral border of the medial femoral condyle and as far lateral as possible without impinging on the notch. The anteromedial border should leave a 2–3 mm rim of subchondral bone visible (Fig. 4.8). If the condyle appears to be between sizes, choose the smaller size to prevent impingement of the femoral component against the native patella. Confirm there is no medial or lateral overhang, and insert a long-headed screw (48 mm) into the most anterior hole. Seat the screw gently, especially in soft bone. *The key to centralizing the femoral component on the tibial insert in extension is to lateralize the component. This avoids edge loading as the knee extends which could increase wear rate or potentially cause premature loosening.*

The rotation should be checked as it can still be adjusted slightly at this stage. The tibia cut surface should be parallel to the posterior surface of the finishing guide. Insertion of the flexion gap checker flush to the tibia cut and supporting the underneath of the finishing guide will ensure the parallel cut. Insert a second oblique screw medial to the first, taking care with the final few revolu-

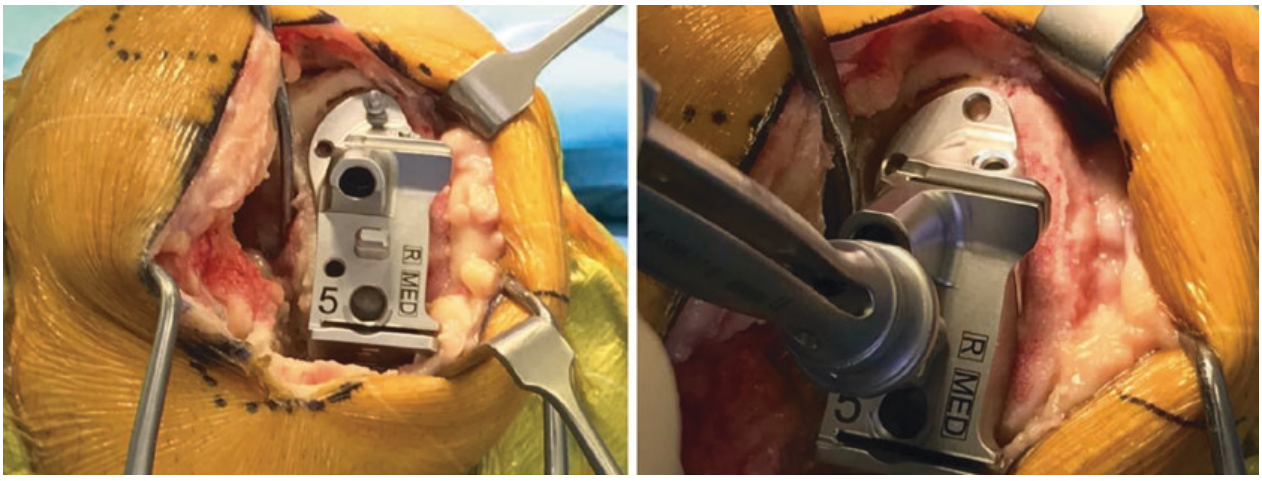

Fig. 4.8 Femoral cutting block position. Note the diathermy marking of anterior tidemark, and ensure the mark is visible. The block is parallel to the lateral wall of the condyle, and the medial side has a rim of 2–3 mm of bone visible. Lateralize the patella with a bone spike placed in the notch levering against the medial side of the patella

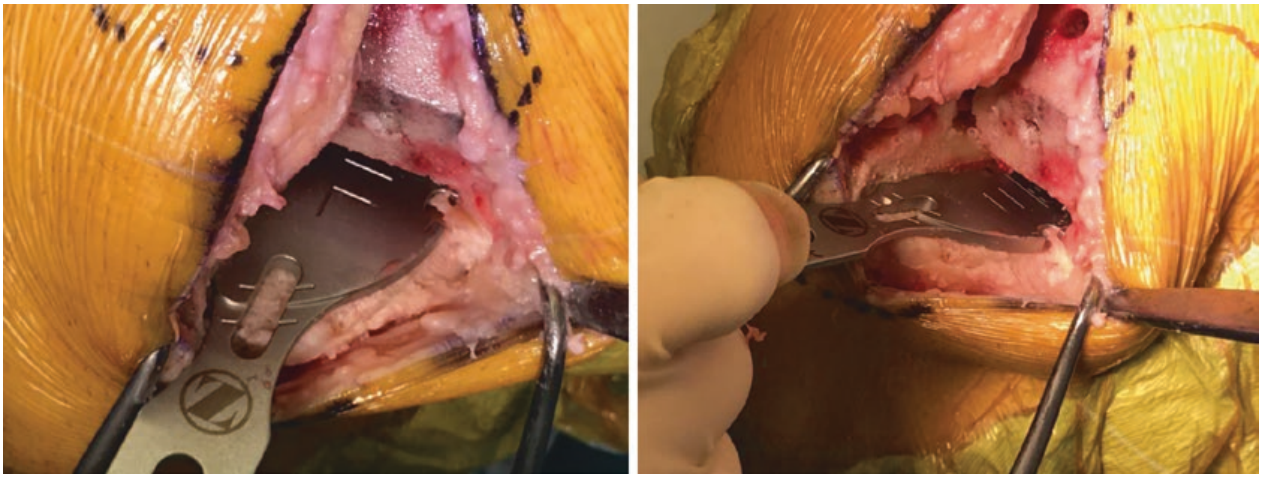

Fig. 4.9 Tibial sizing guide. The guide should be flushed with the anteromedial cortex avoiding any overhang anywhere on the plateau. Correct size is guided by etchings of anterior rim of next size larger and smaller

tions not to dislodge the guide. If a third screw is desired, then it is recommended to use a more posterior hole; however this will require removal prior to performing the chamfer cut. Take note of the length and direction of the screws as it is possible to perforate the posterior cortex, which should be avoided.

Drill the lug holes first. This reduces the volume of subchondral bone; the saw has to cut reducing the chance of the block moving with the vibrations. Protect the MCL and perform the posterior chamfer and condyle resections. Ensure the third screw has been removed prior to completing the chamfer cut and that the saw does not penetrate the posterior structures or damage the ACL. Remove the screws, block, and the bone fragments. Use an osteotome to remove any posterior osteophytes which may interfere with deep flexion.

With the joint space now exposed, the remaining meniscus can be removed. Adducting the hip with knee flexed places the knee in valgus which opens the joint space, and externally rotating the tibia facilitates removal of remaining soft tissue posteriorly.

Size and Prepare the Tibia

Insert the appropriate tibial sizing guide that best covers the cut tibial surface on both anteroposterior and mediolateral dimensions. To ensure the correct size, the posterior edge should be flush with the cortex, and sagittal cut and the sizer should not overhang medially or anteriorly (Fig. 4.9). The PPK has a flange to hook over the posterior edge of the tibia, and the engravings on the sizer indicate the anteromedial limit of each corresponding tibial component. If the best fit in an AP direction has medial overhang, ensure the sagittal tibial cut is far enough lateral. If recutting the sagittal cut is not necessary, then downsize the component. The keel position is cut out of the tibial sizer on the lateral edge – a sagittal saw or osteotome can be used to create space for the keel in the tibia especially if the bone is very sclerotic.

The appropriate size tibial finishing trial is inserted ensuring there is no posterior overhang. Use the impactor if necessary to seat flush on the tibial surface, and secure with a headed screw, carefully seating the screw to prevent movement of the block, especially in soft bone. Drill the peg holes which in the PPK are angled 20° posteriorly.

Trial Reduction

Flex the knee and insert the appropriate sized femoral trial. Insert the longer peg first, and impact into place. Ensure it is seated flush on the cut surfaces. Select the trial insert matching the thickness of the flexion/extension spacer blocks

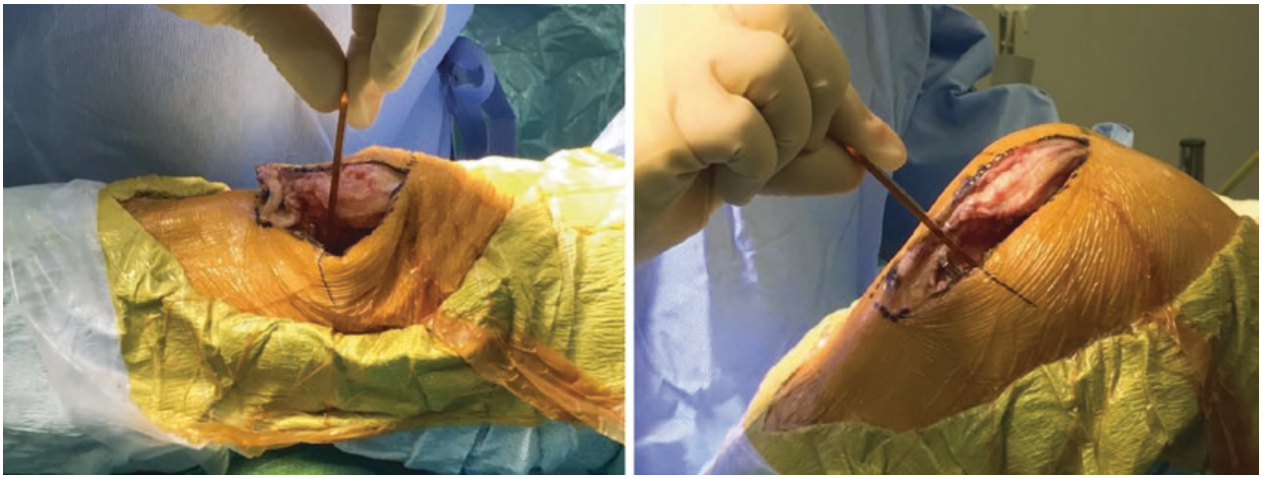

Fig. 4.10 Checking soft tissue tension with 2 mm spacer. The surgeon should be able to slide the spacer into the joint using thumb and index finger only

utilized earlier. Ensure there is no soft tissue interposed between trial components. Extend and then take the knee through a range of motion, and check the alignment and ligament tension. It is imperative that there be at least 2 mm of laxity in both full extension and 100° of flexion as assessed with the spacer (Fig. 4.10). In general, more laxity can be accepted in flexion, given the preservation of both cruciate ligaments. If there is less than 2 mm of laxity present with the 8 mm spacer in place in both flexion and extension, more tibia needs to be resected. If there is more than 2 mm of laxity in flexion and extension, increase the insert size until appropriate tension is achieved. In the system we use, the inserts range from 8 to 14 mm in thickness. Ensure the femoral component articulates with the insert throughout the range of motion and there is no edge loading of the articular insert. Edge loading of the insert risks more rapid wear. Finally, ensure that the femoral component does not impinge upon the patella.

Implanting Components

Prepare the bone surfaces with copious pulsed lavage and dry with a swab. In sclerotic bone cement penetration can be improved with a series of 2 mm holes roughly 5 mm apart. Externally rotating the tibia improves exposure. Place cement on the back of the tibial component and onto the cut tibia, and avoid excessive cement posteriorly on either bone or implant. Pressurize the cement ideally penetrating the bone 3–4 mm either with a cement gun, a finger, or both. Insert the tibial component seating posteriorly first and then anteriorly, and this will squeeze the cement anteriorly like a toothpaste tube, reducing excess cement posteriorly which is difficult to remove. An osteotome or elevator is a useful instrument to use for this manoeuver. Once seated the impactor can be used initially posteriorly and then moving anteriorly to fully seat the component.

Remove excess cement; a 90° curved hemostat will reach excess cement posterior to the component. Ensure no excess cement is hidden behind the MCL as this is an irritating cause of pain. Prior to cementing the senior author (NL) packs a thin layer of swab around the medial cut edge of the tibia, ensuring it does not foul the cement bed. Once the implant is seated, pulling the swab out anteriorly removes the majority of medial cement easily. It is important to stabilize the implant during the removal of the swab.

Turning attention to the femur, wash and dry the bone surfaces. Retract the patella and soft tissues anteriorly to avoid trapping them beneath the implant. Use the 8 mm spacer trial or a small swab to protect the femoral component from the metal tibial plate. Apply a thin layer of cement to the posterior condyle of the implant, ensuring it does not overhang the edges and a thicker layer around the rest of the implant. Pressurize cement

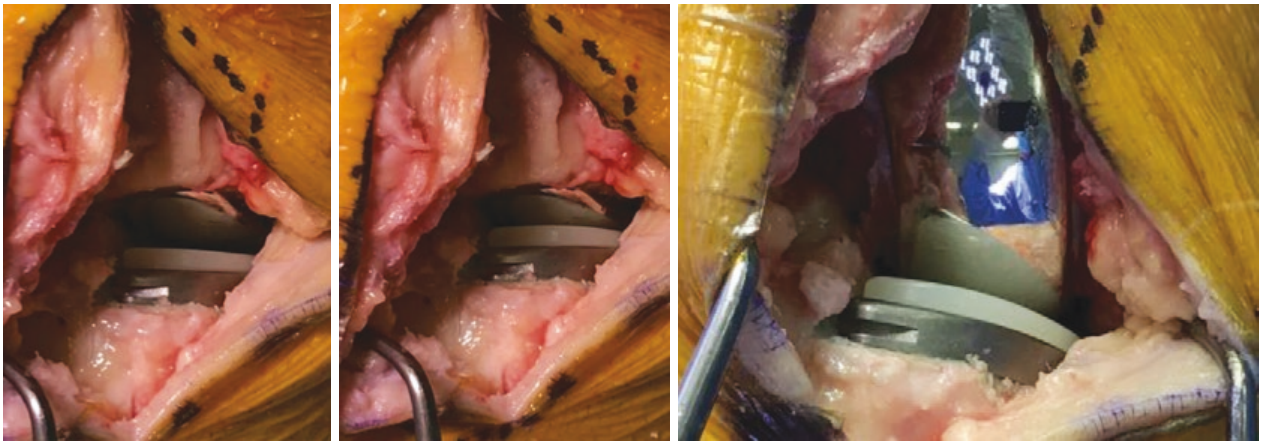

Fig. 4.11 Final implants. Note the appropriate laxity of 2 mm (left and middle images). The central and right images demonstrate the articulation of the femur is in the center of the polyethylene in both extension and flexion

aiming for 3–4 mm of penetration to the distal cut and chamfer. Avoid cement on the posterior condyle as this will get pushed off posteriorly during implantation, where it is difficult to retrieve. Flex the knee fully and insert the femoral implant via the longer peg first, and gently push onto the femur. Then extend the knee to 70°, and impact until flush to the cut surfaces. Remove excess cement taking care not to scratch the articulating surface.

Reinsert the trial bearing to confirm desired thickness. This can be left in situ until cement has cured. Avoid inserting the polyethylene implant prior to cement curing to prevent the tibial component lifting during bearing assembly. Ensure the tibial plate is clear of debris and blood. Push the polyethylene insert into the locking mechanism posteriorly, and then use the provided inserter to seat bearing anteriorly. Take great care to prevent the tibial component lifting, rather than the polyethylene engaging the anterior locking mechanism.

Wash out the knee with pulsed lavage, check for cement fragments especially under the MCL and range of motion with normal articulation of the bearing, and then close the wound (Fig. 4.11).

Summary

Fixed bearing UKR can provide excellent pain relief for patients with unicompartmental osteoarthritis. It has improved kinematics and functional results compared with total knee replacements due to the relative sparing of native soft tissue structures [5], allowing the increasingly active population of patients who suffer with the disease to return to most activities except running. However in inexperienced hands the results can be poor if the main principles are not adhered to. Undercorrection of the coronal deformity is essential. Progression of disease will be accelerated in the contralateral compartment and leads to early conversion to a TKR and reported failure of the UKR. In this scenario it is the joint that has failed rather than the implant. Optimum tibial bone coverage to prevent subsidence of the implant while ensuring there is no overhang anywhere around the plateau. Overhang, particularly deep to the MCL, is poorly tolerated by the patient. Optimal alignment throughout the range of motion will reduce edge loading and thus contact stresses. This in turn will lead to reduced wear rate and improved longevity of the implant.

References

1. Liddle AD, Pandit H, Judge A, Murray DW, Liddle AD, Mrcs DP, et al. Optimal usage of unicompartmental knee arthroplasty: a study of 41 986 cases from the national joint registry for England and Wales. Bone Joint J [Internet]. 2015 [cited 2017 Aug 14];97:1506–11. Available from: http://bjj.boneandjoint.org.uk/content/jbjsbr/97-B/11/1506.full.pdf.
2. Brown NM, Sheth NP, Davis K, Berend ME, Lombardi A V., Berend KR, et al. Total knee arthroplasty has

higher postoperative morbidity than unicompartmental knee arthroplasty: a multicenter analysis. J Arthroplasty [Internet]. 2012 Sep [cited 2017 Aug 10];27(8):86–90. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22560653.

3. Liddle AD, Judge A, Pandit H, Murray DW. Adverse outcomes after total and unicompartmental knee replacement in 101â€˜330 matched patients: a study of data from the National Joint Registry for England and Wales. Lancet [Internet]. 2014 [cited 2017 May 9];384:1437–45. Available from: http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(14)60419-0.pdf
4. Zimmer B. Persona ™ partial knee instrument system surgical technique. 1st ed. Warsaw: Zimmer Biomet; 2017.
5. Parratte S, Pauly V, Aubaniac JM, Argenson JN. No long-term difference between fixed and mobile medial unicompartmental arthroplasty. Clin Orthop Relat Res [Internet]. Springer; 2012 Jan [cited 2017 Nov 24];470(1):61–8. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21732024.

5 The Surgical Steps for Mobile Medial Partial Knee Arthroplasty

Michael Berend and David Murray

Introduction

Medial mobile bearing partial knee replacements (MB-PKA) have been implanted for the past 40 years (Fig. 5.1) [1–23]. The goals of mobile bearing implants are the restoration of normal knee kinematics and pre-arthritic leg alignment, decreased polymer wear through increased implant conformity and lower polyethylene stresses, and stable implant fixation. Importantly, however, mobile bearing PKA does not improve our indications, patient selection, or surgeon performance, and these remain critical elements of PKA clinical success and survivorship. This chapter will review the surgical steps important for the success of a mobile bearing PKA [17, 18].

Fig. 5.1 Mobile bearing medial partial knee replacement, Oxford Knee System, Zimmer-Biomet, Warsaw, Indiana. Twin peg femoral component, keeled tibial component, mobile bearing polyethylene insert

Indications

The main indication for medial PKA is anteromedial osteoarthritis (AMOA) [1, 5, 7]. This is an identifiable arthritic disease pattern originally described by Goodfellow and White et al. (JBJS-Br 1991) [5]. There should be bone-on-bone osteoarthritis in the medial compartment, functionally intact ACL and MCL, and functionally intact lateral compartment cartilage. These criteria are best demonstrated radiographically. Osteonecrosis of the medial femoral condyle or medial tibial plateau is also an indication for medial MB-PKA. For MB-PKA, the Kozinn and Scott [6] contraindications do not apply, so the indications are satisfied in up to 50% of osteoarthritic knees [19].

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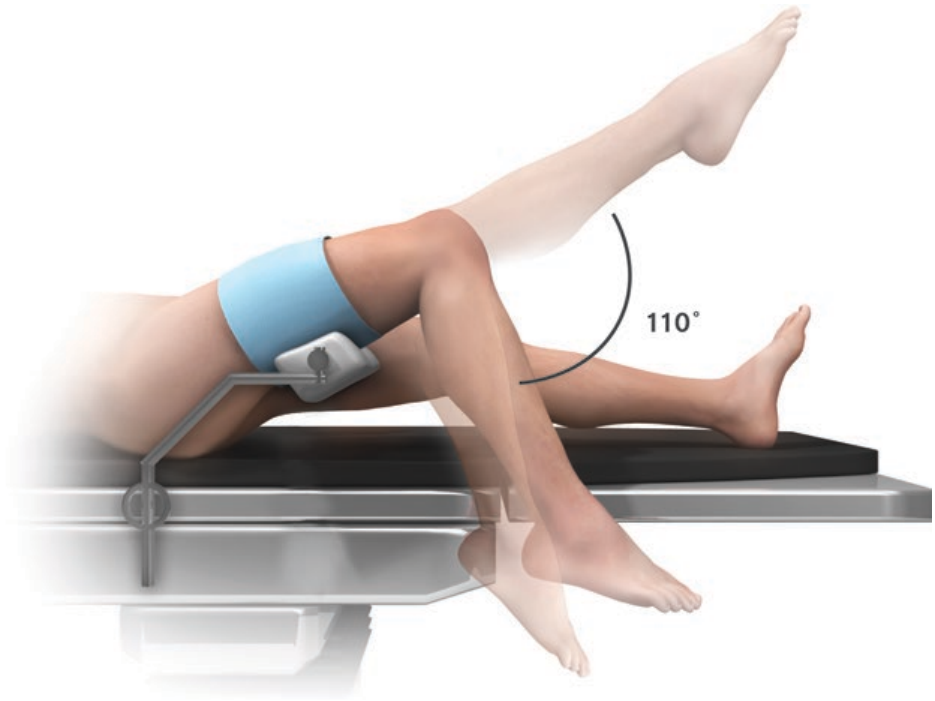

Fig. 5.2 Patient positioning for hanging leg technique with padded thigh support proximal to the popliteal fossa with flexion to over 110°

Surgical Limb Positioning

The operative limb is positioned with a thigh-high tourniquet and supported by a padded posterior thigh support (Fig. 5.2). This allows the leg to hang freely during the procedure. The patient should be moved to the lateral aspect of the bed. Final position should have approximately 30° of hip flexion, which allows the leg to hang flexed at about 110° during the operation. Care should be taken to have the thigh support out of the popliteal fossa. The non-operative leg can be allowed to hang free with a pillow support under the posterior thigh when the surgical table is bent leaving the non-operative leg in approximately 90° of flexion (Figures).

Exposure

After sterile preparation of the leg, the leg is exsanguinated with an Esmarch wrap or by elevation, and the tourniquet is inflated. The incision should be started medial to the superior pole of the patella and slightly angled to end medial to the tibial tubercle. It is extensile both proximally and distally if needed. A self-retaining retractor is inserted. A medial arthrotomy is made and is extended up into vastus medialis and down to the tibial tubercle (Figure).

The deep dissection initially removes the anterior horn of the medial meniscus and a portion of the fat pad that facilitates intra-articular visualization. The self-retaining retractor is then inserted into the joint. Anterior tibial periosteum is elevated to allow visualization of the joint surfaces. There should be no dissection medial to the tibia so as to avoid damage to the deep fibers of the MCL.

Inspection of the ACL, patellofemoral joint surfaces, and lateral joint surfaces should be completed. Osteophytes are removed from the intercondylar notch, the medial femur, and the anterior tibia and adjacent of the ACL attachment to the tibia.

Tibial Preparation

The goal for tibial component placement is neutral varus-valgus alignment and 7° of tibial slope. The rotational position should be in line with the flexion axis/plane of the native knee kinematics. The resection depth should be the minimal amount of needed to fit the tibial tray and a 3–4 mm mobile bearing implant [9, 10]. This is

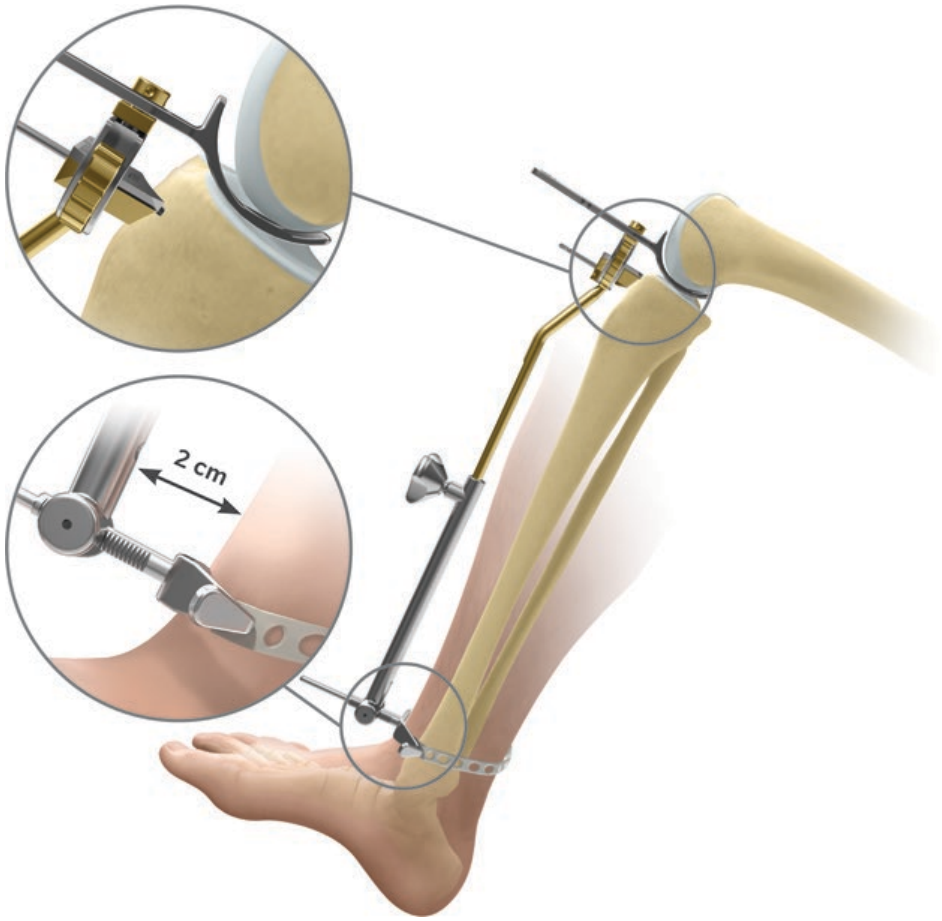

Fig. 5.3 Extramedullary tibial resection demonstrating spoon, G-clamp system that determines resection depth. Tibial slope goal is under 7°

achieved with an extramedullary tibial guide and "spoon / clamp" system that guides resection depth referencing individual patient soft tissue envelope (Fig. 5.3). Care should be taken to protect the MCL from the oscillating saw during the horizontal tibial cut. A thin curved retractor is inserted prior to sawing.

The EM tibial resection guide is positioned parallel to the anterior tibial crest and in neutral varus-valgus alignment. The resection surface on the top portion of the guide has 7° of slope built in (Fig. 5.3). The tendency is to place too much slope in the sagittal plane of the cut in the obese patients as an example. A 1, 2, or 3 mm "spoon" instrument is inserted centrally between the posterior femoral condyle and the medial tibia. This should achieve physiologic soft tissue tension. Making this too tight will underresect the tibia, and making it too loose may slightly over-resect the target depth. A 3 or 4 mm "G-clamp" links the spoon to the top of the tibial resection guide. The guide is then pinned to the proximal tibia in the lateral pinhole. A Kocher clamp often helps stabilize the guide during sawing.

Before making the vertical cut, the medial tibial spine is exposed, and a mark is made with a diathermy (electrocautery) just medial to the apex of the spine. The vertical resection is made in the same plane as the flexion axis of the knee from 40° to 100° of flexion (alternatively it can be directed to the anterior superior iliac spine). The saw may damage a few fibers of the ACL, but this does not matter. A saw blade with a blunt tip is used so as to protect the neurovascular structures in the popliteal fossa.

The horizontal resection can be done with a captured guide or a flat surface depending on surgeon preference. The key is to make a flat cut. If a slotted guide is desired, then the top cutting surface of the guide is modular and can be removed after the depth is set and replaced with a slotted guide. Again the MCL should be protected at this point. Once both saw cuts are completed, the tibial resected bone is removed with a Kocher clamp. If this is difficult to remove, extension of

the knee may help. The femoral guide, set to the appropriate thickness, is then inserted in flexion to confirm adequate tibial bone resection depth. If it is at all tight, posterior medial osteophytes should be removed, and a small amount of cartilage should be removed from the posterior femur, until the guide can easily be inserted (Figures).

Femoral Implant Sizing

The femoral implant size can be preliminarily selected based off of patient gender and height (in general small women should have a small size and large men a large size, and the remainder should be medium). It is then confirmed with the posterior femoral spoon, which has the same radius as the femoral implants. The distal extent of the spoon should recreate the position of where intact femoral cartilage would be without cartilage loss associated with AMOA. Finally it can be checked with the tibial size: A or B tibias are usually associated with small femurs, C or D with medium, and E or F with large. The femoral implant size guides the femoral preparation and should not be changed once the femoral drill holes are created.

Femoral Preparation

An intramedullary linked femoral guide system is utilized (Fig. 5.4). The cannulated IM rod is inserted in line with the medial side of the notch 1 cm superior to the top of the notch. Common errors include placement of the insertion hole too far lateral and too far inferior. The posterior portion of the femoral drill guide is inserted between the posterior femoral condyle and the resected tibial surface with the knee in flexion.

A "link" with parallel pins connects the cannulated IM rod and the drill guide, which sets the drill guide and drill hole position in 7° of valgus

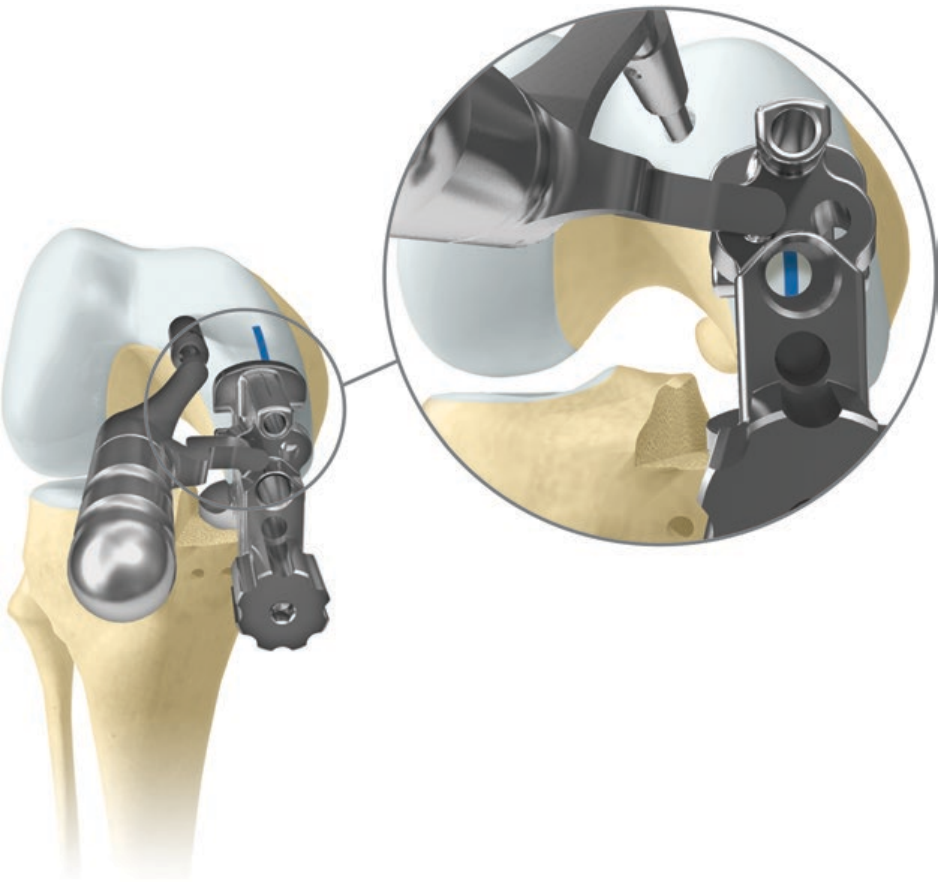

Fig. 5.4 Intramedullary linked femoral drill guide system, Microplasty, Zimmer-Biomet, Inc. The drill guide places the femoral drill holes in 100° of flexion and 7° of valgus. The center of the femoral condyle is marked and the drill holes placed in the central one third of the condyle

and 10° of flexion relative to the IM canal. The posterior foot of the drill guide should be up against the intact posterior femoral cartilage. This sets the implant position in flexion, as the amount of resected cartilage off of the posterior femur is equal to the amount replaced by the femoral implant, thus maintaining the joint line in flexion (Fig. 5.4).

The link controls the orientation of the femoral guide but not its mediolateral position. Its position should be adjusted, so the 6 mm hole is central in the condyle or slightly lateral. The superior-medial portion of the drill guide has the same shape as the final femoral implant, which allows to the position to be adjusted to prevent femoral overhang. The 4 and 6 mm femoral holes are then created in the middle 1/3 of the femur. The posterior femoral cut guide is inserted and the posterior femoral bone removed. Care should be taken at this step to protect the MCL from the oscillating saw.

Flexion and Extension Gap Balancing

Following posterior condyle resection, the remaining medial meniscus is removed, and then the femoral bone is shaped with a spherical mill over the 0-spigot which is inserted into the 6 mm drill hole which closely approximates the spherical center of the femoral condyle (Fig. 5.5). The initial milling does not remove any distal femoral bone and rather creates a spherical shape to accept the corresponding shape of the femoral implant trial and final implant. Any remaining posteromedial femoral osteophytes should be removed.

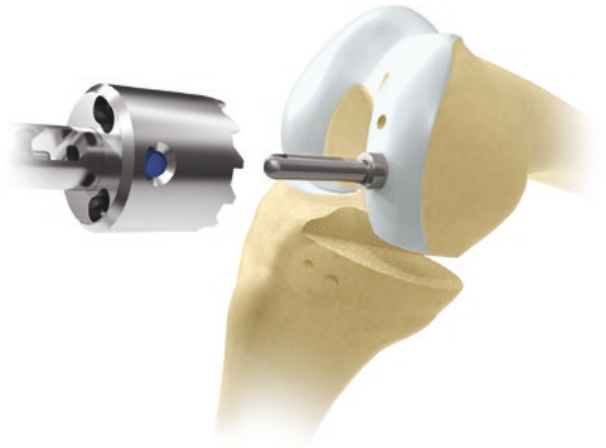

Fig. 5.5 Calibrated distal femoral preparation with spigots and spherical mill system. Microplasty, Zimmer-Biomet

The tibial trial without a keel and the femoral trial are then inserted, and the flexion and extension gaps assessed with calibrated "feeler gauges." The flexion gap is assessed at 110° of flexion. The gauge is removed, and then smaller feeler gauges are inserted to measure the extension gap in 10–20° of flexion. The extension gap is not measured in full extension as the posterior capsule is tight in extension and the aim is to balance the ligaments. The difference between flexion and extension is calculated in millimeters. The spigot size corresponding to the numeric difference between flexion and extension is selected and the distal femur milled again. The flexion and extension gaps are measured again to ensure they are equal. Occasionally a third milling is required to balance the gaps.

Impingement Prevention

With any PKA, most notably with medial MB-PKA, impingement of the polyethylene against retained bone should be avoided. This reduces both polymer wear and dislocation of the mobile bearing device. Impingement in deep flexion and full extension must be assessed during trialing. Instrumentation has been designed to help assess and reduce impingement. A slotted impingement guide helps assess and remove retained posterior osteophytes. Retained osteophytes beyond the extent of the posterior femoral implant should be removed (Fig. 5.6).

Impingement of the bearing in extension can be reduced with use of the impingement guide as well, which removes in a recessed fashion an appropriate amount of anterior femoral bone to permit the mobile bearing to not contact the retained bone during full extension (Figures).

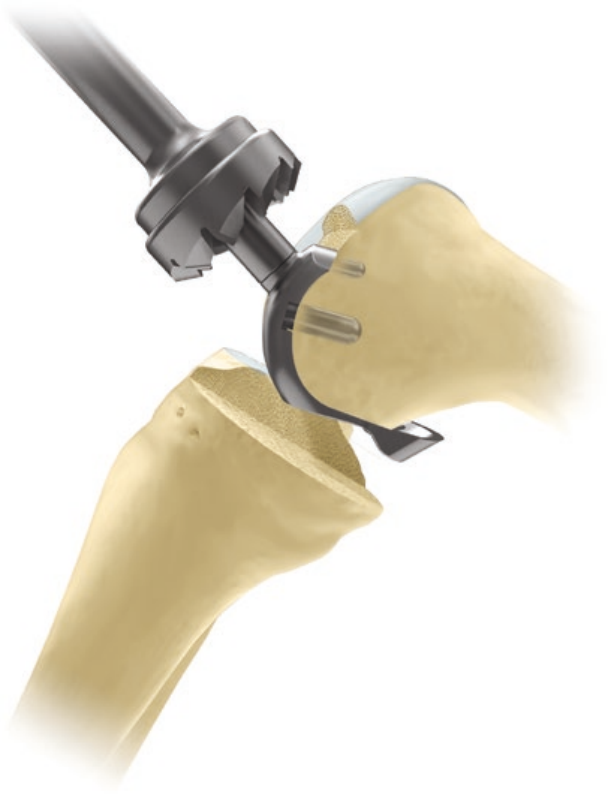

Fig. 5.6 Guide to prevent mobile bearing impingement upon retained anterior and posterior femoral bone

Tibial Preparation

The appropriate size tibial template, femoral, and mobile bearing trials are inserted. Bearing impingement and tracking should be assessed. The bearing should not be jammed against the wall. If it is the vertical tibial cut should be redone 1 or 2 millimeters further laterally. The bearing and femoral component should be removed, and the sizing of the tibial component should be assessed. Ideally the component should be fully supported by the cortex and should not overhang the cortex medially by more than 1 millimeter. Medial tibial osteophytes should be ignored and not removed as the deep fibers of the MCL may be damaged.

The tibial trial should be positioned, so its posterior surface is aligned with the posterior cortex using the removal hook. It is then pinned in place. While holding the pin, so the template will not move, the keel slot is fashioned using the keel cut saw. Any bone debris in the bottom of the slot should be removed with the cemented pick. A final trial reduction is then undertaken to ensure the replacement is working satisfactorily.

Cementation of Tibial and Femoral Implants

Sclerotic surfaces are perforated with a drill bit and then cleaned with antibiotic laden pulsatile lavage and dried. We utilize a cement gun and osteotome to pressurize the cement into the drill holes and tibial keel slot. The tibia is cemented first and excess cement removed with Woodson elevators, nerve hooks, and small suction tips. A surgical high-powered headlight helps assess the posterior aspect of the joint.

The femoral implant is then cemented, excess cement removed, and then both components pressurized at 45° with a calibrated feeler gauge until cement is hard. A feeler gauge 1 millimeter larger than the desired final bearing helps assure cement pressurization and penetration.

Bearing Insertion and Closure

Final bearing is inserted with the knee in 100° of flexion, and then the knee is extended. An audible click assures bearing insertion. Standard pericapsular anesthesia and closure is then performed.

Cementless Fixation

The indications for cemented and cementless fixation are the same, except that in very small patients who would need an XS tibial component, it is sensible to use cemented fixation [23]. The cementless components are not FDA approved for use in the United States.

The surgical technique for cemented and cementless fixation is basically the same, but there are some important differences. On the femoral side with cementless fixation, care has to be taken not to damage the 6 mm hole. In particular it is sensible not to use the bone collar remover as it may damage the hole; instead a rongeur should be used.

Great care should be taken with tibial preparation to minimize the risk of fracture. Tibial recuts should be avoided: if it is difficult to insert the femoral drill guide, a small amount of cartilage should be removed from the posterior femur so as

to elevate the joint line by about 1 mm. The vertical saw cut must not go to deep. This can be facilitated by doing the horizontal cut first and then inserting a shim to stop the vertical cut going to deep. The slotted saw guide, cementless Microplasty templates, and cementless keel cut saws should be used. It should be possible to insert the tibial template by hand. If it will not go in, it is worth repeating the saw cut again and possibly using the cemented pick. The cementless tibial component is partially inserted with the introducer. Soft tissue between the component and the tibial is removed before the component is fully impacted. A light hammer should be used. If the component does not fully seat, it should be left slightly proud as it will settle postoperatively. The femoral component is impacted with a light hammer and punch.

References

1. Berend KR, Lombardi AV Jr, Adams JB. Obesity, young age, patellofemoral disease, and anterior knee pain: identifying the unicondylar arthroplasty patient in the United States. Orthopedics. 2007;30(5 Suppl):19–23.
2. Berend KR, Lombardi AV Jr, Mallory TH, Adams JB, Groseth KL. Early failure of minimally invasive unicompartmental knee arthroplasty is associated with obesity. Clin Orthop Relat Res. 2005;440:60–6.
3. Price AJ, Waite JC, Svard U. Long-term clinical results of the medial Oxford unicompartmental knee arthroplasty. Clin Orthop Relat Res. 2005;435:171–80.
4. Price AJ, Svard U. A second decade lifetable survival analysis of the Oxford unicompartmental knee arthroplasty. Clin Orthop Relat Res. 2010 Aug 13. (Epub ahead of print).
5. White S, Ludkowski PF, Goodfellow J. Anteromedial O\osteoarthritis of the knee. JBJS. 1991;73Br:582–6.
6. Kozinn SC, Scott R. Unicondylar knee arthroplasty. JBJS. 1989;71Am:145–50.
7. Berend KR, Lombardi AV Jr, Hurst JM, Morris M, Indications for UKA, Is there any science, AAOS OLC presentation, Oct 2010.
8. TF MG, Ammeen DJ, Collier JP, Currier BH, Engh GA. Rapid polyethylene failure of unicondylar tibial components sterilized with gamma irradiation in air and implanted after a long shelf life. J Bone Joint Surg Am. 2002;84–A(6):901–6.
9. Small SR, Berend ME, Ritter MA, Buckley CA, Rogge RD. Metal backing significantly decreases tibial strains in a medial unicompartmental knee arthroplasty model. J Arthroplast. 2010;26(5):777–82.
10. Small SR, Berend ME, Ritter MA, Buckley CA. Bearing mobility affects tibial strain in mobile-bearing unicompartmental knee arthroplasty. Surg Technol Int. 2010;19:185–90.
11. Psychoyios V, Crawford RW, O'Connor JJ, Murray DW. Wear of congruent meniscal bearings in unicompartmental knee arthroplasty: a retrieval study of 16 specimens. J Bone Joint Surg Br. 1998 Nov;80(6):976–82.
12. Collier MB, Engh CA Jr, Engh GA. Shelf age of the polyethylene tibial component and outcome of unicondylar knee arthroplasty. J Bone Joint Surg Am. 2004;86-A(4):763–9.
13. Hamilton WG, Collier MB, Tarabee E, McAuley JP, Engh CA Jr, Engh GA. Incidence and reasons for reoperation after minimally invasive unicompartmental knee arthroplasty. J Arthroplast. 2006;21(6 Suppl 2):98–107.
14. McGovern TF, Ammeen DJ, Collier JP, Currier BH, Engh GA. Rapid polyethylene failure of unicondylar tibial components sterilized with gamma irradiation in air and implanted after a long shelf life. J Bone Joint Surg Am. 2002;84-A(6):901–6.
15. Kendrick BJ, Longino D, Pandit H, Svard U, Gill HS, Dodd CA, Murray DW, Price AJ. Polyethylene wear in Oxford unicompartmental knee replacement: a retrieval study of 47 bearings. J Bone Joint Surg Br. 2010;92(3):367–73.
16. Price AJ, Svard U. A second decade lifetable survival analysis of the Oxford unicompartmental knee arthroplasty. Clin Orthop Relat Res. 2011;469(1):174–9. https://doi.org/10.1007/s11999-010-1506-2.
17. Price AJ, Waite JC, Svard U. Long-term clinical results of the medial Oxford unicompartmental knee arthroplasty. Clin Orthop Relat Res. 2005;435:171–80.
18. Svärd UC, Price AJ. Oxford medial unicompartmental knee arthroplasty. A survival analysis of an independent series. J Bone Joint Surg Br. 2001;83(2):191–4.
19. Ritter MA, Faris PM, Thong AE, Davis KE, Meding JB, Berend ME. Intra-operative findings in varus osteoarthritis of the knee. An analysis of pre-operative alignment in potential candidates for unicompartmental arthroplasty. J Bone Joint Surg Br. 2004;86(1):43–7.
20. Gulati A, Chau R, Pandit HG, Gray H, Price AJ, Dodd CA, Murray DW. The incidence of physiological radiolucency following Oxford unicompartmental knee replacement and its relationship to outcome. J Bone Joint Surg Br. 2009;91(7):896–902.
21. Aleto TJ, Berend ME, Ritter MA, Faris PM, Meneghini RM. Early failure of unicompartmental knee arthroplasty leading to revision. J Arthroplast. 2008;23(2):159–63.
22. Clarius M, Hauck C, Seeger JB, James A, Murray DW, Aldinger PR. Pulsed lavage reduces the incidence of radiolucent lines under the tibial tray of Oxford unicompartmental knee arthroplasty: pulsed lavage versus syringe lavage. Int Orthop. 2009;33(6):1585–90. Epub 2009 Feb 14.
23. Pandit H, Jenkins C, Beard DJ, Gallagher J, Price AJ, Dodd CA, Goodfellow JW, Murray DW. Cementless Oxford unicompartmental knee replacement shows reduced radiolucency at one year. J Bone Joint Surg Br. 2009;91(2):185–9.

6 The Surgical Steps for Lateral Partial Knee Arthroplasty

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Introduction

Unicompartmental tibiofemoral osteoarthritis generally affects the medial compartment of the knee, but in 10% of cases, the lateral compartment is primarily involved. In a patient with isolated lateral compartment arthritis, surgical options include osteotomy, total knee arthroplasty, or unicompartmental arthroplasty. In some cases, a lateral unicompartmental knee arthroplasty (UKA) can provide a quicker recovery and enhanced function when compared to total knee arthroplasty (TKA). In addition, it preserves bone stock and can be "easily" revised to a TKA. Although the current 10-year survivorships are greater than 90%, the lateral UKA requires specific indications and remains a technically demanding surgery. The biomechanics differ between the medial and the lateral compartments, explaining the variation between indications and surgical techniques. It is crucial to understand these differences in order to perform a successful lateral UKA with good outcomes at mid- and long-term follow-up.

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Indications

The indications for lateral UKA should be based on both clinical and radiological criteria. The historical indication for lateral UKA is lateral osteoarthritis due to pathological loading associated with valgus deformity and/or a hypoplastic lateral femoral condyle (Fig. 6.1). Current indications include painful osteoarthritis with congenital genu valgum, spontaneous osteonecrosis of the femoral condyle, and post-traumatic or post lateral meniscectomy valgus knee. In the presence of symptomatic lateral compartment osteoarthritis, operative options include osteotomy, unicompartmental arthroplasty, or total knee arthroplasty. With recent technical improvements and modern implants, the indications for lateral UKA have expanded and are less strict than for medial UKA [1]. Furthermore, there also exists a dynamic varus moment in full weight bearing in many valgus knees. If the alignment is less than 15° of valgus, the loads applied on the knee in stance phase pass through the medial compartment. Therefore the postoperative forces on the lateral compartment and thus on the prosthesis are low.

Age should not be an absolute limiting factor, and in certain indications (e.g., post-traumatic), a

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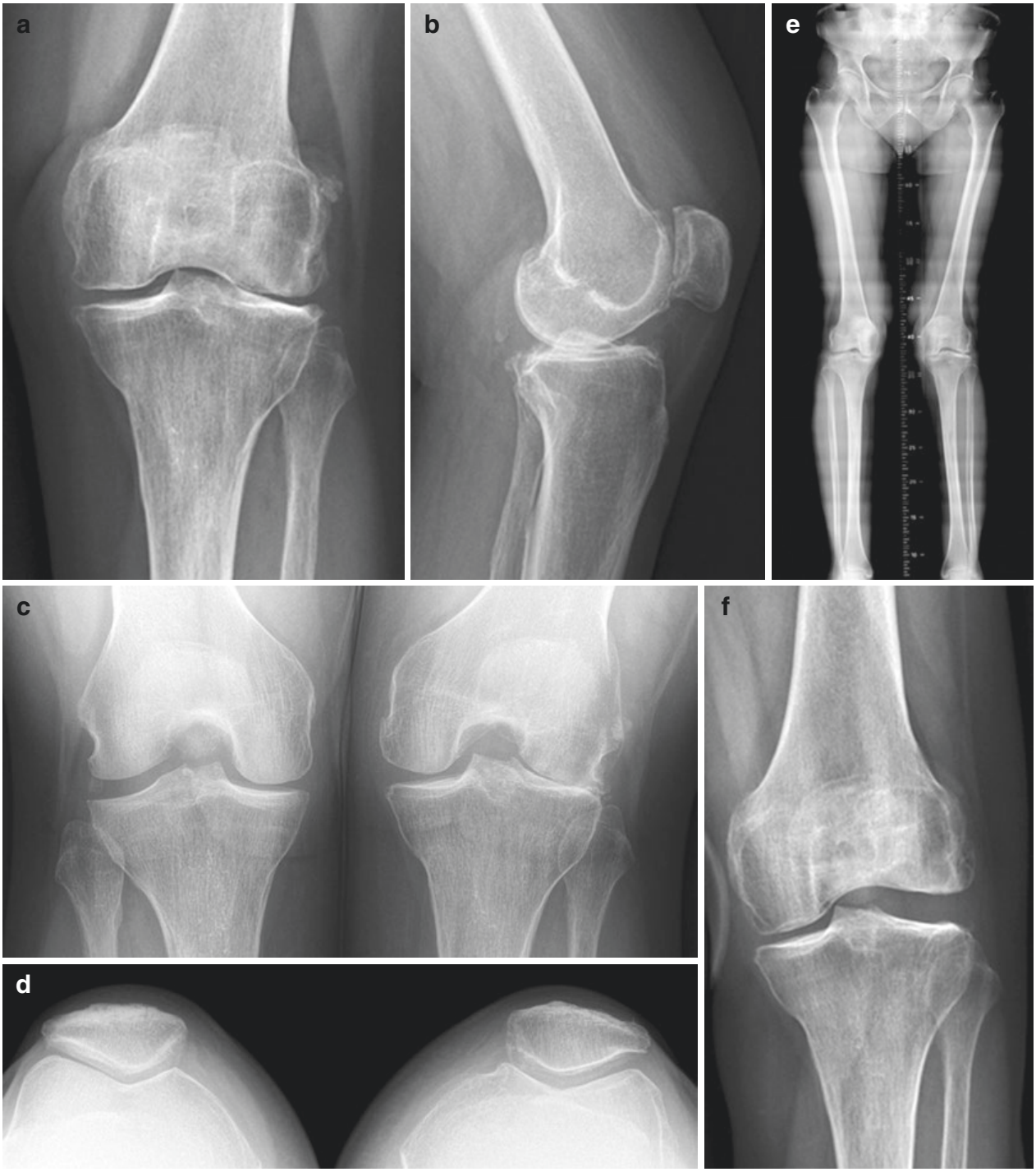

Fig. 6.1 Lateral tibiofemoral osteoarthritis due to valgus deformity and hypoplastic lateral femoral condyle. (**a**) AP view of the left knee showing a lateral tibiofemoral osteoarthritis stage 3 (Kellgren and Lawrence), without mediolateral translation and without significant medial osteoarthritis. (**b**) Lateral view of the left knee showing the lack of anterior translation and lack of posterior saucer-shaped indentation, which would indicate ACL deficiency. (**c**) PA flexion view – advanced lateral tibiofemoral osteoarthritis demonstrated in the left knee. (**d**) Patellar view at 30° of flexion: no significant patellofemoral osteoarthritis. (**e**) Full-length bilateral standing radiograph. The HKA angle is 188°. (**f**) This deformation in genu valgum is easily reducible on the radiographs with varus stress

lateral UKA can be proposed to patients who are less than 60 years old [2, 3]. Distal femoral and/or high tibial varus-producing osteotomy can be performed to treat lateral osteoarthritis due to a valgus axial malalignment in young and active patients. However, the surgical techniques of

varus-producing osteotomy are more demanding than valgus-producing osteotomies. Moreover, outcomes, as well as survival, of a varus-producing osteotomy are generally less predictable compared with a high tibial valgus-producing osteotomy for varus malalignment. Recovery time after osteotomy is reported to be significantly longer when compared to UKA. For these reasons, lateral UKA is the preferred option even in patients less than 60. Additionally, UKA continues to remain an excellent option in the elderly population (85 years and over).

Overweight patients are not strictly contraindicated either. While early reports of UKA considered obesity a relative contraindication, other studies have not found a correlation between body mass index (BMI) and outcomes [4, 5]. The UKA wear seems more related to activity, rather than BMI.

The anterior cruciate ligament (ACL) should be healthy or reconstructed. However, the presence of a moderate clinical anterior laxity does not prevent use of the lateral UKA. The laxity is evaluated clinically as well as on lateral X-rays with anterior stress. On stress views, an anterior translation greater than 10 mm or a posterior saucer-shaped indentation, reflecting ACL deficiency, can be an indication to perform an ACL reconstruction at the time of lateral UKA [6]. Sometimes, MRI can be helpful to assess the ACL.

The preoperative deformity in the frontal plane should be limited to a tibiofemoral angle of 194° for lateral UKA (i.e., overall valgus less than 14°). The reducibility, if not easily done with clinical exam, can be judged on an anteroposterior X-ray with a varus stress. Full correction is not required, as the aim is to demonstrate correction of the part of the deformity caused by intra-articular wear rather than the entire deformity and to demonstrate no collapse with varus stress of the medial compartment.

Finally, the preoperative range of motion must be normal or nearly normal, with flexion greater than 100° and extension lacking no more than 10°.

Clinical or radiological signs of osteoarthritis in the medial or patellofemoral compartments are contraindications for lateral UKA. However, occasional exceptions can be made regarding the patellofemoral compartment. Asymptomatic patellofemoral osteoarthritis can be accepted in selected patients over 70 years old with significant comorbidities and low activity levels. Additionally, a lateral facetectomy can be performed with UKA and provide relief for isolated lateral patellofemoral osteoarthritis.

We consider any form of inflammatory arthritis an absolute contraindication to a lateral UKA due to the potential for rapid degeneration in the remaining compartments.

Preoperative Planning

Clinical Examination

During the clinical examination of a knee considered for a lateral UKA, it is essential for the surgeon to assess the range of motion and the reducibility. If the range of motion is not preserved or if the valgus deformation is not reducible, a lateral UKA may be contraindicated. During the varus stress test, the valgus deformation should be fully or almost fully correctible. The assessment of pain is also essential. Pain in the medial or anterior compartment is considered a contraindication for a lateral UKA. The stability of the joint should also be carefully evaluated in the coronal and sagittal planes. Particular attention should be paid to the assessment of coronal stability in the post-traumatic valgus knee. Assessment of the ACL should be interpreted with caution, as the pivot shift test may be limited due to the pain and swelling in an arthritic knee.

Imaging

The radiographic analysis systematically includes anteroposterior and lateral views of the knee, full-length bilateral standing radiographs, varus and valgus stress radiographs, and a skyline view at 30° of knee flexion. The 45° PA flexion view is also very helpful at demonstrating lateral compartment arthritis not appreciated as well on the AP view (Fig. 6.2) [7].

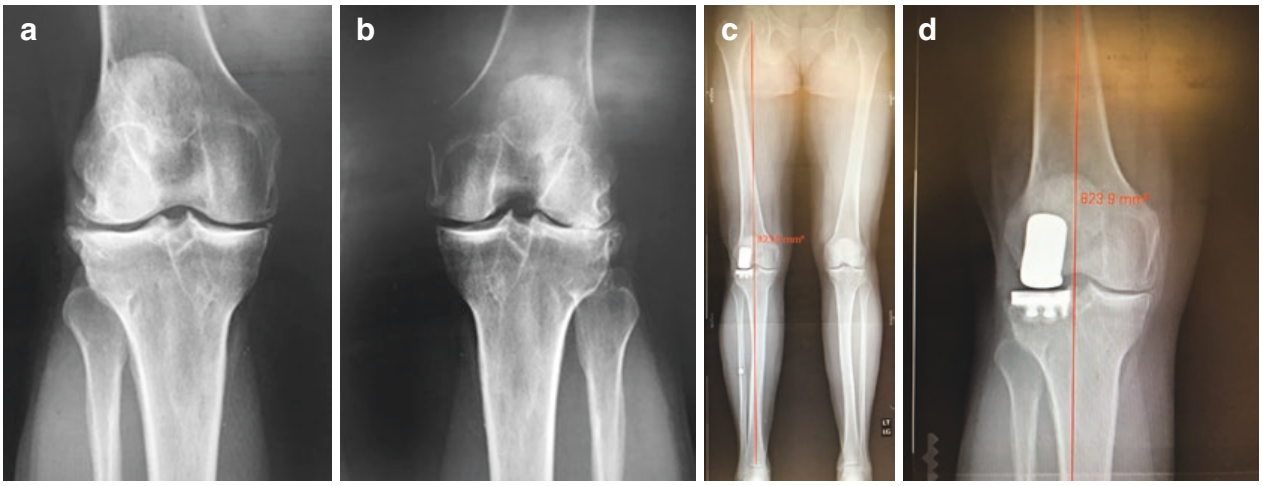

Fig. 6.2 Standing AP and PA flexion radiograph demonstrating lateral compartment stage 4 (Kellgren and Lawerence) tibiofemoral arthritis without much valgus deformity. (**a**) Standing AP radiograph. (**b**) PA flexion radiograph. Postoperative long alignment and standing AP radiographs demonstrating excellent component to component position of the lateral partial knee replacement and no evidence of overcorrection on long alignment radiographs. A resurfacing procedure to avoid overcorrection and progressive medial compartment arthritis. (**c**) Postoperative long alignment radiograph. (**d**) Postoperative standing AP radiograph

On X-rays the surgeon should assess the preoperative valgus deformity of the lower limb, its reducibility, the signs of ACL insufficiency (anterior tibial translation greater than 10 mm, posterior tibial erosion), and the narrowing of the patellofemoral joint space. Tibiofemoral subluxation in the AP view also indicates ACL insufficiency and is therefore a contraindication for UKA.

The preoperative radiographs are essential to determine the origin of the valgus knee. Four distinct situations exist:

- A valgus knee secondary to an underlying coxofemoral pathology, with or without a prosthesis
- An axial deviation by authentic valgus tibial curvature
- Moderate or severe lateral condylar dysplasia
- A post-traumatic valgus knee related to lateral meniscectomy sequelae or a fracture of the tibial plateau or of the lateral condyle

The first two situations are rare, and the preferred treatment is rarely a lateral UKA (TKA or osteotomy is preferred). The presence of lateral condylar dysplasia is the most common indication but warrants special considerations. According to the severity of the dysplasia, the position of the femoral component must be adapted. When condylar dysplasia is severe, it is best not to compensate for this by raising the tibial implant but rather by using a femoral component positioned more distal and more posterior. This technique corrects the dysplasia at its original site both in the coronal and the sagittal planes. This choice makes it possible to avoid creating a joint line discrepancy and to restore an anatomical joint space. In the post-traumatic or post-meniscectomy valgus knee, there is no need to compensate for femoral dysplasia. Rather, the surgeon should anticipate poor bone quality and consider the need for possible bone graft or reinforcing screws in the transverse plane. The use of screws or a plate is recommended to reinforce the subchondral bone in cases of substantial comminution and depression of the lateral tibial plateau (Fig. 6.3) [8].

Occasionally, magnetic resonance imaging (MRI) is completed when there is a clinical question regarding the competence of the ACL.

Patient Expectations

Lateral osteoarthritis is typically well tolerated for a longer period of time than medial osteoarthritis. As such, it is important to understand why

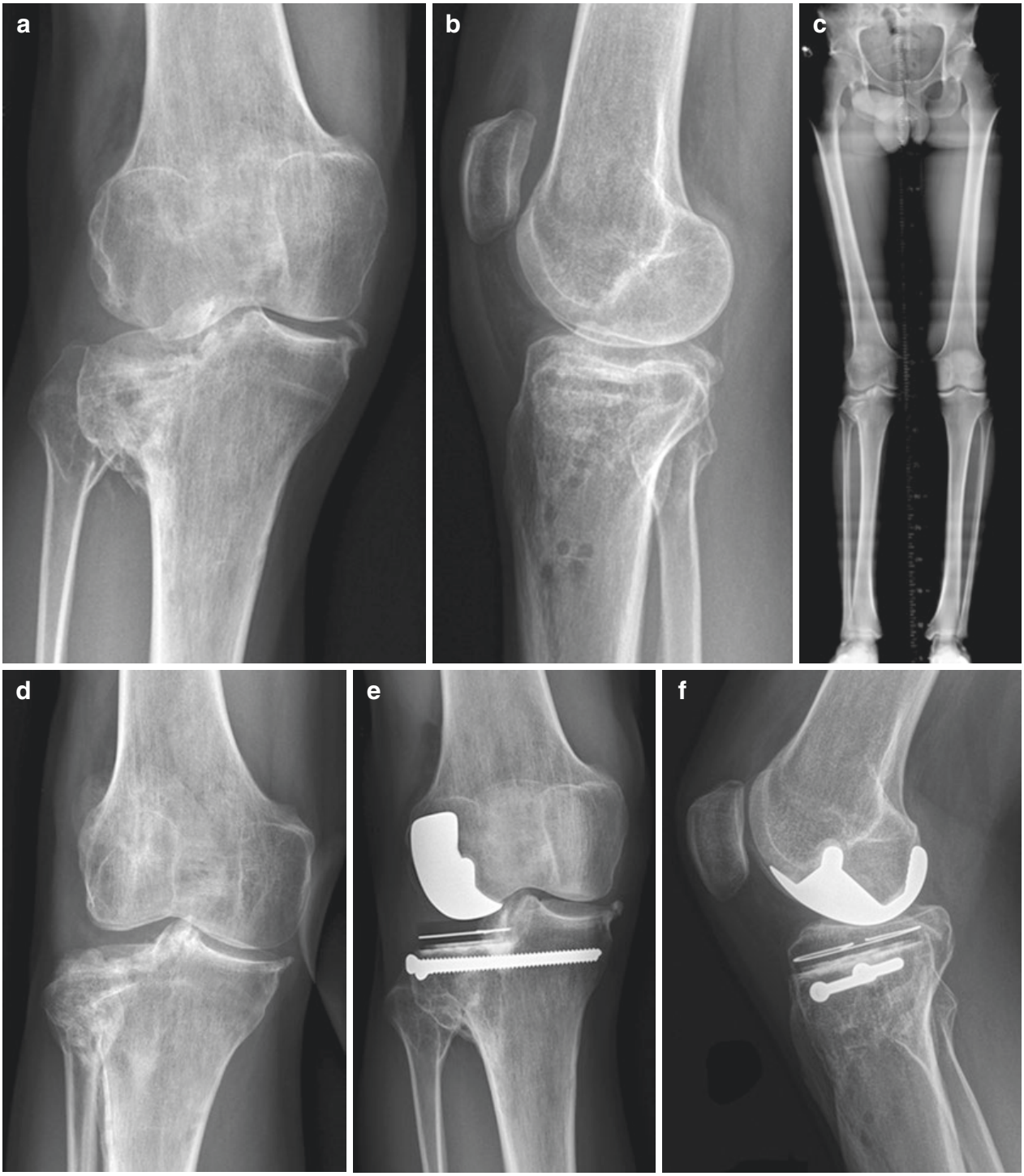

Fig. 6.3 Young patient with a history of lateral tibial plateau fracture, now with a valgus deformity. Lateral UKA associated with reinforcing screws can be a good solution to obtain effective pain relief and a partial correction of the deformity. (**a**) AP view of the right knee. (**b**) Lateral view of the right knee. (**c**) Full-length bilateral standing radiographs. The HKA angle measures 189°. (**d**) This deformation remains reducible on the radiographs with varus stress. (**e**) AP view of lateral UKA with reinforcing screws. (**f**) Lateral view of lateral UKA with reinforcing screws

patients are undergoing lateral UKA if they are young and active. If the main motivation is to return to high-level sporting activities, then lateral UKA is not the most appropriate solution. Intractable pain and a severe limitation in the activities of daily living are the only reasons to justify surgery, particularly for young and active patients. The physical preparation includes main-

tenance of range of motion to limit the risk of a postoperative knee contracture and optimization of the quadriceps' and hamstrings' strength before the surgery.

Operative Technique

Anesthesia and Positioning

The procedure can be performed either under general or epidural anesthesia. The patient is placed supine on a standard operating table with a positioner allowing the knee to be flexed and held at 90° and with or without tourniquet according to the surgeon preference.

Approach

The favored approach by the authors is a lateral parapatellar approach, although some authors have used a medial parapatellar approach [9].

The upper limit of the incision is at the superior pole of the patella, and the distal limit is 2 cm below the joint line on the lateral aspect of the tibial tuberosity. The joint capsule is then opened using a lateral, mid- or sub-vastus approach. The iliotibial band is not released from its distal attachment. An additional resection of the lateral quarter of the patella can improve the exposure (Fig. 6.4). The patella will be retracted medially to make visualization possible. In the event of poor visualization, the incision of the muscle can be extended proximally. An osteotomy of the tibial tuberosity is usually not necessary for a good exposure.

The patellofemoral compartment and the ACL are then checked to confirm the isolated lateral compartment osteoarthritis.

Any osteophytes in the intercondylar notch should be removed to avoid late impingement with ACL. In contrast, the osteophytes located on the lateral femoral condyle should be preserved during the surgery to help with the eventual positioning of the femoral component. In fact, the femoral component should be as lateral as possible, sometimes bordering on the lateral osteophytes. Before the bone cuts, it is important to identify and mark the anterior contact point between the anterior part of the femoral condyle and the anterior part of the tibial plateau. This mark represents the anterior limit of the femoral component.

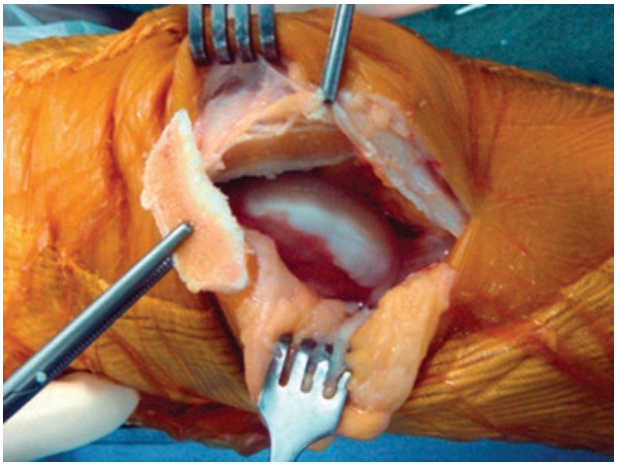

Fig. 6.4 An additional resection of the lateral quarter of the patella and the removal of the lateral portion of the fat pad can improve the exposure

Tips

- Remove the lateral part of the fat pad to improve the exposure and to facilitate the mobilization of the patella.
- Perform a partial lateral facetectomy, if exposure is difficult.
- Keep the lateral osteophytes of the femoral condyle.

Tibial Cut

Release of the lateral tibial margin should be minimal. Respect for peripheral ligamentous structures is essential during UKA and guarantees a final undercorrection during the test of ligamentous balancing.

The tibial axis is often orthogonal (90°). If the surgeon uses the hypoplasic lateral condyle as a reference for the tibial cut, it will result in a valgus tibial resection. Therefore, the tibial cut should be performed with an extramedullary guide to obtain a cut at 90° to the tibial axis. It is very important to perform a minimal tibial resection (4 mm maximum) because it is the femoral side that is most

often affected by lateral compartment osteoarthritis. A small tibial resection allows for the surgeon to maintain the strong support of the tibial cortex along with a large contact area proximally. If the surgeon would like to keep some degree of valgus, it should not be done with the tibial cut but rather with the femoral cut. In our experience there is no indication to have a valgus tibial cut or a deep tibial cut. The slope of the tibial cut should reproduce the natural slope in the lateral compartment to avoid being tight in flexion (anterior slope) and to protect the ACL (high posterior slope).

The sagittal cut should be precise and performed with caution. It should respect the tibial spine eminences, being near to but not involving them. Because the lateral tibial plateau undergoes an external rotation due to the "screw-home" mechanism, the line of the sagittal cut will have some internal rotation thus crossing the patellar tendon which is then in the way of the saw blade. Some surgeons recommend performing the cut through the patellar tendon, whereas others, including us, recommend a careful retraction of the tendon to make this sagittal cut freehand following the selected line (Fig. 6.5). During this sagittal cut, it is also important to not exceed the predetermined distal resection limit. Failure to do so could result in a secondary fracture of the lateral tibial plateau during weight bearing.

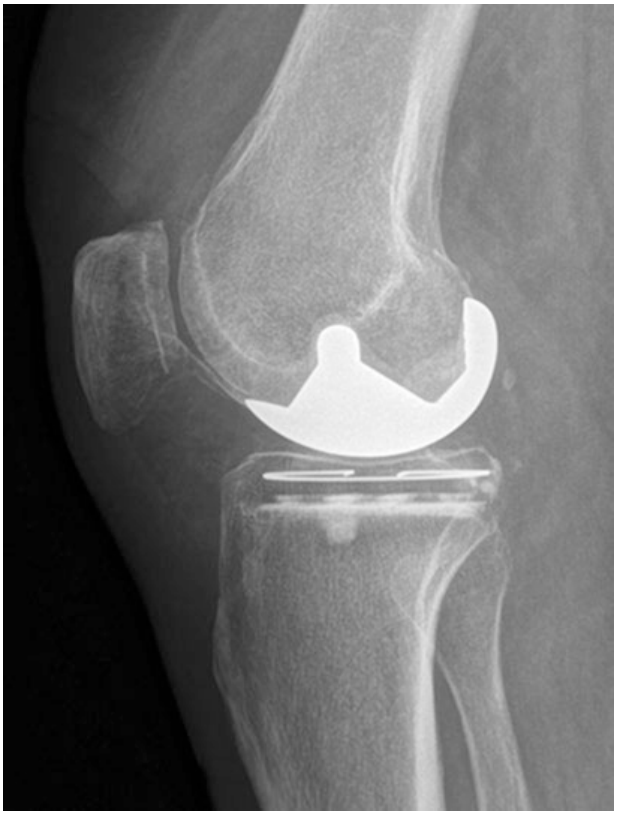

Fig. 6.5 During a lateral UKA for femoral condylar hypoplasia, the femoral implant should not reproduce the femoral anatomy, but it should be more distal and posterior than the native condyle, as on this lateral view

Femoral Cut

The specific technique to perform the femoral cuts depends on the prosthesis, but the principles and major steps are similar between the different implants.

The distal femoral cut is performed either with the help of an intramedullary guide or with a cutting guide that relies on the tibial cut. This distal femoral cut should be minimal to allow for a distalized femoral implant that compensates for the wear of the femur. The extension gap can be then checked using a dedicated spacer block. Next, the remaining femoral cuts (posterior cut and chamfers) are completed with the appropriately sized cutting block once the implant rotation is set.

If the patient presents with femoral condylar hypoplasia, the femoral implant should not reproduce the native femoral anatomy but rather should be positioned more distal and posterior in order to augment the dysplastic condyle (Fig. 6.6). The posterior cut should be minimal to compensate for the posterior offset and to obtain a similar gap in flexion as in extension. Using this method, femoral resurfacing implants can be used to augment and compensate for hypoplasia in lateral UKA with lateral condylar dysplasia.

Tips

- The tibial resection should be minimal (4 mm maximum) and orthogonal.
- The slope of the tibial cut should reproduce the native slope. A pin can be placed along the joint line probing the anterior and posterior margin of the tibial plateau and representing the anatomical slope.
- The sagittal tibial cut should be internally rotated and cross the patellar tendon.

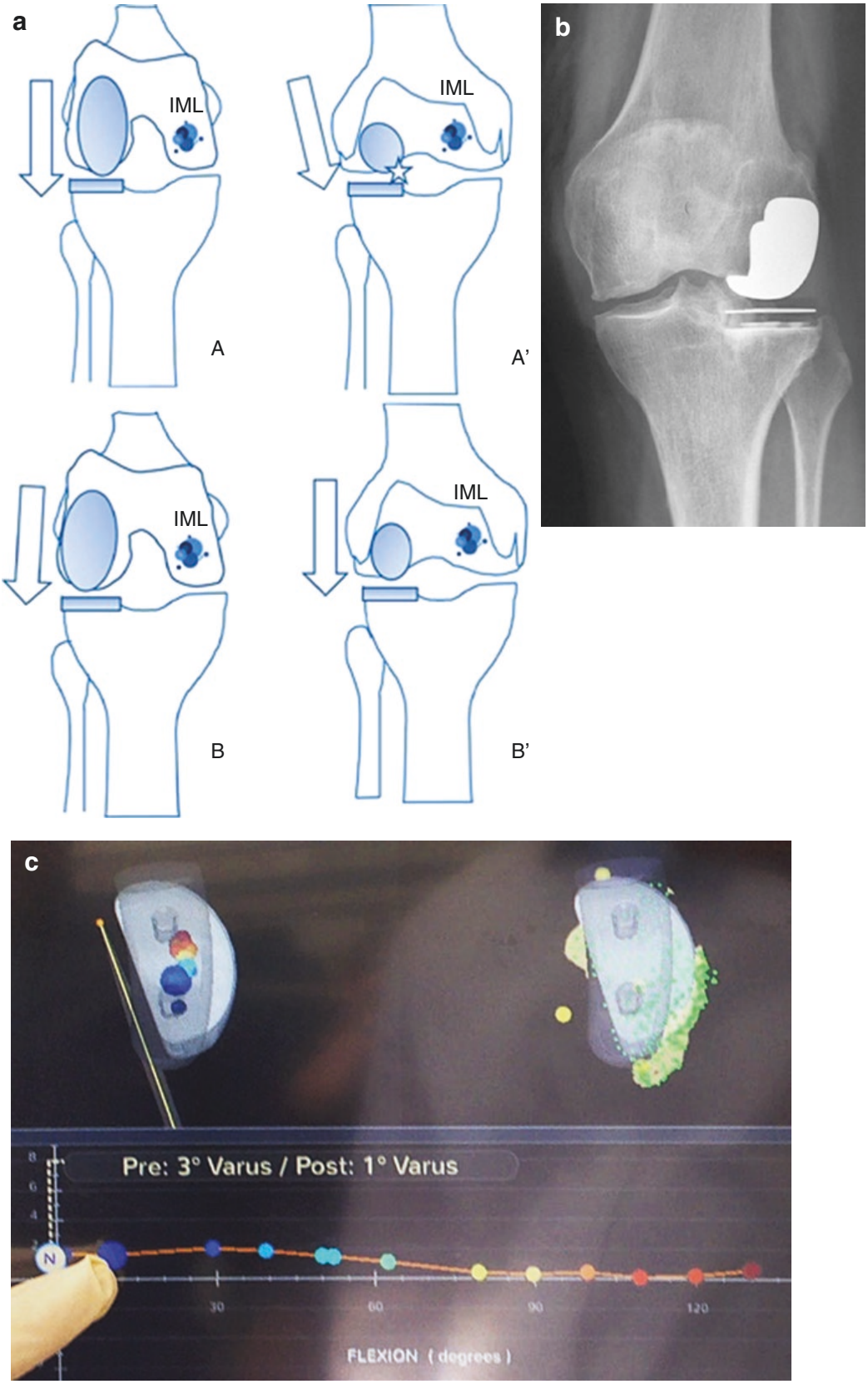

Fig. 6.6 (**a**) Diagram illustrating the effect of the "screw-home mechanism" on femoral implant positioning (flexion-extension). If the femoral implant is centered on the femoral condyle in flexion, there is a risk of impingement between the femoral implant and the tibial spine eminences in extension. In contrast, if the femoral implant is positioned as lateral as possible in flexion, the femoral component will be centered on the tibial component without impingement in extension. (**b**) AP view of a left knee showing the "screw-home" mechanism. A good femoral implant position in flexion may lead to an excessive internal rotation in extension and cause impingement on the tibial spine eminences. (**c**) During robotically assisted UKA, the "screw-home" mechanism is easily identified. This picture of the planning during robotically assisted UKA shows the position of both implants in flexion, with the difference in rotation

Appropriate rotation of the cutting blocks is essential. The lateral aspect of the femoral cutting block should follow the lateral aspect of the condyle to avoid any excessive internal rotation in extension.

The size of the cutting block is determined by searching for the best compromise between an anatomically centered position on the femoral condyle and a long axis perpendicular to the resected tibial plateau. The anterior edge of the femoral component (and thus of the cutting block) should be located at the mark of the anterior contact point identified at the beginning of the surgery. This point is located 1–2 mm posterior to the cartilage-bone interface that was created by making the distal cut. The risk is to choose an oversized femoral component. When choosing between two similar fitting sizes, the surgeon should choose the smaller size to eliminate the risk of positioning the implant too anteriorly where it will conflict with the native patellar groove.

Once the posterior cut and chamfers have been made and the cutting guide is removed, removal of any posterior osteophytes is necessary to obtain optimal flexion and to avoid any posterior impingement with the polyethylene liner in high flexion.

Tips

- Femoral cut should be distalized to compensate for femoral wear.
- With condylar hypoplasia, the femoral component should not reproduce the femoral anatomy but should augment the dysplastic condyle both distally and posteriorly.
- The rotation of the femoral cutting guide should follow the native rotation of the condyle.
- An oversized femoral component should be avoided, due to the risk of impingement with the patella.

Positioning of the Implant

The size of the tibia is chosen after all cuts are completed. The component should maximize tibial coverage without having any overhang in either the coronal or sagittal planes. During the sizing of the tibia and its bone preparation, placing the leg in internal rotation or a lazy figure of four positions allows a better exposure of the lateral tibial plateau.

The positioning of the implants in a lateral UKA is critical to obtain good outcomes. Positioning must take into account the "screw-home" mechanism as the knee comes into extension. During terminal knee extension, between 20° of knee flexion and full extension, external rotation of the tibia occurs (along with a corresponding internal rotation of the femur on the tibial plateau) which results in tightening of both cruciate ligaments, thus locking the knee. This movement is called the "screw-home" mechanism [6]. Due to this phenomenon, even a good femoral implant position in flexion may lead to an excessive internal rotation in extension and cause impingement on the tibial eminences (Fig. 6.7).

Therefore, the tibial implant should be as close as possible to the tibial eminences and should have 10–15° of internal rotation [10–12]. In addition, the femoral positioning in flexion should exaggerate the lateral rotation and be positioned laterally. The femoral implant should be as lateral as possible, almost on the lateral osteophytes, to obtain an ideal contact with the tibia without impingement on the tibial eminences (Figs. 6.6 and 6.8). During component trialing, it is important to check for any impingement of the femoral component against the tibial eminences in extension which can be attributed to a lack of external rotation in flexion. In extension and flexion, the medial aspect of the femoral component should be in line with the middle of the tibial component.

The trial components also allow the surgeon to test the flexion-extension gaps and to choose

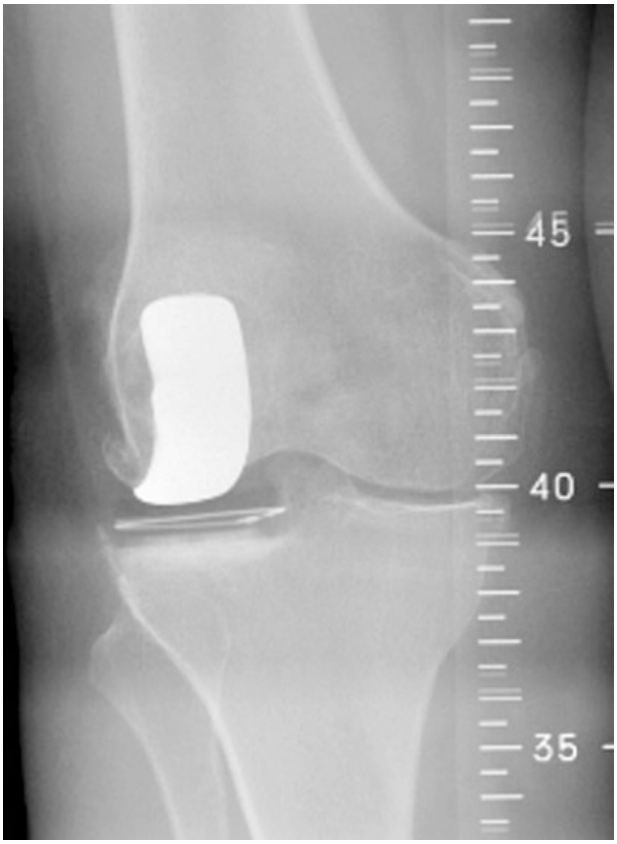

Fig. 6.7 On this AP view of a left UKA with 17 years of follow-up, the femoral implant is as lateral as possible, on the lateral osteophytes

the appropriate height of polyethylene liner. The polyethylene insert is often thicker here than on the medial side due to femoral dysplasia. However, it is essential to undercorrect the deformity in lateral UKAs to avoid any overstuffing of the unresurfaced medial compartment. The philosophy for lateral UKA is to correct only the articular wear (resurfacing procedure) and respect any extra-articular constitutional deformity (not a deformity-correcting procedure). Therefore, at the end of the procedure, the surgeon should confirm the presence of residual laxity on the lateral side by performing a varus stress test at 15° of flexion. This is the best method to guarantee prosthetic undercorrection, provided that no ligament release has been performed.

For placement of the definitive components, the tibial implant is inserted first and then the femoral component. The polyethylene liner may be inserted either after the tibial component or after the femoral component.

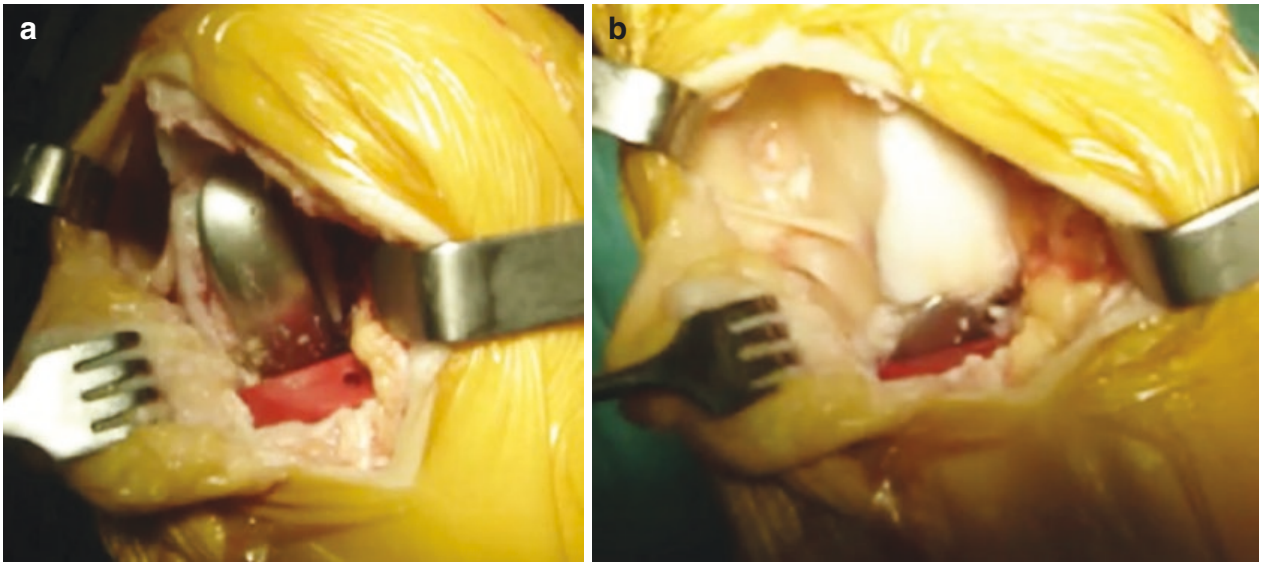

Fig. 6.8 The femoral implant should be as lateral as possible to maintain appropriate contact with the tibia in flexion and extension despite the "screw-home" mechanism. (**a**) View of implants with tibia in flexion. (**b**) View of implants with tibia in extension

Tips

- The positioning of the implants in lateral UKA must take into account the "screw-home" mechanism.
- The tibial implant should have 10–15° of internal rotation.
- The femoral implant should be as lateral as possible, almost on the lateral osteophytes.
- The lateral rotation of the femoral component in flexion should be exaggerated.
- Overcorrection of the deformity should be absolutely avoided; only the articular wear should be corrected.

Closure

The soft tissues are closed in flexion beginning with the closure of the lateral arthrotomy. The alignment is usually not significantly modified, so the Keblish technique is not necessary. According to surgeon preference, a drain can be used if desired. Some surgeons place a brace in extension for the postoperative period, especially if a femoral nerve block anesthetic is used.

Postoperative Rehabilitation

The postoperative management and rehabilitation of patients following lateral UKA is similar to that of total knee arthroplasty. Chemical thromboembolic prophylaxis is important for minimizing the incidence of deep venous thrombosis (DVT) [13, 14], though Liddle et al. [15] showed a lower rate of DVT following UKA when compared to patients undergoing TKA. Aspirin is typically utilized in standard-risk patients, while warfarin or a factor Xa inhibitor is used for high-risk patients. Patients are allowed to bear full weight as tolerated and are instructed to ambulate beginning the day of surgery. Patients who have surgery performed in an outpatient setting are evaluated by a nurse or physical therapist in the recovery unit. Prior to discharging home, patients must demonstrate the ability to ambulate and successfully urinate and have intact motor control of their quadriceps muscle. An assistive device, typically a cane or walker, is used for 1–2 weeks following surgery to aid with stability during ambulation. Outpatient physical therapy sessions and home exercise programs focus on quadriceps strengthening and range of motion exercises. Additionally, recent literature has suggested that formal postoperative physical therapy may not be required for patients following UKA [16].

Complications

Despite employing all measures to ensure an optimal outcome, complications do occur following lateral UKA. The most common complications include early progression of osteoarthritis in the unresurfaced compartment and component loosening [17]. Failure to preoperatively identify arthritic changes in the medial compartment and overcorrection of the limb into a varus alignment are the most frequent causes of early progression to symptomatic medial tibiofemoral osteoarthritis. Tibial component loosening may be less common following lateral UKA when compared with medial UKA. The forces on the lateral compartment and the prosthesis are low due to the dynamic varus moment that exists during stance phase with valgus knees. Appropriate component positioning and meticulous cement technique are important for minimizing this complication. Two additional complications are related to implant size and positioning. The first is internal rotation impingement of the femoral component on the tibial spine during knee extension. This phenomenon is specific to the lateral UKA due to the "screw-home" mechanism of the lateral tibiofemoral compartment. This complication can be avoided by externally rotating the femoral component in flexion and ensuring adequate internal rotation of the tibial component. The second implant-specific complication is impingement of the anterior aspect of the femoral component on the lateral facet of the patella during knee flexion. This occurs when the femoral component is too

large, leading to a prominent implant on the lateral aspect of the trochlear groove. Ideally, the anterior flange of the femoral component should be positioned at or slightly posterior to the junction of the articular cartilage and subchondral bone. Thorough evaluation of the position of the final implants prior to arthrotomy closure should be performed to assess for the integrity of the screw-home mechanism as well as to ensure that there is no impingement of the femoral component on either the patella or tibial spine. Polyethylene wear rates are very low with modern fixed-bearing implants exhibiting a mean wear rate of 0.07 mm/year in one retrieval study [18]. Recurrent hemarthrosis is a rare complication that can be observed after medial or lateral UKA as well as total knee arthroplasty. The average interval between arthroplasty and first hemarthrosis has been shown to be as long as 20 months [19]. Conservative measures are the initial treatment; however some patients progress to require operative intervention. Impingement of proliferative synovium between articulating components is the most commonly postulated cause and is treated with complete synovectomy [20, 21]. Rates of major complications, including infection, stroke, myocardial infarction, and pulmonary embolus, are lower in patients undergoing UKA when compared with patients undergoing TKA [15].

Outcomes

With proper patient selection and surgical technique, literature shows that survival rates of UKA exceed 90% at 10 years and are comparable to TKA [22, 23]. Since tibiofemoral arthritis typically affects the medial compartment, there are fewer studies evaluating the results of lateral UKA. Earlier studies postulated that clinical survivorship is greater in lateral than medial UKAs, while more recent studies show comparable implant survival curves out to 22 years [22, 24]. Use of a mobile-bearing prosthesis for lateral UKA has been associated with high rates of failure and a reported incidence of dislocation as high as 10%, while fixed-bearing implants have demonstrated improved rates of implant survival. Mobile-bearing implants are NOT recommended for use in lateral unicondylar arthroplasty [22]. Patients who had a lateral UKA for a preoperative diagnosis of osteoarthritis or lateral compartment osteonecrosis demonstrated better outcomes than patients undergoing lateral UKA for posttraumatic arthritis [25, 26].

Conclusion

Lateral unicompartmental arthroplasty represents the minority of UKAs, accounting for less than 10% of partial knee replacements performed for tibiofemoral osteoarthritis [22]. Proper patient selection, correct implant size selection and position, and avoiding overcorrection of the preoperative valgus deformity are critically important in ensuring good patient outcomes. Performing lateral UKA as a resurfacing procedure and not as a deformity-correcting procedure helps minimize the complication of progressive medial compartment arthritis (Fig. 6.2). Given the increased mobility of the lateral compartment, a fixed bearing prosthesis should be utilized. The lateral UKA demonstrates equivocal or slightly superior implant survival and outcomes in properly selected patients when compared with the medial unicompartmental arthroplasty. While the lateral unicompartmental arthroplasty represents the road less traveled in the treatment of isolated compartment tibiofemoral arthritis, it is associated with excellent clinical patient outcomes and implant survival.

References

1. Servien E, Ait Si Selmi T, Neyret P, Verdonk P. How to select candidates for lateral unicompartmental prosthesis. Curr Orthop Pract. 2008;19:451–8.
2. Swienckowski JJ, Pennington DW. Unicompartmental knee arthroplasty in patients sixty years of age or younger. J Bone Joint Surg Am. 2004;86-A(Suppl 1):131–42.
3. Lustig S, Lording T, Frank F, Debette C, Servien E, Neyret P. Progression of medial osteoarthritis and long term results of lateral unicompartmental arthroplasty: 10 to 18 year follow-up of 54 consecutive implants. Knee. 2014;21(Suppl 1):S26–32.

4. Argenson JN, Chevrol-Benkeddache Y, Aubaniac JM. Modern unicompartmental knee arthroplasty with cement: a three to ten-year follow-up study. J Bone Joint Surg Am. 2002;84-A:2235–9.
5. Berger RA, Meneghini RM, Jacobs JJ, Sheinkop MB, Della Valle CJ, Rosenberg AG, et al. Results of unicompartmental knee arthroplasty at a minimum of ten years of follow-up. J Bone Joint Surg Am. 2005;87:999–1006.
6. Ollivier M, Abdel MP, Parratte S, Argenson JN. Lateral unicondylar knee arthroplasty (UKA): contemporary indications, surgical technique, and results. Int Orthop. 2014;38:449–55.
7. Rosenberg TD, Paulos LE, Parker RD, Coward DB, Scott SM. The forty-five-degree posteroanterior flexion weight-bearing radiograph of the knee. J Bone Joint Surg Am. 1988;70(10):1479–83.
8. Lustig S, Parratte S, Magnussen RA, Argenson JN, Neyret P. Lateral unicompartmental knee arthroplasty relieves pain and improves function in post-traumatic osteoarthritis. Clin Orthop Relat Res. 2012;470:69–76.
9. Sah AP, Scott RD. Lateral unicompartmental knee arthroplasty through a medial approach: surgical technique. J Bone Joint Surg Am. 2008;90(Suppl 2 Pt 2):195–205.
10. Pennington DW, Swienckowski JJ, Lutes WB, Drake GN. Lateral unicompartmental knee arthroplasty: survivorship and technical considerations at an average follow-up of 12.4 years. J Arthroplast. 2006;21:13–7.
11. Berend KR, Kolczun MC 2nd, George JW Jr, Lombardi AV Jr. Lateral unicompartmental knee arthroplasty through a lateral parapatellar approach has high early survivorship. Clin Orthop Relat Res. 2012;470:77–83.
12. Servien E, Fary C, Lustig S, Demey G, Saffarini M, Chomel S, et al. Tibial component rotation assessment using CT scan in medial and lateral unicompartmental knee arthroplasty. Orthop Traumatol Surg Res. 2011;97:272–5.
13. Griffin T, et al. Unicompartmental knee arthroplasty for the treatment of unicompartmental osteoarthritis: a systematic study. ANZ J Surg. 2007;77(4):214–21.
14. Haas SB, et al. Venous thromboembolic disease after total hip and knee arthroplasty. J Bone Joint Surg Am. 2008;90(12):2764–80.
15. Liddle AD, Judge A, Pandit H, Murray DW. Adverse outcomes after total and unicompartmental knee replacement in 101,330 matched patients: a study of data from the National Joint Registry for England and Wales. Lancet. 2014 Oct 18;384(9952): 1437–45. Erratum in: Lancet. 2015 Feb 28;385(9970): 774.
16. Fillingham YA, Crizer M, Culvern C, Bohl DD, Lonner JH, Della Valle CJ. Formal physical therapy may not be essential following unicompartmental knee arthroplasty: a randomized clinical trial. American association of hip and knee surgeons annual meeting, 2017. Podium Presentation: Paper #55.
17. Bertani A, et al. Unicompartmental-knee arthroplasty for treatment of lateral gonarthrosis: about 30 cases. Midterm results. Rev Chir Orthop Reparatrice Appar Mot. 2008;94(8):763–70.
18. Kendrick BJ, et al. Polyethylene wear in Oxford unicompartmental knee replacement: a retrieval study of 47 bearings. J Bone Joint Surg Br. 2010;92(3):367–73.
19. Worland RL, Jessup DE. Recurrent hemarthrosis after total knee arthroplasty. J Arthroplast. 1996;11(8):977–8.
20. Asanuma K, et al. Recurrent hemarthrosis after unicompartmental knee arthroplasty. Orthopedics. 2011;34(9):e578–80.
21. Ohdera T, et al. Recurrent hemarthrosis after knee joint arthroplasty: etiology and treatment. J Arthroplast. 2004;19(2):157–61.
22. Argenson JN, et al. Long-term results with a lateral unicondylar replacement. Clin Orthop Relat Res. 2008;466(11):2686–93.
23. Engh GA. Orthopaedic crossfire – can we justify unicondylar arthroplasty as a temporizing procedure? in the affirmative. J Arthroplast. 2002;17(4 Suppl 1):54–5.
24. Gacon G. Differences between lateral and medial unicompartmental prostheses. Eur J Orthop Surg Traumatol. 1995;5(3):223.
25. Parratte S, et al. Unicompartmental knee arthroplasty for avascular osteonecrosis. Clin Orthop Relat Res. 2007;464:37–42.
26. Sah AP, Scott RD. Lateral unicompartmental knee arthroplasty through a medial approach. Study with an average five-year follow-up. J Bone Joint Surg Am. 2007;89(9):1948–54.

7 Partial Knee Arthroplasty for Older-Aged Patients

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What Is Older Age?

It is likely that opinions differ on what defines an "older patient." The mean human life span across the world is 72 years of age and moderately higher in developed countries (79 years of age in the USA, 85 in Japan) [1]. In all countries, the survival of females is slightly higher than males. Many physicians agree that for the purposes of knee arthroplasty, a reasonable definition of "older age" is equal to or greater than 70 years of age. This would mean that on average the "older patient" would survive another 10–15 years. This suggests that the necessary life span of a unicondylar arthroplasty would need to be between 10 and 15 years to provide revision-free function for the patient. There are several studies that demonstrate excellent long-term function of unicondylar arthroplasties [2–4]. PKA has also been criticized because of higher rate of revision compared to TKA, but recent work has shown that UKA presented comparable survivorship to TKA (at a mean of 8 years and with a maximum follow-up of 16 years) in patients older than 75 with isolated medial compartment osteoarthritis of the knee [5].

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Why Should I Do a PKA in Older-Aged Patients? What Are the Advantages over Total Knee Arthroplasty?

The demand for musculoskeletal care is expected to increase substantially because of the growth of the population, aging of the population, public expectations, economic growth, investment in health-care interventions, and improved diagnosis and treatment [6]. Increasing life expectancy will lead to increasing number of older (>70 years) patients. This group of patients would expect to stay active and in good health. This combination of increased life expectancy and increased activity implies that there will be an increase in the amount of symptomatic knee osteoarthritis. In addition to increasing numbers of older (> 70 years old) more active patients, there is evidence that a large percentage of patients (up to 80%) with symptomatic OA have angular deformity (one compartment much more involved than the other) which makes them potential candidates for unicondylar arthroplasty [7].

The reported potential advantages of partial knee replacement over total knee arthroplasty include a faster recovery with decreased or no length of inpatient hospitalization, function and kinematics that more closely approach the native knee, and a decreased risk of major complications [8, 9]. Recently Liddle et al. reported that

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patients undergoing TKR are at increased risk of medical complications; they are twice as likely to have a venous thromboembolism, myocardial infarction, or deep infection, three times as likely to have a stroke, and four times as likely to need blood transfusions [10]. As a result, these patients are four times more likely to die in the first 30 days after surgery and about 15% more likely to die during the first 8 years. Inpatient stays are longer, and readmissions are more likely after TKR than after UKA [10]. Thus, because PKA is less harmful than TKA, performing a PKA could represent a valuable option in elderly patients. These findings were confirmed in a comparative retrospective study of Siman et al. which showed that patients older than 75 undergoing UKA demonstrated faster initial recovery when compared to TKA due to its less invasive nature while maintaining comparable complications and mid-term survivorship [11].

Recently several publications have demonstrated that PKA may be preferred for patients aged 70 or greater in terms of clinical outcomes and survivorship [5, 12–14]. Howieson et al., in a meta-analysis based on 13 studies, showed that patients 70 years old or greater who had unicondylar arthroplasty had good KSS results (between 72 and 95) and good KSS function (56–92). Fabre-Aubrespy showed that PKA had a much higher "forgotten joint" score.

Thus, PKA in an older-aged patient is a valuable solution due to the potential reduction of morbidity and mortality and improves function with limited revision rate. But, as for younger patients, indication, type of implant, surgical technique, and preparation of the patient remain an important part of good results.

Another important justification for unicondylar arthroplasty is economic. Ghomrawi et al., using a Markov decision-analytic model, demonstrated that in the USA, unicondylar arthroplasty was more cost-effective than total knee arthroplasty in patients over 65 years of age [15]. Another report from the USA also suggested a significant decrease in cost for PKA over UKA [16]. A report from the UK indicated substantially decreased costs of unicondylar arthroplasty combined with increased functional outcomes over TKA [17], and the cost-effectiveness of PKA was demonstrated in Belgium in another Markov model [18]. A report from Finland concluded that unicondylar arthroplasty was not cost-effective over TKA but did show that PKA in older patients was more cost-effective than in younger patients [19].

When Should I Do a PKA in Older-Aged Patients?

It is clear that all joint arthroplasties have a finite life span. In the older patient, the needed life span is less, and there is a higher chance of the implant functioning till the end of the patient's life than in younger patients. If the survival is acceptable, then the decreased cost and morbidity and the increased function indicate that partial knee replacement may be the better arthroplasty, in the properly elected patient.

The ideal candidate is one who understands the pros and cons of unicondylar arthroplasty and wants the surgery and is willing to accept a slightly higher chance of revision. The list of contraindications to the procedure has decreased since Kozinn and Scott's article of 28 years ago [20]. Pandit et al. applied the Kozinn and Scott criteria to a cohort of patients and found that weight over 82 Kg and presence of chondrocalcinosis or exposed bone in the patellofemoral joint were not associated with poorer results in their cohort and should not be considered contraindications.

Patient Selection

Taking a careful patient history is important to select the correct patient for PKA. The nature and location of the pain can be confirmatory. Localizing the pain to a specific area can be a confirmatory sign, as in the case of medial compartment DJD if the patient points to the medial joint line. A generalized description of pain all over the knee suggests that PKA may not be the right solution. Description of an aching pain worsened with activity and symptoms that wax

and wane are a good description of unicompartmental osteoarthritis. A history of a recent arthroscopy with partial meniscal resection is often a precipitating factor, and these patients are often upset. Sometimes a minor trauma has led to a marked exacerbation of pain. The patient often notes an increasing angular deformity (Fig. 7.1a). The surgeon should note how much passive correction of this malalignment is achievable preoperatively, as this often corresponds to the correction that can be achieved at surgery (Fig. 7.1b).

Understanding the patient's response to nonop treatment may be helpful in determining the success of an arthroplasty. Absence of relief from an intraarticular injection of lidocaine and steroid should prompt the provider to look for other sources of pain, such as referred pain from the hip or spine. Initial improvement from an unloader brace or shoe orthotics suggests mechanical overload in one compartment. Decreased symptoms after a patient starts a quadriceps conditioning program implies that the patient has been compliant in the program, which is important in terms of determining patient activation in their condition. Patients over 70 often have difficulty with balance, and a therapy program using a tilt board and single leg stance

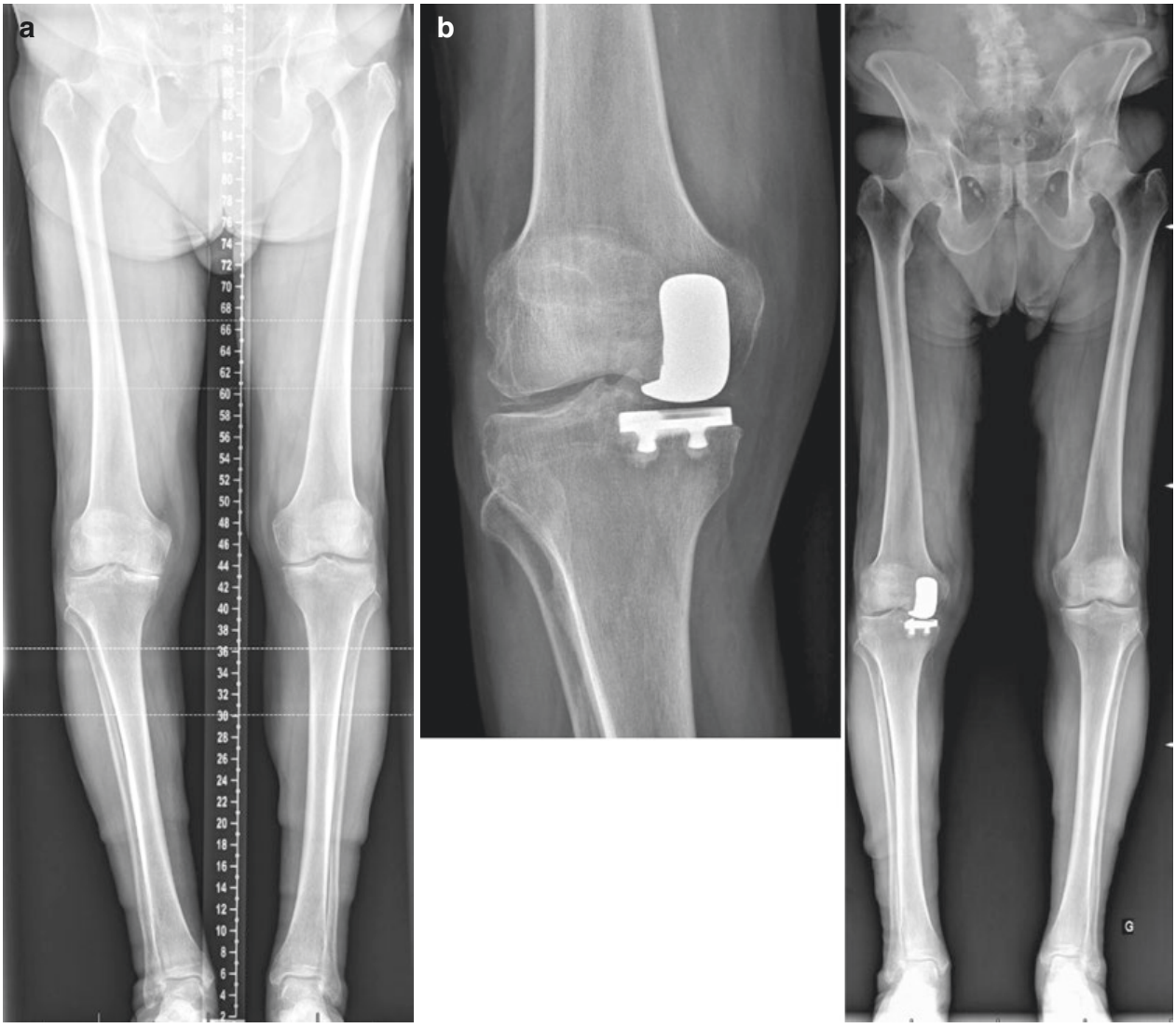

Fig. 7.1 (**a**) Preoperative x-rays of an 82-year-old man with a previous history of meniscal resection who presented a medial knee pain for several months with complaints of increased "bowing" of the right knee. (**b**) Postoperative x-rays at 1-year follow-up. After medial unicondylar arthroplasty, the patient reported his leg was straighter and without pain

exercises is quite helpful whether or not the patient comes to surgery.

Physical exam is important to confirm symptoms recorded in the history. The patient's gait should always be evaluated to look for antalgia, angular malalignment, the presence of a thrust, as well as abnormalities of the hip or ankle such as a Trendelenburg shift or planovalgus deformity of the foot. While the degree of coronal angular deformity that can be treated with PKA has not been completely defined, many authors suggest that >20° varus or valgus deformity may be inappropriate for PKA. The presence of a sagittal flexion contracture of >10° may be difficult to correct with PKA. The varus valgus exam can often give clues as to the degree of wear in the contralateral compartment, but if the surgeon is unsure, a stress x-ray may be taken. If the articular surface on the less involved side is essentially normal, unicondylar arthroplasty can be performed with good results despite the presence of osteophytes, which can be removed during the arthroplasty [21].

The surgeon should consider the imaging studies carefully in determining whether a patient is a candidate for PKA. A plain series of AP, lateral, and Merchant views are required. Certainly weightbearing AP x-rays are important, and a PA flexion view in 40° of flexion is very helpful in distinguishing posterior wear of the femoral condyle, particularly common on the lateral side. If the surgeon is concerned about the condition of the articular cartilage on the contralateral side, a stress x-ray can be made using a lead-shielded glove applying force against the deformity.

In a shared decision-making model, if the patient is a reasonable candidate for unicondylar arthroplasty, this option should be presented to the patient and the risk/benefits related to TKA. If the patient is not interested in PKA after appropriate education, it is not prudent to try to convince them.

Once the decision for surgery is made, the surgeon should consider the patients comorbidities carefully, and optimize any modifiable risk factors prior to surgery, and also consider whether these comorbidities preclude outpatient surgery designation.

Tips and Tricks in Performing PKA in Older-Aged Patients

Determining the bone quality of an "older patient" is important to determine implant selection. Although cementless implants are being developed for PKA, cemented fixation is currently preferred in the "older patient." Since there is evidence of some decline in immune function in patients over 80 years of age, commercially mixed antibiotic-loaded cement is reasonable in these patients.

Some reports have questioned the efficacy of thin (< 7 mm thickness) all polyethylene tibial components, and it is wise to consider metal-backed tibial components in all "older patients" but certainly in patients with considerable osteopenia. In osteopenic bone surgeons should exercise care in placement of pins used to affix cutting jigs to the tibia to avoid stress "risers" in the tibia which can lead to fracture.

The degree of deformity which can be addressed in an "older patient" is certainly no greater than in other patients, and varus or valgus deformities greater than 20° should in most cases be addressed with TKA.

New technology in knee arthroplasty (navigation, patient-specific instrumentation, robotics) has not been able to demonstrate efficacy at this point. While there has been great interest in robotically assisted PKA to increase precision, this has not led to improved clinical results at current follow-up.

Medial unicondylar arthroplasty is by far the most common PKA performed, with the ratio of medial to lateral unicondylar arthroplasties performed between 5:1 and 10:1. The incidence of patellofemoral arthroplasty (PFA) is likely less than lateral unicondylar arthroplasty, although for "older patients" with isolated patellofemoral arthritis, it can be a very good operation with less morbidity and better function if properly performed.

Is Outpatient Surgery Suitable for Older-Aged Patients Having a PKA?

Outpatient surgery for PKA is widely developed in the USA and in countries of the north part of Europe. For a few years, outpatient surgery has

been used more and more in central Europe, primarily for economic reasons. Meanwhile outpatient surgery is effective and safe with acceptable clinical outcome [22]. To achieve the well-established and adequate standardized protocols, inclusion and exclusion criteria and a change in mindset for both the patient and the multidisciplinary team are the key factors for the implementation of outpatient surgery. Regarding older-aged patients, Husted et al. studied predictors of length of stay and patient satisfaction and they showed that after hip and knee replacement surgery, older age was considered as a risk factor of increasing length of stay [23]. However, Berger et al. reported that patient age, weight, and BMI do not appear to be limiting factors for outpatient knee arthroplasty [24]. As such, even if older age is debating regarding length of stay, it is important to consider all the factors surrounding older patient and preparation (joint class, physiotherapy, hemoglobin, nutrition, and medical condition), intraoperative management (multimodal analgesia, tourniquet, tranexamic acid, cortisone), and postoperative management (early mobilization, deep venous thrombosis prophylaxis) remain the key points.

Conclusion

Older patients require less longevity of implants than younger patients, are less tolerant of surgery, have a somewhat decreased activity than younger patients, and may be the ideal indication for PKA. There are considerable cost savings in PKA over TKA if the revision rate continues to decline through good patient selection, proper implants, and good surgical technique.

References

1. World Health Statistics 2016: Monitoring health for sustainable development goals. Paris: World Health Organization; 2016. p. 3–12.
2. Emerson RH, Higgins LL. Unicompartmental knee arthroplasty with the oxford prosthesis in patients with medial compartment arthritis. J Bone Joint Surg Am. 2008;90(1):118–22.
3. Berger RA, Meneghini RM, Jacobs JJ, Sheinkop MB, Della Valle CJ, Rosenberg AG, Galante JO. Results of unicompartmental knee arthroplasty at a minimum of ten years of follow-up. J Bone Joint Surg Am. 2005;87(5):999–1006.
4. Argenson JN, Blanc G, Aubaniac JM, Parratte S. Modern unicompartmental knee arthroplasty with cement: a concise follow-up, at a mean of twenty years, of a previous report. J Bone Joint Surg Am. 2013;95(10):905–9.
5. Fabre-Aubrespy M, Ollivier M, Pesenti S, Parratte S, Argenson JN. Unicompartmental knee arthroplasty in patients older than 75 results in better clinical outcomes and similar survivorship compared to total knee Arthroplasty. A matched controlled study. J Arthroplasty. 2016;31(12):2668–71. https://doi.org/10.1016/j.arth.2016.06.034. Epub 2016 Jun 29.
6. Iorio R, Robb WJ, Healy WL, Berry DJ, Hozack WJ, Kyle RF, et al. Orthopaedic surgeon workforce and volume assessment for total hip and knee replacement in the United States: preparing for an epidemic. J Bone Joint Surg Am. 2008;901:598–605.
7. Riddle DL, Jiranek WA, Neff RS, Whitaker D, Hull JR, Extent of tibiofemoral osteoarthritis before knee arthroplasty: multicenter data from the osteoarthritis initiative. Clin Orthop Relat Res. 2012;470(10):2836–42. https://doi.org/10.1007/s11999-012-2328-1. Epub 2012 Mar 27.
8. Newman J, Pydisetty RV, Ackroyd C. Unicompartmental or total knee replacement the 15-year results of a prospective randomised controlled trial. J Bone Joint Surg (Br). 2009;91-B:52–7.
9. Lim JW, Cousins GR, Clift BA, Ridley D, Johnston LR. Oxford Unicompartmental knee arthroplasty versus age and gender matched total knee arthroplasty – functional outcome and survivorship analysis. J Arthroplast. 2014;29(9):1779–83.
10. Liddle AD, Judge A, Pandit H, Murray DW. Adverse outcomes after total and unicompartmental knee replacement in 101 330 matched patients: a study of data from the National Joint Registry for England and Wales. Lancet 2014 Jul 7. [Epub ahead of print].
11. Siman H, Kamath AF, Carrillo N, Harmsen WS, Pagnano MW, Sierra RJ. Unicompartmental knee arthroplasty vs total knee arthroplasty for medial compartment arthritis in patients older than 75 years: comparable reoperation, revision, and complication rates. J Arthroplast. 2017;32(6):1792–7.
12. Tadros BJ, Dabis J, Twyman R. Short-term outcome of unicompartmental knee arthroplasty in the octogenarian population. Knee Surg Sports Traumatol Arthrosc. 2017 Jul 25. https://doi.org/10.1007/s00167-017-4639-y. [Epub ahead of print].
13. Iacono F, Raspugli GF, Akkawi I, Bruni D, Filardo G, Budeyri A, Bragonzoni L, Presti ML, Bonanzinga T, Marcacci M. Unicompartmental knee arthroplasty in patients over 75 years: a definitive solution? Arch Orthop Trauma Surg. 2016;136(1):117–23. https://doi.org/10.1007/s00402-015-2323-6. Epub 2015 Sep 8.
14. Howieson A, Farrington W. Unicompartmental knee replacement in the elderly: a systematic review. Acta Orthop Belg. 2015;81(4):565–71.

15. Ghomrawi HM, Eggman AA, Pearle AD. Effect of age on cost-effectiveness of unicompartmental knee arthroplasty compared with total knee arthroplasty in the U.S. J Bone Joint Surg Am. 2015;97(5):396–402.
16. Shankar S, Tetreault MW, Jegier BJ, Andersson GB, Della Valle CJ. A cost comparison of unicompartmental and total knee arthroplasty. Knee. 2016;23(6):1016–9.
17. Willis-Owen CA, Brust K, Alsop H, Miraldo M, Cobb JP. Unicondylar knee arthroplasty in the UK National Health Service: an analysis of candidacy, outcome and cost efficacy. Knee. 2009;16(6):473–8.
18. Peersman G, Jak W, Vandenlangenbergh T, Jans C, Cartier P, Fennema P. Cost-effectiveness of unicondylar versus total knee arthroplasty: a Markov model analysis. Knee. 2014;21(Suppl 1):S37–42.
19. Koskinen E, Eskelinen A, Paavolainen P, Pulkkinen P, Remes V. Comparison of survival and cost-effectiveness between unicondylar arthroplasty and total knee arthroplasty in patients with primary osteoarthritis: a follow-up study of 50,493 knee replacements from the Finnish Arthroplasty register. Acta Orthop. 2008;79(4):499–507.
20. Kozinn SC, Scott R. Unicondylar knee arthroplasty. J Bone Joint Surg Am. 1989;71-A:145–50.
21. Markhardt BK, Li G, Kijowski R. The clinical significance of osteophytes in compartments of the knee joint with normal articular cartilage. AJR Am J Roentgenol. 2018;210(4):W164–71.
22. Kort NP, Bemelmans YFL, Schotanus MGM. Outpatient surgery for unicompartmental knee arthroplasty is effective and safe. Knee Surg Sports Traumatol Arthrosc. 2017;25(9):2659–67. https://doi.org/10.1007/s00167-015-3680-y. Epub 2015 Jul 1.
23. Husted H, Holm G, Jacobsen S. Predictors of length of stay and patient satisfaction after hip and knee replacement surgery: fast-track experience in 712 patients. Acta Orthop. 2008;79(2):168–73.
24. Berger RA, Kusuma SK, Sanders SA, Thill ES, Sporer SM. The feasibility and perioperative complications of outpatient knee arthroplasty. Clin Orthop Relat Res. 2009;467(6):1443–9.

8 Functional Results and Survival of Femorotibial Partial Knee Arthroplasty

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Registry Outcome Analysis

Outcomes of unicompartmental knee arthroplasthy (UKA) are substantially variable according to different national registries. In the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) [1], according to a record of 5894 revisions of UKA, the cumulative percent revision rate at 16 years for primary UKAs performed for osteoarthritis is 23.4%. The main reasons for revision are loosening (39.9%), progression of disease (31.3%), and pain (8.9%). The major factor affecting the outcome of UKA is age, with the rate of revision decreasing with increasing age. Also, in this registry, females have a significantly higher rate of revision. No difference in the rate of revision has been observed comparing medial and lateral UKA.

In the National Joint Registry for England, Wales, Northern Ireland, and the Isle of Man (NJR) [2], the revision rate for UKA has been reported to be 2.8 times higher than the observed rate for all types of knee replacement at 13 years. It has been observed that first revision of an implant is slightly less likely in females than males, but, in general terms, a patient from a younger age group is more likely to be revised irrespective of gender. On the contrary, female patients are more likely to have a unicondylar implant revised compared to their male, age-equivalent, counterpart. The reverse pattern has been observed in patellofemoral implant survivorship.

According to the Swedish Knee Arthroplasty Register (SKAR) [3], the use of UKAs, after having diminished for many years, has increased considerably since 2014 and now accounts for 7% (6.7% medial, 0.3% lateral) of the primary knee arthroplasties. A total of 1598 revisions of UKAs has been reported in the SKAR during the period 2006–2015, with an increased revision rate compared to the two previous decades, mainly because of a relatively higher proportion of younger patients with higher risk. The implant of choice for the revision has been a TKA in 91% of cases, while only 0.3% of the failed UKAs has been revised with a second UKA. In contrast with the NJR, a higher risk of revision has been observed in men than in women, even if not significant. The risk of revision for infection is reported as considerably lower than for TKA as well as the need for revision with stabilized implants, arthrodesis, or amputation.

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The New Zealand Joint Registry (NZJR) [4] reports 853 revisions of the 10,474 registered UKA (8%) from January 1999 to December 2016. A further 90 had a second revision, 14 a third revision, and 1 had a fourth revision. Six hundred ninety-one of the 853 (81%) were revised to TKA and 162 (19%) were revised to further UKA. The average 6-month Oxford score following conversion of a UKA to a TKA is similar to that for a revised primary TKA. For the 17-year period and as of July 2017, the mean unicompartmental knee score was 39.67 (SD 7.2, range 3–48).

UKA and Obesity

Obesity has been historically considered a contraindication to UKA, as it could determine poor clinical outcomes and increased revision rates [5], [6, 7]. Recent studies have continued to support obesity as a contraindication to UKA [8, 9]. Bonutti et al. [8] reported a 12.5% higher failure rate after a minimum follow-up of 24 months in obese compared with nonobese patients. Kandil et al. [9] reviewing a large national database of 1823 obese and 1019 morbidly obese patients found a twofold greater risk of major complications in obese compared to nonobese patients (5.3 vs. 2.3%, respectively) and a threefold greater risk of major complications in morbidly obese compared to nonobese patients (7.2 vs. 2.3%, respectively) within 90 days postoperatively. However, some recent studies have widened the indications for UKA, including patients with higher BMI [10–14]. Cavaignac et al. [10] found no difference in UKA survival rates in patients with BMIs over or under 32, at an average 12-year follow-up. Murray et al. [11] found no association between failure rate and BMI at a mean 5-year follow-up. In a study performed by Tabor et al. [14] on 100 UKAs in 82 patients stratified according to BMI and followed over a period of 20 years, obese patients had a paradoxically decreased revision rate. Decreased revision rate in mobile-bearing designs in patients with increased BMI has been also observed by Emerson et al. [15]. In a recent study by Plate et al. [13], of 746 medial robotic-assisted UKAs (672 patients), BMI did not negatively influence the rate of revision surgery to TKA.

Femorotibial Replacement with Associated Patellar Arthritis

Anterior knee pain and osteoarthritis in the patellofemoral joint (PFJ) have been commonly considered contraindications for UKA [5]. However, a number of studies have shown that neither anterior knee pain nor the presence of OA on the medial side of the PFJ influenced the functional outcomes after a mobile-bearing UKA in the short term [16–20]. Pandit et al. [20] in a long-term follow-up series of mobile-bearing Oxford UKA (OUKA) reported few revisions for anterior knee pain or progression of OA in the PFJ. Beard et al. [17] studied the influence of anterior knee pain or radiological evidence of PFJ OA on the patient-reported outcome of Oxford medial UKA. They found that patients with medial patellofemoral degeneration had a similar outcome to those without such degeneration. However, inferior functional outcomes have been reported 2 years postoperatively in knees with lateral PFJ OA [16, 17, 19, 21–23].

Hamilton et al. [18] recently analyzed 805 UKA in 677 patients with full-thickness cartilage loss affecting the medial side of the PFJ in 74 (9.2%), the lateral side in 13 (1.6%), both sides in 38 (4.7%), and the trochlea in 161 knees (20%); full-thickness cartilage loss at either the medial or lateral side with reciprocal full-thickness loss at the trochlea was observed in 96 knees (11.9%). They found that neither the presence of preoperative anterior knee pain, nor radiographic changes on the medial side of the PFJ, nor exposed bone seen intraoperatively on the medial patella or in the trochlea, compromised the 15-year implant survival or 10-year functional outcome, even on stair descent, following medial mobile-bearing UKA. The overall revision rate was low (4%), and there was no difference in revision rates whether patients did or did not have preoperative anterior knee pain or whether they did or did not show damage to the medial or lateral side of the PFJ.

Damage on the lateral side of the PFJ has a more complex analysis: in several papers it is not associated with a compromised overall functional outcome or survival, but it is generally associated with some decreased performance on stair descent. Konan and Haddad [24] demonstrated that the presence of patellar chondral lesions was associated with early and persistent anterior knee pain; however, this seemed to resolve at the 18-month follow-up. Presence of lateral or central PFJ chondral lesions was associated with decreased knee score and function.

Pongcharoen and Reutiwarangkoon [25] compared patients with and without severe arthritis of the lateral facet of the patella following mobile-bearing UKA. They found that anterior knee pain, pain scores, and functional scores were not different between the two groups following a medial OUKA. However, the knee scores of patients with severe arthritis of the lateral facet were worse than those in patients without severe arthritis of the lateral facet of the patella.

Song et al. [26] compared the outcomes of patients with or without PFJ OA who underwent medial UKA; at median follow-up of 5.4 years (3.1–10.2), no significant inter-group difference was found in terms of anterior knee pain, HSS score, or range of movement. Berger et al. [27], in their 10-year follow-up revision study including multiple UKA designs, reported a relatively low failure rate related to the patellofemoral and/or adjacent tibiofemoral compartment, ranging from 3% to 9%. Foran et al. [28] reported radiographic evidence of progression of patellofemoral or adjacent tibiofemoral compartment degeneration in most of their patients with minimal effect on clinical outcomes. The same group reported that only 2 out of 51 medial fixed-bearing UKAs were revised because of progressive PFJ degeneration.

One of the common explanations on why PFJ damage does not affect the function or survival after UKA is that in most people, it is asymptomatic. In people aged between 34 years and 55 years, the incidence of asymptomatic radiographic evidence of OA of the PFJ has been reported to be 30%, with postmortem studies demonstrating that significant OA of the PFJ is present in nearly all elderly individuals who had not reported knee pain [29]. Noble and Hamblen [30] reported an incidence PFJ OA of 79% in 100 randomly selected cadavers aged >65 years at autopsy. It is therefore likely that PFJ damage is asymptomatic in most people within the knee arthroplasty age, including those with painful medial OA, and therefore will not compromise the outcome of UKA. As the presence of anterior knee pain before UKA is not related to the state of the PFJ, it is likely to be related to the medial OA and will also resolve after UKA [19].

Medial UKA

A number of studies reported excellent midterm clinical outcomes independently regardless of whether the design was a mobile or fixed-bearing medial UKA. Four-Martin et al. [31], in a 10-year outcome study of 511 knees (in 402 patients), using the mobile-bearing OUKA, reported significant improvement in the mean Knee Society score from 51.5 points (26–68) preoperatively to 90.2 (72–100) postoperatively and mean active knee flexion increasing from 105.5° (85–135°) to 130.9° (110–140°) [31]. Argenson et al. [32] reported on 160 medial metal-backed fixed-bearing UKAs in 147 patients at a mean follow-up of 20 years. The mean Knee Society (KSS) knee and function scores were 91 points (50–100) and 88 points (45–100), respectively. Mean active flexion increased from 119° (85–135°) preoperatively to 127° (80–145°) at the last follow-up. Likewise, in a series of 53 medial UKAs with an all-polyethylene tibial design, Manzotti et al. reported mean KSS knee and function scores of 80.1 points and 84.7 points, respectively, with a mean active knee flexion of 120.6° at a mean follow-up of 14.7 years [33]. Some debate is still ongoing on the functional outcomes of UKA compared to TKA for medial osteoarthritis. Thienpont et al. [34], in a retrospective comparison of 51 UKA patients with 50 TKA patients, reported similar results with the forgotten joint score at 1 year following surgery. Liddle et al. [35], in a study of 14,076 matched patients from the National Joint Registry for England and

Wales, reported that UKA provided higher scores with the Oxford knee score and the EQ 5D than TKA at short term and higher satisfaction and lower complication rates at 6 months after surgery. Sun et al. [36], in a randomized controlled study, showed that a lower complication rate and similar clinical outcomes can be achieved with mobile-bearing UKA in comparison with a fixed-bearing TKA, even if the OUKA revision rate in their series was 25%. Nonetheless, Newman et al. [37] showed persistant better results with UKA at 15 years with no greater failure rate. Favorable outcomes, both in terms of survival and functional results, have been reported for UKA dealing with avascular necrosis (AVN) as well. Bruni et al. [38] reported a mean KSS of 87.1, a mean WOMAC score of 12, and a survival rate of 89% at 10 years, in 84 patients undergoing medial UKA for osteonecrosis. Heyse et al. [39] reported a KSS increase from a preoperative 85 +/− 30 to 173 +/− 27 and a mean WOMAC score of 7.7 at the latest follow-up in 28 knee, with a survival rate of 93.1% at 10 years. Parratte et al. [40] reported 96% of implant survival at 12 years in 31 patients and only one revision to TKA for aseptic loosening. The mean KSS knee score was 95 points and the mean functional score was 88 at 7 years.

Medium- and long-term studies suggest good 10-year survival of around 95% for UKA performed for medial OA in high-volume units [32, 33, 41, 42].

Forster-Horváth et al. [43] showed a survival estimate of 97.9% at 2 years, 94.1% at 5 years, and 91.3% at 10 years following medial fixed-bearing UKA.

Studies reporting on the survivorship of several fixed-bearing implants (Zimmer I and II, Marmor, St Georg, Brigham) showed that 10-year survival rates ranged between 80% and 93.7%. A series from the designing unit of the OUKA has reported 98% cumulative survival at 10 years [44]. Price et al. [42] reported 92% survival at 15 years in a series performed at an independent centre. In this series (as in other series of the OUKA) a high rate of radiolucent lines was noted adjacent to the tibial component, although the significance of these lines is uncertain. Argenson et al. [32] reported 74% implant survival for the metal-backed, fixed-bearing Miller-Galante UKA at 20 years. They reported that the two most common reasons for revision were progression of arthritis in the uninvolved compartments (65%) and polyethylene wear (25%). The mean time for revision to TKA or addition of a PFA was 13 years (3 months to 21 years). Similar results are reported for fixed-bearing devices with all-polyethylene tibial components [41]. However, these results may be device-dependent: a recent randomized study reported very poor survival for a UKA with an all-polythene tibial component compared with the metal-backed version of the same device [45]. The 10-year survival with the all-polythene tibial component was 56.5% (95% confidence interval (CI) 31.9 to 75.2), compared with 93.8% (95% CI 77.3 to 98.4) in the metal-backed group ($P < 0.001$), although the numbers at risk were relatively low at 10 years (7 and 16 for all-polythene and metal-backed components, respectively). On the basis of the current literature, there is no consensus as to whether fixed- or mobile-bearing UKA gives better results in terms of survival or clinical outcome in the long term. While mobile-bearing implants have a higher rate of early bearing dislocation, polyethylene wear remains a complication of fixed-bearing devices in the longer term (although in patients with no evidence of infection or osteolysis, liner exchange may be a successful procedure in cases of polyethylene wear 21). Parratte et al. [46] reported a retrospective comparison of 79 fixed-bearing UKA with 77 knees with mobile-bearing UKA, reporting no significant difference in the rate of revision at a minimum of 15 years of follow-up (12 of 77 knees were revised in the mobile-bearing group, compared with 10 of 79 in the fixed-bearing group, $P = 0.44$). Similarly, Confalonieri et al. [47] reported no difference in clinical outcomes between the two designs of UKA. Gleeson et al. [48] reported a prospective nonrandomized study of 91 patients undergoing either fixed (57 knees) or mobile-bearing [47] UKA. The rate of revision was higher in the mobile-bearing group, owing to a number of bearing dislocations, but this difference was not significant. Likewise, no significant difference

was reported in either the Bristol or the Oxford knee scores between the groups, although a small difference in the pain component of the Bristol score was reported in favor of the fixed-bearing implant ($P = 0.014$).

In contemporary practice, the discussion has focused on comparing the results of UKA and TKA. A study of 27-year data from the Finnish Joint Registry compared the survival of 4713 patients with UKA performed for primary OA (mean age of 64 years; mean follow-up of 6 years) with that of 83,511 patients who had undergone TKA (with a mean age of 70 years and a mean follow-up of 6 years) [49]. Survival for UKA was 89% at 5 years, 81% at 10 years, and 70% at 15 years, compared with 96%, 93%, and 88%, respectively, for TKA. UKA had inferior long-term survivorship compared with cemented TKA, adjusted for age and gender (hazard ratio 2.2; $P < 0.001$) [49]. The authors acknowledged that comparing survival directly by using arthroplasty register survival reports might be inadequate because of differences in indications, implant designs, and patient demographics in patients having UKA and TKA. Despite these limitations, they concluded that while UKA has advantages, the risk of revision remains higher than expected with a TKA [49]. In 2014, Liddle et al. [50] reported the rates of adverse events for matched UKA or TKA patients extracted from the England and Wales total joint registry. They concluded that the higher revision/reoperation rate of UKA should be balanced against a lower occurrence of complications, readmission, and mortality. Based on their analysis, if the 100 patients receiving TKA had received UKA instead, there would have been one fewer death and three more reoperations in the first 4 years after surgery.

Lateral UKA

Lateral UKA is much less common than medial UKA, as it accounts for approximately 1% of all knee arthroplasty procedures [51]. Several studies have shown that fixed-bearing UKA represents the best solution in cases of isolated lateral femorotibial compartment disease [52–55]. Smith et al. [55] reported a minimum 5-year follow-up of 41 lateral UKAs, with the mean total KSS changing from 100 points to 159, mean OKS from 20 points to 37 points, and mean WOMAC from 36 points to 22 points. Argenson et al. [56] reviewed 39 patients with 40 lateral cemented metal-backed UKA, reporting mean KSS knee and function scores of 88 points and 78 points, respectively, at a mean follow-up of 12.6 years and a survival rate of 92% at 10 years and 84% at 16 years. Sah et al. [54] reported a series of 49 UKAs in 45 patients at 5 years and showed an increase in KS and FS from 39 and 45 points preoperatively to 89 and 80 points postoperatively at an average of 5.2 years and 0% of revision rate. Lustig et al. [53] reported a series of 54 lateral UKAs in 52 patients, with mean KSS knee and function scores of 95 points and 82 points, respectively, and a survival rate of 98.08% at 10 years. No revisions for wear, infection, or patellofemoral OA were performed.

On the other hand, mobile-bearing lateral UKA has been associated with a high rate of bearing dislocation [57]. Gunther et al. [58] reported a 21% overall failure rate and a 10% rate of bearing dislocation. For this reason a new design of the OUKA with a domed tibial component (ODLPKR) and a biconcave mobile-bearing has been introduced. With this modification, Weston-Simons et al. [59] reported 1.5% of bearing dislocation at a mean follow-up of 4 years and an overall revision rate of 92% at 8 years. With the same domed implant, Altuntas et al. [60] reported no dislocation and 96.9% implant survivorship at maximal follow-up of 3 years in a series of 64 lateral UKAs. Walker et al. [61] performed a comparison study between the Oxford domed lateral UKA and a cruciate-retaining TKA and showed 96% survival with an OKS pre-op mean score of 29 improving to 43 at the final review. Newman et al. [62] reported 7% revision rate, in terms of any ODLPKR component including the bearing being replaced; the mean OKS of 26 preoperatively improved to a mean of 42 at the final follow-up. Marson et al. [63] reported a survival rate of 92% and a mean OKS of 36.6 at the final review.

UKA in Young Patients

Young age is considered to be a relative contraindication to UKA still today [5]. Excellent long-term results have been reported for the OUKA used in the medial compartment, with survival rates up to 98% after 10 years and up to 91% after 20 years [44]. Based on these encouraging results, the indication for UKA has been extended to younger and more active patients with high expectations concerning their postoperative level of physical activity [64]. Walker et al. [65] demonstrated that a vast majority of young (under 60 years old) and active patients following mobile-bearing medial UKA were able to return to a high level of regular physical activities: the return to activity rate was 93% at the final review 4.4 years after surgery. The UCLA score improved significantly from 3.3 ± 1.5 [2–9] preoperatively to 6.8 ± 1.5 (2–10) at final review ($P < 0.001$). There was no statistically significant difference in the postoperative UCLA score between patients with bilateral or unilateral UKA (n.s.). Patients with bilateral UKA reached a mean postoperative UCLA score of 6.8 ± 1.6 (3–10), and patients with unilateral UKA achieved a mean postoperative score of 6.6 ± 1.1 (5–9). In reference to the postoperative UCLA score, 62% of our patients were highly active, defined as a UCLA score ≥ 7. In this specific group of patients, the most common activities were cycling (85%), long walks (57%), swimming (52%), and hiking (45%). In addition, 29% of these patients were active in high-impact activities such as soccer (10%), downhill-skiing (9%), tennis (5%), or jogging (5%).

Fisher et al. demonstrated a rate of return to activity of 93%, 18 months after medial OUKA in a series of 76 patients [66]. Hopper et al. reported a return to activity rate of 96.7% in a series of 37 patients, 22 months after OUKA [67]. Felts et al. [68] performed 65 UKAs in 62 patients younger than 60 (mean age, 54.7 years; mean BMI, 28 kg/m2), using modular prostheses with a cemented metallic tibial tray (Miller-Galante, Zimmer, Warsaw, IN, USA). A significant improvement in the IKS knee and function scores was demonstrated at the final follow-up of 11.2 ± 5 years. The mean KOOS score at the end of the study was 86 out of 100 (range, 21–100) for the pain items, 83 out of 100 (range, 27–100) for the symptom items, 80 out of 100 (range, 21–100) for the daily life items, 66 of 100 (range, 0–100) for the sports items, and 78 out of 100 (range, 30–100) for the quality-of-life items. Twenty-six patients (40%) in the series had a UCLA score equal to or higher than 8, corresponding to physical activities such as cycling, golf, dancing, or sports with repeated impacts on the knee (tennis and running). For 90% of the patients, their knee no longer limited their physical or recreational activities. The Kaplan-Meier survival analysis showed a 94% 12-year survival rate (95% CI, 0.87–0.96). Biswas et al. [69]. analyzed 85 fixed-earing medial unicompartmental arthroplasties with a mean age of 49 years; at a mean of 4.0 years (range 2–12 years), the mean preoperative Knee Society score improved from 49 to 95.1 points, and the mean UCLA activity score was 7.5 (range 5–9). Estimated survivorship was 96.5% at 10 years.

UKA in Elderly Patients

UKA may represent a good alternative to TKA in the older patient. Since it represents a less aggressive surgery, it would be ideal in this population because of the lower morbidity, less blood loss, faster recovery, and more physiologic motion than TKA. Previous studies in the elderly demonstrated that UKA may have advantages in terms of its lesser surgical invasiveness and quicker return to function when compared to TKA [70]. Numerous studies in the general population have shown good and comparable results after both UKA and TKA. Iacono et al. [71] reported excellent functional results at a mean follow-up of 9 years with only 3% of failures in patients older than 75 years and only one revision. 92.6% of patients rated their joint as good/excellent according to the KSS score. Tadros et al. [72] recently showed that OKS and EQ-5D scores improved significantly 1 year postoperatively in patients over 80 years old, and this improvement remained significant at 2 years

postoperative. The octuagenarian group reported a mean satisfaction rate of 91.3% (SD 12.1) at 2 years, greater than the other two groups of younger patients. LOS was 4.5 days (SD 2.2), somewhat longer than the younger group. The cohort survivorship at 7.7 years was found to be 90%. Fisher et al. performed a retrospective analysis comparing the short-term outcome between UKA and TKA in patients older than 70 years (mean age 76 years). Patients undergoing UKA had improved Knee Society scores (KSS) at 1 and 2 years comparatively to the TKA group. Range of movement was superior at all time points. Ingale et al. [73] compared the functional outcome of the Oxford phase 3 UKA in an octogenarian group with younger cohorts. The objective KSS did not show any difference between the octogenarian group and the younger groups. Functional KSS scores were compared among all age groups, but the octogenarian score improvement was significantly less than the younger groups at 1-year follow-up. There was, however, no difference at 3 and 5 years. Siman et al. [74] compared 120 UKA (106 patients) and 188 TKA (170 patients) procedures of patients 75 years and older. The average clinical follow-up was 3.5 ± 1.8 years and 4.6 ± 2.2 years for the UKA and TKA groups. UKA patients experienced significantly shorter operative time, shorter hospital stay, lower intraoperative estimated blood loss, lower postoperative transfusions, greater postoperative ROM, and higher level of activity at time of discharge. Five-year survivorship estimates (free of revision) for UKA and TKA were 98.3% (95% CI, 94.4–100) and 98.8% (95% CI, 96.7–100), while five-year complication-free survival estimates for UKA and TKA were 90.8% (95% CI, 82.2–96.1) and 87.0% (95% CI, 81.4–92.2), respectively. The KSS at the final follow-up did not differ between UKA and TKA. Lim et al. [75] compared a population of a mean of 70-year-old patients that performed UKA or TKA from 2001 to 2013: the average hospital stay for UKA was 4 days compared to 7 days for the TKA group ($P = 0.000$). The preoperative KSS for pain and total scores were not significantly different between UKA and TKA (6.61 vs 6.05, $P = 0.219$ and 37.58 vs 36.43, $P = 0.328$, respectively), whereas the preoperative function score was significantly better for the UKA group (55.65 vs 51.10, $P = 0.000$). At 1 year, the KSS pain score was significantly better in the TKA group (41.08 vs 44.14, $P = 0.009$). However, it was not significantly different at 3 and 5 years of follow-up ($P = 0.314$ and $P = 0.064$, respectively). The KSS (function) remained significantly better with UKA until 3 years of follow-up but were not significantly different at any point of the 5-year study. In the majority of complication categories, there were fewer complications in the UKA group. At 12 years, of the 602 UKAs recorded, 38 (6.30%) had required revision (95% CI 10.47–11.13), whereas of the 602 TKAs recorded, only 18 (2.99%) had required revision (95% CI 11.08–11.44). Fabre-Aubrespy et al. [76] recently revised 101 patients who underwent UKA matching them one-to-one with TKA group based on age, gender, body mass index, and preoperative Knee Society score (KSS). At the last follow-up, patients from UKA group had better KSS than in TKA group, (respectively KSS-function 82.8 ± 12.2 vs 79.2 ± 13.1 and KSS-knee 88.2 ± 8.9 vs 82.3 ± 12.5 $P = 0.0005$). KOOS were also higher in UKA group as well as the rate of forgotten knees (42% vs 25% $P = 0.01$). At the16-year survivorship mark, the revision free rate for any reason was similar in the two groups (91.8% vs 94.6%).

Conclusion

UKA has gone through many design advancements since the first designs were introduced in the 1960s. Indeed, most of the literature reviewed has shown very acceptable clinical results and survivorship obtained with this operation. While registry data shows a lower survivorship than that seen with TKA, the pure data do not get into the individual trigger point for a surgeon to recommend revision surgery. This is especially noteworthy in patients with unexplained pain. Surgeons, in general, may innately recommend revision more quickly for unhappy patients with a UKA compared with a TKA, simply because

logically, the surgeon realizes he or she can readily go to that operation. An unhappy patient with a TKA only can be revised to a similar or more complex TKA, and this concept may generate a greater inertia for the surgeon to recommend revision. Nevertheless, the survivorship data suggests that UKA gives very acceptable survivorship, and in the young patient, it may represent a bone conserving, first replacement.

Clinical data suggests that patellofemoral osteoarthritis, for the most part, can be ignored if a patient were a candidate for UKA. Few would argue, however, that a totally destroyed patellofemoral joint would make the surgeon think more seriously about doing a TKA instead of a UKA. Although some data supports successful results in obese patients, perhaps the very obese patients with BMI > 35 or 40 would serve as a relative contraindication due to the risk of loosening in the very long term, for which there is less data. Of course, each surgeon may interpret the data differently and form their own separate indications for these patients.

UKA is indeed mostly indicated for medial osteoarthritis. Fixed- or mobile-bearing components appear to perform equally well for this scenario. However, for lateral UKA the data supports using a fixed-bearing implant. The data may continue show improvement with the new polyethylene modifications for the Oxford system, but the current recommendation is to use a fixed-bearing design for treatment of lateral joint osteoarthritis.

Data should continue to be collected for the younger, more active patient. In the 45–65 age group, upper tibial and distal femoral osteotomy is being less recommended in favor of performing UKA. While data shows conversion to total knee replacement may not be surgically challenging, there is still the issue of tibial plateau bone loss depending on the UKA model and cause for failure. Perhaps, more data will come through regarding cementless UKA designs as a future preferred method of fixation that would benefit the young and hopefully reduce the incidence of tibial or femoral component loosening.

UKA in the very old is an excellent application of this technology. Recommendation for this surgery in the older population can be based on the level of expertise of each hospital's anesthesia department and their proficiency with regional anesthesia. In the hospital where general anesthesia is more common for joint replacement patients, UKA is definitely the surgical operation with a lower complication rate. Also, the shorter hospital stay and less invasive operative intensity may provide a safer option to these patients, especially those with medical comorbidities.

References

1. Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR). Hip, knee & shoulder arthroplasty: 2017 annual report. Adelaide: AOA; 2017.
2. 14th Annual Report of the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man. National Joint Registry. http://www.njrcentre.org.uk. 2017.
3. The Swedish Knee Arthroplasty Register – Annual Report 2017. http://www.knee.se, http://www.gangbar.se. 2017.
4. The New Zealand Joint Registry Seventeen Year Report (January 1999–December 2016). http://www.nzoa.org.nz. NZOA; 2017.
5. Kozinn SC, Scott R. Unicondylar knee arthroplasty. J Bone Joint Surg Am. 1989;71(1):145–50. PubMed PMID: 2643607.
6. Berend KR, Lombardi AV Jr, Mallory TH, Adams JB, Groseth KL. Early failure of minimally invasive unicompartmental knee arthroplasty is associated with obesity. Clin Orthop Relat Res. 2005;440:60–6. PubMed PMID: 16239785.
7. Heck DA, Marmor L, Gibson A, Rougraff BT. Unicompartmental knee arthroplasty. A multicenter investigation with long-term follow-up evaluation. Clin Orthop Relat Res. 1993;286:154–9. PubMed PMID: 8425338.
8. Bonutti PM, Goddard MS, Zywiel MG, Khanuja HS, Johnson AJ, Mont MA. Outcomes of unicompartmental knee arthroplasty stratified by body mass index. J Arthroplast. 2011;26(8):1149–53. PubMed PMID: 21256695.
9. Kandil A, Werner BC, Gwathmey WF, Browne JA. Obesity, morbid obesity and their related medical comorbidities are associated with increased complications and revision rates after unicompartmental knee arthroplasty. J Arthroplast. 2015;30(3):456–60. PubMed PMID: 25453628.
10. Cavaignac E, Lafontan V, Reina N, Pailhe R, Wargny M, Laffosse JM, et al. Obesity has no adverse effect on the outcome of unicompartmental knee replacement at a minimum follow-up of seven years. Bone Joint J. 2013;95-B(8):1064–8. PubMed PMID: 23908421.

11. Murray DW, Pandit H, Weston-Simons JS, Jenkins C, Gill HS, Lombardi AV, et al. Does body mass index affect the outcome of unicompartmental knee replacement? Knee. 2013;20(6):461–5. PubMed PMID: 23110877.
12. Naal FD, Neuerburg C, Salzmann GM, Kriner M, von Knoch F, Preiss S, et al. Association of body mass index and clinical outcome 2 years after unicompartmental knee arthroplasty. Arch Orthop Trauma Surg. 2009;129(4):463–8. PubMed PMID: 18414881.
13. Plate JF, Augart MA, Seyler TM, Bracey DN, Hoggard A, Akbar M, et al. Obesity has no effect on outcomes following unicompartmental knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2017;25(3):645–51. PubMed PMID: 25863681.
14. Tabor OB Jr, Tabor OB, Bernard M, Wan JY. Unicompartmental knee arthroplasty: long-term success in middle-age and obese patients. J Surg Orthop Adv. 2005;14(2):59–63. PubMed PMID: 16115429.
15. Emerson RH Jr, Hansborough T, Reitman RD, Rosenfeldt W, Higgins LL. Comparison of a mobile with a fixed-bearing unicompartmental knee implant. Clin Orthop Relat Res. 2002;404:62–70. PubMed PMID: 12439239.
16. Beard DJ, Pandit H, Gill HS, Hollinghurst D, Dodd CA, Murray DW. The influence of the presence and severity of pre-existing patellofemoral degenerative changes on the outcome of the Oxford medial unicompartmental knee replacement. J Bone Joint Surg. 2007;89(12):1597–601. PubMed PMID: 18057359.
17. Beard DJ, Pandit H, Ostlere S, Jenkins C, Dodd CA, Murray DW. Pre-operative clinical and radiological assessment of the patellofemoral joint in unicompartmental knee replacement and its influence on outcome. J Bone Joint Surg. 2007;89(12):1602–7. PubMed PMID: 18057360.
18. Hamilton TW, Pandit HG, Maurer DG, Ostlere SJ, Jenkins C, Mellon SJ, et al. Anterior knee pain and evidence of osteoarthritis of the patellofemoral joint should not be considered contraindications to mobile-bearing unicompartmental knee arthroplasty: a 15-year follow-up. Bone Joint J. 2017;99-B(5):632–9. PubMed PMID: 28455472.
19. Liddle AD, Pandit H, Jenkins C, Price AJ, Dodd CA, Gill HS, et al. Preoperative pain location is a poor predictor of outcome after Oxford unicompartmental knee arthroplasty at 1 and 5 years. Knee Surg Sports Traumatol Arthrosc. 2013;21(11):2421–6. PubMed PMID: 23000922.
20. Pandit H, Hamilton TW, Jenkins C, Mellon SJ, Dodd CA, Murray DW. The clinical outcome of minimally invasive phase 3 Oxford unicompartmental knee arthroplasty: a 15-year follow-up of 1000 UKAs. Bone Joint J. 2015;97-B(11):1493–500. PubMed PMID: 26530651.
21. Goodfellow JW, O'Connor J. Clinical results of the Oxford knee. Surface arthroplasty of the tibiofemoral joint with a meniscal bearing prosthesis. Clin Orthop Relat Res. 1986;205:21–42. PubMed PMID: 3698380.
22. Pandit H, Jenkins C, Gill HS, Smith G, Price AJ, Dodd CA, et al. Unnecessary contraindications for mobile-bearing unicompartmental knee replacement. J Bone Joint Surg. 2011;93(5):622–8. PubMed PMID: 21511927.
23. Thompson SA, Liabaud B, Nellans KW, Geller JA. Factors associated with poor outcomes following unicompartmental knee arthroplasty: redefining the "classic" indications for surgery. J Arthroplast. 2013;28(9):1561–4. PubMed PMID: 23523214.
24. Konan S, Haddad FS. Does location of patellofemoral chondral lesion influence outcome after Oxford medial compartmental knee arthroplasty? Bone Joint J. 2016;98-B(10 Supple B):11–5. PubMed PMID: 27694510. Pubmed Central PMCID: 5047133.
25. Pongcharoen B, Reutiwarangkoon C. The comparison of anterior knee pain in severe and non severe arthritis of the lateral facet of the patella following a mobile bearing unicompartmental knee arthroplasty. Springerplus. 2016;5:202. PubMed PMID: 27026898. Pubmed Central PMCID: 4769708.
26. Song EK, Park JK, Park CH, Kim MC, Agrawal PR, Seon JK. No difference in anterior knee pain after medial unicompartmental knee arthroplasty in patients with or without patellofemoral osteoarthritis. Knee Surg Sports Traumatol Arthrosc. 2016;24(1):208–13. PubMed PMID: 25274099.
27. Berger RA, Meneghini RM, Jacobs JJ, Sheinkop MB, Della Valle CJ, Rosenberg AG, et al. Results of unicompartmental knee arthroplasty at a minimum of ten years of follow-up. J Bone Joint Surg Am. 2005;87(5):999–1006. PubMed PMID: 15866962.
28. Foran JR, Brown NM, Della Valle CJ, Berger RA, Galante JO. Long-term survivorship and failure modes of unicompartmental knee arthroplasty. Clin Orthop Relat Res. 2013;471(1):102–8. PubMed PMID: 22895691. Pubmed Central PMCID: 3528926.
29. Kumm J, Tamm A, Lintrop M, Tamm A. The prevalence and progression of radiographic knee osteoarthritis over 6 years in a population-based cohort of middle-aged subjects. Rheumatol Int. 2012;32(11):3545–50. PubMed PMID: 22083615.
30. Noble J, Hamblen DL. The pathology of the degenerate meniscus lesion. J Bone Joint Surg. 1975;57(2):180–6. PubMed PMID: 1173585.
31. Faour-Martin O, Valverde-Garcia JA, Martin-Ferrero MA, Vega-Castrillo A, de la Red Gallego MA, Suarez de Puga CC, et al. Oxford phase 3 unicondylar knee arthroplasty through a minimally invasive approach: long-term results. Int Orthop. 2013;37(5):833–8. PubMed PMID: 23503637. Pubmed Central PMCID: 3631504.
32. Argenson JN, Blanc G, Aubaniac JM, Parratte S. Modern unicompartmental knee arthroplasty with cement: a concise follow-up, at a mean of twenty years, of a previous report. J Bone Joint Surg Am. 2013;95(10):905–9. PubMed PMID: 23677357.
33. Manzotti A, Cerveri P, Pullen C, Confalonieri N. A flat all-polyethylene tibial component in medial unicompartmental knee arthroplasty: a long-term study.

Knee. 2014;21(Suppl 1):S20–5. PubMed PMID: 25382363.
34. Thienpont E, Opsomer G, Koninckx A, Houssiau F. Joint awareness in different types of knee arthroplasty evaluated with the forgotten joint score. J Arthroplast. 2014;29(1):48–51. PubMed PMID: 23688851.
35. Liddle AD, Pandit H, Judge A, Murray DW. Patient-reported outcomes after total and unicompartmental knee arthroplasty: a study of 14,076 matched patients from the National Joint Registry for England and Wales. Bone Joint J. 2015;97-B(6):793–801. PubMed PMID: 26033059.
36. Sun PF, Jia YH. Mobile bearing UKA compared to fixed bearing TKA: a randomized prospective study. Knee. 2012;19(2):103–6. PubMed PMID: 21345681.
37. Newman J, Pydisetty RV, Ackroyd C. Unicompartmental or total knee replacement: the 15-year results of a prospective randomised controlled trial. J Bone Joint Surg. 2009;91(1):52–7. PubMed PMID: 19092004.
38. Bruni D, Iacono F, Raspugli G, Zaffagnini S, Marcacci M. Is unicompartmental arthroplasty an acceptable option for spontaneous osteonecrosis of the knee? Clin Orthop Relat Res. 2012;470(5):1442–51. PubMed PMID: 22278850. Pubmed Central PMCID: 3314777.
39. Heyse TJ, Khefacha A, Fuchs-Winkelmann S, Cartier P. UKA after spontaneous osteonecrosis of the knee: a retrospective analysis. Arch Orthop Trauma Surg. 2011;131(5):613–7. PubMed PMID: 20734200.
40. Parratte S, Argenson JN, Dumas J, Aubaniac JM. Unicompartmental knee arthroplasty for avascular osteonecrosis. Clin Orthop Relat Res. 2007;464:37–42. PubMed PMID: 17589365.
41. O'Rourke MR, Gardner JJ, Callaghan JJ, Liu SS, Goetz DD, Vittetoe DA, et al. The John Insall award: unicompartmental knee replacement: a minimum twenty-one-year followup, end-result study. Clin Orthop Relat Res. 2005;440:27–37. PubMed PMID: 16239780.
42. Price AJ, Waite JC, Svard U. Long-term clinical results of the medial Oxford unicompartmental knee arthroplasty. Clin Orthop Relat Res. 2005;435:171–80. PubMed PMID: 15930935.
43. Forster-Horvath C, Artz N, Hassaballa MA, Robinson JR, Porteous AJ, Murray JR, et al. Survivorship and clinical outcome of the minimally invasive Uniglide medial fixed bearing, all-polyethylene tibia, unicompartmental knee arthroplasty at a mean follow-up of 7.3years. Knee. 2016;23(6):981–6. PubMed PMID: 27506988.
44. Murray DW, Goodfellow JW, O'Connor JJ. The Oxford medial unicompartmental arthroplasty: a ten-year survival study. J Bone Joint Surg. 1998;80(6):983–9. PubMed PMID: 9853489.
45. Hutt JR, Farhadnia P, Masse V, LaVigne M, Vendittoli PA. A randomised trial of all-polyethylene and metal-backed tibial components in unicompartmental arthroplasty of the knee. Bone Joint J. 2015;97-B(6):786–92. PubMed PMID: 26033058.
46. Parratte S, Pauly V, Aubaniac JM, Argenson JN. No long-term difference between fixed and mobile medial unicompartmental arthroplasty. Clin Orthop Relat Res. 2012;470(1):61–8. PubMed PMID: 21732024. Pubmed Central PMCID: 3237998.
47. Confalonieri N, Manzotti A, Pullen C. Comparison of a mobile with a fixed tibial bearing unicompartimental knee prosthesis: a prospective randomized trial using a dedicated outcome score. Knee. 2004;11(5):357–62. PubMed PMID: 15351409.
48. Gleeson RE, Evans R, Ackroyd CE, Webb J, Newman JH. Fixed or mobile bearing unicompartmental knee replacement? A comparative cohort study. Knee. 2004;11(5):379–84. PubMed PMID: 15351413.
49. Niinimaki T, Eskelinen A, Makela K, Ohtonen P, Puhto AP, Remes V. Unicompartmental knee arthroplasty survivorship is lower than TKA survivorship: a 27-year Finnish registry study. Clin Orthop Relat Res. 2014;472(5):1496–501. PubMed PMID: 24249531. Pubmed Central PMCID: 3971215.
50. Liddle AD, Judge A, Pandit H, Murray DW. Adverse outcomes after total and unicompartmental knee replacement in 101,330 matched patients: a study of data from the National Joint Registry for England and Wales. Lancet. 2014;384(9952):1437–45. PubMed PMID: 25012116.
51. Scott RD. Lateral unicompartmental replacement: a road less traveled. Orthopedics. 2005;28(9):983–4. PubMed PMID: 16190078.
52. Argenson JN, Parratte S, Bertani A, Aubaniac JM, Lombardi AV Jr, Berend KR, et al. The new arthritic patient and arthroplasty treatment options. J Bone Joint Surg Am. 2009;91(Suppl 5):43–8. PubMed PMID: 19648624.
53. Lustig S, Elguindy A, Servien E, Fary C, Munini E, Demey G, et al. 5- to 16-year follow-up of 54 consecutive lateral unicondylar knee arthroplasties with a fixed-all polyethylene bearing. J Arthroplast. 2011;26(8):1318–25. PubMed PMID: 21414745.
54. Sah AP, Scott RD. Lateral unicompartmental knee arthroplasty through a medial approach. Study with an average five-year follow-up. J Bone Joint Surg Am. 2007;89(9):1948–54. PubMed PMID: 17768191.
55. Smith JR, Robinson JR, Porteous AJ, Murray JR, Hassaballa MA, Artz N, et al. Fixed bearing lateral unicompartmental knee arthroplasty – short to mid-term survivorship and knee scores for 101 prostheses. Knee. 2014;21(4):843–7. PubMed PMID: 24831525.
56. Argenson JN, Parratte S, Bertani A, Flecher X, Aubaniac JM. Long-term results with a lateral unicondylar replacement. Clin Orthop Relat Res. 2008;466(11):2686–93. PubMed PMID: 18574650. Pubmed Central PMCID: 2565025.
57. Argenson JN, Komistek RD, Aubaniac JM, Dennis DA, Northcut EJ, Anderson DT, et al. In vivo determination of knee kinematics for subjects implanted with a unicompartmental arthroplasty. J

Arthroplast. 2002;17(8):1049–54. PubMed PMID: 12478517.
58. Gunther TV, Murray DW, Miller R, Wallace DA, Carr AJ, O'Connor JJ, et al. Lateral unicompartmental arthroplasty with the Oxford meniscal knee. Knee. 1996;3:33–9.
59. Weston-Simons JS, Pandit H, Kendrick BJ, Jenkins C, Barker K, Dodd CA, et al. The mid-term outcomes of the Oxford domed lateral unicompartmental knee replacement. Bone Joint J. 2014;96-B(1):59–64. PubMed PMID: 24395312.
60. Altuntas AO, Alsop H, Cobb JP. Early results of a domed tibia, mobile bearing lateral unicompartmental knee arthroplasty from an independent centre. Knee. 2013;20(6):466–70. PubMed PMID: 23274066.
61. Walker T, Gotterbarm T, Bruckner T, Merle C, Streit MR. Total versus unicompartmental knee replacement for isolated lateral osteoarthritis: a matched-pairs study. Int Orthop. 2014;38(11):2259–64. PubMed PMID: 25112651.
62. Newman SDS, Altuntas A, Alsop H, Cobb JP. Up to 10 year follow-up of the Oxford domed lateral partial knee replacement from an independent centre. Knee 2017 Sep 30. PubMed PMID: 28974402.
63. Marson B, Prasad N, Jenkins R, Lewis M. Lateral unicompartmental knee replacements: early results from a district general hospital. Eur J Orthop Surg Traumatol. 2014;24(6):987–91. PubMed PMID: 23842661.
64. Callaghan JJ. Unicompartmental knee replacement: introduction: where have we been? Where are we now? Where are we going? Clin Orthop Relat Res. 2005;430:272–3. PubMed PMID: 15662335.
65. Walker T, Streit J, Gotterbarm T, Bruckner T, Merle C, Streit MR. Sports, physical activity and patient-reported outcomes after medial unicompartmental knee arthroplasty in young patients. J Arthroplast. 2015;30(11):1911–6. PubMed PMID: 26088397.
66. Fisher N, Agarwal M, Reuben SF, Johnson DS, Turner PG. Sporting and physical activity following Oxford medial unicompartmental knee arthroplasty. Knee. 2006;13(4):296–300. PubMed PMID: 16809040.
67. Hopper GP, Leach WJ. Participation in sporting activities following knee replacement: total versus unicompartmental. Knee Surg Sports Traumatol Arthrosc. 2008;16(10):973–9. PubMed PMID: 18696051.
68. Felts E, Parratte S, Pauly V, Aubaniac JM, Argenson JN. Function and quality of life following medial unicompartmental knee arthroplasty in patients 60 years of age or younger. Orthop Traumatol Surg Res. 2010;96(8):861–7. PubMed PMID: 21087906.
69. Biswas D, Van Thiel GS, Wetters NG, Pack BJ, Berger RA, Della Valle CJ. Medial unicompartmental knee arthroplasty in patients less than 55 years old: minimum of two years of follow-up. J Arthroplast. 2014;29(1):101–5. PubMed PMID: 23731786.
70. Yang KY, Wang MC, Yeo SJ, Lo NN. Minimally invasive unicondylar versus total condylar knee arthroplasty – early results of a matched-pair comparison. Singap Med J. 2003;44(11):559–62. PubMed PMID: 15007494.
71. Iacono F, Raspugli GF, Akkawi I, Bruni D, Filardo G, Budeyri A, et al. Unicompartmental knee arthroplasty in patients over 75 years: a definitive solution? Arch Orthop Trauma Surg. 2016;136(1):117–23. PubMed PMID: 26350386.
72. Tadros BJ, Dabis J, Twyman R. Short-term outcome of unicompartmental knee arthroplasty in the octogenarian population. Knee Surg Sports Traumatol Arthrosc. 2017;25 PubMed PMID: 28744756.
73. Ingale PA, Hadden WA. A review of mobile bearing unicompartmental knee in patients aged 80 years or older and comparison with younger groups. J Arthroplast. 2013;28(2):262–7. e2. PubMed PMID: 22819378.
74. Siman H, Kamath AF, Carrillo N, Harmsen WS, Pagnano MW, Sierra RJ. Unicompartmental knee arthroplasty vs total knee arthroplasty for medial compartment arthritis in patients older than 75 years: comparable reoperation, revision, and complication rates. J Arthroplast. 2017;32(6):1792–7. PubMed PMID: 28215968.
75. Lim JW, Cousins GR, Clift BA, Ridley D, Johnston LR. Oxford unicompartmental knee arthroplasty versus age and gender matched total knee arthroplasty – functional outcome and survivorship analysis. J Arthroplast. 2014;29(9):1779–83. PubMed PMID: 24805827.
76. Fabre-Aubrespy M, Ollivier M, Pesenti S, Parratte S, Argenson JN. Unicompartmental knee arthroplasty in patients older than 75 results in better clinical outcomes and similar survivorship compared to total knee arthroplasty. A matched controlled study. J Arthroplast. 2016;31(12):2668–71. PubMed PMID: 27480824.

9 Patellofemoral Arthroplasty: Indications, Surgical Techniques, and Outcome

David Barrett and Arun Mullaji

Introduction

Patellofemoral arthroplasty offers the option of a more minimal approach to isolated patellofemoral osteoarthritis, in keeping with the approach to partial knee surgery of the medial and lateral aspects of the tibiofemoral joint. Similar to initial early efforts in unicondylar surgery, patellofemoral arthroplasty (PFA) suffered some early setbacks, but recent advancements in understanding of the patellofemoral joint have led to changes in both design and techniques in patellofemoral joint resurfacing. The development of the patellofemoral joint may be described in three distinct generations. Initially, the first-generation designs were highly variable and failed very early for a number of technical reasons. Second-generation systems attempted to address early high failure rates by using designs of the anterior one-third knee joint replacement as a patellofemoral arthroplasty. These second-generation systems reduced implant-related failures yet were often revised early for soft tissue-related issues such as clicking and effusion. Subsequently, with more detailed knowledge of the patellofemoral kinematic profile, a third generation of patellofemoral designs have been developed and show early improvement on historical high failure rates of the earlier two generations of patellofemoral arthroplasty. Despite these changes, many surgeons still regard isolated patellofemoral arthroplasty with some caution, and the number of patellofemoral resurfacing procedures carried out remains far less than the indications for patellofemoral resurfacing.

The number of patellofemoral joint arthroplasties performed remains low when compared to the overall incidence of total knee arthroplasty [1]. The number of patients suitable for this procedure is relatively high [2]; however, patellofemoral arthroplasty is performed at a much lower rate than would be predicted by the number of isolated patellofemoral cases which are documented. National Joint Registry figures indicate patellofemoral arthroplasty has a significantly higher revision rate than both unicondylar resurfacing and total knee joint replacement [3] when performed by surgeons who are inexperienced or unused to the technical procedure.

Historically, a patellofemoral joint resurfacing is revised early for either technical issues such as clicking, dislocation of subluxation, or joint effusion and soft tissue pain, or for progression to tibiofemoral joint arthritis [4–6]. Evidence exists that the use of third-generation prostheses with more accurate patient indications and patient selection may allow for patellofemoral arthroplasty to exhibit revision rates similar to that of total knee arthroplasty yet offer significant

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improvement in functionality and knee joint kinematics for patients who are often quite young at the time of presentation.

Commonly, patients present early due to patellofemoral maltracking which produces an accelerated wear profile for this particular part of the knee joint. Patients commonly present between the ages of 40 and 55 and yet have pristine tibiofemoral joints. The attraction of patellofemoral arthroplasty is resurfacing of the affected part of the joint alone while leaving the cruciate ligaments intact. The knee effectively is kinematically normal, and the patellofemoral joint arthroplasty may act as an intermediate solution for the patient aged 45 seeing them through 12 or 15 years to a more senior age, approaching 60 by which time if they have development of tibiofemoral joint arthritis, a total knee joint replacement is more appropriate and acceptable.

Indications

The role of patient selection and appropriate indications for patellofemoral arthroplasty are key in understanding firstly the disease but also avoiding cases which will progress early to tibiofemoral arthritis and significantly lead to early revision to total joint arthroplasty.

Patients suitable for patellofemoral arthroplasty should have of course gone through all the conservative treatments including physical therapy, bracing and taping, medication, injection, and activity modification along with weight loss. Patients should be screened for the risk factors in developing main joint osteoarthritis which include obesity and abnormal tibiofemoral alignment [7]. The characterization of patellofemoral pain is difficult and complex, but a detailed history from the patient will reveal pain exacerbated by episodes of high flexion or patellofemoral loading such as kneeling, squatting, and ascending and descending on stairs. Surgeons should be sure to exclude neuropathic pain or complex regional pain syndrome as well as secondary pain or referred pain. Tendonitis and inflammatory arthropathy may present as anterior pain or anterior knee pain discomfort.

Aspects in the history of a patellofemoral arthritis patient may include a lifetime of anterior knee pain or discomfort and especially discomfort in the teenage years and early 20s. Many patients will have disordered or abnormal patellofemoral anatomy and may present with a history of recurring lateral patella dislocation or subluxation. Many will have had multiple previous surgeries that may influence the choice of patellofemoral arthroplasty due to previous soft tissue manipulations or scarring. Occasionally there will be a history of significant patellar trauma which will produce post-traumatic arthritis limited to the patellofemoral joint. In the absence of a definable radiological or imaging study confirming patellar arthritis, symptoms suggesting degenerative disease should be treated with caution and the cause of the symptoms re-examined [8]. Patellofemoral arthroplasty is not a treatment for patella or anterior knee joint pain but a salvage procedure for bone-on-bone isolated patellofemoral arthritis.

In terms of examination, the surgeon should particularly note the range of movement of the joint and presence of patellofemoral crepitus, the position the patella related to patella baja or alta, and the presence of lateral maltracking or lateral subluxation, as well as apprehension from the patient on eliciting patella displacement. The patient's definition of pain and localization of discomfort is also important as well as examination of the hip and ankle to exclude the possibility of referred pain but also to analyze the possibility of malalignment and malrotation which will give rise to secondary patella maltracking and accelerated wear. Noting patella tilt and recording the areas of scarring around the knee are relevant in these cases [9].

The imaging studies required are often simple, and traditional radiographs of four views are significant in the first choice of assessing patellofemoral arthritis. The important views are the standing long leg tibiofemoral view AP, lateral view, and tunnel view 45°. Most important is the 30° patella skyline view, and the surgeon should ensure that the radiographers are supplying a skyline view at 30° rather than the more commonly adopted and easier to achieve, 45°. The

x-rays will allow statements to be made regarding the trochlea morphology and the definition about whether the trochlea is within normal limits or dysplasia [10]. Additionally, the surgeon should measure the patella height, and this is a reflection of either the length of the patella tendon or the shortened trochlea [11]. This assessment of patella height is particularly important to ensure that post-surgery the patella is engaging with the trochlea, reducing the risk of clicking or subluxation. This series of x-rays will allow the exclusion of the possibility of tibiofemoral arthritis, and assessment should be made of tibiofemoral alignment. Malalignment in the tibiofemoral joint along with obesity is one of the factors in progression of arthritis from the patellofemoral join to the main joint effecting early revision [10]. Overall, the x-ray series should confirm bone-on-bone contact in the patellofemoral joint, and patellofemoral arthroplasty is not indicated for early wear or patellofemoral pain but end-stage bone-on-bone contact and osteoarthritis of this part of the knee articulation.

While x-rays form the main assessment of the imaging studies, an MR scan will give an indication to the degree of cartilaginous loss and will allow measurements of the tibial tubercle/trochlea groove (TT/TG distance). This is regarded as abnormal above 15 mm, and the Caton-Deschamps ratio is an indication of patella alta or baja. Some surgeons find a bone scan helpful to show bone inflammation and overload, but arthroscopy probably does not have a role of assessment to the patellofemoral joint in that bone-on-bone contact should be clearly visible on a radiograph if patellofemoral joint arthroplasty is to be entertained.

Patients (Figs. 9.1 and 9.2) having the correct indications for isolated patellofemoral knee resurfacing may fall broadly into one of three groups.

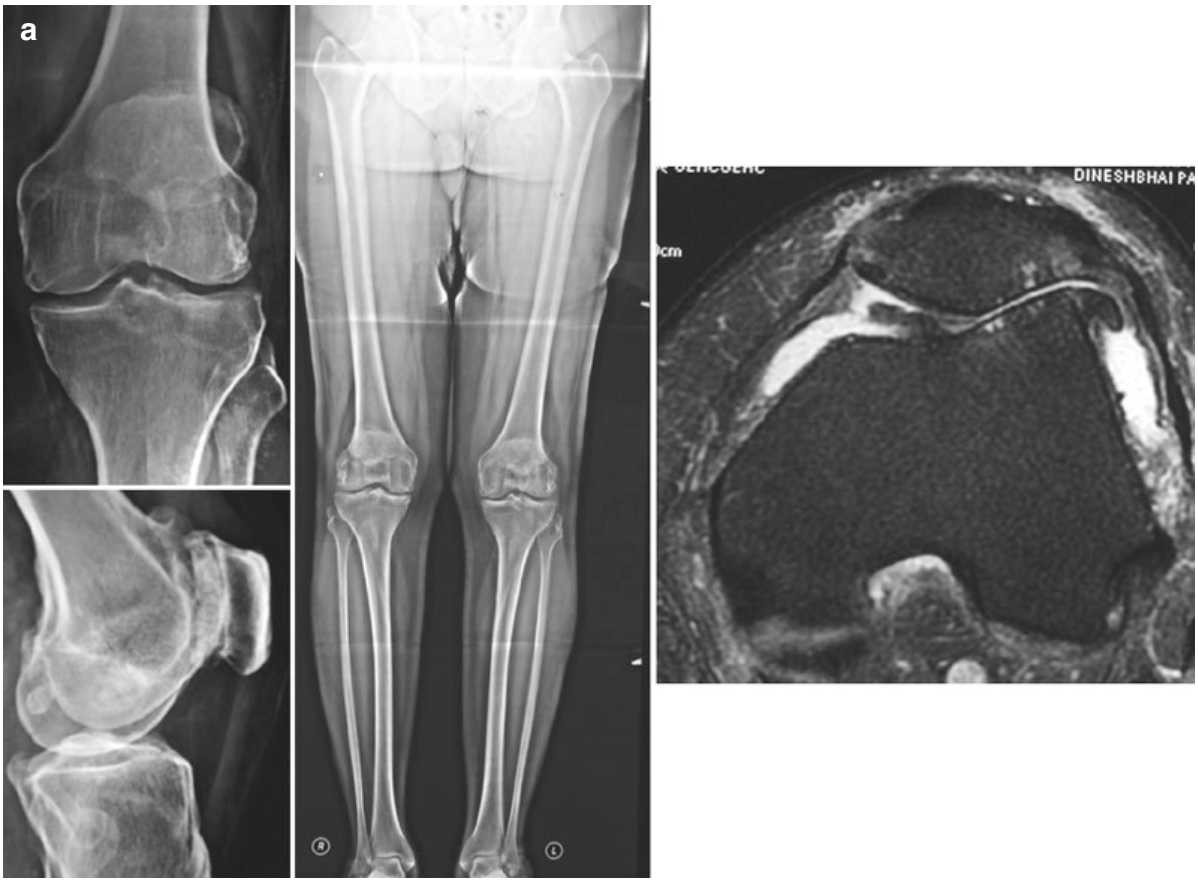

Fig. 9.1 (**a**) Radiographs and MR scan image of a 61-year-old male with PFJ OA, normal alignment, and unaffected tibiofemoral articulation, before surgery. (**b**) Postoperative radiographs after PFJ arthroplasty

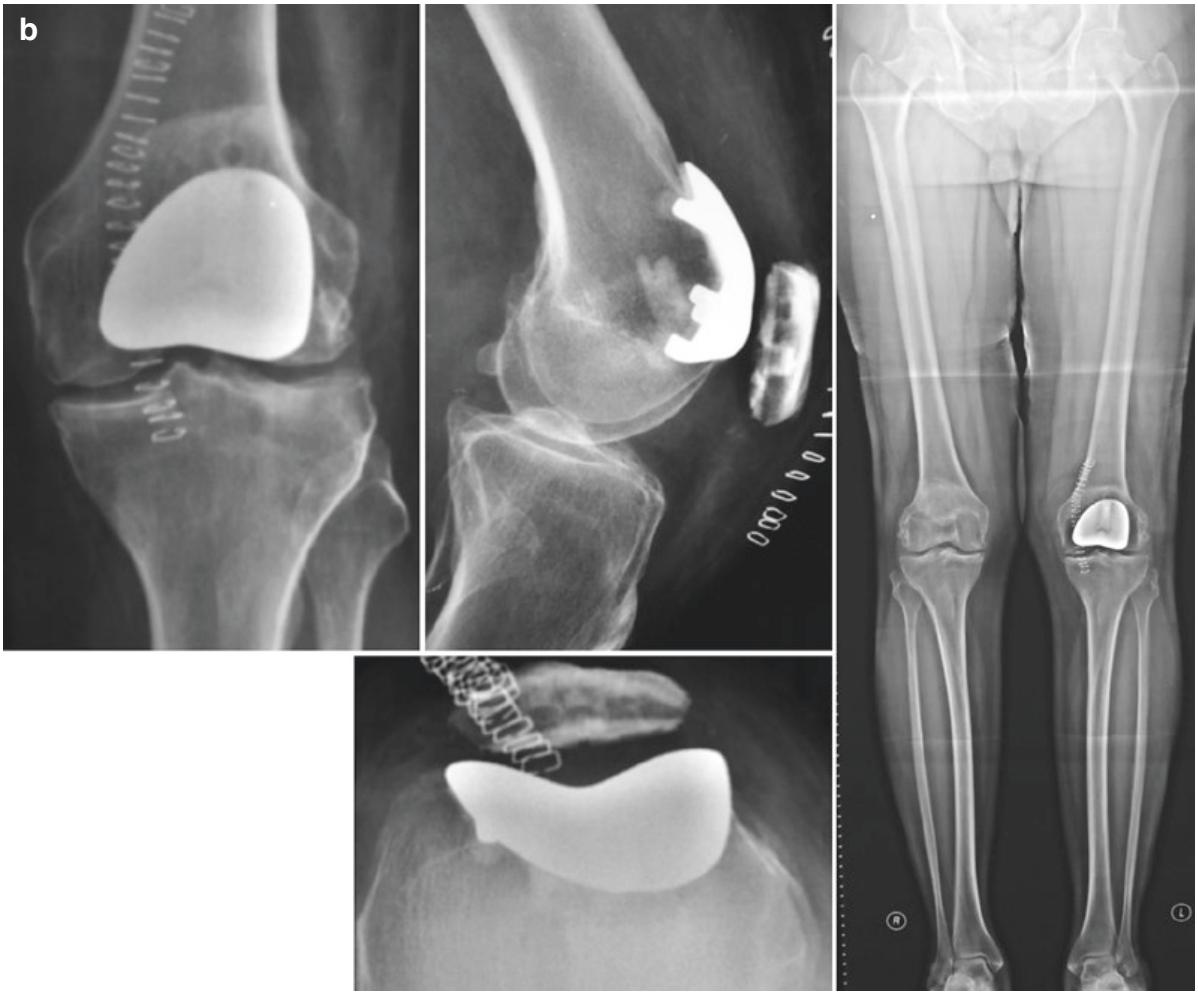

Fig. 9.1 (continued)

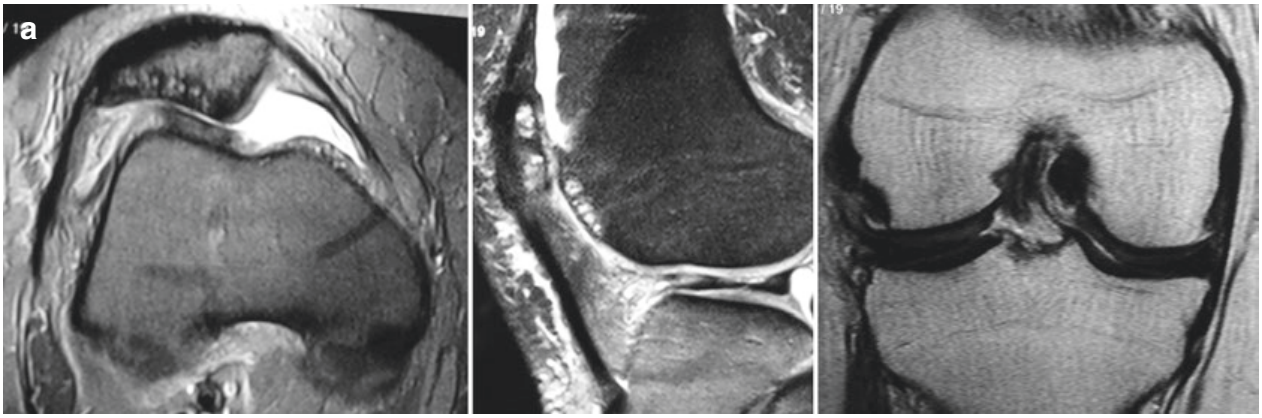

Fig. 9.2 (**a**) MR scan images of a 46-year-old female with PFJ OA, patellar subluxation, but showing healthy cartilage in the tibiofemoral joint. (**b**) Postoperative radiographs after PFJ arthroplasty. (**c**) Clinical photographs depicting near full range of motion 1 year after PFJ arthroplasty

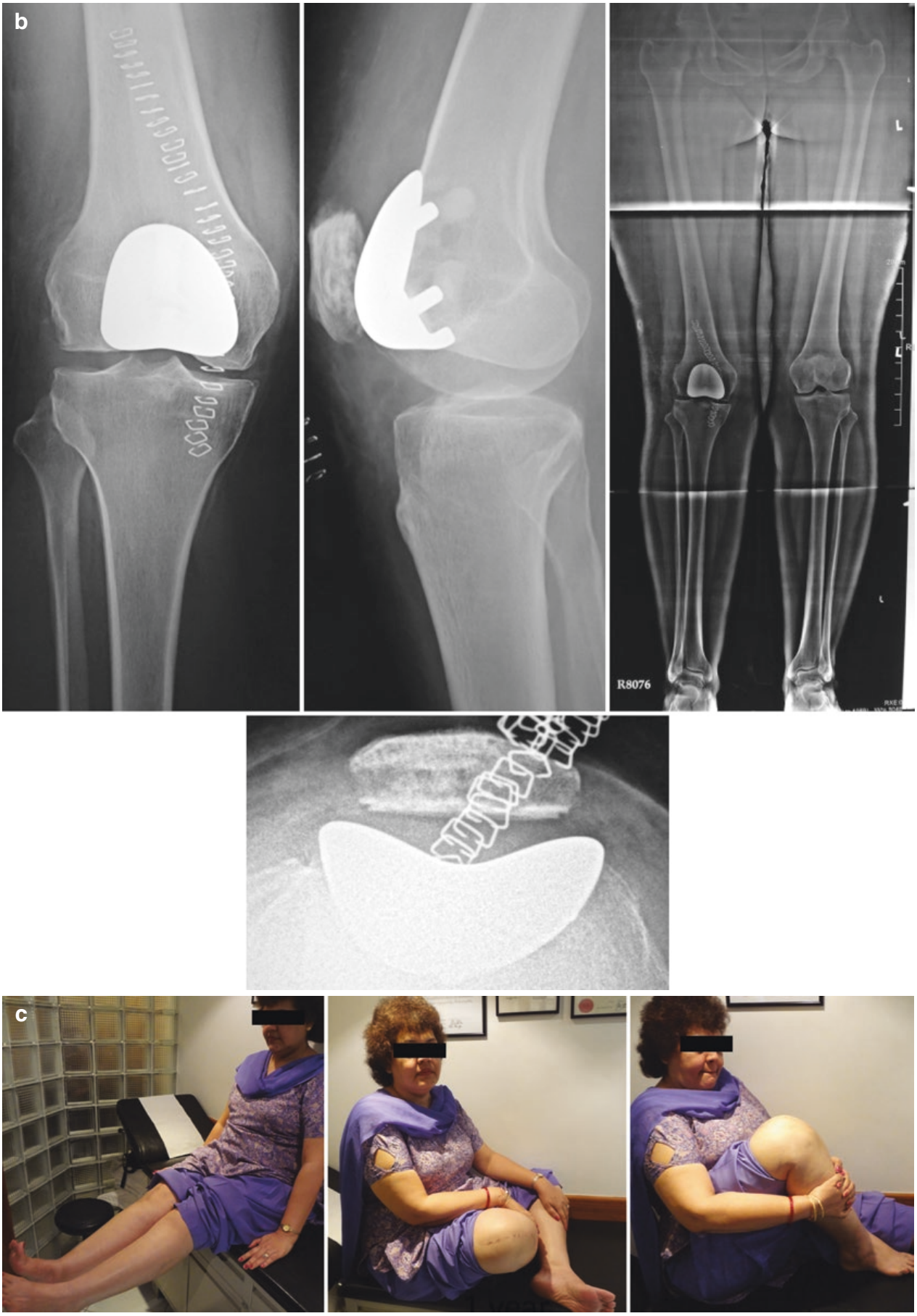

Fig. 9.2 (continued)

Dysplastic Patellofemoral Joint

These patients present as a result of historical patellofemoral malalignment and malrotation and will have exhibited increased or excessive loading in the patellofemoral joint throughout their lifetime. As a result, the patellofemoral articulation prematurely wears leading to their presentation at the age of 45–55 years. More commonly in females, they have disordered patellofemoral mechanics and abnormal or dysplastic trochlea anatomy. These patients are very suitable for isolated patellofemoral knee resurfacing given that they have a disorder of anatomy and excessive loading leading to premature but isolated wear of the patellofemoral joint with good preservation of the tibial femoral joint and, in absence of the risk factors of tibiofemoral malalignment or obesity, have a low chance to progress to generalized tibiofemoral wear. Those with highly disorganized or maltracking patellofemoral joints may require secondary ligament surgery in addition to address patellofemoral malrotation at the time of patellofemoral joint arthroplasty.

Posttraumatic Patellofemoral Patients

These patients have suffered direct trauma to the patellofemoral joint and therefore have isolated posttraumatic osteoarthritis of that joint with a relatively good sparing of the tibiofemoral joint. They may well have normal alignment or anatomy. These patients also represent good cases for patellofemoral joint arthroplasty as they have few risk factors for progression in the tibial femoral joint. Caution: the surgeon should bear in mind that those patients who have suffered patellofemoral trauma and have had previous surgical procedures to reconstitute a fractured patella or have suffered a degree of tendon scarring as a result of injury may have a low-lying patella or patella baja, which is itself a contraindication for patellofemoral arthroplasty.

Normal Morphology with Patellofemoral Arthritis

These patients have a normal alignment and morphology of the patellofemoral joint but appear to have premature patellofemoral arthritis in isolation. These patients because of their normal patellofemoral alignment may go on to progress to generalized tibiofemoral arthritis, and indeed the presentation of patellofemoral arthritis may be the first sign of a more generalized wear pattern that may develop later. These patients should be screened carefully, and those with risk factors of obesity or tibiofemoral malalignment are at a high risk for secondary developmental tibiofemoral arthritis. While these patients may be appealing to the surgeon because of the ease of surgery in the absence of a requirement to recorrect malpositional malalignment, they do represent the highest risk for tibiofemoral progression leading to an earlier revision.

Surgical Technique

The surgical technique of patellofemoral arthroplasty has shown a number of incremental changes over the years, as our understanding of the patellofemoral kinematics and patella dynamic movement has increased.

The surgical technique divides itself into two opposing approaches, whether to use the standard technique for total knee arthroplasty in placing and positioning the trochlea component as an anterior one-third of a knee joint replacement orientated along the standard anatomical landmarks for total knee arthroplasty or alternatively use the new knowledge of patellofemoral kinematics to orientate a much smaller and narrower inlay type of prosthesis within the trochlea anatomy, orientated to the patients bony contours to replicate the trochlea track in existence. This approach follows the patient's own anatomy without reference to the standard markers for total joint arthroplasty.

Prior to undergoing a surgical solution for patellofemoral arthroplasty, the patient should

have excluded all conservative means of management of patellofemoral pain and should also be counselled about their expectations following patellofemoral arthroplasty. The patient should appreciate the historical need for revision of the implant and the fact that the treatment of patellofemoral arthroplasty is a pain-relieving operation to avoid bone-on-bone contact in the patellofemoral joint, rather than a solution for improving athletic prowess or allowing running or other sporting activities. The patient should also be warned about the prospect of revision, the conversion to a total joint arthroplasty with the passage of time. The possibility of ligament realignment procedures carried out at the same time as patellofemoral arthroplasty is dependent on the preoperative measurement of the patella height, or the tibial tubercle offset which may require distalization or medialization of the tibial tubercle or medial patellofemoral ligament reconstruction. Surgeons should be able to make these decisions about the possibility of ligament surgery prior to operation based on the assessment of the radiographs and patella height. Approximately between 10% and 15% of patients undergoing patellofemoral arthroplasty for maltracking will require some form of additional ligament procedure.

The skin incision is normally a midline longitudinal one, but many patients will have had a previous ligament stabilization or other procedures related to the patellofemoral maltracking, and surgeons should select an appropriate incision based on the previous incisions around the knee. Characteristically a medial patellofemoral approach is used although there are some advocates of a lateral patellofemoral approach if there is very significant lateral malangulation or maltracking of the patellofemoral joint. Whether a medial or lateral parapatellar approach is performed, a midline incision is recommended because of the possibility of further surgery or conversion to a total joint arthroplasty.

The surgical approach by the majority is the medial approach, and the key element is to preserve the VMO which is key and a significant stabilizer of the patellofemoral arthroplasty. Special note should be made of the medial patellofemoral ligament through this approach which may require repair on closure. Usually there is lateral maltracking which is given rise to accelerated wear, and there are some proponents of lateral approach. This has the advantage of maintaining the medial patellofemoral ligament and performing a lateral release as part of the lateral patellofemoral approach [12]. It also allows direct access to the most worn part of the patellofemoral joint, but subluxation of the patella is more difficult from this angle and may be more difficult for surgeons unused to this approach. Currently the most popular approach is the medial parapatellar one.

Patellar preparation is carried out at the next stage, and early patella preparation allows for subluxation of the patella with ease into the lateral gutter and decompresses the articulation, making the trochlea preparation easier. In addition to inspecting the tibiofemoral joint for signs of advancing wear, the surgeon should note the extent and situation of wear in the patellofemoral joint which will give knowledge as to the necessity of any realignment or repositioning of surgery. The patella may be "circumcised" by the use of an electric cautery, removing the synovium and fat tissue around the patella down to the level of the osseotendinous junction both superiorly and inferiorly. This action allows easier mobilization of the patella, and some surgeons indicate this may produce "denervation" of the patella although there is little scientific evidence for this fact. The patella button selected for the patella resurfacing may be of the simple dome type or may be a more sophisticated offset dome or anatomic design, which allows more physiological resurfacing. Placement of the patella resurfacing should be dictated by the position of the apex of the patient's natural patella, to maintain a natural patella profile and aid stable tracking. Therefore, the apex of the patients natural profile is marked, and subsequently the patella cut is performed with an oscillating saw to remove the bone thickness that will be occupied by the subsequent polyethylene resurfacing with the apex of the polyethylene dome positioned in the same place

as the patient's natural apex. This apex led positioning may lead to the polyethylene dome being offset medially exposing a lateral osteophyte or surface of the patella bone. An osteotomy with a saw would allow this osteophyte to be removed which decompresses the lateral retinacular ligament and at the same time avoids exposed bone surface. The decrease below 12 mm thickness is undesirable as there is an increased instance of patellofemoral fracture should the host bone be cut to less than 12 mm. If an inset patella is to be used, there is less problem regarding the remaining osteoarticular surface, but the inset patella should be positioned directly over the apex of the patella itself.

Preparation of the trochlea is the most controversial part of arthroplasty of the patellofemoral joint. Surgeons still remain in two groups regarding the optimal implantation. Common to both techniques will be the removal of synovium, fat, and osteophytes around the trochlea, and there may be very significant and prominent osteophytes around the lateral side of the trochlea. These should be removed primarily to allow visualization of the shape and morphology of the trochlea and avoid any soft tissue tension or erroneous impression of lateral maltracking caused by osteophytes. For surgeons who belong to the total knee school of patellofemoral replacement, key to alignment will be the use of Whiteside's line, the epicondylar line, or posterior condylar line to orientate a trochlea cutting jig in the correct position on the trochlea. Subsequently an anterior cut is made with a saw blade often in 3° of external rotation to exit at the anterior cortex above the articular cartilage of the most superior portion of the trochlea. The subsequent distal part of the implant may often be finished with a burr down to the intercondylar notch of the femur. A surgical note is that the intercondylar notch is filled with osteophytes, and these should be cleared prior to the preparation of the trochlea as this can lead the surgeon astray in terms of trochlea positioning at a later stage. The size of the trochlea implant is dependent on the cover of the cut surface of the trochlea, and the length of the implant is based on the nose of the implant fitting over the top of the intercondylar notch with the most superior part of the implant extending to the line of the articular cartilage above the trochlea. It is essential not to put in a trochlea component that is too short as this will produce clicking or catching of the articular surface of the patella as flexion is instigated.

The school of surgeons more recently changing their attitude to patellofemoral arthroplasty and adopting an individual approach to patellofemoral replacement will use the natural patient anatomy to produce a more individualized alignment of the trochlea, situating the implant within the natural anatomy of the patients' own trochlea to avoid soft tissue impingement. Therefore, the sizing of the trochlea is performed by measuring the differing trial inserts from the apex of the trochlea to the end of the articular surface on the anterior cortex. The correct size trial is then outlined on the articular cartilage of the trochlea, and the rotation and valgus-varus tilt of the implant are dictated by the patient's own anatomy in terms of the patient's trochlea track as well as the internal-external rotation of the existing trochlea shoulders. The preparation is often free hand or by robotic navigation to allow accurate burring of the tissue with a high-speed burr, and this accurate preparation allows the setting of the trochlea implant within the osseocartilaginous contour of the patients own trochlea. In this way, excessive soft tissue pressure is avoided, and there is a lesser chance of soft tissue pain and clicking, as the surfaces of the trochlea and surrounding knee are congruent and confluent. Trial implants should be inserted on the trochlea, and patellofemoral articulation and the tracking of the patellofemoral joint should be assessed during the surgery. The effect of the quadriceps and the medial retinacula can be reproduced by a clip on the quads tendon pulled proximately by the surgeon to reproduce quads pressure and a temporary suture repairing the VMO muscle to the quads tendon to replicate its effect on tracking. Patella tracking should be exemplary at this point, and indication of patella tilt or subluxation should be addressed by the surgeon before closure, and this may require reconstruction of the MPFL, lateral retinacular release, or distalization or medialization of the tibial tubercle depending

on the various bony and tendon measurements made at the preoperative assessment. Care should be taken to ensure that the nose of the trochlea implant is buried securely in the intercondylar notch to avoid any clicking or locking of the patellofemoral prosthesis as the knee moves from flexion to extension, and it should be ensured that the trochlea is long enough to fully engage the patella even in full extension or hyperextension which is common in these patients.

The position of the distal nose of the trochlea component should be buried in the intercondylar notch not only to avoid patella catching but also to avoid anterior cruciate ligament impingement. The intercondylar notch is often deformed by osteophytes, and therefore particular attention should be paid to removing the osteophytes before assessing the original anatomy of the intercondylar notch and ensuring that the distal nose is implanted well within the intercondylar notch. This wish to achieve the intercondylar notch position is common in both the onlay and inlay techniques and represents the first point of positioning of the trochlea prosthesis.

The second point of positioning the trochlea prosthesis is also common to both onlay and inlay techniques, being the most proximal portion and border of the articular cartilage at the beginning of the trochlea, the entry point of the patella. It is essential that the implant reaches the full extent of the articular portion of the trochlea to ensure it engages the patella at the commencement of flexion. Therefore, these are the two primary points to be aware of when positioning the trochlea component and are common to both onlay and inlay techniques. The valgus and varus orientation of the component is also common to both techniques and should follow the direction of the trochlea notch on the native femur. A point of contention is the external/internal rotation of the trochlea prosthesis, and it is here that the two groups of the opinion differ. Rotational malalignment of the trochlea prosthesis may be suggested using standard total knee replacement techniques derived from total knee replacement surgery, involving regional anatomical landmarks.

Total knee arthroplasty implant techniques require balance, flexion, and extension gaps, and if the tibial cut is perpendicular to the long axis over the tibia, to compensate for the natural tibial plateau varum, the femoral component is externally rotated when the knee is flexed. Characteristically this is about 3° external rotation and is characterized by influence of the "grand piano" sign with rotation [13]. The appearance of the "grand piano" sign of the cut surface of the trochlea is positively correlated with approximately 3° of external rotation [14]. Where the rotation is less and the anterior cut of a total knee lacks similar rotation, a "butterfly" is produced showing 0° of external rotation in relation to the epicondylar axis [14]. Therefore, surgeons using the posterior condyle or the epicondylar lines with an onlay technique will commit themselves to approximately 3° of external rotation as a baseline for an existing total knee replacement philosophy, and the orientation of the anterior cut will "lock in" to the rotation of the patellofemoral joint. However, the patellofemoral resurfacing is not one-third of a total knee arthroplasty, much as is the philosophy of unicompartmental resurfacing not being equivalent to the philosophy of knee replacement. Therefore, an alternative philosophy has been developed to orientate the rotational access of the trochlea so that it matches the lateral contour of the patients' existing trochlea. The trochlea may be more significantly externally rotated, to match the patients existing anatomy. This positions the trochlea to be matched to the patella track, leading to theoretically decreased chance of soft tissue complications and soft tissue pain post-surgery. Surgeons who adopt this newer philosophy tend to use an inlay technique and operate on the knee with robotic assistance or free hand using a high-speed burr allowing contouring of the patients' trochlea.

Controversy continues between the two groups and the two philosophies of trochlea component positioning, but basically there are several caveats.

Internal rotation should be avoided as this would produce patella maltracking and abnormal soft tissue tension. The native trochlea is the commencement for trochlea implant orientation, and the artificial trochlea should follow the

patients' native trochlea and alignment. Excess external rotation should be avoided as this may lose the control of the patella tracking with the use of the older philosophy of total knee alignment; there is an increased incidence of lateral release to allow the tighter lateral soft tissues to accommodate the new position of the trochlea. With the inlay matching the native trochlea, there is a lesser incidence of lateral release. However, in terms of trochlea positioning, there are a few guides that should be followed.

1. The distal tip of the trochlea implant must not be proud and should be situated within the intercondylar notch to avoid impingement.
2. The triangular area of the component should be congruent or slightly below the adjacent articular cartilage.
3. The proximal implant edge should not notch the anterior distal femur.
4. The lateral and medial implant margin should be rotated as to provide a congruent and confluence surface with the existing femoral articular surface in an inlay trochlea choice.

The possibility of tuberosity surgery is present in approximately 10% of patellofemoral resurfacing. The tuberosity can be moved in a number of different directions, but a contraindication for patellofemoral arthroplasty is patella baja, where the patella tendon is scarred or fibrosed from previous trauma or surgery, and the patella is drawn downward into the intercondylar notch with a Caton-Deschamps ratio of less than 0.8. This is a contraindication to patellofemoral surgery, and patellar tendon lengthening should be considered as a separate procedure before any necessary patellofemoral arthroplasty. The tuberosity is most commonly distalized or medialized to address patellofemoral maltracking although there is a danger of increasing the patellofemoral articulation forces if there is over-medialization [15]. Thus, medialization and visualization should aim to bring the patella down, allowing it to engage with the proximal trochlea at the commencement of extension, and medialization should perform the same prospect. Anteriorization to reduce the patellofemoral contact is not relevant to patellofemoral arthroplasty and may not produce a reduction of compression forces that is significant [16].

Once any required ligament surgery is performed and the implant trials are in place, the articulation and tracking of the patella components should be assessed. This should be smooth and progressive to perform maximum extension; there is often recurvatum in these cases of isolated patellofemoral arthritis. The movement of the patella should be smooth in the entry into the trochlea notch, and subsequent progression should be smooth without clicks or jumps as the lateral and medial retinacula are actively recruited and subsequently become lax. There should be no abrupt movements or clicks as the patella runs through the trochlea and passes through the intercondylar notch onto the medial and lateral femoral condyles.

If it is apparent that there is catching or lateral tilt movement and the patella tilts laterally or glides laterally, a lateral lengthening procedure such as a Z cut may be necessary. Here a lateral release differs from the lateral release described as a total knee arthroplasty by the surgeon. There is every reason that a lateral release might be required in patellofemoral surgery, whereas a lateral release of a total knee arthroplasty is regarded as a cause for concern, indicating failure to externally rotate the femoral component. In patellofemoral surgery, it may reflect the tightness of tissues and the inability to cope with a realignment procedure. Therefore, a lateral lengthening is preferably to a lateral release allowing the lateral retinacular fibers to continue their function controlling the movement of the patella.

The closure can be routine dependent on the tension required in the medial retinacula, and there is an opportunity to double breast the repair to stabilize the patellofemoral joint if required.

The postoperative recovery and rehabilitation is key to a patellofemoral arthroplasty. Patients are encouraged to weight-bear on the day of operation and will take a few steps from the bed to encourage early mobilization. However, many patients have suffered muscle wastage and have

issues with muscle strength and endurance. Physical therapy should focus on increasing the strength and improvement of these muscle fibers particularly the VMO and hamstrings. A pain-relieving "cocktail" injected in the periarticular tissues at the time of surgery is important in reducing the pain appreciation and allowing early mobilization with building of confidence for these patients.

Outcome

Clinical outcome and implant survival in isolated patellofemoral arthroplasty depend on the implant design, surgical technique, and patient selection. Early failure of patellofemoral arthroplasty is commonly related to patellar maltracking and instability. The incidence of patellar maltracking after isolated patellofemoral arthroplasty has been reported to be much higher for the inlay design (17–35%) compared to the onlay design (1%) [17–20]. Component rotation of the inlay-type trochlea components is based on the native trochlea inclination which tends to place the component in internal rotation with respect to the anteroposterior axis of the femur leading to a higher incidence of patellar instability [21]. However, onlay-type trochlea components are implanted by resecting the anterior trochlea surface flush to the anterior femoral cortex which places the trochlea component perpendicular to the anteroposterior axis of the femur leading to improved patellar tracking [21]. Late failures of patellofemoral arthroplasty have been attributed to progression of tibiofemoral arthritis. Studies have reported an incidence of 12–25% revision rates in patients due to progression of tibiofemoral arthritis at a mean follow-up of 5–15 years after patellofemoral arthroplasty [22–24]. Furthermore, the risk of revision was much more in patients where the primary indication was primary osteoarthritis when compared to patients where the primary indication was trochlea dysplasia [23–25]. Feucht et al. [26] in a matched-pair analysis of inlay versus onlay type of PFA prosthesis reported no significant difference in clinical outcome with either a second-generation inlay or onlay trochlea component but less progression of tibiofemoral OA with an inlay trochlea component.

The survival rates for PFA have shown disparity depending on whether an inlay- or onlay-type component is used. The older inlay-type implant design had a greater risk for revision due to difference between surface anatomy of the native trochlea and the trochlea implant and due to greater risk for malrotation depending on native trochlea inclination. The 5-year cumulative revision rate, as per data published by the Australian National Joint Registry, was greater than 20% for inlay prostheses and less than 10% for onlay designs [18]. Hoogervorst et al. [27] in a retrospective analysis of 33 Richards' type II PFA implants reported a survival of 73% at 10 years with 21% of these prostheses being converted to total knee arthroplasty (TKA) after a mean time of 5.5 years. Isolated patellofemoral arthritis can also be treated with TKA. Dy et al. [28] in a meta-analysis reported that isolated patellofemoral arthritis treated with PFA are more likely to experience complications and require reoperation or revision when compared to TKA. However, they further reported no significant difference in clinical outcome, reoperation, revision, or complications between second-generation PFA implants and TKA implying the role of implant design on clinical outcome and survival in patients undergoing PFA [28].

Patients with prior patellofemoral surgery, low-grade patellofemoral arthritis, and associated tibiofemoral arthritis have been reported to have poor outcome after isolated PFA [29, 30]. Patellofemoral anomalies such as patella alta and trochlea dysplasia are frequently seen in patients with isolated patellofemoral arthritis, and achieving optimum component rotation is essential for the success of PFA [31]. Clinical outcomes and long-term survival rates have improved significantly with the use of modern generation onlay-type PFA prostheses, and PFA has emerged as a cost-effective joint-preserving procedure in younger patients [32]. However, the significance of proper patient and implant selection and meticulous surgical technique in a patient undergoing PFA cannot be overemphasized.

Complications

Patella Instability

The majority of causes for early revision is persisting or recurring patella instability with its symptoms of giving way and clicking. Recurrent effusions may also result following persisting instability. In the postoperative phase, it may be clear that an overzealous lateral release may eventually cause lateral instability as the lateral patellofemoral ligament is employed to retain extensive lateral instability [12, 33]. Occasionally the patients who have suffered osteoarthritis as a result of dysplasia find that their instability returns when they lose the friction and discomfort of osteoarthritis. Subsequent patellofemoral resurfacing may expose the instability caused by previous attempted lateral releases or medial patellofemoral ligament reconstruction. The third-generation patellofemoral resurfacing will not significantly provide patella instability as the ethos of patellofemoral resurfacing has moved away from the wish to "capture" the patella in ever-deepening trochlea groove designs of the late 1980s and 1990s. Therefore, patella stability is dependent on the alignment and soft tissue tension around the patellofemoral articulation [34]. Avoiding recurrent laxity is key and dependent upon the surgeon having a good knowledge of the soft tissue procedures around the patellofemoral joint. Ligament reconstruction procedures should be evaluated as part of the preoperative assessment of the knee. Component loosening is a very rare complication of patellofemoral arthroplasty and usually presents as a subsequent effect of varus malalignment and maltracking giving rise to catastrophic retropatellar and polyethylene wear.

Main joint degeneration or the onset of arthritis is a post-surgery complication which may occur in the early years after the patellofemoral joint resurfacing. The key to avoidance of this is attention to the tibiofemoral alignment, coupled with obesity, which is the significant risk factor.

Conclusion

In conclusion, patellofemoral arthroplasty offers an exciting possibility in orthopedics, related to the recent increase and knowledge in terms of patellar kinematics and implant manufacture reaching a third generation.

The kinematics and dynamic form of the patellofemoral joint is more understood, and there is a growing evidence that positioning of the trochlea implant within the natural patient anatomy rather than using standard knee joint algorithms may give better patient-related results in terms of soft tissue pain and patellofemoral tracking. While historic revision rates remain high, there is evidence that these newer techniques are allowing patellofemoral arthroplasty to approach the revision rates of other compartmental resurfacings in the knee such as the medial and lateral implants. Understanding the complexities of trochlea placement and the controversies affecting this complex joint is key for surgeons undertaking this surgery. However, outcomes can be extremely pleasing, and the longevity and function of a well-performed and well-rehabilitated patellofemoral arthroplasty are rewarding.

References

1. Lidgren L, Robertsson O. Annual Report 2006-The Swedish knee arthroplasty Register.www.knee.nko.se/English/online/uploadedFiles/107_SKAR2006_Englv2.pdf. Accessed 20 May 2007.
2. McAlindon TE, Snow S, Cooper C, Dieppe PA. Radiographic patterns of osteoarthritis of the knee joint in the community: the importance of the patellofemoral joint. Ann Rheum Dis. 1992;51(7):844–9.
3. National Joint Registry 14th Report 2017. www.njr-reports.org.uk.
4. Ackroyd CE, Newman JH, Evans R, Eldridge JD, Joslin CC. The Avon patellofemoral arthroplasty: five-year survivorship and functional results. J Bone Joint Surg Br. 2007;89(3):310–5.
5. Nicol SG, Loveridge JM, Weale AE, Ackroyd CE, Newman JH. Arthritis progression after patellofemoral joint replacement. Knee. 2006;13(4):290–5.
6. Parvizi J, Stuart MJ, Pagnano MW, Hanssen AD. Total knee arthroplasty in patients with isolated patellofemoral arthritis. Clin Orthop Relat Res. 2001;392:147–52.

7. Lonner J. Patellofemoral arthroplasty. J AAOS. 2007;15(8):495–506.
8. Leadbetter WB, Seyler TM, Ragland PS, Mont MA. Indications, contraindications, and pitfalls of patellofemoral arthroplasty. J Bone Joint Surg Am. 2006;88:122–37.
9. Staubli HU, Durrenmatt U, Porcellini B, Rauschning W. Anatomy and surface geometry of the patellofemoral joint in the axial plane. J Bone Joint Surg Br. 1999;81-B(3):452–8.
10. Tecklenburg K, Dejour D, Hoser C, Fink C. Bony and cartilaginous anatomy of the patellofemoral joint. Knee Surg Sports Traumatol Arthrosc. 2006;14:235–40.
11. Biedert RM, Albrecht S. The patellotrochlear index: a new index for assessing patellar height. Knee Surg Sports Traumatol Arthrosc. 2006;14:707–12.
12. Desio SM, Burks RT, Bachus KN. Soft tissue restraints to lateral patellar translation in the human knee. Am J Sports Med. 1998;26(1):59–65.
13. Cui WQ, Won YY, Baek MH, Kim KK, Cho JH. Variations of the 'grand-piano sign' during total knee replacement. J Bone Joint Surg Br. 2006;88-B(11):1441–7.
14. Schoettle PB, Zanetti M, Seifert B, Pfirrmann WA, Fucentese SF, Romero J. The tibial tuberosity – trochlear groove distance; a comparative study between CT and MRI scanning. Knee. 2006;13:26–31.
15. Paley D. Sagittal plane knee considerations. In: Paley D, editor. Principles of deformity correction. Rev ed. Berlin: Springer; 2005. p. 509–69.
16. Fulkerson JP. Monograph series 29: common patellofemoral problems. Rosemont: American Academy of Orthopaedic Surgeons; 2005.
17. Lonner JH. Patellofemoral arthroplasty: pros, cons, and design considerations. Clin Orthop Relat Res. 2004;428:158.
18. Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR). https://aoanjrr.dmac.adelaide.edu.au/en/home; 2010.
19. Tauro B, Ackroyd CE, Newman JH, et al. The Lubinus patellofemoral arthroplasty. A five- to ten-year prospective study. J Bone Joint Surg (Br). 2001;83(5):696.
20. Kamath AF, Slattery TR, Levack AE, et al. Trochlear inclination angles in normal and dysplastic knees. J Arthroplast. 2013;28(2):214.
21. Lonner JH, Bloomfield MR. The clinical outcome of patellofemoral arthroplasty. Orthop Clin North Am. 2013;44(3):271–80.
22. Kooijman HJ, Driessen AP, van Horn JR. Long-term results of patellofemoral arthroplasty. A report of 56 arthroplasties with 17 years of follow-up. J Bone Joint Surg Br. 2003;85(6):836–40.
23. Odumenya M, Costa ML, Parsons N, et al. The Avon patellofemoral joint replacement: five-year results from an independent centre. J Bone Joint Surg Br. 2010;92(1):56–60.
24. Nicol SG, Loveridge JM, Weale AE, et al. Arthritis progression after patellofemoral joint replacement. Knee. 2006;13(4):290–5.
25. Dahm DL, Kalisvaart MM, Stuart MJ, Slettedahl SW. Patellofemoral arthroplasty: outcomes and factors associated with early progression of tibiofemoral arthritis. Knee Surg Sports Traumatol Arthrosc. 2014;22(10):2554–9.
26. Feucht MJ, Cotic M, Beitzel K, Baldini JF, Meidinger G, Schöttle PB, Imhoff AB. A matched-pair comparison of inlay and onlay trochlear designs for patellofemoral arthroplasty: no differences in clinical outcome but less progression of osteoarthritis with inlay designs. Knee Surg Sports Traumatol Arthrosc. 2017;25(9):2784–91.
27. Hoogervorst P, de Jong RJ, Hannink G, van Kampen A. A 21% conversion rate to total knee arthroplasty of a first-generation patellofemoral prosthesis at a mean follow-up of 9.7 years. Int Orthop. 2015;39(9):1857–64.
28. Dy CJ, Franco N, Ma Y, Mazumdar M, McCarthy MM, Gonzalez Della Valle A. Complications after patello-femoral versus total knee replacement in the treatment of isolated patello-femoral osteoarthritis. A meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2012;20(11):2174–90.
29. Willekens P, Victor J, Verbruggen D, Vande Kerckhove M, Van Der Straeten C. Outcome of patellofemoral arthroplasty, determinants for success. Acta Orthop Belg. 2015;81(4):759–67.
30. deDeugd CM, Pareek A, Krych AJ, Cummings NM, Dahm DL. Outcomes of patellofemoral arthroplasty based on radiographic severity. J Arthroplast. 2017;32(4):1137–42.
31. Mofidi A, Veravalli K, Jinnah RH, Poehling GG. Association and impact of patellofemoral dysplasia on patellofemoral arthropathy and arthroplasty. Knee. 2014;21(2):509–13.
32. Chawla H, Nwachukwu BU, van der List JP, Eggman AA, Pearle AD, Ghomrawi HM. Cost effectiveness of patellofemoral versus total knee arthroplasty in younger patients. Bone Joint J. 2017;99-B(8):1028–36.
33. Cohen ZA, Henry JH, McCarthy DM, Mow VC, Ateshian GA. Computer simulations of patellofemoral joint surgery. Am J Sports Med. 2003;31(1):87–98.
34. Feller JA, Amis AA, Andrish JT, Arendt EA, Erasmus PJ, Powers CM. Surgical biomechanics of the patellofemoral joint. Arthroscopy. 2007;23(5):542–53.

10 Bicompartmental Knee Arthroplasty

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Introduction

Bicompartmental knee arthroplasty (BCR) is a resurfacing of the patellofemoral and either the medial or lateral tibiofemoral compartments. The approach has been performed since the 1980s and emerged from developments in partial knee replacement including unicondylar (UKA) and patellofemoral (PFA) prostheses [1, 2]. BCR allows preservation of the cruciate ligaments and increased motion and may provide improved proprioception [3]. A small study of eight BCR patients by Wang et al. [4] showed that those patients had gait patterns and knee mechanics comparable to healthy control subjects. However, Chung et al. [5] reported similar isokinetic knee muscle strength and physical performance (timed up and go, stair climbing, and 6-min walk test) when directly comparing patients who received BCR or total knee arthroplasty (TKA) at 1 year after surgery.

BCR can be performed using two completely separate implants for the patellofemoral and the tibiofemoral compartments, or a single-piece femoral component can be used to articulate with the patella and the tibial surface creating a fixed relationship between the two compartments [6]. A meta-analysis of early BCR designs in 884 patients reported a 30% complication rate, with 7.2% revision at 3.7 years [7]. Technical challenges remain, making BCR more difficult to perform than standard TKA. However, recent improvements in instrumentation and prosthetic design have renewed interest in BKA as an alternative procedure for younger, active patients with bicompartmental arthritis.

Surgical Technique

The single-piece femoral components were developed in an attempt to simplify the surgical technique and make the operation similar to a TKA. The procedure can be performed through a limited, minimally invasive surgical approach or a standard arthrotomy. There are two techniques for this approach: one uses a standard "off-the-shelf" femoral component and the other uses a custom-made implant.

Standard Implant Technique

The tibial resection is performed using an extramedullary guide that is first set for the varus and valgus alignment with reference to the tibial shaft

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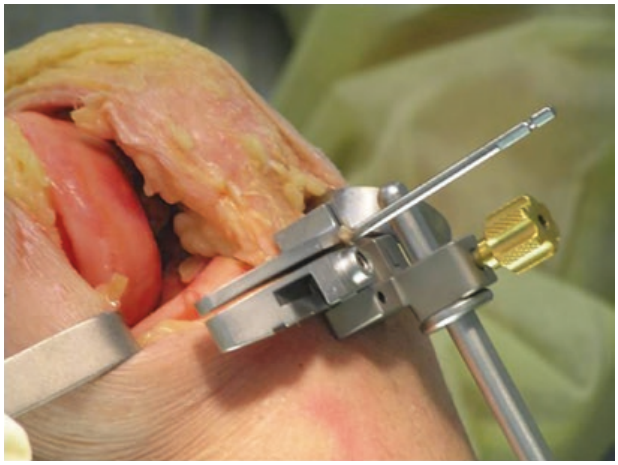

Fig. 10.1 The extramedullary tibial resection guide for the BCR standard implant

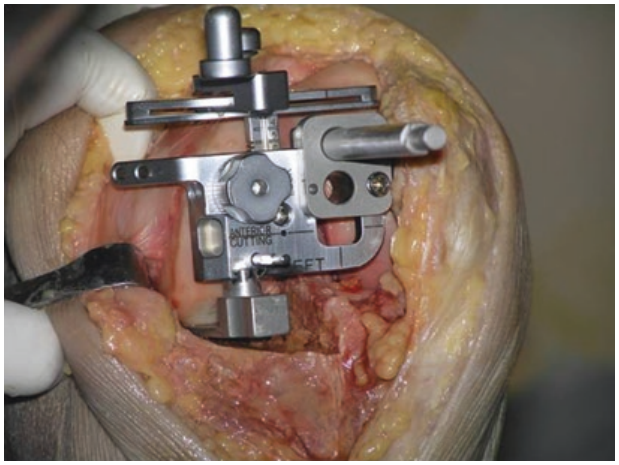

Fig. 10.2 Anterior femoral resection guide inserted over the intramedullary reference rod

(Fig. 10.1). The depth is set at 2 mm below the deepest point on the medial articular surface. The sagittal alignment, or slope, should be between 5° and 7° to match the preexisting tibial slope. Occasionally, a tibia will have a slope that is in excess of 10°, especially in the patient of Eastern descent. It is best not to increase the slope above 9°. If this angle is decreased from the natural slope, the flexion gap will be tightened, and some adjustment will need to be made to match the extension gap.

The tibial resection is completed using power saws for both the vertical and horizontal cuts. A pin can be inserted through the cutting guide that protects the remaining tibial surface from any undercutting. After the cut is completed, a spacer is placed into the knee in 90° of flexion and in full extension. The two gaps should be equal at this point. The most common presentation will be an extension gap that is smaller than the flexion gap because of a preexisting flexion contracture. This can be corrected by resecting more bone from the distal femur at the time of the distal resection. If the flexion gap is smaller than the extension gap, the slope of the tibial cut can be increased up to 8 or 9° and will increase the flexion gap without affecting the extension gap.

After the gaps have been evaluated, the anteroposterior femoral axis (AP axis) is drawn on the surface of the femur for rotational reference, and an intramedullary hole is made into the femoral canal just above the insertion of the posterior cruciate ligament at the base of the AP axis. The

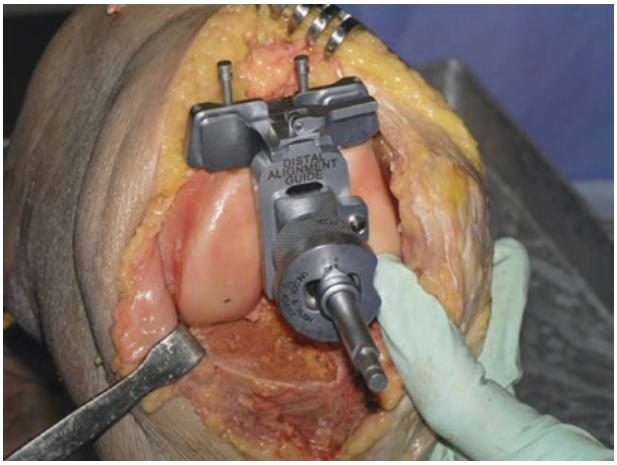

Fig. 10.3 The distal resection femoral guide

anterior femoral resection is performed with an instrument that is inserted over the intramedullary rod and set parallel to the AP axis (Fig. 10.2). The cut is made flush with the anterior femoral cortex similar to the cut for a traditional TKA. The distal cut is made with another instrument that locks onto the intramedullary rod (Fig. 10.3). The depth is set on the medial side to equal the flexion gap, and the angle of the distal cut is set with reference to the lateral femoral cortex so that the final cut will set the prosthesis flush with the lateral cortex and with the cartilaginous surface of the lateral femoral condyle. This cut is critical and is difficult to set to the exact depth.

After the distal femoral resection is completed, the space in flexion and full extension is again checked to be sure that the two are equal. If they are acceptable, the medial femoral condyle

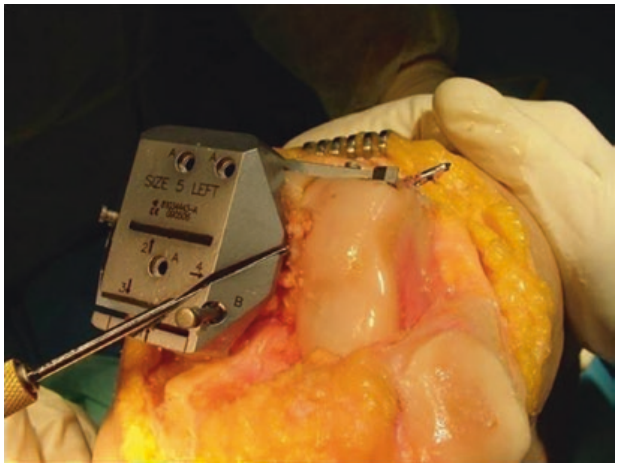

Fig. 10.4 The cutting block showing the guide pin to protect the lateral femoral condyle

is sized by referring to the anteroposterior thickness. A finishing block is placed on the distal femoral cut surface and references the medial femoral condyle width and the location of the lateral femoral cortex (Fig. 10.4). This is another step that is unique for the bicompartmental surgery and is not typical for TKA. The final cuts are completed on the femoral side. The tibial tray size is chosen, and the trial components are inserted into the knee. The patellar surface is resected either with an oscillating saw or a rotary blade, and an onlay or inlay patellar component is positioned on the cut surface.

The knee is moved through a complete range of motion to evaluate the patellar tracking and the relationship of the medial femoral condyle to the tibial articular surface implant. The components are removed, the surfaces are lavaged, and all components are cemented in position at the same time.

The wound is closed, and a light dressing is applied so that motion can be instituted on the day of surgery. The patients are all anticoagulated and discharged within the first 2–3 days after surgery.

Custom Implant Technique

The custom technique requires a CT examination of the knee before surgery. Custom instruments are made at the same time and can be applied to the surface of the femoral condyles to outline the areas of contact of the prosthesis and indicate the areas that require cartilage removal (Fig. 10.5). The femoral and tibial implants are manufactured to match the boney surfaces of the knee after the cartilage surface has been removed on the femoral side and after the planned depth of resection has been completed on the tibial side (Fig. 10.6). After the tibial resection is completed, the flexion and extension gaps are evaluated to confirm proper spacing and balance. The patella is resurfaced and all components are then cemented.

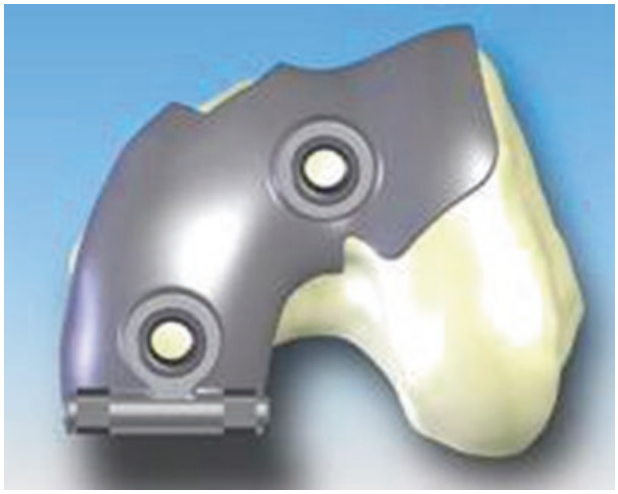

Fig. 10.5 Custom instrument for the removal of the cartilage surface on the femur

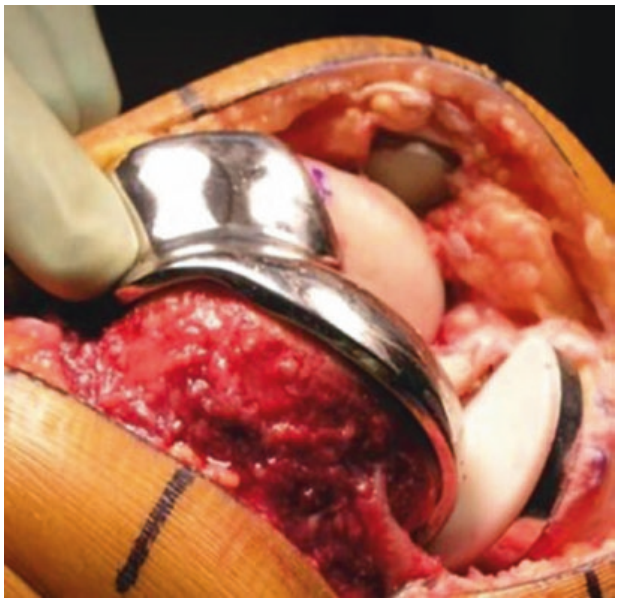

Fig. 10.6 The custom implant after cementing

Combined Bicompartmental Prosthesis

By combining two small implants, unicompartmental and patellofemoral, bicompartmental arthritis of the knee can be treated without sacrificing the ligaments and the affected compartment. Respecting the correct indication is key to success and foresees combining both UKA and PFJ indications, in particular arthritis of the femoral-tibial compartment due to joint space narrowing (not tibial deformity) associated with lateral patella facet arthritis, entire patellofemoral arthritis (kissing lesion), or post-traumatic patellofemoral arthritis.

The advantage of combined implants is that it is possible to treat both medial and lateral tibiofemoral arthritis and patellofemoral arthritis at the same time, while monoblock design is available only to treating medial and patellofemoral arthritis.

Limb realignment and correct patellofemoral tracking are fundamental objectives of the surgical treatment. There are various unicompartmental (measured resection and resurfacing, fixed/mobile plate) and patellofemoral implant designs on the market; although there are no set rules, the surgeon generally prefers to combine designs from the same manufacturer, not just for consistency in approach philosophy (measured resection versus resurfacing) but also in order to respect the characteristics of the individual patient (resurfacing is best when the condyle is worn out).

It is essential to respect the individual surgical technique of each implant, the principles of which remain unchanged if PFJ is added. It is necessary to keep around some mm of cartilage between the femoral and trochlear components, which are sunk in the cartilage, to avoid the contact on different planes between the metal components, with the consequence of a not smooth and continuous gliding surface. Furthermore, while there is no unanimous opinion regarding the order of compartment replacement, most surgeons prefer to start with the unicompartmental tibiofemoral prosthesis which realigns the limb, optimizing the patellofemoral tracking, before replacing the second compartment.

Surgical Technique

The medial unicompartmental prosthesis approach involves minimally invasive medial access which clearly exposes both compartments, eventually with a small double snip of the vastus medialis obliquus and the quadriceps tendon, or with subvastus approach. The subvastus approach, however, especially in males or in case of post-traumatic stiff OA of the patella, can pose some issues in the correct, wide necessary exposure of the trochlea. Furthermore, if the opposite compartment is the one in question, access is lateral according to Keblish or, where appropriate, via median incision. In lateral arthrotomy, it is important to section and then save the Hoffa pad for the subsequent closure as the lateral capsule is thinner and more fragile. The use of the tourniquet is not recommended in either case, except during cementation, to avoid changing the patellofemoral tracking.

A free hand incision is made to the patella to expose the joint and facilitate the removal of osteophytes on the medial femoral and tibial side; this must not be done on the external femoral side if the external condyle is hypoplastic.

The first step is the tibial cut, carried out with an extramedullary guide (Figs. 10.7 and 10.8):

- In coronal plane, the cut is at 90° (or slightly varus) for measured resection, 2–3° varus for resurfacing as described by Cartier, and 90° for lateral UKA cases.

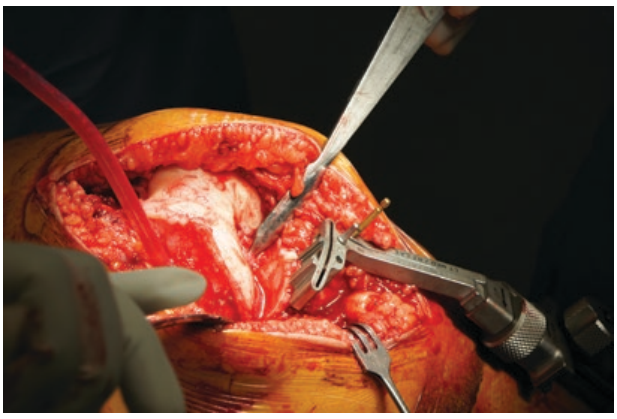

Fig. 10.7 The extramedullary tibial resection guide for the measured resection Uni

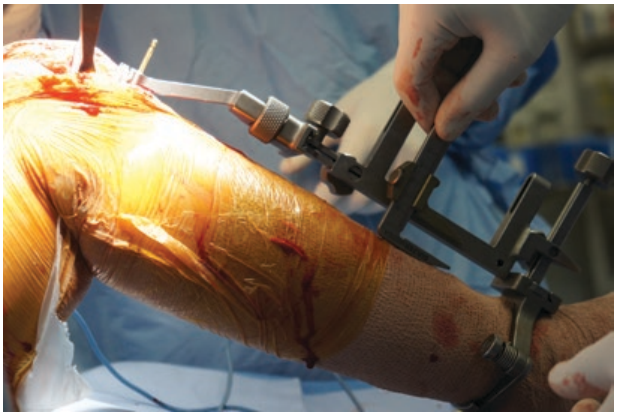

Fig. 10.8 Check of the tibial slope

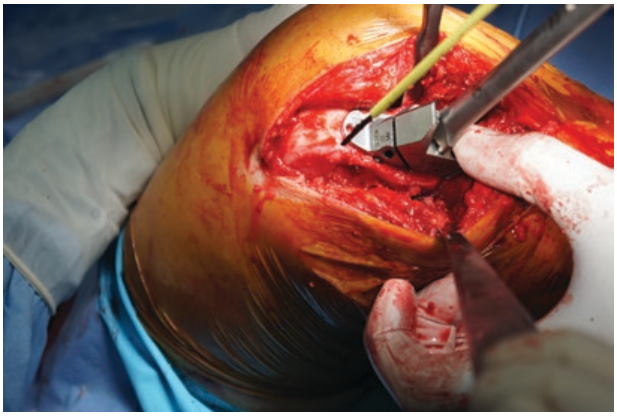

Fig. 10.9 Femoral cutting mask for posterior and chamfer cuts

- In sagittal plane, the cut is made with a 3–5° slope for medial UKA, in order to respect the native slope. For lateral UKA, however, the slope is 0°, and the cut plane must be internally rotated to accommodate the natural kinematics of the external condyle.

The femur is then prepared: the spacer block is positioned at the correct level, the distal femoral cut is executed, and gaps are checked using a spacer. It is possible to use the cutting mask for posterior and chamfer cuts and for pegs (Fig. 10.9). The femoral component must be centrally positioned or, rather, lateralized on the medial condyle avoiding at the same time a tibial spine impingement; component position is also as lateral as possible in the case of lateral UKA. The aim is to functionally position the femoral component in the center of the tibial plateau in flexion and to avoid edge loading on the plastic. Joint mobility and stability are checked with trial implants; in particular, it is important to leave slight laxity (1–2 mm) to avoid overloading the contralateral compartment. At this point, the trial implants are left in place, and the patellofemoral replacement can now be addressed.

The position of the trochlear component is important and must be chosen based on preoperative testing and the UKA position; cutting guides can be extramedullary or intramedullary placed, and the three positions are to be considered in each case:

- Rotational alignment: external rotation increases and favors lateral tracking of the patella, but it is best to reduce external rotation in cases of maltracking in order to optimize patellar stability; in either case, the correct medial and lateral retinaculum balance is essential to avoid asymmetrical tension or dislocation.
- Varus-valgus alignment: influences patellar tracking in the initial degrees of flexion; in patients with valgus knee, particularly women, the component's valgus angle must be increased.
- Flexion-extension position: it is better to use a slightly flexed component, which favors knee flexion, rather than an extended one which limits joint mobility in flexion.
- In any case, we are talking about a 1–2 mm or degree shift which ensures that the new trochlear surface glides smoothly with the remaining cartilage.

The trochlear cut can also be made free hand (Fig. 10.10); the "grand piano sign" indicates, however, that the proximal part of the femoral component does not create steps with the anterior cortex, and the patella can move in the new joint without "derailing." The mask can be positioned at this point to prepare the trochlea, remembering that a few mm of cartilage must be left between the trochlea and the femoral component to avoid impingement. The trochlea can be downsized to avoid conflict with the UKA's femoral component as long as the patella is well contained within. The trochlea must be positioned 1 mm below the cartilage to recreate

a bump-free smooth sliding surface. Site preparation depends on the model, but generally guided drills are used. Milling, for example, by way of a small motorized high-speed mill, can remove a predetermined thickness of the trochlea's cartilage and subchondral bone (Figs. 10.11 and 10.12).

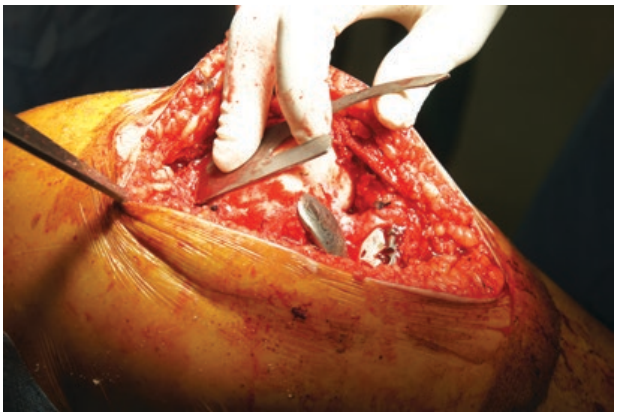

Fig. 10.10 Anterior femoral cut for trochlear preparation

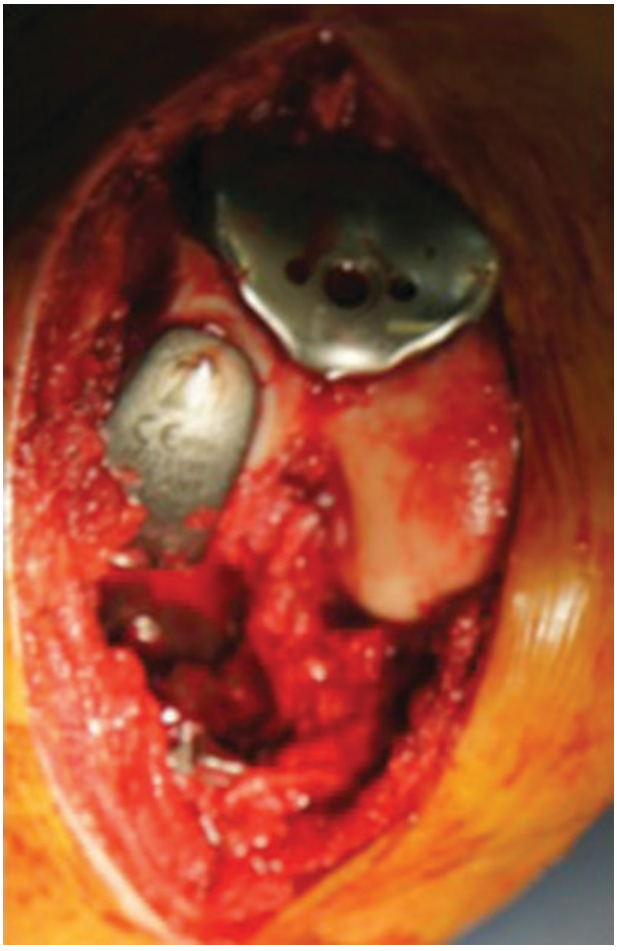

Fig. 10.11 Milling technique

The next step after the placement of the trial trochlear component is the patella replacement, which does not necessarily have to be placed medially and proximally as in TKA; the position must be that which best allows it to move smoothly within the newly implanted trochlea.

The trial components make it possible to ensure the patellofemoral articulating surface is smooth sliding and bump-free during flexion-extension using the "finger-sign" test: during the passive flexion-extension motion, a finger placed on the knee cap should not feel any bumps or clicks.

Pulse lavage is carried out, the tourniquet can be activated, and the definitive implants can be cemented: first UKA (tibia and then femur) using an insert of increased thickness to facilitate cement penetration and then the trochlea and the patella, flexing the knee 90° to increase the pressure on the trochlea. Finally, the definitive liner is positioned and suturing carried out. Draining is unnecessary. Intra-articular tranexamic acid is injected to reduce bleeding, and the knee is kept flexed for the next 2 h. When suturing the external approach, it is necessary to suture the Hoffa pad to give extra hold.

Rehabilitation is immediate, joint mobilization and assisted ambulation begin at day 1 post-op, and the patient is discharged on day 3. In cases of lateral access, it is advisable not to force knee flexion immediately so as to avoid capsular dehiscence and hematoma.

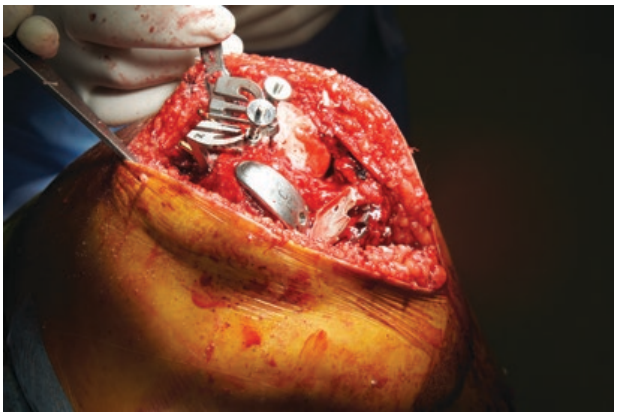

Fig. 10.12 Some millimeters of cartilage must be preserved between femoral and trochlear components

Results

Two Separate Components

In the late 1980s, European surgeons who were performing partial knee arthroplasties sought to combine partial implants without moving to a total replacement. Argenson et al. [8] operated on 181 knees for primary patellofemoral disease and added a medial replacement in 57%. The early results were encouraging and similar to TKA in the first few years; however, there was a 30% revision rate into the second decade, with an overall survivorship of 54% at 17 years [9]. Twenty-eight of 69 knees that were available for long-term follow-up underwent revision for loosening at an average of 7.9 years. Failure of the patellofemoral implant accounted for the vast majority (20/28) cases. Argenson concluded that the results may have been compromised by limited early instrumentation and the combination of a variety of different implants.

Cartier et al. [10] performed 72 patellofemoral arthroplasties (PFAs) and included a medial UKA in 30 knees. Good or excellent results were reported in 85% of patients at 2–12 years of follow-up, with 92% having satisfactory pain relief.

Heyse et al. [11] reported on nine knees (mean age, 64) treated with medial UKA and PFA. At a mean follow-up of 12 years, no revision surgeries were necessary, although one asymptomatic patient had substantial progression of lateral arthritis. Knee Society pain and function scores increased from 39 to 92 ($p = 0.007$) and 30 to 83 ($p = 0.002$), respectively. All patients were satisfied or very satisfied. Kamath and colleagues [12] examined the results of 29 patients (mean age, 59 years) who underwent modular unlinked BKA. At 31-month follow-up, the range of motion increased from 122 to 133 ($p < 0.001$). There was no evidence of component subsidence of progression of radiolucent lines. Significant improvements in pain and function outcomes scores were reported. One patient underwent revision to TKA at 3 years for instability.

Benazzo et al. [24] published a study of 30 patients surgically treated for UKA and PFJ with 2 different designs. Twenty-five patients were female, with an average age of 66.5 years and an average follow-up of 59 months. The specific scores (HSS, KSS, and OKS) demonstrated excellent results at mid-term follow-up in both groups; only one patient underwent TKA revision for all-polyethylene tibial baseplate loosening.

Lonner has continued to refine bicompartmental replacement using two separate implants [13, 14]. Unlinking the trochlear and medial femoral condylar prostheses allows independent resurfacing of the individual compartments and ensures appropriate orientation of each component. Improvements in component geometry may improve patellar tracking, while robotic assistance is now being used to optimize prosthesis position and alignment.

Single Femoral Component (Monolithic Design)

Rolston and colleagues [15] designed a monolithic femoral component that combined the femoral trochlear groove and the medial femoral condyle replacement (Journey Deuce Bi-Compartmental Knee System; Smith & Nephew, Inc., Memphis, TN). This prosthesis articulated with a unicondylar type of tibial plateau insert and with an all-polyethylene patellar component. Both the anterior cruciate ligament (ACL) and posterior cruciate ligaments (PCL) are retained. The mechanical axis in 137 patients was reported to be satisfactorily corrected with this prosthesis in 95% of cases with minimal overcorrection (3.6%) from varus to valgus (Rolston and Siewert. The Journal of Arthroplasty Vol. 24 No. 7 2009). However, the coronal alignment of the monolithic design is determined by the position of the lateral prosthetic edge with reference to the remaining lateral femoral condyle. Variable distal femur morphology may lead to inconsistent alignment with standard sizes, potentially resulting in decreased prosthesis longevity.

Engh et al. [16] compared 50 patients (mean age, 59 years) with medial and patellofemoral arthritis who were randomized to receive a BCR (Journey Deuce) or a TKA (Genesis II; Smith & Nephew, Inc., Memphis, TN). At 2-year follow-up, equivalent Knee Society scores (93.6 vs. 92.6, $P = 0.43$) and Oxford knee scores

(43 vs. 41, $P = 0.35$) were reported for both groups. One TKA underwent revision for tibial component loosening; one BCR knee was revised for patellar subluxation, and two BCR tibial trays developed stress fractures that required revision.

Tria [17, 18] performed 100 cases and reported on the first 40 patients (mean age, 70 years) undergoing BCR (Journey Deuce). At 5-year follow-up, Knee Society scores had improved from 49 to 84 and the function score from 57 to 81. Final postoperative flexion was 120°. One patient developed patellar subluxation and was treated successfully with lateral release at 6 weeks postoperatively. Five patients were revised to a standard TKA with a good result for global pain. Two tibial tray fractures occurred and were revised to TKA. Ten patients (24%) had persistent anterior knee pain.

Palumbo et al. [19] reported the results of the Journey Deuce BCR in 36 knees (mean age, 66 years). At 21-month follow-up, the Knee Society functional survey and Western Ontario McMaster Osteoarthritic Index Survey scores were 65.4 and 75.8, respectively. Progressive radiolucencies were observed in the tibial tray in 61% of cases. Five patients (14%) underwent conversion to TKA for persistent pain. At the time of revision surgery, all five tibial trays were noted to be loose with one catastrophic baseplate fracture. Fifty-three percent of patients stated that they would not repeat the surgery. These authors concluded that this prosthesis provided inconsistent pain relief and unacceptable functional results for bicompartmental arthritis and abandoned of the implant.

Dudhniwala et al. [20] reported early aseptic tibial loosening and 40% survivorship at 54 months with the Journey Deuce in 15 patients (mean age, 57 years). Implantation of the prosthesis was stopped due to unfavorable results. Morrison and colleagues [21] compared functional outcomes of BCR ($n = 21$) and TKA ($n = 33$) in patients with osteoarthritis of the patellofemoral and medial compartments. Implant selection was not randomized. In the early postoperative period, the BCR cohort had significantly less pain ($p = 0.020$) and better physical function ($p = 0.015$). These trends did not continue for the past 3 months. A significantly higher complication rate ($p = 0.045$) was observed in the BCR group with one patellar subluxation, one patellar fracture, and three revisions due to pain. These investigators eventually recommended TKA for patients with this bicompartmental pattern of arthritis.

Steinert [22] recently reported clinical results using the custom BCR system (iDuo, ConforMIS Inc., Burlington, MA). Forty-four patients (mean age, 59 years) underwent the replacement without patellar resurfacing. At 1-year follow-up, one case was revised to TKA for tibial tray loosening, and three additional cases underwent patellar resurfacing. Significant improvements in pain and functional outcomes were reported.

Minas et al. [23] reported 2–5-year results using the same custom prosthesis at the closed meeting of the Knee Society. He evaluated 55 patients (59 knees) with an average age of 51 and an average follow-up of 45 months. At 5 years the survival rate was 94%. Three knees (5%) required revision to TKA at an average of 26 months. Twenty-two percent required subsequent surgical procedures, which was primarily arthroscopic synovectomy due to adhesions (14 knees).

Conclusions

Modular BCR is an emerging knee-resurfacing treatment option that provides a conservative alternative to TKA. Isolated bicompartmental arthritis involving the medial or lateral and patellofemoral compartments, limited bony deformity or deficiency, preserved motion, and intact cruciate ligaments can be effectively managed with this treatment method. The surgical technique is demanding, and the surgeon' s skill consists mainly in getting back the knee as it was before OA changes occurred, with the appropriate bone cuts in order to fill the lost spaces and accommodate the patella femoral tracking accordingly.

At present, replacing the compartments with separate prostheses has been a more reliable approach. However, the monolithic femoral component that is custom designed is showing improved results and may be an easier technique for the future.

References

1. MacIntosh DL. Hemiarthroplasty of the knee using a space occupying prosthesis for painful varus and valgus deformities. J Bone Joint Surg Am. 1958;40:1431.
2. McKeever DC. Tibial plateau prosthesis. Clin Orthop. 1960;18:86–95.
3. Sabatini L, Ravera L, Atzori F, Massè A. Outcomes of bicompartmental knee arthroplasty: a review. Int J Orthop. 2014;1(3):100–8.
4. Wang H, Dugan E, Frame J, et al. Gait analysis after bi-compartmental knee replacement. Clin Biomech. 2009;24(9):751.
5. Chung JY, Min BH. Is bicompartmental knee arthroplasty more favourable to knee muscle strength and physical performance compared to total knee arthroplasty? Knee Surg Sports Traumatol Arthrosc. 2013;21(11):2532–41.
6. Thienpont E, Price A. Bicompartmental knee arthroplasty of the patellofemoral and medial compartments. Knee Surg Sports Traumatol Arthrosc. 2013;21:2523–31.
7. Callahan CM, Drake BG, Heck DA, Dittus RS. Patient outcomes following unicompartmental or bicompartmental knee arthroplasty. A meta-analysis. J Arthroplast. 1995;10(2):141–50.
8. Argenson JN, Guillaume JM, Aubaniac JM. Is there a place for patellofemoral arthroplasty? Clin Orthop Relat Res. 1995;321:162–7.
9. Parratte S, Pauly V, Aubaniac JM, Argenson JN. Survival of bicompartmental knee arthroplasty at 5 to 23 years. Clin Orthop Relat Res. 2010;468(1):64–72.
10. Cartier P, Sanouiller JL, Grelsamer R. Patellofemoral arthroplasty. 2-12-year follow-up study. J Arthroplast. 1990;5(1):49–55.
11. Heyse TJ, Khefacha A, Cartier P. UKA in combination with PFR at average 12-year follow-up. Arch Orthop Trauma Surg. 2010;130(10):1227–30.
12. Kamath AF, Levack A, John T, Thomas BS, Lonner JH. Minimum two-year outcomes of modular bicompartmental knee arthroplasty. J Arthroplast. 2014; 29(1):75–9.
13. Lonner JH. Patellofemoral arthroplasty: the impact of design on outcomes. Orthop Clin North Am. 2008;39(3):347–54.
14. Lonner JH. Modular bicompartmental knee arthroplasty with robotic arm assistance. Am J Orthop (Belle Mead NJ). 2009;38(2 Suppl):28–31.
15. Rolston L, Bresch J, Engh G, Franz A, et al. Bicompartmental knee arthroplasty: a bone-sparing, ligament-sparing, and minimally invasive alternative for active patients. Orthopedics. 2007;30(8 Suppl):70–3.
16. Engh GA, Parks NL, Whitney CE. A prospective randomized study of bicompartmental vs. total knee arthroplasty with functional testing and short term outcome. J Arthroplast. 2014;29(9):1790–4.
17. Tria AJ Jr. Bicompartmental arthroplasty of the knee. Instr Course Lect. 2010;59:61–73.
18. Tria AJ Jr. Bicompartmental knee arthroplasty: the clinical outcomes. Orthop Clin North Am. 2013;44(3):281–6.
19. Palumbo BT, Henderson ER, Edwards PK, et al. Initial experience of the journey-deuce bicompartmental knee prosthesis: a review of 36 cases. J Arthroplast. 2011;26(6 Suppl):40–5.
20. Dudhniwala AG, Rath NK, Joshy S, Forster MC, White SP. Early failure with the journey-deuce bicompartmental knee arthroplasty. Eur J Orthop Surg Traumatol. 2016;26(5):517–21.
21. Morrison TA, Nyce JD, Macaulay WB, Geller JA. Early adverse results with bicompartmental knee arthroplasty: a prospective cohort comparison to total knee arthroplasty. J Arthroplast. 2011;26(6 Suppl):35–9.
22. Steinert AF, Beckmann J, Holzapfel BM, Rudert M, Arnholdt J. Bicompartmental individualized knee replacement : use of patient-specific implants and instruments (iDuo™). Oper Orthop Traumatol. 2017;29(1):51–8.
23. Minas T, Ogura T, Le K, Bryant T. Patient outcomes and satisfaction after bicompartmental individualized knee arthroplasty with patient specific implants and instruments. The closed meeting of the knee society, Columbus, USA. September 15, 2017.
24. Benazzo F, Rossi SMP, Ghiara M. Partial knee arthroplasty: patellofemoral arthroplasty and combined unicompartmental and patellofemoral arthroplasty implants – general considerations and indications, technique and clinical experience. Knee. 2014;21(S1):S43–6.

11 The Complications and Modes of Failure of Partial Knee Arthroplasty

Matthieu Ollivier and Matthew P. Abdel

Introduction

Between 1998 and 2005, the use of unicompartmental knee arthroplasty (UKA) increased at a rate nearly triple that of total knee arthroplasty (TKA) [1]. Several reports have already demonstrated survivorship greater than 90% at 10 years after modern UKA implantation [1–5]. However, data extracted from national joint registries (NJR) exhibits a relatively high failure rate for UKA [6]. Complications and mode of failure of UKAs have distinctive characteristics without any established consensus on failure etiology and appropriate treatment. Additionally, the incidence and type of complications are different, depending on patients, surgeons, and implant-related issues [7]. The purpose of this chapter is to present an analysis of the recent literature to describe UKA complications and the mechanisms of failure.

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Epidemiology and Risk Factors of UKA Failures

The most recent NJR analysis demonstrated UKA survivorship of 91.8% (95% confidence interval [CI], 91.3–92.3%) at 5 years and 89.1% (95% CI, 88.3–89.9%) at 8 years. These numbers are lower than those typically found in historical series as they represent revision rates across an entire country rather than results of high-volume arthroplasty centers. NJR studies have demonstrated important risk factors for failure in terms of patient selection and surgical practice.

If preoperative patient-reported outcome measures (PROMs) predict postoperative outcomes, patients with severe preoperative disease are no less satisfied following surgery despite reporting poorer PROMs [8, 9].

Age has a positive effect on outcome by each metric. Older patients derive the greatest benefit from UKA and have lower revision rates than younger patients. These findings, together with the lower rates of perioperative morbidity and mortality associated with UKA, suggest that older patients fare particularly well with UKA [10].

Men and women appear to achieve similar clinical outcomes and satisfaction levels. There is a small but statistically significant difference in 8-year survivorship, with women more likely to require revision. One reason may be the higher incidence of inflammatory arthropathies in women; UKAs implanted in patients with undiagnosed

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inflammatory arthritis are at higher risk of revision secondary to disease progression.

Neither BMI nor ASA score has demonstrated any influence on outcomes, but preoperative morbidity and comorbidities such as anxiety/depression have been shown to predispose to adverse outcomes (implant survival, PROMs, and satisfaction). Patients typically have better outcomes if a consultant rather than a trainee performs their UKA. Revision rates are lower, and satisfaction rates higher in high-volume centers (supporting previous studies of both TKR and UKR). There is a large effect up to 40 cases per year, but there is a plateau above this level.

Causes of Unicompartmental Knee Arthroplasty Failures

The main causes of UKA failure include bearing dislocation (in mobile designs), aseptic mechanical loosening, polyethylene wear, progression of osteoarthritis (OA) in the unreplaced compartments, infection, impingement, periprosthetic fracture, arthrofibrosis, and unexplained pain [1, 7, 11, 12]. Bearing dislocation continues to be touted as the predominant mechanism of failure in mobile UKAs [7, 13, 14], whereas polyethylene wear and aseptic loosening remain the main causes of failure of fixed UKAs [1, 7]. Septic complications and degeneration of the unrelated compartments have also been reported in both mobile and fixed designs.

Aseptic Mechanical Loosening

While aseptic mechanical loosening has been recently reported as the most frequent cause of failure of the modern TKA [15], newer instrumentation, improved prosthetic designs, and cross-linked polyethylene have significantly reduced its incidence in modern UKA.

Risk factors such as young age, overweight body mass index (BMI), and varus deformity are often responsible for the mechanical failure of unicompartmental implants (Fig. 11.1).

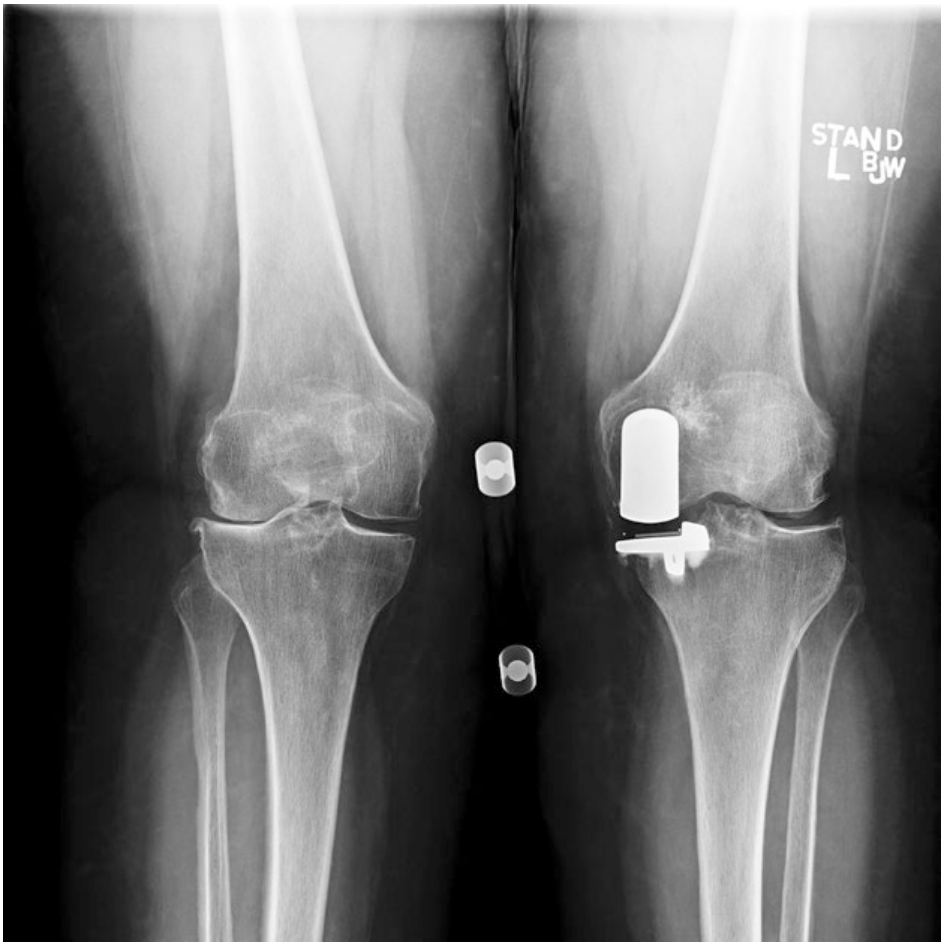

Fig. 11.1 Anteroposterior standing radiograph of a 58-year-old female 7 years after a left medial unicompartmental knee arthroplasty completed at an outside institution now with radiographic evidence of loosening likely exacerbated by her body mass index of 48 kg/m^2

Fixed-bearing UKA results in greater contact stress on the polyethylene insert due to low conformity, which may eventually lead to failure associated with tibial component loosening or subsidence [7]. However, poor implant positioning is the main cause of mechanical loosening due to inadequate contact between femoral and tibial implants, or an excessive tibial slope which eventually produces wear-induced periprosthetic osteolysis, further increasing adverse mechanical outcomes [16]. Wrong indications for a UKA in patients with altered kinematics are also responsible for early loosening (i.e., torn anterior cruciate ligament).

Progression of Osteoarthritis

Progression of OA in the contralateral compartment and/or in the patellofemoral joint (PFJ; Fig. 11.2) is one of the major causes of failure following mobile and fixed UKA. Overcorrection of the mechanical axis may lead to degenerative changes in the contralateral compartment [17].

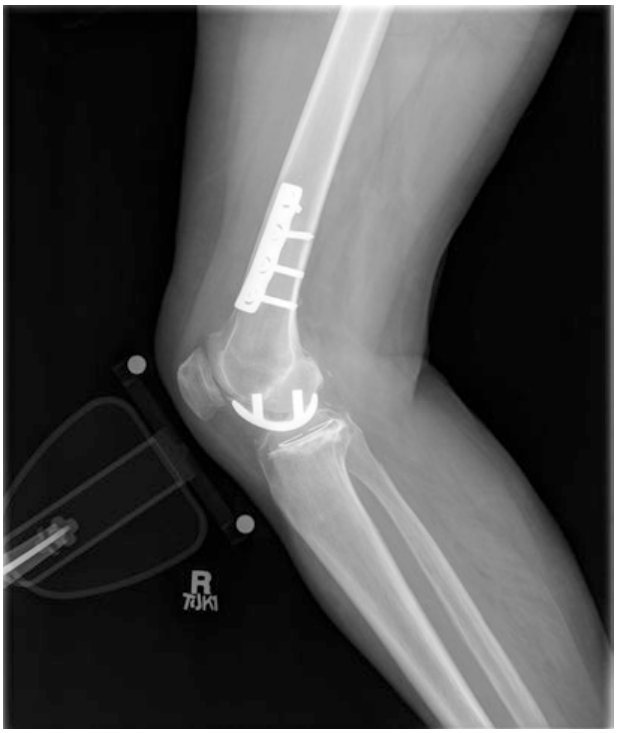

Fig. 11.2 Lateral radiograph of a 72-year-old female with progression of osteoarthritis in the patellofemoral compartment 11 years after her index medial unicompartmental knee arthroplasty

Recent literature has confirmed satisfactory results of UKA performed in patients suffering from mild chondrocalcinosis, which is no longer a contraindication [18]. Rapid progression of OA may occur in patients with systemic inflammatory diseases, as such rheumatoid or psoriatic arthritis, which are contraindicated in UKA. Degeneration of the PFJ may occur in the presence of an oversized femoral component by potential impingement upon the patellar cartilage [1]. Progression of OA in the contralateral and/or patellofemoral compartment can be characterized by radiographic evidence of joint space narrowing and osteophyte formation in the initial stage, which eventually leads to the development of pain, subchondral sclerosis, and loss of joint space in the unreplaced compartments [19].

Polyethylene Wear

Polyethylene wear is a complication specific to the fixed-bearing design (Fig. 11.3), secondary to the higher surface deformation and delamination in comparison to mobile bearings [9]. Revision for polyethylene wear usually occurs after 8 years, but early catastrophic failures due to wear have been reported [16]. Wear affects joint alignment and stability, leading to increased loading at the bone-implant interface which further accelerates loosening [16]. Factors associated with accelerated polyethylene wear after UKA are component malpositioning, deformity

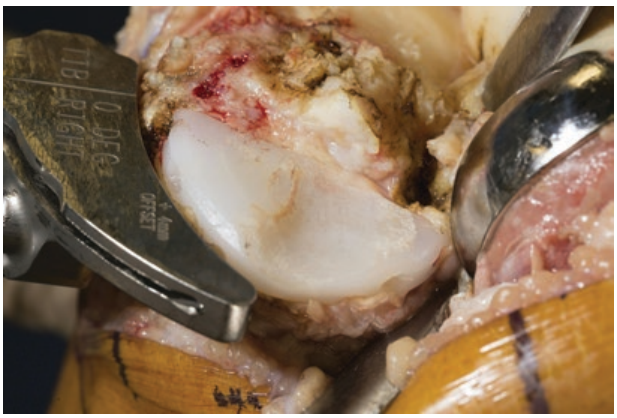

Fig. 11.3 Intraoperative picture of a 79-year-old female who became ACL deficient after her medial unicompartmental knee arthroplasty, resulting in excessive posterior polyethylene wear mandating revision

undercorrection, a thin polyethylene surface (<6 mm), and the manufacturing process and sterilization method of polyethylene [16]. Modern instrumentation helps avoid component malpositioning and edge loading, even with a minimally invasive approach. Polyethylene exchange might be an acceptable option when wear is isolated, with no sign of subsidence or loosening of metallic implants being well fixed [20]. Furthermore, recent improvements in manufacturing processes such as cross-linking may be valuable in some fixed and mobile designs.

Periprosthetic Joint Infection

Limited literature exists regarding the treatment of periprosthetic joint injections (PJI) following UKA. Unpublished data from the Mayo Clinic (Hernandez et al.) identified a small series of patients who developed PJI after UKA according to the MSIS criteria. All patients were treated with either a two-stage exchange or irrigation and debridement with single-staged liner exchange (Figs. 11.4a, b). Interestingly, survivorship free of reinfection after UKA PJI treatment was 70% at 5 years yet was distinctly different for the two-stage cohort (100% at 5 years) versus the irrigation and debridement cohort (58% at 5 years). Treatment of PJI following UKA may be associated with a high prevalence of subsequent complications including high rates of reinfection. The results of this study suggest that PJI following UKA may eventually lead to late component loosening and/or progression of osteoarthritis later requiring conversion to TKA.

Periprosthetic Fracture

Periprosthetic fractures are rare but represent a serious complication in UKA. They are typically observed around the tibial condyles; this can be attributed to the increased pressure and load applied on the proximal tibia. Rarely, periprosthetic fractures of the femoral condyle may occur, which may be due to the impaction force, direction, or diminished load resistance on the distal femur [21].

Arthrofibrosis

The incidence of arthrofibrosis after UKA is much lower than that of TKA since minimally invasive procedures cause reduced damage to the

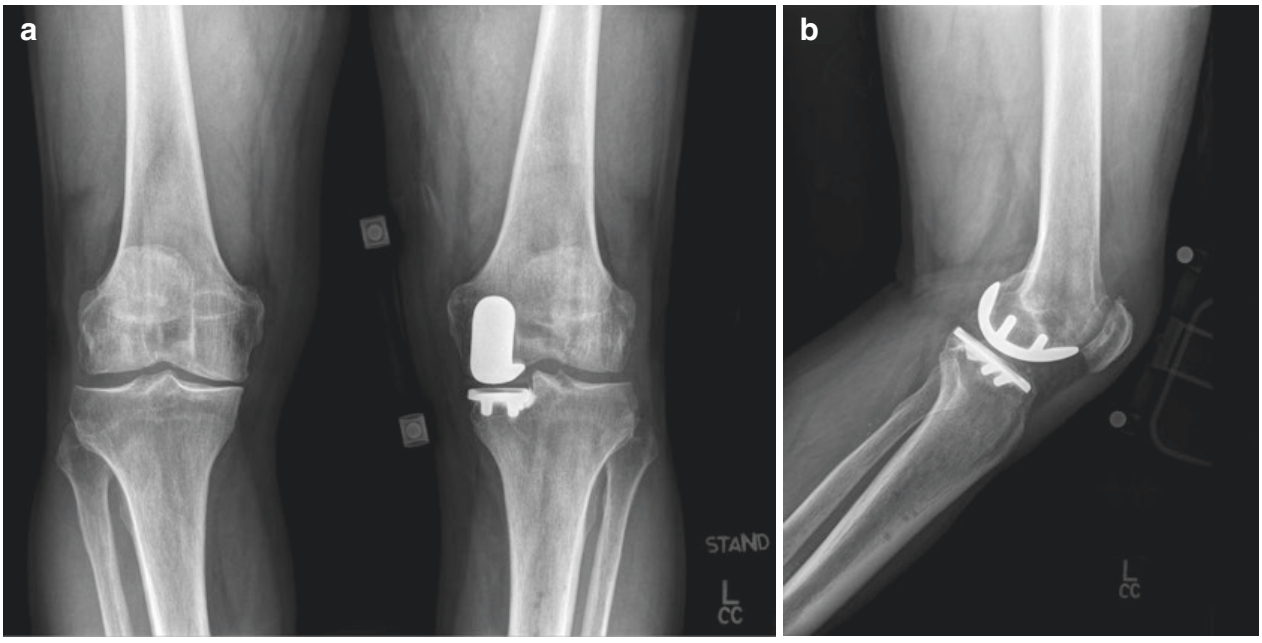

Fig. 11.4 Anteroposterior (**a**) and lateral (**b**) radiographs of a 75-year-old male who underwent urgent irrigation and debridement with polyethylene exchange for an acute periprosthetic joint infection

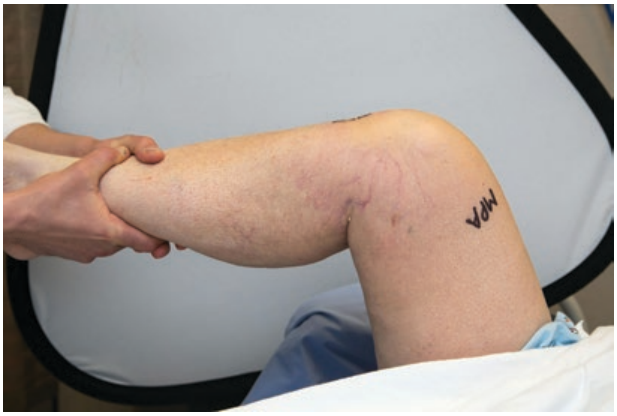

Fig. 11.5 While rare, this 66-year-old female developed stiffness with flexion limited to 85° 6 weeks after her medial unicompartmental knee arthroplasty, mandating a manipulation under anesthesia that resulted in 130° of flexion

extensor mechanism and suprapatellar pouch and stimulate less scar formation (Fig. 11.5) [22]. Additionally, modern designs of UKA have significantly reduced the incidence of prosthetic impingement and/or impingement of the femoral component with the patella.

Lateral UKA Specificity

Osteoarthritis progression seems to play a more dominant role in failures of lateral UKA. This difference might be explained by very different anatomy and kinematics of the medial and lateral compartment of the knee. Malalignment of the joint is an important factor in the etiology of OA [23, 24], and biomechanical studies showed that this malalignment can cause decreased viability and promote degenerative changes of cartilage of the knee [25].

When performing a lateral UKA, surgeons must be aware that no deformity overcorrection should be done to avoid early progression of arthritis in the medial compartment. Dislocations are particularly common in lateral UKA, as the lateral collateral ligament (LCL) is slack in flexion, in contrast to the medial side, in which the medial collateral ligament (MCL) is tight. As such, careful clinical examination and/or stress x-rays should be performed before planning a mobile-bearing lateral UKA [26, 27].

References

1. Foran JR, Brown NM, Della Valle CJ, Berger RA, Galante JO. Long-term survivorship and failure modes of unicompartmental knee arthroplasty. Clin Orthop Relat Res. 2013;471(1):102–8. Epub 2012/08/17.
2. Koshino T, Sato K, Umemoto Y, Akamatsu Y, Kumagai K, Saito T. Clinical results of unicompartmental arthroplasty for knee osteoarthritis using a tibial component with screw fixation. Int Orthop. 2015;39(6):1085–91. Epub 2014/10/25.
3. Schlueter-Brust K, Kugland K, Stein G, Henckel J, Christ H, Eysel P, et al. Ten year survivorship after cemented and uncemented medial Uniglide unicompartmental knee arthroplasties. Knee. 2014;21(5):964–70.
4. Vasso M, Del Regno C, Perisano C, D'Amelio A, Corona K, Schiavone PA. Unicompartmental knee arthroplasty is effective: ten year results. Int Orthop. 2015;39(12):2341–6. Epub 2015/07/02.
5. Yoshida K, Tada M, Yoshida H, Takei S, Fukuoka S, Nakamura H. Oxford phase 3 unicompartmental knee arthroplasty in Japan--clinical results in greater than one thousand cases over ten years. J Arthroplast. 2013;28(9 Suppl):168–71. Epub 2013/10/23.
6. Niinimaki TT, Murray DW, Partanen J, Pajala A, Leppilahti JI. Unicompartmental knee arthroplasties implanted for osteoarthritis with partial loss of joint space have high re-operation rates. Knee. 2011;18(6):432–5. Epub 2010/11/26.
7. Kim KT, Lee S, Lee JI, Kim JW. Analysis and treatment of complications after unicompartmental knee arthroplasty. Knee Surg Relat Res. 2016;28(1):46–54. Epub 2016/03/10.
8. Parratte S, Pauly V, Aubaniac JM, Argenson JN. No long-term difference between fixed and mobile medial unicompartmental arthroplasty. Clin Orthop Relat Res. 2012;470(1):61–8. Epub 2011/07/07.
9. Bhattacharya R, Scott CE, Morris HE, Wade F, Nutton RW. Survivorship and patient satisfaction of a fixed bearing unicompartmental knee arthroplasty incorporating an all-polyethylene tibial component. Knee. 2012;19(4):348–51. Epub 2011/06/08.
10. Sierra RJ, Kassel CA, Wetters NG, Berend KR, Della Valle CJ, Lombardi AV. Revision of unicompartmental arthroplasty to total knee arthroplasty: not always a slam dunk! J Arthroplast. 2013;28(8 Suppl):128–32. Epub 2013/07/28.
11. Clark M, Campbell DG, Kiss G, Dobson PJ, Lewis PL. Reintervention after mobile-bearing Oxford unicompartmental knee arthroplasty. Clin Orthop Relat Res. 2010;468(2):576–80. Epub 2009/09/22.
12. Springer BD, Scott RD, Thornhill TS. Conversion of failed unicompartmental knee arthroplasty to TKA. Clin Orthop Relat Res. 2006;446:214–20. Epub 2006/05/05.
13. Bergeson AG, Berend KR, Lombardi AV Jr, Hurst JM, Morris MJ, Sneller MA. Medial mobile bearing unicompartmental knee arthroplasty: early survivorship

and analysis of failures in 1000 consecutive cases. J Arthroplast. 2013;28(9 Suppl):172–5. Epub 2013/03/26.
14. Weston-Simons JS, Pandit H, Gill HS, Jackson WF, Price AJ, Dodd CA, et al. The management of mobile bearing dislocation in the Oxford lateral unicompartmental knee replacement. Knee Surg Sports Traumatol Arthrosc. 2011;19(12):2023–6. Epub 2011/03/04.
15. Dalury DF, Pomeroy DL, Gorab RS, Adams MJ. Why are total knee arthroplasties being revised? J Arthroplast. 2013;28(8 Suppl):120–1. Epub 2013/07/28.
16. Argenson JN, Parratte S. The unicompartmental knee: design and technical considerations in minimizing wear. Clin Orthop Relat Res. 2006;452:137–42. Epub 2006/08/15.
17. Vasso M, Del Regno C, D'Amelio A, Viggiano D, Corona K, Schiavone PA. Minor varus alignment provides better results than neutral alignment in medial UKA. Knee. 2015;22(2):117–21. Epub 2015/02/11.
18. Hernigou P, Pascale W, Pascale V, Homma Y, Poignard A. Does primary or secondary chondrocalcinosis influence long-term survivorship of unicompartmental arthroplasty? Clin Orthop Relat Res. 2012;470(7):1973–9. Epub 2011/12/14.
19. Pandit H, Hamilton TW, Jenkins C, Mellon SJ, Dodd CA, Murray DW. The clinical outcome of minimally invasive phase 3 Oxford unicompartmental knee arthroplasty: a 15-year follow-up of 1000 UKAs. Bone Joint J. 2015;97-b(11):1493–500. Epub 2015/11/05.
20. Lunebourg A, Parratte S, Galland A, Lecuire F, Ollivier M, Argenson JN. Is isolated insert exchange a valuable choice for polyethylene wear in metal-backed unicompartmental knee arthroplasty? Knee Surg Sports Traumatol Arthrosc. 2016;24(10):3280–6. Epub 2014/10/26.
21. Ten Brinke B, de Haan LJ, Koenraadt KL, van Geenen RC. Medial femoral condyle fracture as an intraoperative complication of Oxford unicompartmental knee replacement. Knee Surg Sports Traumatol Arthrosc. 2016;24(10):3191–3. Epub 2014/12/07.
22. Pandit H, Jenkins C, Barker K, Dodd CA, Murray DW. The Oxford medial unicompartmental knee replacement using a minimally-invasive approach. J Bone Joint Surg. 2006;88(1):54–60. Epub 2005/12/21.
23. Hunter DJ, Wilson DR. Role of alignment and biomechanics in osteoarthritis and implications for imaging. Radiol Clin N Am. 2009;47(4):553–66. Epub 2009/07/28.
24. Hunter DJ, Sharma L, Skaife T. Alignment and osteoarthritis of the knee. J Bone Joint Surg Am. 2009;91(Suppl 1):85–9. Epub 2009/02/21.
25. Roemhildt ML, Beynnon BD, Gauthier AE, Gardner-Morse M, Ertem F, Badger GJ. Chronic in vivo load alteration induces degenerative changes in the rat tibiofemoral joint. Osteoarthr Cartil. 2013;21(2):346–57. Epub 2012/11/06.
26. Scott RD. Lateral unicompartmental replacement: a road less traveled. Orthopedics. 2005;28(9):983–4. Epub 2005/09/30.
27. Argenson JN, Parratte S, Bertani A, Flecher X, Aubaniac JM. Long-term results with a lateral unicondylar replacement. Clin Orthop Relat Res. 2008;466(11):2686–93. Epub 2008/06/25.

Revision of Partial Knee Arthroplasty

12

Giles R. Scuderi, Lisa Renner, Clemens Gwinner, Philipp von Roth, and Carsten Perka

Reason for Revision

The main causes of unicompartmental knee arthroplasty (UKA) failure include aseptic loosening, tibial polyethylene wear, progression of osteoarthritis (OA) in the other compartments of the knee, periprosthetic fracture, bearing dislocation in mobile-bearing designs, impingement, arthrofibrosis with limited motion, infection, and unexplained pain [1–7]. The type of treatment is chosen on an individual basis and depends on the underlying cause, physical examination, and radiological findings. Clinical and radiographic evaluation should clearly define the etiology of failure prior to revision surgery.

Unexplained Pain

The prevalence of postoperative unexplained pain continues to cause considerable controversies, yet it is reported to occur more often after UKA than after TKA [8]. Even though most surgeons might know that pain is rather a symptom than a cause for failure, the most common reason for revision of UKA is still "unexplained pain." Without a definitive reason for failure, a revision UKA has a very high risk for persisting pain with the following TKA [9].

Revision UKA should not be performed

in case of "unexplained pain."

In cases of unexplained pain, magnetic resonance imaging can serve as a supplemental diagnostic imaging modality, as OA progression might be underrated in plain radiographs [10]. A diagnostic arthroscopy with direct visualization of the adjacent compartments, aspiration of joint fluid with leucocyte count, and synovial biopsies can complete the work-up for unexplained pain after UKA. In addition, psychosocial factors, chronic pain syndrome in history, causalgia (reflex sympathetic dystrophy), radiculopathia, neuroma, and neuropathia should be excluded.

Aseptic Loosening

Younger age, obesity, and residual varus deformity have been identified as risk factors

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for aseptic loosening or subsidence of UKA [6]. Aseptic loosening has been identified with component malalignment, undercorrection of the preoperative deformity, excessive posterior tibial slope, anterior cruciate ligament instability, and tibial polyethylene wear. Asymmetric loading of the tibial polyethylene may produce polyethylene debris that can lead to osteolysis resulting in bone loss with femoral and/or tibial component loosening and subsidence. Cementless fixation with limited or fibrous ingrowth has resulted in femoral component loosening (Fig. 12.1).

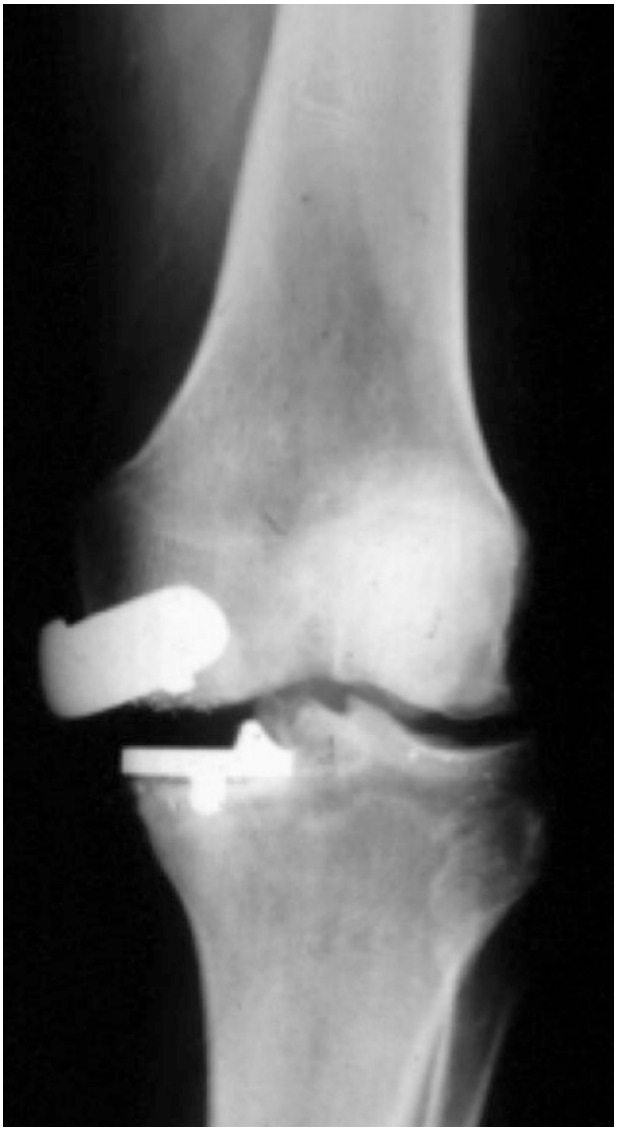

Fig. 12.1 AP radiograph of uncemented femoral component loosening with displacement of the femoral component

Radiographic analysis for aseptic loosening will reveal change in component position or bone resorption adjacent to either the femoral or tibial components. Deep tibial resection is also a risk factor for aseptic loosening, because the tibial head loose bone strength forms proximal to distal. Treatment for aseptic loosening requires conversion to total knee arthroplasty (TKA) with components that will augment the resultant bone loss.

Progression of Osteoarthritis

Progression of osteoarthritis in the contralateral compartment or the patellofemoral joint is a common cause of failure in UKA [2]. Overcorrection of the limb alignment with UKA will cause degenerative changes in the contralateral compartment. Degenerative changes of the patellofemoral joint may occur in the presence of an oversized and/or malrotated femoral component with impingement with the patella (Fig. 12.2).

Radiographic evaluation for progression of OA will reveal contralateral or patellofemoral joint space narrowing, osteophyte formation, joint space narrowing, and subchondral sclerosis. Treatment for progression of OA may be addressed with isolated replacement of the newly involved compartment or preferably conversion to TKA.

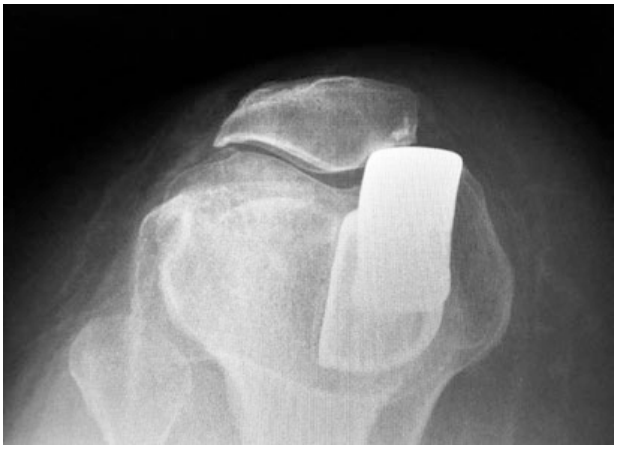

Fig. 12.2 Merchant view showing oversized femoral component with impingement of the medial facet of the patella

Polyethylene Wear

Polyethylene wear is more common with fixed-bearing UKA and is associated with component malposition, component malrotation, undercorrection of the preoperative deformity, quality and processing of the polyethylene, and thickness of the tibial polyethylene <6 mm in modular components. If the polyethylene wear occurs with components that are well fixed and appropriately aligned with no evidence of osteolysis or metallosis, related to complete polyethylene wear-through, then a new modular tibial insert can be placed. However, in most cases there are contributing factors that have caused polyethylene wear, so conversion to TKA is the most common procedure for tibial polyethylene wear.

Periprosthetic Fracture

Periprosthetic fractures are rare but commonly occur at the tibial plateau beneath the tibial component and can be related to multiple pin holes created during placement of the tibial cutting guide, osteolysis, and bone resorption beneath the tibial component related to polyethylene wear or direct trauma [11]. If the tibial component is well fixed and in appropriate alignment, osteosynthesis and fracture management may be appropriate. However, if the fracture is associated with component loosening, malalignment, or bone loss due to osteolysis, conversion to TKA is recommended.

Periprosthetic femoral condyle fractures are an even rarer occurrence but may occur intraoperatively during impaction of the femoral component or late due to femoral osteolysis. Intraoperative femoral condylar fractures may be treated with internal fixation if the femoral component is well fixed and in appropriate position. If the component is associated with component loosening or malalignment, then conversion to TKA is recommended.

Bearing Dislocation

Bearing dislocation is a complication of mobile-bearing UKA and could be related to component malposition, unbalanced flexion and extension gaps, impingement of the mobile-bearing insert, or instability [1]. With a medial mobile-bearing UKA, the medial collateral ligament (MCL) is an important stabilizing structure. MCL release during the initial procedure or late injury may result in medial instability with the possibility of bearing dislocation. Bearing dislocation has also been associated with component loosening. Bearing dislocation in lateral UKA is due to laxity of the lateral collateral ligament in flexion. Treatment of bearing dislocation may be treated with bearing exchange to a thicker bearing or conversion to TKA.

Arthrofibrosis

Limited range of motion following UKA is lower than TKA but has been associated with overstuffing the flexion and extension gaps, femoral and tibial component impingement, or patellofemoral impingement. If the components are appropriately sized and positioned, postoperative arthrofibrosis within the first six weeks may be addressed with manipulation under anesthesia. Hereinafter, arthroscopic lysis of adhesions should be conducted. When the components are malpositioned or oversized with femoral-tibial or patellofemoral impingement, then conversion to TKA may be necessary.

Infection

The incidence of infection following UKA is lower than after TKA. In the event of an acute infection, irrigation and debridement with intravenous antibiotic therapy may be considered [12]. However, with cases of failed irrigation and debridement or in cases of chronic infection, two-stage revision with insertion of antibiotic spacer, intravenous antibiotic therapy, and conversion to TKA is recommended.

Patient Preparation (Scuderi)

An extensive preoperative evaluation should be performed prior to revision including physical examination, radiographs, serology, and

aspiration, especially if infection is suspected. Bone scintigraphy is not a reliable study to determine loosening or infection in the first 2 years after UKA [9]. Conversion of a failed UKA to TKA could be a technically difficult procedure depending on the mode of failure. Preoperative planning is mandatory with attention directed toward exposure, component removal, implant choice, ligament integrity, and management of bone defects, when considering conversion of UKA to TKA. While primary components may be utilized in selective cases with minimal bone loss, revision components with metal augments and stem extensions should be available for cases with significant bone loss.

Radiographic Evaluation of Painful UKA

Coronal alignment of the femoral and tibial components can be evaluated on short AP radiographs or long-leg AP radiographs that include the hip, knee, and ankle. The reliability of short AP radiographs has been questioned because patient positioning, deformity of the limb, and flexion contracture can influence accurate measurements and evaluation [13]. However, in clinical practice, short AP radiographs usually surface to determine component alignment and radiolucent lines.

Femoral or tibial component loosening on radiographic evaluation includes component migration, fracture of the cement mantle, or a progressive and complete radiolucent line adjacent to the component. The incidence of radiolucent lines increases with longer follow-up [14]. Incidental radiolucent lines may be noted in asymptomatic patients. However, patients with radiographic evidence of loosening, progressive radiolucent lines, and persistent pain usually require surgical intervention with conversion of the UKA to TKA. Polyethylene wear or tibial component subsidence may be observed with change in limb alignment noted on an AP radiograph.

The difficulty in evaluating radiolucent lines, suggestive of loosening, on radiographs sometimes necessitates fluoroscopic-guided radiographs [13]. When fluoroscopy is not available, Monk et al. have described a technique for the diagnosis of femoral component loosening using accurately aligned lateral radiographs in extension and flexion. If radiolucent lines or gaps are present between the component and cement on one radiograph and not on the other, the femoral component is loose [15].

On the AP radiograph, the tibial component should be flush with the tibial cortex, since overhang can cause soft tissue impingement and pain, while inadequate bone coverage can cause subsidence of the component [16]. With medial UKA, the tibial component should also be just medial to the apex of the tibial spine. On the lateral radiograph, the tibial component should reach the posterior tibial cortex.

Radiographic evaluation will also reveal progression of osteoarthritis in the contralateral compartment or the patellofemoral joint. Osteoarthritis is classified according to the degree of joint space narrowing, subchondral sclerosis, osteophyte formation, and joint alignment.

Process Optimization in Perioperative Management

There is great potential for process optimization in perioperative management in the revision UKA. Most techniques have been intentionally established for primary TKA but were also been proven for revision of TKA. However, these therapeutic options have not been established specifically for revision of UKA. However, since the level of pain, blood loss, and postoperative rehabilitation of revision of UKA is very similar to primary TKA and simple revision of TKA, several therapeutic options can help in achieving an optimal outcome for patients undergoing revision UKA. By applying local infiltration anesthesia, an efficient optimization of pain therapy is possible [17]. The standardized use of tranexamic acid is a proven coagulation therapy with resulting reduction of swelling and hematoma formation [18, 19]. This results in a further postoperative pain reduction and better rehabilitation. The use

of a tourniquet can be limited to the time of cementing in order to reduce substantial muscle damage [20].

Common Surgical Errors Leading to Failure (Scuderi)

Medial UKA

While patient selection plays an important role in the outcome of unicompartmental knee arthroplasty, accurate surgical technique is critical to a successful result. Errors in surgical technique can lead to early failure [21]. The postoperative tibiofemoral angle is an important factor impacting the prognosis. Malalignment of the femoral and or tibial component has been found to lead to early failure, especially if the tibiofemoral angle is greater than 3° of varus or greater than 7° of valgus following a medial UKA [22].

Fracture of the medial tibial plateau or medial metaphysis may occur with inaccurate placement of the tibial component [23]. In resecting the medial tibia, care should be taken not to undercut the eminence of the tibial spine since this may lead to fracture and avulsion of the tibial eminence with the ACL. The sagittal tibial resection should also not extend deeper than the coronal resection since this may lead to fracture of the tibial metaphysis.

Lateral UKA

Overcorrection of a valgus deformity to varus with a lateral UKA should be avoided since this will cause overload of the medial compartment and development of medial arthritis. The natural divergence of the lateral femoral condyle in flexion should be taken into consideration to avoid impingement of the tibial spine in extension [24]. Care should be taken to avoid excessive tibial slope when resecting the lateral tibial plateau, since it will affect ligament balancing. The tibial component should be internally rotated 15–20o on the sagittal plane and aligned with the natural posterior slope [24].

Surgical Technique (Roth/Perka)

Revision Strategies

In every painful or failed partial knee arthroplasty, infection has to be ruled out first in order to set a one- vs. two-stage procedure. Compared to revision of total knee arthroplasty, there is less literature on the revision strategies for aseptically failed partial knee arthroplasty. Most authors consider that changing a partial knee arthroplasty to a total knee arthroplasty is technically less demanding compared to the revision of a total knee arthroplasty [25]. Nevertheless, due to the femoral and—in particular—tibial bone defects and potential ligamentous insufficiencies, the revision of a partial knee arthroplasty can be a technically demanding intervention that should be left to the more experienced knee surgeon, to whom all possible treatment options are available. In most cases, partial knee arthroplasty can be revised to a total knee arthroplasty. In principle, these are the following surgical strategies:

- Revision with retention of the metal components (e.g., early infection; isolated wear with good alignment, correct rotation, and stable ligaments)
- Revision of a partial knee to a partial knee
- Revision to a total knee arthroplasty with a cruciate-retaining or cruciate-scarifying design
- Revision to stemmed total knee arthroplasty with a higher constraint (e.g., condylar constrained, rotating or full hinge)

Several studies analyzed the revision of a partial knee arthroplasty to a partial knee arthroplasty. The reason for revision for that strategy might be a dislocated inlay or an isolated loosened femoral or tibial component. However, it has been shown that this procedure is associated with a three- to fourfold increased re-revision rate [26–28]. So it seems to be very difficult to detect the requirements for this strategy.

The most frequently performed procedure is the revision to a total knee arthroplasty with a cruciate-retaining or cruciate-scarifying design.

Only in rare cases partial knee arthroplasty has to be revised to a rotational of full hinge: according to Khan et al., 15 (8%) of 201 partial knee arthroplasties were revised to a hinged system [29]. The choice of implant is mainly driven by the extent of the bone defect after removal of the implants and on the ligamentous situation. The reason for the choice of a hinge is mostly the damaged MCL due to deep tibial resection [30].

Approach and Exposure

In case of a failed medial or patellofemoral partial knee arthroplasty, the choice of the approach is usually an easy decision, and the existing approach can be used. In contrast, a failed lateral partial knee arthroplasty might result in a more demanding revision through the lateral approach. As the vascular supply of the periarticular soft tissues arises from the medial aspect of the joint, the most lateral of the existing incisions should be used. Therefore, the revision surgeon should be familiar with both the medial (including mid- and subvastus approach) and lateral approach including their options for extension. After skin incision, the joint is recommended to be opened via a standard medial (or lateral) parapatellar capsulotomy. Next, the tibial plateau has to be exposed via subperiosteal dissection of the deep layer of the medial collateral ligament. For a better exposition, the tibial head can now be put in external rotation and be partially dislocated anteriorly. Next, the cement bone interface has to be clearly dissected.

Implant Removal

Even in case of well-fixed implants, the removal of the components can be easily achieved by using different sizes and thicknesses of chisels, a burr, an oscillating saw, or a manual Gigli saw. The most important focus of the process of implant removal is the preservation of the bone stock. A sufficient debridement of the intraarticular soft tissues is mandatory in order to remove polyethylene wear, remaining cement (polymethylacrylate), and bone fragments. All necrotic or granulomatous tissue has also to be removed. In case of doubt, frozen sections or intraoperative test for infection like the alpha-defensin immunoassay and leukocyte esterase colorimetric strip test can be performed in order to rule out a periprosthetic infection [31]. The cement should be broken in a mosaic-like pattern with small chisels and removed.

Recreation of the Tibia

Relevant bone loss is usually only a problem on the tibial side. The tibial resection at the level where the medial component was placed should be avoided, and the remaining defect should be augmented. In principle, epiphyseal defects (up to 5 mm) can be restored by cement or autologous bone. For all defect reconstruction strategies, a tibial stem extension is recommended (Fig. 12.3).

However, one should keep in mind a varus deviation after medial (or valgus after lateral) partial knee arthroplasty of the final implant during impaction. Bone defects ranging from 5 to 8 mm can be treated with autologous bone from the lateral plateau and be protected with a short tibial stem extension (e.g., 30 mm). Defects measuring more than 8 mm should be reconstructed with metal augments or wedges. Again, a tibial stem is recommended by most authors (Fig. 12.4).

The restoration of the joint should be initiated with the tibia as the fundament. The recreation of the joint line in revision of partial knee arthroplasty is usually less demanding than in revision of total knee arthroplasty. Some authors recommend using the height of the patella (distance proximal edge of tibial tuberosity to the joint line 22 mm) or the fibular head (distance tip of the fibular head to the lateral joint line 14 mm) [32]. As the distances of the tibial tuberosity to the patella and of the fibular head to the lateral joint line show a pretty wide range (patella 10–33 mm, fibular head 4–22 mm), most surgeons prefer the distance of 1/3 of the transepicondylar axis (TEA) distally to the TEA [33]. In revision of partial knee arthroplasty, the basis of

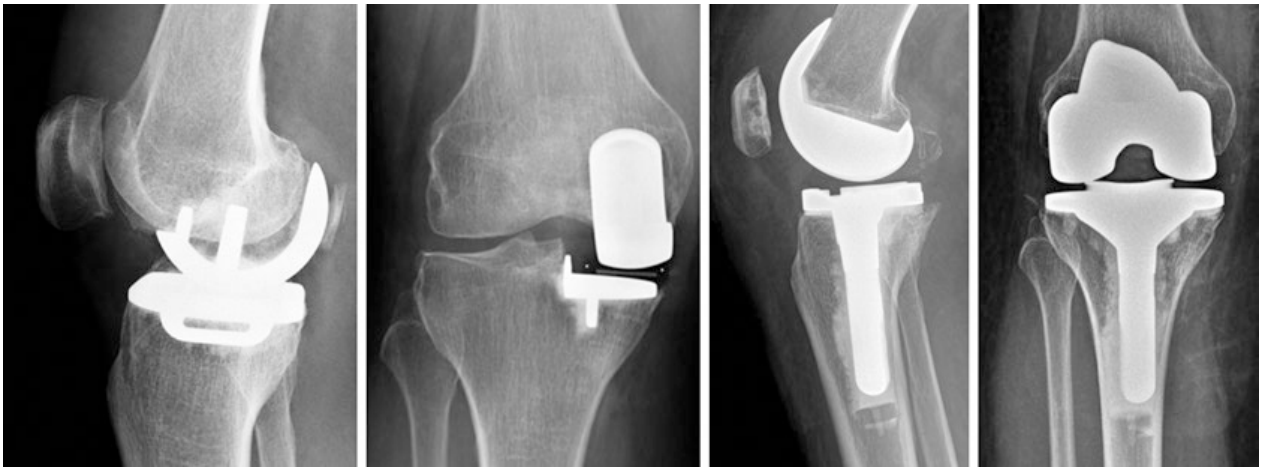

Fig. 12.3 Failed partial knee arthroplasty due to overcorrection and resulting in malalignment of the femoral component and consecutive partial dislocation of the mobile inlay with soft tissue impingement. After resection of the lateral plateau, the defect of the medial plateau measured 2 mm. The revision was performed via an augmentation of the medial defect with cement and a short tibial stem extension

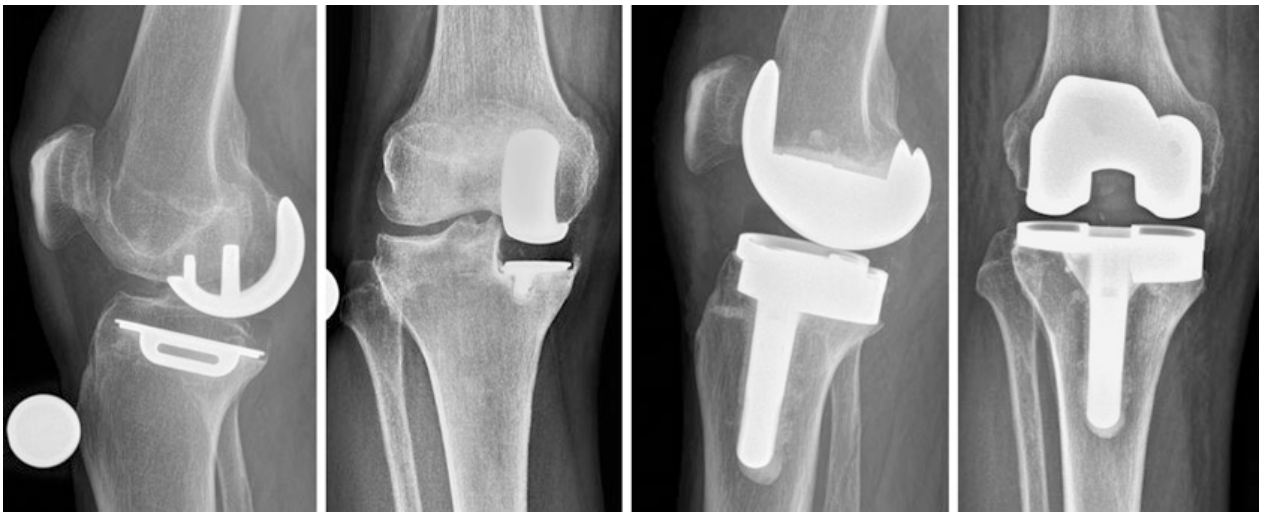

Fig. 12.4 Failed partial knee arthroplasty due to aseptic loosening of the tibial component. After removal of the implant and resection of the lateral plateau, the defect of the medial plateau measured 10 mm. The revision was performed with a metal augment and a short tibial stem extension

the lateral (or medial) meniscus is also a helpful indicator for the correct restoration of the joint line (Fig. 12.5).

Most authors prefer setting the rotation related to the medial third of the tibial tuberosity. From a functional point of view, the second toe in a 90° flexed ankle is another very often used option. If the coverage of the tibial plateau can only be achieved with a suboptimal orientation of the tibial component with regard to the bony landmarks, a rotating platform may help setting both a good coverage and an adequate rotation via the mobile inlay.

Recreation of the Femur

After removal of the femoral component, a bone defect may be present in the distal or/and posterior aspect of the condyle. In most cases, the impaction of autologous bone from the contralateral bony resection in combination with a short femoral stem extension (e.g., 30 mm) solves the problem. If the defect exceeds 5 mm, the metal augments and wedges in various sizes are available in the majority of revision systems.

After having prepared the tibial component, the flexion gap should be prepared first. The first

step is setting the correct rotation of the future femoral component. Putting a chisel between the medial femoral condyle and the component sizer can help in avoiding excessive internal rotation (Fig. 12.6).

After having set the rotation, the size of the flexion gap has to be checked. In case of a large flexion gap, one should consider using the largest acceptable femoral component and/or metal augments for the posterior condyle.

After having prepared the flexion gap, the resection of the distal femur can be performed in a way that the extension gap meets the size of the prepared flexion gap. One has to keep in mind that the change of the joint line has a negative influence on future knee flexion. According to the study of Kowalczewski et al., the change of the joint line should not exceed 4 mm [34].

After having finalized balancing, the flexion and extension gap trial implants should be used in order to check mediolateral stability over the full range of motion and patellofemoral tracking. In case of remaining instability, the threshold using an implant with a higher constraint should be very low as the most common reason for revision of total knee arthroplasty is instability [35].

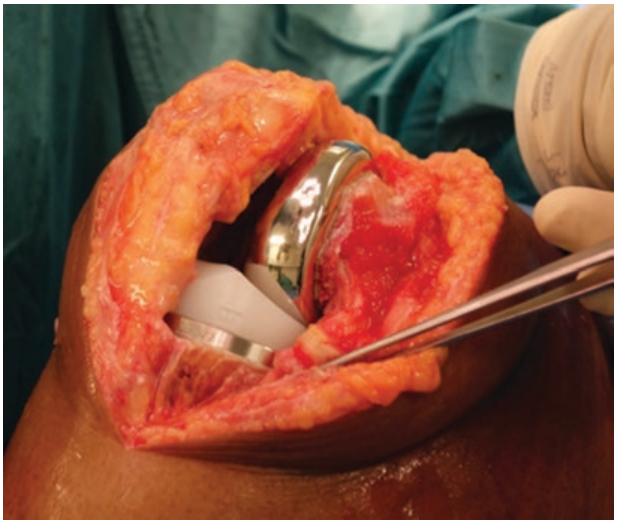

Fig. 12.5 As in TKA the basis of the meniscus can be a helpful indicator for checking the correct restoration of the joint line

Level of Constraint

The level of constraint following conversion of UKA to TKA is dependent upon the integrity of the collateral ligaments and posterior cruciate ligaments. In most cases, the medial and lateral collateral ligaments are intact, and either a cruciate-retaining or posterior-stabilized primary implant can be implanted depending upon the surgeon preference. If there is a deficiency of the ipsilateral collateral ligament, instability, or inability

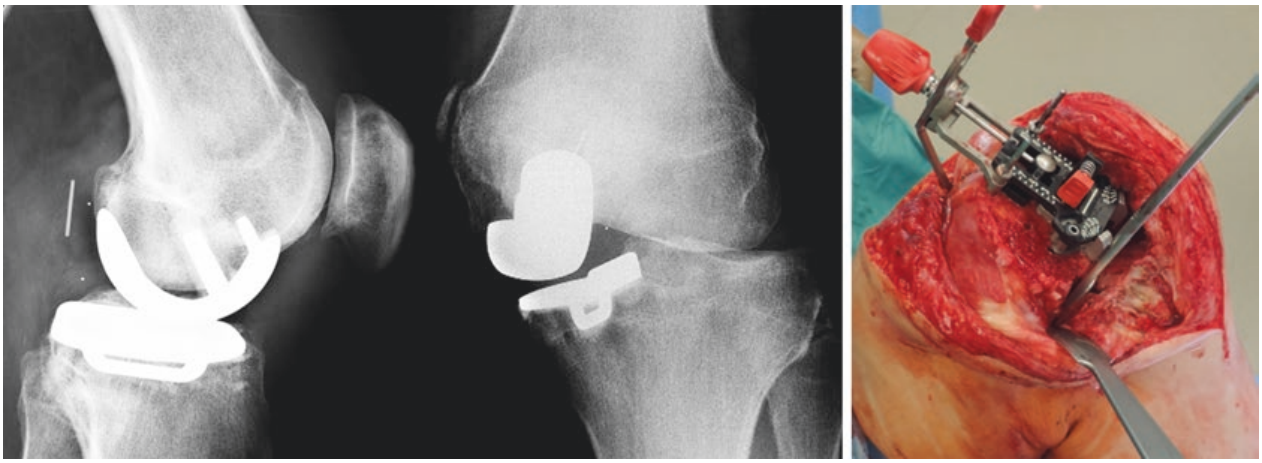

Fig. 12.6 The patient suffered recurred posterior dislocation of the inlay of the mobile-bearing partial knee arthroplasty. In order to avoid excessive external rotation of the femoral component, a chisel was put between the femoral condyle and the component sizer

to balance the flexion-extension gaps, a constrained implant should be implanted following the principles of revision of TKA [36].

Clinical Result of Revision

One of the main rationales for UKA is the idea of an easier revision than revision of TKA and subsequently comparable function to a primary TKA [37, 38]. Until recently the literature regarding outcome of revision of UKA is characterized by small retrospective studies, short-term follow-up, and data collected by designing surgeons. Therefore, significant clinical results of revision may be not really predictable. Furthermore "success" of revision is defined differently: time to re-revision, change in pain, range of motion, outcome scores, or bony defects, just to mention a few of them. First clinical results were already published in 1987 by Barrett et al. [39] examining 29 UKA which were revised to a TKA with a follow-up of 4.6 years showing acceptable results while emphasizing the need for bone grafts and long stems in revision. As several studies have been conducted on implants, which are either withdrawn from the market or have been changed significantly in its design, this may no longer represent clinical reality.

However, recently published literature give us an idea of clinical results of outcome of revision. Data from national [26, 27] and local [28] registries, controlled trials [40, 41], as well as larger case series show results for some of the outcome parameters compared to primary TKA and revision of TKA.

Re-revision Rate

Pearse et al. [26] investigated over 4000 UKA from the New Zealand Joint Registry of which 236 required a revision. Most of them were revised to a TKA; however, 31 were revised to another UKA (complete exchange). Compared to *primary* TKA, re-revision rate of TKR after UKR (uni to total, U2T) was four times higher and even 13 times higher in patients who were revised to another UKR (uni to uni, U2U). Data from the Australian Orthopaedic Association National Joint Replacement Registry including 1948 revision show a significant higher re-revision rate for U2U compared to U2T regardless if only the insert was changed or the complete arthroplasty was changed (revision for infection was excluded in this analysis) [27]. U2T has a cumulative percent revision of 15 at 5 years which is comparable for re-revision rate of a TKA where both components were exchanged – however, it is not equal to revision rate of primary TKA which is significantly lower at that point of time.

Functional Outcome/Pain/Patient Satisfaction

Whereas primary UKA tend to have better functional results than primary TKA, UKA revised to TKA show a significantly worse outcome [26]. The mean Oxford knee score after revised UKA resembles that after revised TKA. The Knee Society score and subjective assessment (WOMAC score) show statistically significant differences between patients after primary TKA and TKA after UKA [42]. This stays consistent in long-term follow-up after 10 years measured with the WOMAC [41].

The reason for revision may be an important factor for satisfaction in revision of surgery for UKA [9]. Patients who undergo revision for unknown pain are prone to have a persistent pain and may not experience a profound improvement. This may be especially important before planning a revision and getting informed consent with the patient.

Bone Loss/Complexity

Already in 1991, Padgett et al. [43] found major osseous defects in about two thirds of his patients during revision; however, revision of UKA is accompanied with less bony defects as revision of TKA [28]. Depending on the reference, in only 50% of revisions, the use of a "primary" TKA (no augments,

no stems, no bone grafts) is possible [28, 40]. The height of polyethylene inlay tends to be thicker than in primary TKA [42]. Tibial augments are required more frequently in UKA with mobile bearing than fixed bearing, hinting at a different wear pattern of the bearing type; however, overall difficulty of surgery was considered similar for both implants [44].

Costs

Compared to revision of TKA, revision of UKA costs less due to lower implant costs [28]. However, it can assumed that in the light of a shorter survival of UKA, overall cost savings for primary UKA are outweighed by prices for earlier revision [45].

Despite promising clinical results, TKA after revision of a UKA is not comparable to primary TKA. In the clinical practice, the following facts and recommendation should be present:

- Clinical outcome after revision of UKA may be poorer than primary TKA.
- A failed UKA should not be revised to another UKA.
- Reason for revision influences the outcome of revision with unexplained pain resulting in less satisfied patients.
- Revision of a UKA may end up with bony defects and instability – therefore stems, augments, and revision arthroplasties should be available at any point.

Literatures

1. Pandit H, et al. The clinical outcome of minimally invasive phase 3 Oxford unicompartmental knee arthroplasty: a 15-year follow-up of 1000 UKAs. Bone Joint J. 2015;97-B(11):1493–500.
2. Vasso M, et al. Minor varus alignment provides better results than neutral alignment in medial UKA. Knee. 2015;22(2):117–21.
3. Argenson JN, Parratte S. The unicompartmental knee: design and technical considerations in minimizing wear. Clin Orthop Relat Res. 2006;452:137–42.
4. Dyrhovden GS, et al. Have the causes of revision for total and unicompartmental knee arthroplasties changed during the past two decades? Clin Orthop Relat Res. 2017;475(7):1874–86.
5. Springer BD, Scott RD, Thornhill TS. Conversion of failed unicompartmental knee arthroplasty to TKA. Clin Orthop Relat Res. 2006;446:214–20.
6. Kim KT, et al. Analysis and treatment of complications after unicompartmental knee arthroplasty. Knee Surg Relat Res. 2016;28(1):46–54.
7. Foran JR, et al. Long-term survivorship and failure modes of unicompartmental knee arthroplasty. Clin Orthop Relat Res. 2013;471(1):102–8.
8. Baker PN, et al. Revision for unexplained pain following unicompartmental and total knee replacement. J Bone Joint Surg Am. 2012;94(17):e126.
9. Kerens B, et al. Revision from unicompartmental to total knee replacement: the clinical outcome depends on reason for revision. Bone Joint J. 2013;95-B(9):1204–8.
10. Park CN, et al. Role of magnetic resonance imaging in the diagnosis of the painful unicompartmental knee arthroplasty. Knee. 2015;22(4):341–6.
11. Van Loon P, de Munnynck B, Bellemans J. Periprosthetic fracture of the tibial plateau after unicompartmental knee arthroplasty. Acta Orthop Belg. 2006;72(3):369–74.
12. Labruyere C, et al. Chronic infection of unicompartmental knee arthroplasty: one-stage conversion to total knee arthroplasty. Orthop Traumatol Surg Res. 2015;101(5):553–7.
13. Sarmah SS, et al. The radiological assessment of total and unicompartmental knee replacements. J Bone Joint Surg Br. 2012;94(10):1321–9.
14. Tanavalee A, Choi YJ, Tria AJ Jr. Unicondylar knee arthroplasty: past and present. Orthopedics. 2005;28(12):1423–33. quiz 1434-5.
15. Monk AP, Keys GW, Murray DW. Loosening of the femoral component after unicompartmental knee replacement. J Bone Joint Surg Br. 2009;91(3):405–7.
16. Chau R, et al. Tibial component overhang following unicompartmental knee replacement--does it matter? Knee. 2009;16(5):310–3.
17. Hu B, et al. Local infiltration analgesia versus regional blockade for postoperative analgesia in total knee arthroplasty: a meta-analysis of randomized controlled trials. Pain Physician. 2016;19(4):205–14.
18. Smit KM, et al. One dose of tranexamic acid is safe and effective in revision knee arthroplasty. J Arthroplast. 2013;28(8 Suppl):112–5.
19. Samujh C, et al. Decreased blood transfusion following revision total knee arthroplasty using tranexamic acid. J Arthroplast. 2014;29(9 Suppl):182–5.
20. Pfitzner T, et al. Influence of the tourniquet on tibial cement mantle thickness in primary total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2014;24:96–101.
21. Fehring TK, et al. Early failures in unicondylar arthroplasty. Orthopedics. 2010;33(1):11.
22. Perkins TR, Gunckle W. Unicompartmental knee arthroplasty: 3- to 10-year results in a community hospital setting. J Arthroplast. 2002;17(3):293–7.
23. Ji JH, et al. Complications of medial unicompartmental knee arthroplasty. Clin Orthop Surg. 2014;6(4):365–72.

24. Kim KT, et al. Clinical results of lateral unicompartmental knee arthroplasty: minimum 2-year follow-up. Clin Orthop Surg. 2016;8(4):386–92.
25. Marmor L. Unicompartmental knee arthroplasty. Ten-to 13-year follow-up study. Clin Orthop Relat Res. 1988;226:14–20.
26. Pearse AJ, et al. Survival and functional outcome after revision of a unicompartmental to a total knee replacement: the New Zealand National Joint Registry. J Bone Joint Surg Br. 2010;92(4):508–12.
27. Hang JR, et al. Outcome of revision of unicompartmental knee replacement. Acta Orthop. 2010;81(1):95–8.
28. Dudley TE, et al. Registry outcomes of unicompartmental knee arthroplasty revisions. Clin Orthop Relat Res. 2008;466(7):1666–70.
29. Khan Z, et al. Conversion of unicompartmental knee arthroplasty to total knee arthroplasty: the challenges and need for augments. Acta Orthop Belg. 2013;79(6):699–705.
30. Maes M, Luyckx T, Bellemans J. Does a conservative tibial cut in conventional total knee arthroplasty violate the deep medial collateral ligament? Knee Surg Sports Traumatol Arthrosc. 2014;22(11):2735–9.
31. Wyatt MC, et al. The alpha-defensin immunoassay and leukocyte esterase colorimetric strip test for the diagnosis of periprosthetic infection: a systematic review and meta-analysis. J Bone Joint Surg Am. 2016;98(12):992–1000.
32. Servien E, et al. Reliability of bony landmarks for restoration of the joint line in revision knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2008;16(3):263–9.
33. Ozkurt B, et al. The medial and lateral epicondyle as a reliable landmark for intra-operative joint line determination in revision knee arthroplasty. Bone Joint Res. 2016;5(7):280–6.
34. Kowalczewski JB, et al. Does joint line elevation after revision knee arthroplasty affect tibio-femoral kinematics, contact pressure or collateral ligament lengths? An in vitro analysis. Arch Med Sci. 2015;11(2):311–8.
35. Thiele K, et al. Current failure mechanisms after knee arthroplasty have changed: polyethylene wear is less common in revision surgery. J Bone Joint Surg Am. 2015;97(9):715–20.
36. Scuderi GR. Revision total knee arthroplasty: how much constraint is enough? Clin Orthop Relat Res. 2001;392:300–5.
37. Johnson S, Jones P, Newman JH. The survivorship and results of total knee replacements converted from unicompartmental knee replacements. Knee. 2007;14(2):154–7.
38. Newman J, Pydisetty RV, Ackroyd C. Unicompartmental or total knee replacement: the 15-year results of a prospective randomised controlled trial. J Bone Joint Surg Br. 2009;91(1):52–7.
39. Barrett WP, Scott RD. Revision of failed unicondylar unicompartmental knee arthroplasty. J Bone Joint Surg Am. 1987;69(9):1328–35.
40. Chou DT, et al. Revision of failed unicompartmental knee replacement to total knee replacement. Knee. 2012;19(4):356–9.
41. Jarvenpaa J, et al. The clinical outcome of revision knee replacement after unicompartmental knee arthroplasty versus primary total knee arthroplasty: 8-17 years follow-up study of 49 patients. Int Orthop. 2010;34(5):649–53.
42. Becker R, John M, Neumann WH. Clinical outcomes in the revision of unicondylar arthroplasties to bicondylar arthroplasties. *A matched-pair study*. Arch Orthop Trauma Surg. 2004;124:702–4.
43. Padgett DE, Stern SH, Insall JN. Revision total knee arthroplasty for failed unicompartmental replacement. J Bone Joint Surg Am. 1991;73(2):186–90.
44. Bloom KJ, et al. The effects of primary implant bearing design on the complexity of revision unicondylar knee arthroplasty. J Arthroplast. 2014;29(1):106–9.
45. Koskinen E, et al. Comparison of survival and cost-effectiveness between unicondylar arthroplasty and total knee arthroplasty in patients with primary osteoarthritis: a follow-up study of 50,493 knee replacements from the Finnish arthroplasty register. Acta Orthop. 2008;79(4):499–507.

13 Robotic-Assisted Unicompartmental Knee Arthroplasty

Andrew Battenberg, Sébastien Parratte, and Jess Lonner

Introduction

Unicompartmental arthroplasty (UKA) has been shown to be a highly effective treatment for isolated compartmental arthritis and focal osteonecrosis of the knee [1]. A recent systematic review reported 92% 10-year survivorship for medial UKA [2]. Despite reports of excellent outcomes, functionality, and survivorship from high-volume surgeons, higher revision rates and decreased survivorship of UKA have been demonstrated in lower-volume surgeons [3]. Epinette et al. performed a multicenter study analyzing 418 failed UKAs and found that 19% of revisions occurred within the first year and 48.5% within the first 5 years, with loosening being the main reason for failure, accounting for 45% of revisions [4]. Technical problems, including faulty implantation and inadequate positioning of the components, accounted for 11.5% of failures [4].

Achieving consistently accurate alignment in UKA is difficult using conventional approaches [5–8]. Component positioning beyond 2° of the desired alignment may occur in as many as 40–60% of cases with conventional techniques [8, 9]. There is considerable variability in tibial component varus, tibial slope, and overall limb alignment even in the hands of skilled and experienced skilled surgeons [5]. The issue is exacerbated with use of minimally invasive surgical technique [6, 7, 10]. In a study of 221 consecutive UKAs using an MIS approach, the tibial component average is 6° of varus (standard deviation ±4°) with a range of 18° varus to 6° valgus [7]. Unlike TKA, which can accommodate variability in component alignment, small errors in alignment may predispose to failure [5, 7, 11, 12].

Robotic technology has been advanced with the goal of increasing surgical precision, improving component and limb alignment, optimizing soft tissue balance, and ultimately reducing revision rates due to technical errors [13]. Although adoption of robotics in joint arthroplasty has been gradual, robotic technology is being used in 15–20% of UKA performed in the United States [14] with projections that more than 35% of UKAs will be performed with robotic assistance within 10 years [15]. Likewise, growing interest in and technological advancement of robotic technologies are further manifested by recent increases in patent activity and the number of peer-review publications related to this sector [16].

This chapter gives an overview of the two contemporary semiautonomous robotic technologies

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used in UKA, early radiographic and clinical outcomes, potential drawbacks of robotic UKA, and future directions of robotics.

Current Designs of Robotic UKA

The concept of robotics is relatively new in orthopedic surgery with the first robotic-assisted surgery – a total hip arthroplasty – performed in 1992 using the Robodoc autonomous system [17]. There is a distinction between autonomous robotic systems and the semiautonomous systems discussed in this chapter. Autonomous systems involve pre-programming the system with parameters that define the amount and orientation of bone resection, which the autonomous system completes independent of surgeon control [18]. The one current autonomous robotic system (TSolution One, THINK Surgical Inc., Fremont, CA) is approved by the United States Food and Drug Administration for THA but not TKA or UKA. Semiautonomous systems involve the mapping of condylar landmarks and determination of alignment, which also define the amount and orientation of bone removal. The systems remove the bone within pre-established parameters and safe zones, but the tools are controlled by the surgeon with input from the robotic system.

Currently, there are two semiautonomous robotic systems that have both FDA approval in the United States and CE Mark approval in Europe for robotic-assisted UKA and TKA: (1) Mako (Stryker, Mahwah, NJ) and (2) Navio (Smith & Nephew, Memphis, TN). Both semiautonomous robotic devices are controlled and manipulated by the surgeon and augment the surgeon's movements to achieve the desired bony resections. However, they differ in their preoperative planning, intraoperative function, and safety mechanisms that prevent inadvertent bony preparation.

Mako

The Mako robotic arm first received US FDA clearance for use in UKA in November 2005, with a system modification approved by the FDA in December 2008. It is a semi-active tactile robotic arm that requires a preoperative CT scan as part of preoperative planning [19, 20] (Fig. 13.1). The preoperative CT is used to create a three-dimensional model to determine component sizing, positioning, and bone resection, which is then confirmed and adjusted intraoperatively based on the patient's specific kinematics. Intraoperatively, percutaneous pins are placed in the tibia and femur and are attached to optical arrays to determine the position of the limb in space. The knee is put through range of motion and the ligaments stressed, and a virtual plan is

Fig. 13.1 The Mako semi-active tactile robotic arm

created based on the soft tissue balance through that range if the components are positioned and oriented according to the plan. Further adjustments to the preoperative plan and templating can be made to achieve appropriate balance and limb alignment, before any bone resections are made.

The robotic arm and burr are directly controlled by the surgeon to make the bony resections. Haptic constraint provides tactile feedback beyond which movement of the burr is restricted, thus safeguarding against inadvertent bone removal.

Navio

The Navio is a lightweight handheld image-free robotic sculpting device that initially received CE Mark and US FDA clearance in February and December 2012, respectively [13] (Fig. 13.2). It combines image-free intraoperative registration, planning, and navigation with precise bone preparation and dynamic soft tissue balancing. The Navio system continuously tracks the position of the lower limb and the handheld burr, so that limb position can be adjusted constantly during surgery without compromising registration, accuracy, or safety. The ability to change position allows for improved exposure and the use of mobile windows to gain access to various parts of the knee and facilitates use of a minimally invasive surgical approach commonly utilized in UKA.

Similar to the Mako system, the Navio uses intraoperative optical tracking arrays for determining the position of the knee surfaces and limb in space. Percutaneous pins in the proximal tibia and distal femur are attached to the optical tracking arrays to intraoperatively establish mechanical and rotational axes of the limb, as well as the centers of the hip, knee, and ankle. The condylar anatomy is mapped by painting the surfaces with optical probes, and a virtual model of the knee is created. Because intraoperative mapping creates the model of the knee, preoperative CT scanning is not necessary. Varus and valgus stresses are applied, and three-dimensional positions are captured throughout knee range of motion

Fig. 13.2 The Navio handheld image-free robotic sculpting device with handpiece

(Fig. 13.3). Using a soft tissue balancing algorithm, implant sizes, position, and orientation are established virtually. Adjustments can be made to fine-tune soft tissue balance – including implant slope, rotation, alignment and depth of resection, and component translation.

Bony resection is made using a 5 or 6 mm handheld burr. The Navio's safeguard mechanism is a modulation of the exposure and speed of the burr, which further distinguishes the system from the haptic constraint mechanism of the Mako robotic arm (Fig. 13.4).

Fig. 13.3 Example of an intraoperative graphic demonstrating gap spacing through an entire range of motion

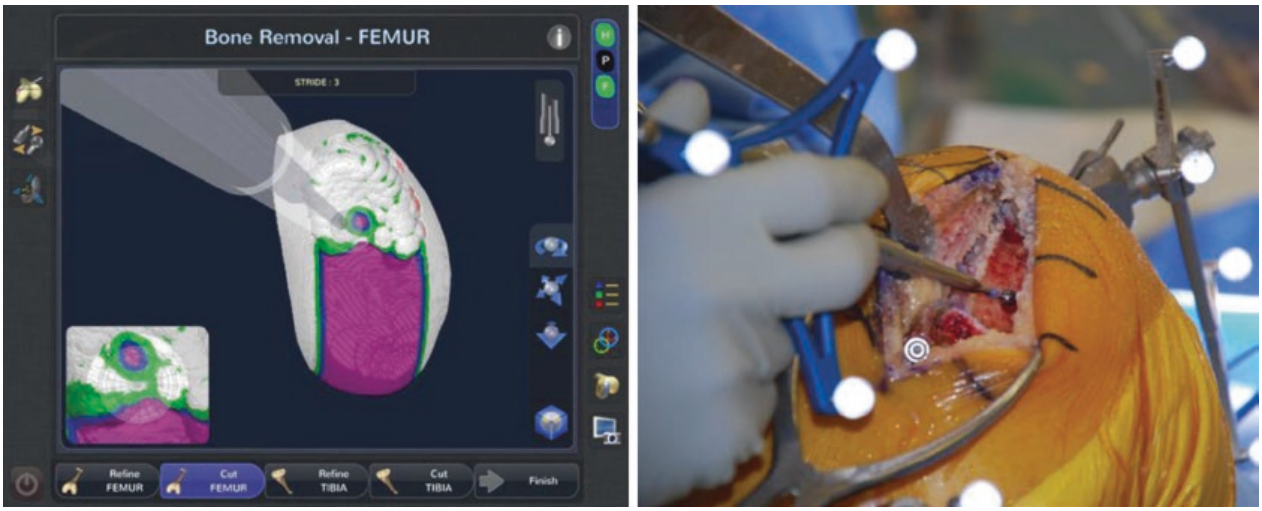

Fig. 13.4 Example of surgical bone removal prior to implantation with the Navio system

Accuracy and Clinical Outcomes of Robotic UKA

Accuracy, Alignment, Balance, and Kinematics

Most studies evaluating the potential role of robotic assistance in UKA have used accuracy of component placement and alignment as a surrogate measure of success. The majority have found that, compared to conventional methods, robotic-assisted UKA improves the accuracy of surgery, even through minimally invasive approaches [21–25, 29–32]. Furthermore, studies show that semiautonomous robotic systems are accurate in controlling the surgical variables they set out to control, resulting in execution of the preoperative and intraoperative plan, while helping eliminate outliers. Overall, accuracy and precision appear to be comparable between the image-based and imageless systems [18]. The relevant literature for each system is reviewed below.

Mako

Bell et al. performed the first prospective, randomized controlled trial of robotic vs conventional UKA in 120 patients (62 Mako UKAs and 58 conventional UKAs) [21]. Postoperative CT scans were used to demonstrate that robotic-assisted UKA resulted in lower RMS errors in all parameters for both the tibial and femoral components and that positioning in robotic-assisted UKA was within 2° of the target coronal, sagittal, and axial positions in a significantly higher percentage of patients compared to conventional techniques ($p < 0.02$ for all parameters).

Lonner and colleagues compared the senior surgeon's initial 31 patients who underwent robotic-assisted medial UKA using Mako to 27 patients that received medial UKA through a conventional approach, finding that the average root mean squared errors (RMSE) of the postoperative component placement compared to the preoperative plan were significantly reduced with use of robotics [22]. There was greater tibial slope accuracy (RMSE 1.9° robotic; 3.1° conventional) and 2.6 times less variance in the robotic cohort. The tibial component was also placed in more varus with conventional UKA (2.7°) than with robotic UKA (0.2° varus, $p < 0.001$).

Dunbar et al. measured the accuracy of Mako component positioning in 20 medial UKA patients using pre- and post-op 3D CT scans. The femoral component was within 0.8 mm and 0.9°, and tibial component was within 0.9 mm and 1.7° of the pre-op plan in all directions [23].

Pearle and colleagues measured mechanical axis accuracy in ten patients undergoing medial UKA using Mako and found that all mechanical axis parameters were within 1.6° of the preoperative plan [24].

In a cadaveric study, Citak et al. compared implant positioning of Mako vs conventional UKA and found RMS error for Mako-assisted UKA to be 1.9 mm and 3.7° for the femoral component and 1.4 mm and 5° for tibial component vs 5.4 mm and 10.2° and 5.7 mm and 19.2° using conventional techniques [25].

Plate and colleagues studied soft tissue balancing in 52 patients using the Mako system at 0°, 30°, 60°, 90°, and 110° of flexion. The authors found that ligament balancing was accurate up to 0.53 mm of the preoperative plan, with 83% of cases within 1 mm of the planned laxity throughout the full range of motion [26].

Though the previous studies demonstrate promising and fairly uniform results, not all studies have entirely favored robotic-assisted UKA. MacCallum et al. compared 177 conventional UKAs to 87 robotic-assisted Mako UKAs and found that tibial baseplate positioning was more precise in the coronal and sagittal planes for robot-assisted cases ($p < 0.001$). Robot-assisted cases were also noted to be 16.6 min longer than conventional cases [27]. A separate study by Hansen et al. compared 32 Mako UKAs to 32 conventional UKAs with over 2 years follow-up. Reproduction of the preoperative femoral axis was superior with robot assistance ($p = 0.013$), but there was no difference in recreation of tibial slope ($p = 0.409$) [28]. Similar to MacCallum et al., Hansen and colleagues found that the Mako system added a mean 20 min of tourniquet time compared to conventional UKA. Mako-assisted cases did clear physical therapy an average of

10.3 h earlier and had 8 h shorter length of stay in the study, but the reasoning for this observed difference is unclear.

Navio

Currently there are fewer published studies of Navio-assisted UKA, but early data suggests comparable results as the Mako system.

Smith et al. used Navio assistance on 20 synthetic knees (10 right, 10 left), finding angular RMSE ranging from 1.05 to 1.52 for the femoral component and 0.66 to 1.32 for the tibial component. Translational RMS errors averaged 0.61 mm with a maximum of 1.18 mm. Mean surface overcut was 0.14 mm for the femur and 0.21 mm for the tibia [29, 30]. In a follow-up study, Lonner and colleagues evaluated Navio's precision of bony preparation in 25 cadavers using the planned vs actual component position. The authors found RMS angular error was 1.42–2.34°, and RMS translational error was 0.92 mm–1.61 mm for the femoral component. For the tibial component, RMS angular error was 1.95–2.60°, and RMS translational error was 0.97 mm–1.67 mm [31].

Picard and colleagues studied 65 patients undergoing Navio-assisted medial UKA [32]. Full-length, double-stance, weight-bearing X-rays were used to measure pre- and postoperative alignment. Average preoperative alignment was 4.5° varus (range 0–12° varus), and average postoperative alignment was corrected to 2.1° (range 0–7° varus). The postoperative mechanical axis alignment was within 1° of the intraoperative plan in 91% of cases, and the mean difference between planned alignment and postoperative alignment was 1.8°.

Bone Conservation

In addition to improvements in component and limb alignment, robot assistance has been shown to result in a more conservative tibial cut compared to conventional methods [33]. In a comparison of 8421 robot-assisted UKA and 27,989 conventional UKA, Ponzio et al. found that polyethylene thickness – a proxy of resection depth – was 8 mm or 9 mm in 93.6% of robotic cases vs 84.5% of conventional cases. Inserts >10 mm occurred in 6.4% of robotic cases vs 15.5% of conventional cases, and maximum polyethylene thickness was 11 mm vs 14 mm for robotic vs conventional, respectively. There were no significant differences between sizing of Mako and Navio cases [33].

More conservative tibial resections are important in UKA for two primary reasons. First, proximal tibial bone becomes weaker with deeper resection, and thus it is biomechanically advantageous to minimize bone resection. Second, in the event of a future revision to TKA, more aggressive tibial resections are substantially more challenging to reconstruct and more likely to require the use of tibial augments [34]. Schwarzkopf and colleagues studied 37 conversions of UKA to TKA and found that in patients who had larger tibial cuts during UKA (>12 mm), 70% required augments and/or stems during conversion. Alternatively they found that only 11% of patients who had more conservative tibial resections required augments or stems. Importantly, clinical outcomes were similar to primary TKA when conversion using primary TKA components (without augments) was possible [34].

Functional Outcomes

Data is emerging regarding the functional outcomes derived as a result of the enhanced positioning and soft tissue balance in robotically assisted UKA [35]. One prospective study compared the early clinical outcomes in 139 patients undergoing medial UKA randomized to using either manual traditional surgical cutting jigs or robotic arm-assisted technology. From the first postoperative day through to week 8 postoperatively, the median pain scores for the robotic arm-assisted group were 55.4% lower than those observed in the manual surgery group ($p = 0.040$), and at 3 months postoperatively, the robotic arm-assisted group had better Knee Society Scores (KSS), although no difference was noted with the Oxford Knee Scores. At 1 year postoperatively, there were no longer significant differences in the KSS; however, a greater proportion of patients

receiving robotic arm-assisted surgery improved their UCLA activity scores [35].

At this time, mid- and long-term outcomes studies are lacking in robotic-assisted UKA, in large part because of its nascency. Pearle and colleagues performed a multicenter review of 1135 robotic-assisted Mako UKAs with minimum 2-year follow-up (mean, 29.6 months; range, 22–52 months) [36]. They reported 98.8% survivorship with a total of 11 revisions, a survivorship slightly better than other large reports of conventional UKA at this short-term follow-up period [37, 38]. Additionally, 92% of patients reported they were satisfied with the operation [36].

To further assess whether robotic-assisted UKA provides clinically superior functional outcomes compared to conventional UKA, or that the improved precision of robotics impacts mid- and long-term durability, more studies are needed. This data may help validate the proposed benefits of improved alignment and kinematics achieved with robotic UKA. Additionally, the potential for improved UKA outcomes in the hands of novice surgeons is an important area of future study.

Potential Limitations of Robotic UKA

Cost

One undeniable barrier to widespread implementation and adoption of robotic UKA is the high initial capital cost for each system, although newer systems are less expensive than earlier generation robotic technologies [39, 40]. Additionally, there are maintenance costs, including servicing and software, as well as the cost of disposable elements used in each case. Systems that require preoperative CT scans have an added, and often nonreimbursable, cost, which is particularly concerning in bundled care programs.

Swank et al. analyzed hospital expenditures associated with robotic knee arthroplasty and found the upfront cost to be approximately $800,000 [39]. Assuming an inpatient-to-outpatient ratio of 1:3, the estimated mean per-case contribution profit would be $5790 for robotic cases. This suggests that capital costs of robotic UKA may be recovered in as few as 2 years if 50, 70, and 90 robotic cases were performed in the first 3 years [19, 39].

Moschetti et al. performed a Markov analysis of an image-guided system assuming an initial capital cost of $934,728 and annual 10% servicing charges for 4 years, amounting to $1.362 million in total cost [40]. Using an annual revision risk of 0.55%, they estimated an incremental cost-effectiveness ratio of $47,180 per quality-adjusted life year. Additionally, they estimated that each robotic-assisted UKA costs $19,219 per case versus $16,476 for conventional UKA and concluded that robotic-assisted UKA is cost-effective in centers performing >94 cases annually and if the 2-year revision rates are less than 1.2%.

It is true that cost (therefore, value) has many variables and depends on the initial capital cost, realized annual servicing charges, and avoidance of additional expenses such as preoperative CT scans and reduction in early revisions [41]. For example, assuming an initial cost of $500,000 for an image-free robotic system, return on investment can be attained with 25 annual cases, nearly one quarter the number of cases needed for a CT image-based system. There is optimism that as the field of robotics continues to advance and there is increased implementation, economies of scale and increased competition will continue to drive pricing reductions.

Operative Time and Learning Curve

Additional concerns regarding adoption of robotics for UKA are increased operative time and the learning curve required to use the equipment and achieve precision. Wallace et al. studied the number of surgeries required for five surgeons to reach a steady-state surgical time (95% of total learning) during their initial experience with the Navio robot [42]. The average improvement was 46 min from slowest to fastest surgical time with the cutting phase decreasing an average of 31 min during the initial 15 cases. It took an average of eight procedures to reach a steady-state surgical

time (range, 5–11) with a mean steady-state surgical time of 50 min (range, 37–55 min). A study by Jinnah et al. found the learning curve using the Mako robot to be an average of 13 cases, with no increased risk to the patient during the initial learning cases [43]. Importantly, robotics significantly decreases the learning curve during the adoption of the UKA procedure and enables even inexperienced surgeons to achieve precise and accurate component placement compared to the use of conventional instrumentation [44–46].

Radiation Exposure

Systems that require preoperative CT scans for surgical mapping and planning increase the risk of radiation exposure to patients. Ponzio et al. found that the mean effective dose of radiation from preoperative CT scans required for image-based robot-assisted UKA was 4.8 ± 3.0 mSv (millisieverts), approximately equivalent to 48 chest radiographs [47]. Twenty-five percentage of patients in that study of 211 patients had one or more additional CT scans, with a maximum effective dose of 103 mSv. The US FDA has stated that an effective CT radiation dose of 10 mSv may be associated with the possibility of fatal cancer in 1 in 2000 patients compared with the natural incidence. Therefore, the risk of radiation exposure should not be considered negligible, and steps should be taken to reduce and avoid exposure to avoidable radiation. It is important to note that radiation risk is not inherent to all robotic systems, as image-free systems do not require CT scans and, thus, are not associated with this potential drawback. It is also important to note that CT technology and protocols are constantly changing and there is potential in the future for lower dose protocols that may lower patient risk.

Pin Placement and Soft Tissue Complications

Robotic systems currently require insertion of percutaneous pins intraoperatively for optical tracking arrays. The intraosseous placement of pins creates stress risers in the bone, especially if placed in diaphyseal bone, and poses the risk of pin-related periprosthetic fracture [41, 48, 49]. Therefore, it is imperative that optical array pins be placed in metaphyseal bone. Inadvertent pin placement can also theoretically cause neurovascular laceration, and there is a potential risk of pin site infection postoperatively.

Another concern is the risk of iatrogenic complications that may occur as a direct result of using robotic technology. One study of an autonomous robotic device in a series of 100 TKAs (which is not FDA approved for TKA in the United States) reported a 5% incidence of patellar tendon disruption [50]. In contrast, in a series of 1064 consecutive cases using the semiautonomous, surgeon-driven technologies covered in this chapter, Lonner and Kerr had no soft tissue injuries related to use of the robotic bone preparation method [51].

Conclusions and Future Direction

Advances in medical and robotic technology have led to the development and growing popularity of robotic-assisted surgery, particularly in arthroplasty. Early results with current semiautonomous systems are very promising. Studies have demonstrated that robotic-assisted surgery improves mechanical alignment and implant positioning, with higher precision of bone preparation compared to conventional techniques. The added ability to quantify and balance soft tissue tension through range of motion may further benefit mechanics, kinematics, and outcomes. While it is anticipated that these improvements will translate to better mid-term and long-term outcomes and implant survivorship, more clinical data is needed to investigate whether indeed functional outcomes and durability will be impacted. Furthermore, the potential for improved UKA outcomes in the hands of novice surgeons is an important area of future study. For robotic technology to move to more widespread adoption, long-term and functional outcomes need to be evaluated, cost effectiveness further proven, and surgical efficiencies optimized.

References

1. Lum ZC, Lombardi AV, Hurst JM, Morris MJ, Adams JB, Berend KR. Early outcomes of twin-peg mobile-bearing unicompartmental knee arthroplasty compared with primary total knee arthroplasty. Bone Joint J. 2016;98-b:28–33.
2. van der List JP, McDonald LS, Pearle AD. Systematic review of medial versus lateral survivorship in unicompartmental knee arthroplasty. Knee. 2015;22(6):454–60.
3. New Zealand Joint Registry. http://www.nzoa.org.nz/news/new-zealand-joint-registry-thirteen-year-report.
4. Epinette JA, Brunschweiler B, Mertl P, Mole D, Cazenave A. Unicompartmental knee arthroplasty modes of failure: wear is not the main reason for failure: a multicenter study of 418 failed knees. Orthop Traumatol Surg Res. 2012;98:S124–30.
5. Collier MB, Eickmann TH, Sukezaki F, McAuley JP, Engh GA. Patient, implant, and alignment factors associated with revision of medial compartment unicondylar arthroplasty. J Arthroplast. 2006;21(6 Suppl 2):108–15.
6. Fisher DA, Watts M, Davis KE. Implant position in knee surgery: a comparison of minimally invasive, open unicompartmental, and total knee arthroplasty. J Arthroplast. 2003;18(7 Suppl 1):2–8.
7. Hamilton WG, Collier MB, Tarabee E, McAuley JP, Engh CA Jr, Engh GA. Incidence and reasons for reoperation after minimally invasive unicompartmental knee arthroplasty. J Arthroplast. 2006;21(6 Suppl 2):98–107.
8. Keene G, Simpson D, Kalairajah Y. Limb alignment in computer-assisted minimally-invasive unicompartmental knee replacement. J Bone Joint Surg Br. 2006;88:44–8.
9. Cobb J, Henckel J, Gomes P, et al. Hands-on robotic unicompartmental knee replacement: a prospective, randomised controlled study of the acrobot system. J Bone Joint Surg Br. 2006;88:188–97.
10. Romanowski MR, Repicci JA. Minimally invasive unicondylar arthroplasty: eight-year follow-up. J Knee Surg. 2002;15:17–22.
11. Hernigou P, Deschamps G. Alignment influences wear in the knee after medial unicompartmental arthroplasty. Clin Orthop Relat Res. 2004;423:161–5.
12. Hernigou P, Deschamps G. Posterior slope of the tibial implant and the outcome of unicompartmental knee arthroplasty. J Bone Joint Surg Am. 2004;86-A(3):506–11.
13. Lonner JH. Robotically assisted unicompartmental knee arthroplasty with a handheld image-free sculpting tool. Orthop Clin North Am. 2016;47:29–40.
14. Orthopedic Network News. Hip and knee implant review. 2013. Available at: www.OrthopedicNetworkNews.com. 24 July 2013.
15. Medical Device and Diagnostic Industry. March 5, 2015. http://www.mddionline.com.
16. Dalton DM, Burke TP, Kelly EG, Curtin PD. Quantitative analysis of technological innovation in knee arthroplasty: using patent and publication metrics to identify developments and trends. J Arthroplast. 2016;31:1366–72.
17. Bargar WL. Robots in orthopaedic surgery: past, present, and future. Clin Orthop Relat Res. 2007;463:31–6.
18. Lonner JH, Moretti VM. The evolution of image-free robotic assistance in unicompartmental knee arthroplasty. Am J Orthop. 2016;45(5):249–54.
19. van der List JP, Chawla H, Pearle AD. Robotic-assisted knee arthroplasty: an overview. Am J Orthop. 2016;45(4):202–11.
20. Jacofsky DJ, Allen M. Robotics in arthroplasty: a comprehensive review. J Arthroplast. 2016;31:2353–63.
21. Bell SW, Anthony I, Jones B, MacLean A, Rowe P, Blyth M. Improved accuracy of component positioning with robotic-assisted unicompartmental knee arthroplasty: data from a prospective, randomized controlled study. J Bone Joint Surg Am. 2016;98:627–35.
22. Lonner JH, John TK, Conditt MA. Robotic arm-assisted UKA improves tibial component alignment: a pilot study. Clin Orthop Relat Res. 2010;468:141–6.
23. Dunbar NJ, Roche MW, Park BH, Branch SH, Conditt MA, Banks SA. Accuracy of dynamic tactile-guided unicompartmental knee arthroplasty. J Arthroplast. 2012;27(5):803–808.e1.
24. Pearle AD, O'Loughlin PF, Kendoff DO. Robot-assisted unicompartmental knee arthroplasty. J Arthroplast. 2010;25(2):230–7.
25. Citak M, Suero EM, Citak M, et al. Unicompartmental knee arthroplasty: is robotic technology more accurate than conventional technique? Knee. 2013;20:268–71.
26. Plate JF, Mofidi A, Mannava S, et al. Achieving accurate ligament balancing using robotic-assisted unicompartmental knee arthroplasty. Adv Orthop. 2013;2013:837167.
27. MacCallum KP, Danoff JR, Geller JA. Tibial baseplate positioning in robotic assisted and conventional unicompartmental knee arthroplasty. Eur J Orthop Surg Traumatol. 2016;26:93–8.
28. Hansen DC, Kusuma SK, Palmer RM, Harris KB. Robotic guidance does not improve component position or short-term outcome in medial unicompartmental knee arthroplasty. J Arthroplast. 2014;29:1784–9.
29. Smith JR, Picard F, Rowe PJ. The accuracy of a robotically-controlled freehand sculpting tool for unicondylar knee arthroplasty. J Bone Joint Surg Br. 2013;95(Suppl):68.
30. Smith JR, Riches PE, Rowe PJ. Accuracy of a freehand sculpting tool for unicondylar knee replacement. Int J Med Robot. 2014;10:162–9.
31. Lonner JH, Smith JR, Picard F, et al. High degree of accuracy of a novel image-free handheld robot for unicondylar knee arthroplasty in a cadaveric study. Clin Orthop Relat Res. 2015;473:206–12.
32. Picard F, Gregori A, Bellemans J, et al. Handheld robot-assisted unicondylar knee arthroplasty: a clinical

review. 14th annual meeting of the International Society for Computer Assisted Orthopaedic Surgery. Milan, Italy, June 18–21, 2014.
33. Ponzio DY, Lonner JH. Robotic technology produces more conservative tibial resection than conventional techniques in UKA. Am J Orthop. 2016;45:e465–8.
34. Schwarzkopf R, Mikhael B, Li L. Effect of initial tibial resection thickness on outcomes of revision UKA. Orthopedics. 2013;36:e409–14.
35. Blyth MJG, Anthony I, Rowe P, Banger MS, MacLean A, Jones B. Robotic arm-assisted *versus* conventional unicompartmental knee arthroplasty: exploratory secondary analysis of a randomised controlled trial. Bone Joint Res. 2017;6:631–9.
36. Pearle AD, van der List JP, Lee L, Coon TM, Borus TA, Roche MW. Survivorship and patient satisfaction of robotic-assisted medial unicompartmental knee arthroplasty at a minimum two-year follow-up. Knee. 2017;24:419–28.
37. Pandit H, Jenkins C, Gill HS, Barker K, Dodd CA, Murray DW. Minimally invasive Oxford phase 3 unicompartmental knee replacement: results of 1000 cases. J Bone Joint Surg Br. 2011;93(2):198–204.
38. Yoshida K, Tada M, Yoshida H, Takei S, Fukuoka S, Nakamura H. Oxford phase 3 unicompartmental knee arthroplasty in Japan—clinical results in greater than one thousand cases over ten years. J Arthroplast. 2013;28(9 Suppl):168–71.
39. Swank ML, Alkire M, Conditt M, Lonner JH. Technology and cost-effectiveness in knee arthroplasty: computer navigation and robotics. Am J Orthop. 2009;38(2 Suppl):32–6.
40. Moschetti WE, Konopka JF, Rubash HE, Genuario JW. Can robot-assisted unicompartmental knee arthroplasty be cost-effective? a markov decision analysis. J Arthroplast. 2016;31:759–65.
41. Lonner JH. Robotically assisted unicompartmental knee arthroplasty with a handheld image-free sculpting tool. Oper Tech Orthop. 2015;25:104–13.
42. Wallace D, Gregori A, Picard F, et al. The learning curve of a novel handheld robotic system for unicondylar knee arthroplasty. Paper presented at: 14th Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery. Milan, Italy, June 18–21, 2014.
43. Jinnah R, Horowitz S, Lippincott C, et al. The learning curve of robotically assisted UKA. 22nd annual Congress of ISTA. Big Island, October 22–24, 2009.
44. Hamilton WG, Ammeen D, Engh CA Jr, et al. Learning curve with minimally invasive unicompartmental knee arthroplasty. J Arthroplast. 2010;25(5):735.
45. Karia M, Masjedi M, Andrews B, Jaffry Z, Cobb J. Robotic assistance enables inexperienced surgeons to perform unicompartmental knee arthroplasties on dry bone models with accuracy superior to conventional methods. Adv Orthop. 2013;2013:481039.
46. Coon TM. Integrating robotic technology into the operating room. Am J Orthop. 2009;38:7.
47. Ponzio DY, Lonner JH. Preoperative mapping in unicompartmental knee arthroplasty using computed tomography scans is associated with radiation exposure and carries high cost. J Arthroplast. 2015;30:964–7.
48. Wysocki RW, Sheinkop MB, Virkus WW, et al. Femoral fracture through a previous pin site after computer-assisted total knee arthroplasty. J Arthroplast. 2008;23:462–5.
49. Sinha RK. Outcomes of robotic arm-assisted unicompartmental knee arthroplasty. Am J Orthop. 2009;38(2 Suppl):20–2.
50. Chun YS, Kim KI, Cho YJ, Kim YH, Yoo MC, Rhyu KH. Causes and patterns of aborting a robot-assisted arthroplasty. J Arthroplast. 2011;26:621–5.
51. Lonner JH, Kerr GJ. Low rate of iatrogenic complications during unicompartmental knee arthroplasty with two semi-autonomous robotic systems, Jess Lonner, MD unpublished data.

14 Tibiofemoral Partial Knee Arthroplasty Implant Designs

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Introduction

Partial or unicompartmental knee arthroplasty (PKA or UKA) is a highly effective treatment option, particularly for the young and active patient, and offers several advantages over total knee arthroplasty (TKA), including faster recovery time, greater range of motion and function, preservation of normal kinematics, lower infection rate, shorter hospital stay, and greater cost-effectiveness [1, 2]. Nonetheless, in recent years, a downward trend in UKA use as a proportion of all primary knee arthroplasties has been reported in several national joint registries. In USA, UKA use reduced from about 6.8% of all primary procedures in 2012 to 3.2% in 2016 [3]. The Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) reports a decrease in UKA usage from 14.5% in 2003 to 5.1% in 2016 (although it increased slightly from 4.4% in 2015) [4]. However, the UK National Joint Registry (NJR) has reported UKA usage to remain consistently at around 9% for several years [5]. The reason behind the downward trend in UKA usage is not entirely clear, but it may be related to reports of significantly higher cumulative revision rate for UKA compared to TKA, particularly in registries. For example, the AOANJRR reports cumulative percent revision rate (CPRR) for UKA at 5, 10, and 15 years, to be 8.1%, 14.6%, and 22.1%, respectively [4]. In contrast, CPRR for primary TKA for OA diagnosis was reported to be 3.6%, 5.3%, and 7.4%, at 5, 10, and 15 years, respectively. The UK NJR reports 5- and 10-year cumulative percentage probability of revision (CPPR) for UKA to be 6.6% and 12.3%, respectively, compared to CPPR of 2.1% and 3.4% for TKA [5]. Swedish registry also reports significantly higher revision risk for UKA compared to TKA. However, researchers have cautioned against relying purely on revision rates when deciding upon appropriate intervention for individual patients [6]. This is due to potential for various biases, including selection bias emanating from use of UKA in younger and more active patients, measurement bias due to lower threshold for revising a UKA vs. TKA, and reporting bias stemming from focus on revision rate alone while ignoring established advantages of UKA such as better functional outcomes and lower

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risk of serious complications such as infection and amputation [6]. Continuing improvements in our understanding of factors such as patient selection, and advances in surgical and implant technologies, could further enhance the long-term outcomes of unicompartmental knee arthroplasty. With this backdrop in mind, this chapter aims to educate the readers on the primary forms of UKA implant designs and the current evidence demonstrating their relative advantages and disadvantages.

Mobile vs. Fixed-Bearing UKA

One of the major areas of distinction between UKA designs is the use of fixed-bearing vs. mobile-bearing (Fig. 14.1). The advocated benefits of mobile-bearing UKA include reduced surface and subsurface stresses in the polyethylene insert, better replication of natural tibiofemoral mechanics, and reduced transmission of shear forces during femoral condyle rollback in the lateral compartment. However, opponents of the concept suggest greater technical difficulty with regard to ligament balance and alignment and increased the risk for bearing dislocation and impingement [7]. While both fixed and mobile-bearing UKA are used widely, the use of fixed-bearing UKA appears to be growing. For example, in the UK fixed-bearing designs accounted for 44.5% of all UKAs in 2016 compared to only 17.7% in 2003 [5].

The clinical outcomes of fixed vs. mobile-bearing UKA have been the subject of a few meta-analysis and systematic reviews. A meta-analysis published in 2009 by Smith et al. included analysis from five randomized and non-randomized clinical trials comparing mobile and fixed-bearing UKA [8]. They found no reports of significant differences in clinical and functional outcomes measures, including Knee Society Scores, Oxford Knee Score, Italian Orthopaedic UKR's Users Group (GIUM) score, Bristol Knee Score, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores, the Short Form-36 score, or range of motion, between fixed- and mobile-bearing groups. Two studies included in their analysis reported no difference between fixed and mobile UKAs with respect to pain [9, 10], while one study reported total pain score assessed using the Bristol Knee Score to be significantly better in the fixed-bearing designs at 2 years [11]. Meta-analysis did not identify any significant difference in the relative risks for aseptic loosening, persistent pain, progression of tibiofemoral or patellofemoral degenerative changes, intraoperative tibial plateau fractures, tibial component subsidence, or the frequency of revision surgery between mobile- and fixed-bearing UKA [8]. A more recent systematic review and meta-anal-

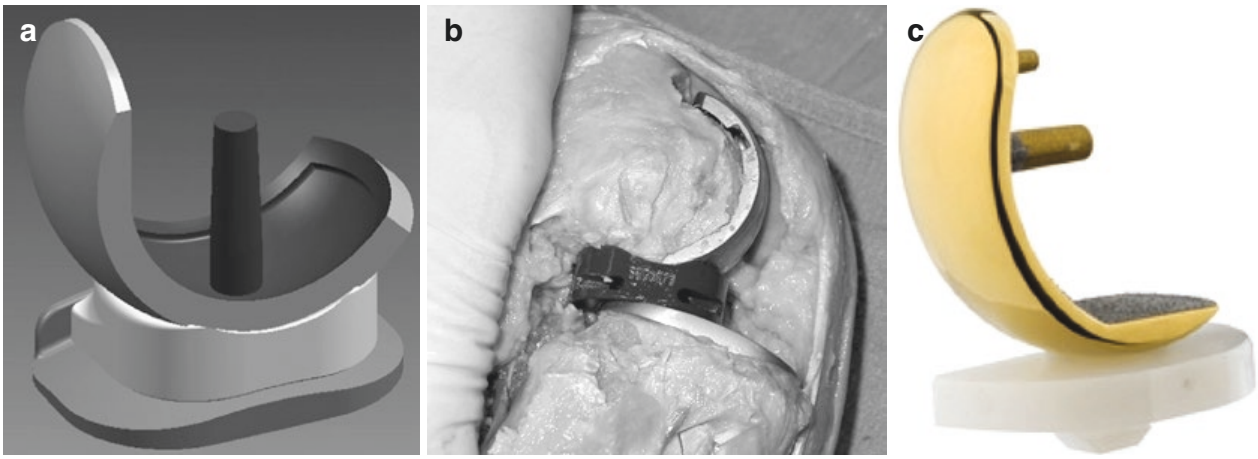

Fig. 14.1 (**a**) CAD model of metal-backed mobile-bearing Oxford® lateral UKA (Zimmer Biomet, Warsaw IN, USA) with dome-shaped tibial tray [19]. (**b**) Photograph of cadaver knee with the domed Oxford® UKA in high flexion showing posterior location of the mobile bearing [19]. (**c**) Fixed-bearing Uniglide™ UKA with TiN-coated femoral component and all-polyethylene tibial onlay component (Corin Group PLC, Cirencester, UK) [30]

ysis by Peersman et al. included analysis of RCTs, cohort studies, and case series and generally echoed the prior findings of Smith et al. [12]. No difference in clinical outcomes as measured by KSS was observed up to 5 years of follow-up, but a trend for faster decrease in KSS scores was noted for mobile-bearing designs at 10 and 15 years [12]. The top three reasons for revision in fixed-bearing UKA were progressive OA, aseptic loosening, and pain, while for mobile-bearing UKA, these were aseptic loosening, progressive OA, and dislocation. The overall revision rate, expressed as revisions per 100 observed component years (OCY), for fixed-bearing UKA (0.9/100 OCY; 95%CI 0.65–1.21) was somewhat lower than that of mobile-bearing designs (1.51/OCY; 95% CT 1.11–1.93), but authors did not determine it to be substantially different. However, Peersman et al. found a shorter average time to failure in the mobile-bearing group and postulated that this may indicate greater susceptibility of mobile-bearing UKA outcomes to technical errors. Systematic review by Ko et al. also reported similar overall reoperation rates of mobile- vs. fixed-bearing designs (1.392 vs. 1.377/100 OCY, respectively) [13]. However, unlike Peersman et al., they found the time to reoperation for progression of arthritis and persistent pain to be similar between mobile- and fixed-bearing groups.

In the UK NJR, CPPR for fixed- and mobile-bearing UKA were similar at 10.1% and 11.8%, respectively [5]. However, significant variations were seen when comparing outcomes by specific implant brands. The 7- and 10-year survivorship of three of four main brands of fixed-bearing UKA (ZUK, now marketed by Lima Corporate as Physica ZUK, San Daniele del Friuli, Italy; M/G® Uni, Zimmer, Warsaw IN, USA; AMC/Uniglide™, Corin Group PLC, Cirencester, England, UK) ranged from 5.3% to 7.6% and 6.7% to 10%, respectively. The Oxford® UKA (Zimmer Biomet, Warsaw, IN, USA), which was the main brand of mobile-bearing UKA in the NJR registry, had a 10-year CPPR of 11.5%, which was notably higher than the best-performing fixed-bearing design (ZUK) with a 10-year CPPR of 6.6%. On the other hand, the AMC/Uniglide™ mobile UKA and Preservation™ (DePuy International Ltd., Leeds, England) fixed-bearing UKA had the lowest CPPR (7-year CPPR of 12.4% and 12.9%, respectively). The top three reasons for revision in fixed- and mobile-bearing UKA were reported to be aseptic loosening, pain, and implant wear, although dislocation/subluxation was also an additional important reason for revision for mobile-bearing UKA. In the Australian registry, the fixed-bearing ZUK implant and the mobile-bearing Oxford® implant were the two most commonly used UKA designs [4]. The CPRR of the cemented Oxford® design at 5, 10, and 15 years was 8.4%, 14.7%, and 22.4%, which was higher than CPRR of 4.9% and 8.9% for ZUK at 5 and 10 years. In contrast to NJR and AOANJRR, the Swedish registry found similar risk of revision for Oxford and ZUK designs.

The perceived advantages of mobile bearing on polyethylene wear have not been supported clinically, with the 2017 NJR report showing CPRR at 10 years for men under 55 years old, to be lower for fixed-bearing designs at 13.43% vs. 17.94% for mobile-bearing designs [5]. Mobile-bearing designs (UKA and TKA) were developed to reduce polyethylene contact stresses to mitigate the historical challenges of polyethylene delamination caused by fatigue failure of the material [14]. However, with improvements in polyethylene sterilization and manufacturing processes, fatigue-related mechanisms became less of an issue. Adhesive/abrasive wear, which dominate in the absence compromised fatigue strength, do not necessarily reduce with bearing conformity [14]. Further, unlike rotating platform mobile-bearing TKA where rotation and translational motions are decoupled, in mobile-bearing UKA, the bearing is free to slide only in the anteroposterior direction. This results in continued potential for multi-directional motion and cross-shearing of polyethylene [15, 16]. This factor together with use of polished trays in fixed-bearing UKA may explain the findings of greater volumetric wear in modern mobile-bearing UKA compared to fixed-bearing designs. Using displacement-controlled simulator testing, Burton et al. found significantly greater total

wear rate (combination of medial and lateral UKA) for mobile-bearing variations of Preservation™ UKA, compared to its fixed-bearing counterpart (16.9 vs. 2.4 mm^3/million cycle (MC) under high kinematics conditions and 10.6 vs. 3.6 mm^3/MC under intermediate kinematics conditions) [15]. Similarly, using force-controlled simulators, Kretzer et al. found greater wear rate for Univation® mobile-bearing UKA (Aesculap AG, Tuttlingen, Germany) compared to Univation® fixed-bearing design (16.1 vs. 10.6 mm^3/MC) [16]. Brockett et al. found higher wear rates for Oxford® mobile-bearing UKA compared to Sigma® HP fixed-bearing UKA (DePuy International, UK) under both intermediate (9.2 ± 7.8 vs. 3.1 ± 0.8 mm^3/MC) and high kinematics conditions (11.3 ± 11.1 vs. 4.5 ± 4 mm^3/MC) [17]. However, at least part of the differences in wear rate in this study could be related to differences in polyethylene material used in the two UKA systems. Interestingly, Taddei et al. found higher in vitro weight loss for mobile-bearing vs. fixed-bearing UKA with femoral implants mounted on metal blocks (8.7 ± 2.0 mg and 2.6 ± 1.1 mg) but slightly lower weight loss for the mobile-bearing with implants mounted on synthetic femur (4.5 ± 2.2 mg vs. 6.7 ± 1.4 mg).

With regard to kinematic benefits of mobile-bearing UKA, Li et al. used RSA to study in vivo weight-bearing kinematics and reported significant increase in tibial internal rotation with flexion in mobile-bearing vs. fixed-bearing (9.5° vs. 4.2° at 90° of knee flexion) and significantly less anteroposterior translation in mobile-bearing vs. fixed-bearing knees (2 mm vs. 4.2 mm) [9]. Knee stability, determined as anteroposterior or rotational movement relative to neutral position, has however been reported to be similar between mobile- and fixed-bearing UKA [18].

While mobile-bearing UKA has been a popular treatment choice for medial OA, one of the most frequent criticisms of this design has been the high rate of dislocations when used to treat lateral compartment OA. The Oxford® domed lateral UKA, composed of a convex domed tibial tray and a biconcave bearing, was specifically developed to reduce the risk of bearing dislocation (Fig. 14.1a, b) [19]. During in vitro studies, it was shown to increase femoral distraction needed for bearing dislocation by 25% to 37%, compared to a flat lateral bearing [20]. One of the first clinical evaluations of this design from a non-design group reported a dislocation incidence of 6.2% at 3 years, which was lower than historical rates but still of concern [21]. The authors attributed this partly to elevation of the lateral joint line and advocated for better training. The longest reported clinical follow-up for the Oxford® domed lateral UKA is that by Newman et al. At a median follow-up of 7 years, the revision rate was 7%, with one patient (1 of 64 knees/58 patients) sustaining bearing dislocation [22]. Perhaps in recognition of concerns regarding lateral bearing dislocation, the manufacturer has also made available a fixed-bearing variant of the Oxford® design specifically for lateral UKA.

In summary, mobile-bearing UKA may better replicate native knee kinematics; however, bearing dislocation remains an important cause for revision for these designs. Overall both mobile- and fixed-bearing UKAs have similar functional outcomes and long-term survivorship, although registry data seems to indicate potential advantage of fixed-bearing UKA with regard to revision rates.

All-Polyethylene vs. Metal-Backed UKA

All-polyethylene and metal-backed tibial components represent another area of distinction in UKA implant design. All-polyethylene designs are available either as inlay or onlay components, while metal-backed designs are of the onlay type (Fig. 14.1c). Inlay designs are implanted by cementing the tibial component into a pocket carved on the tibial plateau, thereby relying on subchondral bone support (e.g., Repicci II®, Biomet, Inc., Warsaw, IN, USA; RESTORIS® MCK, MAKO Surgical Corp., Fort Lauderdale, FL, USA), while onlay components are cemented directly on the resected tibial surface, relying both on cortical and cancellous bone support. The theoretical benefits of the all-polyethylene

designs are (a) greater bone preservation (for insert thickness < 9–10 mm, which is approximately total thickness of the thinnest metal-backed fixed-bearing UKA construct), reduced backside wear, and reduced implant cost [23]. However, concerns have been raised about dramatic increase in stresses and strains transmitted to underlying bone with all-polyethylene designs compared to metal-backed designs.

Scott et al. used an FEM model validated against physical testing of UKA components to measure cancellous bone stresses for onlay style all-polyethylene designs compared to metal-backed design from the same manufacturer (Sigma®, DePuy, Raynham, MA) [24]. The all-polyethylene designs had significantly greater volume of pathologically overstrained cancellous bone (strain magnitudes >3000με), which was not significantly addressed by increasing insert thickness from 6 to 10 mm. All-polyethylene implants also had more pronounced anteromedial strain concentrations. This concurred with prior mechanical tests performed by the authors, where all-polyethylene implants displayed 1.8–6 times greater microdamage than metal-backed implants. Similar findings were reported by Walker et al. who found 6 mm polyethylene inlays to be associated with 6 times more peak stress at the tibial surface and up to 13.5 times more strain in areas of softer bone at the interface, compared with metal-backed onlays [25]. Walker et al. found strains for 8 mm all-polyethylene onlays to be reduced compared with the 6 mm inlays but still significantly higher than for the metal-backed onlay. Such findings have raised concerns about increased risk of early failures due to tibial loosening, subsidence, and pain for all-polyethylene implants.

The clinical outcomes of all-polyethylene UKA are somewhat mixed, with several studies showing excellent mid- to long-term survivorship for all-polyethylene designs, while others suggesting inferior outcomes compared to metal-backed designs. For example, Porteous et al. have reported on a series of 479 knees treated with a fixed-bearing all-poly tibia (St. Georg™ Sled, Waldemar Link GmbH & Co. Hamburg, Germany) design with 20–35-year follow-up and 87% not requiring revision at 20 years [26]. Lustig et al. reported survivorship of 93.5% at 10 years for an all-polyethylene onlay UKA (HLS Uni Evolution™, Tornier, Grenoble, France), with prosthesis removal as end point and 89.1% at 10 years with either prosthesis failure or degenerative changes in opposite compartment as end point [27]. Manzotti et al. reported survivorship of 96.1% at 5 years, and 91.6% at 15 years, for another all-polyethylene onlay design (UC-Plus Solution, Smith and Nephew, Memphis, USA) [28]. Hawi et al. reported 8-year survivorship of an all-polyethylene UKA (Endo Model®, Waldemar Link GmbH & Co. Hamburg, Germany) to be 95.4% [29]. Forster-Horvath reported 5-year survival rate to be 94.1% with revision surgery as end point and estimated survival rate of 91.3% at 10 years for Uniglide™ all-polyethylene UKA [30].

In contrast, Saenz et al. reported inferior outcomes for an all-polyethylene onlay design (EIUS, Stryker, Mahwah, NJ) with survivorship of 89% at mean follow-up of 3 years, which compared unfavorably to survivorship of metal-backed designs (range 82–98% at 10 years) [23]. Similarly, Furnes et al. examined the Norwegian arthroplasty register and found an estimated 5-year survivorship of two all-polyethylene tibial designs (Duracon®, Stryker, Berkshire, United Kingdom; Miller-Galante all-polyethylene Uni, Zimmer, Warsaw, Indiana, USA) to be 83% and 80%, respectively, compared to 89–92% for metal-backed designs [31]. Hutt et al. conducted a randomized study of all-polyethylene onlay versus metal-backed onlay implants (Accuris™ UKA, Smith and Nephew, London, United Kingdom) for medial osteoarthritis and reported 7-year survivorship of 94% for metal-backed and only 57% for the all-poly design [32]. Van der List et al. retrospectively compared outcomes of patients' all-polyethylene inlays UKA, metal-backed UKA (RESTORIS® MCK), and TKA (Vanguard®, Zimmer Biomet, Warsaw, IN, USA) [2]. At an average follow-up of 5 years, they did not find any difference in revision rates between the groups; however, patients with metal-backed UKA reported significantly better functional outcomes than those with all-polyethylene UKA

(92.0 ± 10.4 vs. 82.4 ± 18.7, $p = 0.010$) and TKA (92.0 ± 10.4 vs. 79.6 ± 18.5, $p < 0.001$), while no significant differences were found between all-polyethylene inlay UKA and TKA.

In summary, biomechanical data for all-polyethylene components shows significantly higher cancellous bone stress and strain relative to metal-backed designs, which could lead to increased risk of tibial component subsidence, aseptic loosening, and pain. Clinical outcomes of all-polyethylene UKA appear to be mixed, with some reports indicating equivalent performance to metal-backed designs and others indicating significantly worst performance. Therefore, additional large series clinical studies, registry data, and meta-analysis are needed. Till then caution may be warranted with regard to use of all-polyethylene designs, and outcomes may be highly dependent on surgical technique, patient selection, and specific implant designs.

Cemented vs. Cementless UKA

Cemented fixation continues to be the gold standard in UKA; however, there is continued interest in cementless designs. For example, cementless Oxford® UKA accounted for 25.8% of all UKAs implanted in Australia in 2016 and 60% of all UKAs in New Zealand [4, 33]. The proposed advantages of cementless UKA include reduced surgical time, reduced incidence of tibial radiolucencies (and by association tibial loosening), ease of revision surgery, and avoiding cementation errors that can lead to impingement or wear from third body cement particles [7, 34]. On the other hand, uncemented UKA implants are more expensive than cemented implants (~450 Euros as per Akan et al.) [35]. Most common types of cementless fixation include porous titanium with hydroxyapatite coating (e.g., Oxford® UKA; AMC/Uniglide™, Fig. 14.2a) and hydroxyapatite coating alone (Unix UKA, Stryker, Mahwah, NJ, USA). More recently an additively manufactured cementless UKA has also been designed (Tritanium® UKA, Stryker Orthopaedics, Mahwah, NJ, USA, Fig. 14.2b), and in in vitro tests, it was shown to have more favorable micromotion and subsidence behavior compared to a traditional cementless UKA (Oxford® UKA) [36]. Two recent systematic review articles provide an excellent summary of available clinical evidence regarding cementless UKA. Van der List et al. reported a cumulative revision rate of 2.9% at 4 years and an extrapolated 5-year survivorship of 96.4% for cementless UKA [37]. Campi et al. reported cumulative 5-year survivorship of 98.7–100% for cementless Oxford® UKA, 10-year survival of 92% for Unix UKA, 10-year survivorship of 97.4% for AMC/Uniglide™ UKA, and 13-year survivorship of 88% for Alpina® UKA (Biomet, Bridgend, UK) [34]. Both studies reported the most common failure modes for cementless UKA as being progression of OA, bearing dislocation, and aseptic loosening. Most of this evidence stems from cohort studies (randomized trials and case series). The New Zealand joint registry reported unce-

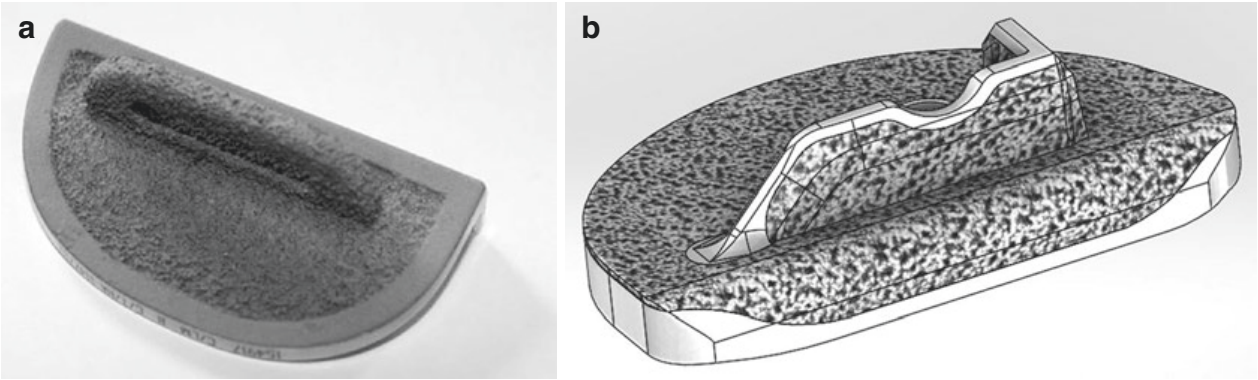

Fig. 14.2 (**a**) Oxford® Partial Knee cementless tibial tray (Zimmer Biomet, Warsaw, IN, USA) [42]. (**b**) Cad rendering of additively manufactured Stryker Tritanium® fixed-bearing UKA (Stryker Orthopaedics, Mahwah, NJ) [36]

mented Oxford® UKA (accounting for 27.3% of total UKA cases) to have a low revision rate of 0.8/100 component years (ocys), but the lowest revision rate was that for the cemented ZUK implant at 0.54 /100 OCY [33]. However, both prostheses had relatively short mean implantation time (3–4 years). In the AOANJRR, cementless Oxford® UKA had a CPRR of 6.8% and 13.2% at 5 and 10 years, respectively, compared to 8.4% and 14.7%, for the cemented version. However, CPRR for both were higher than that of the cemented ZUK design, which had one of the lowest revision rates.

Relatively few studies have compared cemented vs. cementless implants from the same manufacturers. Schlueter-Brust et al. reported 10-year survivorship for cohort of 240 patients with medial Uniglide® UKA of which 152 were cemented, 78 uncemented, and 10 hybrid (eight femurs, two tibias cemented) UKAs. The cemented group had a 10-year survival rate of 95.4% compared to 97.4% for the uncemented group (no statistically significant difference) [38]. In a matched pair analysis, Panzram et al. reported no significant difference in the incidence of radiolucent lines at mean of 5 years follow-up for cemented vs. cementless Oxford® UKA implants and 5-year implant survival of 89.7% for cementless group and 94.1% for cemented group [39]. One patient was revised for tibial plateau fracture, which the authors indicated may be related to greater susceptibility of cemented UKA to fracture due to the need for impaction to achieve press fit. In a randomized control trial of cemented vs. cementless Oxford® UKA, Pandit et al. reported better Knee Society functional scores and change in scores for cementless group at 5 years [40]. The cementless group also had lower number of radiolucencies (2/27 knees vs. 20/30 knees) and no incidences of complete radiolucencies as opposed to nine complete radiolucencies in cemented group [40]. In another randomized control trial comparing cemented and cementless Oxford® UKA using RSA, Kendrick et al. reported tibial radiolucencies in cementless group to be narrow (< 1 mm) and significantly less common than the cementless group (6 of 21 vs. 13 of 21) at 2 years [41]. Further, the cementless group showed no complete radiolucencies, whereas 5 of 21 cemented knees had complete radiolucencies. Akan et al. reported no significant difference in clinical results or survival rates for cemented (mean follow-up 42 months) vs. uncemented Oxford® UKA (mean follow-up 30 months), although surgical time was lower for the cementless group (average time of 36.1 min vs. 45.3 min) [35]. Periprosthetic tibial plateau fractures are rare but serious complication of UKA. Biomechanical study performed by Seeger et al. showed this to be a particular risk for cementless Oxford® UKA implants compared to cemented Oxford® UKA implants in the presence of extended vertical saw cuts and reduced bone mineral density [42]. In the cemented group, median loads of 3.7 kN led to tibial fractures, compared to a 1.6 kN for the cementless group. Nonetheless, only one case of non-traumatic tibial fracture has been reported following cementless UKA by Panzram et al. [39], and Seeger et al. reported one case each of tibial plateau fracture in cemented and cementless groups [42].

In summary, these studies indicate functional outcomes and survivorship of cementless implants to be at least comparable to that of cemented implants in the short and mid-term, with significantly lower incidence of radiolucencies. In addition to porous-coated implants, newer cementless designs on the horizon look to leverage additive manufacturing to achieve improved initial fixation and reliable bone ingrowth.

Femoral Resurfacing vs. Resection and Reaming

Majority of UKA designs are of the type requiring resection of the femoral bone using cutting guides to create a broad surface of cancellous bone for implant support. On the other hand, implants such as the Oxford® UKA employ a combination of spherical reamers to prepare the distal bone and cutting guides for resection of the posterior condyles. The third type of femoral preparation involves resurfacing to replace primarily the cartilage layer, thereby minimizing

amount of femoral bone removed. Examples of resurfacing designs include the original Marmor prosthesis (1972, Richards Manufacturing Company, Memphis, TN, USA), its successor the Repicci II® implant (Biomet, Inc., Warsaw, IN, USA), the St. Georg™ Sled prosthesis (1969), and its successor the Endo-Model® Sled UKA (1981, Waldemar Link GmbH & Co. Hamburg, Germany). The Repicci II® UKA utilizes an all-polyethylene inlay-style tibial insert together with a resurfacing CoCr femoral implant. In the Australian registry, 5- and 10-year CPRR for this device are reported to be 7.9% and 17.7%, respectively [4]. O'Donnell et al. reported a revision rate of 19% at a mean of 6.2 years and survivorship of 78% at 9 years, for patients treated with Repicci II® UKA implants [43]. Most common reasons for revision were progression of disease to other compartments, followed by tibial tray subsidence and aseptic loosening. In contrast, developer of the Repicci II® implant reported substantially lower revision rate of 4% at 8-year follow-up [44]. For the Endo-Model® Sled UKA, the Australian registry reported 5- and 10-year CPRR of 7.6% and 14.4%, respectively [4]. The 2016 Swedish knee registry reported no significant difference in revision rate for the Endo-Link® prosthesis relative to three most commonly used prosthesis in the registry, including the Oxford® and ZUK implants.

In summary, depending on implant design, three types of femoral bone preparation are utilized in UKA, namely, resection, reaming, and resurfacing. With regard to resurfacing implants, the preservation of more bone has not been shown to translate into improved clinical outcomes, although it could affect other aspects of surgery such as ease of implantation or revision.

Patient-Specific vs. Off-the-Shelf UKA

In keeping with this chapter's specific focus on implant design, only custom/patient-specific implants are discussed in this section. The reader is directed to other chapters within this book as well as other publications are available on the topics of patient-specific instrumentation and robotics [45, 46].

At least two manufacturers have custom UKA implants cleared for US/European markets (iUni®, ConforMIS, Billerica, MA, USA; Bodycad Unicompartmental Knee System™, Park City, UT, USA; Fig. 14.3). Custom implants are designed based on the combination of CT/MRI imaging and long-standing AP radiograph and are provided together with custom 3D-printed

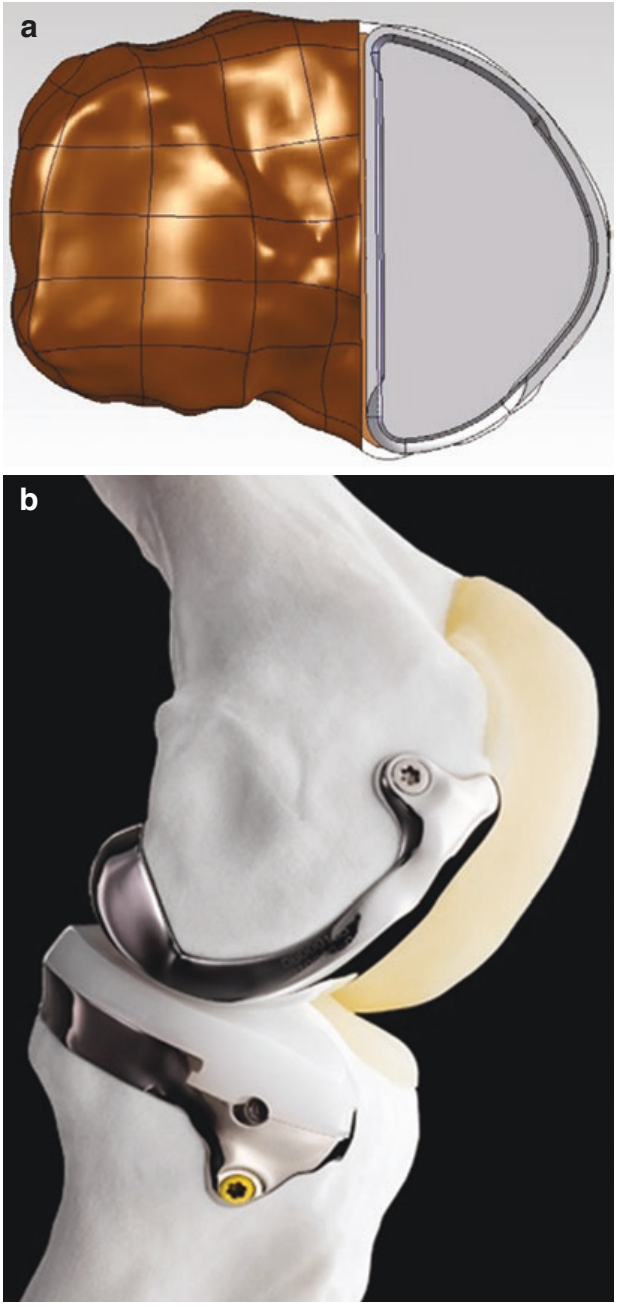

Fig. 14.3 (**a**) iUni® tibial implant, ConforMIS, Billerica, MA, USA [47]. (**b**) Bodycad Unicompartmental Knee System™, Park City, UT, USA [61]

instrumentation as a single-use kit. Postulated benefits of custom UKA implants include (a) better anatomical fit thereby maximizing bone coverage and reduced risk of soft-tissue irritation, (b) improved positioning accuracy, (c) better joint feel and function, (d) bone preservation, and (e) improved surgical/operating room efficacy. However, the available biomechanical and clinical evidence supporting use or benefits of custom UKA is still relatively limited.

Carpenter et al. performed virtual surgery on CT-based models of 30 subjects to compare tibial coverage of 5 different off-the-shelf UKA implants vs. custom UKA (iUni®) [47]. The patient-specific implants were found to provide significantly greater cortical rim coverage versus the off-the-shelf designs (77% v. 43% medially and 60% v. 37% laterally). They also observed slightly lower average maximum rim overhang for custom implants (difference < 0.5 mm) and significantly lower average maximum under coverage relative to off-the-shelf designs (0.9 mm vs. 3 mm medially and 1.2 mm vs. 2.2 mm laterally). The authors postulated potentially advantages with regard to risk of tibial loosening or subsidence, although they noted absence of studies showing a direct causal link between tibial coverage and durability of implant fixation [47]. Demange et al. compared a consecutive series of 33 patients with patient-specific lateral UKA (iUni®) to that of another consecutive series of 20 lateral UKA patients with standard implants (M/G® Uni) [48]. Bone coverage evaluation using plain radiographs showed mean tibial implant lateral coverage mismatch (defined as absolute value of overhang/underhang) to be 1.0 mm (range 0–5.7 mm) in the patient-specific implant group versus 3.3 mm (range 0.4–7.8 mm) in the standard implant group. Majority of the difference was attributable to implant underhang rather than overhang. They also reported survivorship of 97% for the patient-specific group at average follow-up of 37 months compared to 85% at an average follow-up of 32 months for the standard implant group [48]. However, the survivorship of the standard implant group reported in this study is lower than typically reported range in cohort and registry studies (range 94.7–98.3% at 2–3-year follow-up [49]). In a prospective multicenter study of custom UKA implants (110 medial and 10 lateral iUni® UKAs, at 8 centers), Sinha et al. reported a cumulative revision rate of 3.3% at an average follow-up of 2 years (2 revisions for tibial loosening and 2 for disease progression) [50]. Additionally, 99% of patients reported being satisfied with their UKR, with 89% reporting to be very or extremely satisfied and 89% reporting that their knees felt "natural."

In summary, custom UKA implants appear to provide better anatomical fit to maximize bone coverage. However, as of today there is minimal evidence supporting other postulated benefits such as reduced risk of soft-tissue irritation, better joint feel and function, and improved surgical/OR efficacy.

Alternate UKA-Bearing Materials

Like total knee arthroplasty implants, the most common materials used in UKA are cobalt-chromium-molybdenum (CoCrMo) alloy for the femoral component, titanium (Ti6Al4V) or CoCrMo alloy for the tibial tray, and high-crosslinked or conventional UHMWPE for the tibial insert. With regard to polyethylene, most manufacturers tend to adopt the polyethylene offerings of their TKA systems within their respective UKA implants. Nonetheless, there continues to be interest in potential use of alternative materials for UKA-bearing surfaces including ceramic coatings, bulk ceramics, and high-performance polymers most notably polyether-ether ketone (PEEK). The motivation behind this is the continued quest to reduce generation of articular wear debris and hypersensitivity concerns in select patients and achieving more natural bone stress/strain distribution to mitigate long-term risk of aseptic loosening.

Atsui et al. reported short-term outcomes for a cemented alumina ceramic UKA (Kyocera, Kyoto, Japan) in ten consecutive patients treated for osteonecrosis of the knee [51]. No revisions were reported at an average follow-up of 42 months, and no patients had progressive radiolucency wider than 2 mm. Good to excellent

outcomes were reported for all patients with KSS increasing from 50.6 to 90.8 at final follow-up. In addition to the limitation of the small study size, only patients with a low activity and age > 60 years were included. No subsequent reports of bulk-ceramic unicompartmental knees or existence of a current commercial product could be found. On the other hand, UKA implants with ceramized metals have been available commercially from a few different manufacturers since at least 1998. These include both ceramic-coated metal components and oxidized zirconium implants.

Coatings employed in UKA include titanium nitride (TiN) (e.g., Uniglide®; Fig. 14.1c) and zirconium nitride (ZrN) (e.g., Univation®, Aesculap AG, Tuttlingen, Germany) and titanium niobium nitride (TiNbN) (e.g., Oxford® Partial Knee; PorEx® Endo Model®, Link Co., Hamburg, Germany). Affatato et al. conducted knee simulator testing of a mobile-bearing UKA (Univation® M,) with GUR 1020 UHMWPE (gamma irradiation to 30 ± 2 kGy) meniscus specimens articulating against CoCr femoral components coated with a multilayer ZrN coating. The multilayer coating is composed of a top layer of ZrN, five intermediate layers alternating between chromium nitride and chromium CrCN, and a final bond coat of thin adhesive chromium agent (AS-2008) [52]. The multilayer construct is aimed at arresting ion diffusion and ensuring mechanical integrity of the coating by providing a gradation of coating stiffness. The coated femoral component and tibial trays showed no signs of scratching, burnishing, or pitting following three million cycles of knee simulator testing. The overall measured wear rate was 1.3 mg/Mc, which appeared to be favorable relative to other reports in literature (simulator test wear rates, 2.9–6.6 mg/Mc), but the study did not have any direct controls to compare against. No loss of coating was observed following three million test cycles. Both new and tested components showed macropores and micropores, which were likely created by the coating process. With regard to TiNbN-coated implants, no unicompartmental-specific data is available. However, a few studies pertaining to TiNbN-coated TKA implants have been published. Malikian et al. found no notable reduction in polyethylene wear for TiNbN-coated TKA femoral components compared to CoCr TKA femoral components during knee simulator wear testing [53]. This was despite a clear reduction in roughness progression for the TiNbN-coated femorals. In a retrospective comparison of short-term (mean 2-year follow-up) clinical outcomes for a TiNbN-coated TKA and conventional TKA of the same design, Thienpont et al. found no differences in clinical, radiographic, or patient-reported outcomes [54].

Unlike ceramic coatings applied to a metal substrate, oxidized zirconium (OxZr) is created via thermal diffusion, which transforms the surface of wrought zirconium-niobium alloy (ZrNb, 2.5% niobium) to a monoclinic ZrO2 layer of approximately 5 μm thickness. Total knee implants made of OxZr material have been on the market since 1997, and UKA components were introduced in 2003. While no unicompartmental specific data is available, several clinical and laboratory studies have been published regarding OxZr TKA implants demonstrating reduced in vitro wear rates relative to CoCr implants and excellent mid- to long-term outcomes [55].

Grupp et al. evaluated the suitability of PEEK containing 30% discontinuous pitch fibers (CFR-PEEK-Optima LT1 CP 30, Invibio Ltd., Thornton-Cleveleys, UK) and PEEK containing 30% polyacrylonitrile (PAN)-based carbon fibers (CFR-PEEK-Optima LT1 CA 30) for replacing the polyethylene tibial inserts in fixed-bearing UKA (Univation® F) [56]. However, the results did not support the use of CFR-PEEK PAN or CFR-PEEK pitch as the bearing material. The wear rates of CoCr29Mo6 UKA components articulating against CFR-PEEK PAN (5.2 ± 6.92 mm^3/MC) and CFR-PEEK pitch (5.1 ± 2.3 mm^3/MC) were not significantly different from those of CoCr articulating against conventional GUR 1020 UHWMPE (8.6 ± 2.17 mm^3/MC). All bearing components were packed under a nitrogen atmosphere and sterilized by gamma irradiation (30 ± 2 kGy) and subjected to accelerated aging according to ASTM F2003–02. Further, a wide scatter was noted in wear behavior for CFR-PEEK PAN with wear rates of individual samples

ranging from 0.9 mm^3/MC to 19.2 mm^3/MC. Brockett et al. evaluated wear performance of virgin PEEK (Optima Natural, Invibio) and CFR-PEEK pitch (PEEK Optima™ Wear Performance, Invibio Ltd., Thornton-Cleveleys, UK) in a low-conformity configuration (flat inserts) articulating with CoCr (Sigma® CR, DePuy International Ltd., UK) femoral component [57]. They observed very high wear rates for PEEK and CFR-PEEK (252 ± 159 mm^3/Mc and 209 ± 37 mm^3/Mc respectively) compared to that of conventional polyethylene tested in the same manner (3.47 ± 0.7 mm^3/Mc). These high wear rates were resulted from surface cracking and delamination, leading the authors to conclude unsuitability of PEEK and CFR-PEEK as bearings for low-conformity knee implants.

Another alternative form of UKA proposed by Chaudhary et al. involves reversal of the conventional material pairing, with a metal-backed polyethylene femoral component (~9 mm thick) articulating against a polished metal tibial plate (~3 mm thick) [58]. The proposed benefit of this concept (referred to as "early intervention"/"EI" implant) is preservation of stronger tibial bone stock. The femoral component replaces only the portion of the distal femur (over a flexion arc of 42 deg), which is most frequent site of early cartilage loss [58, 59]. In a finite element study, Chaudhary et al. showed comparable stresses and strains in underlying bone for the 3 mm EI tibial component and a metal-backed polyethylene onlay component [60]. However, the 3 mm EI component required only 2 mm resection as opposed to 6 mm resection required for the metal-backed onlay, thereby preserving more of the stronger proximal tibial bone. Knee simulator wear testing of this concept showed higher but acceptable wear rate relative to conventional UKA (4.73 ± 0.27 mg/Mc for EI implant vs. 3.07 ± 0.39 mg/Mc for conventional UKA) with both employing highly crosslinked polyethylene stabilized with vitamin E [59].

In summary, several materials including bulk-ceramics, oxidized zirconia, ceramic coatings, and PEEK are available or are being explored as alternatives to CoCr-UHMWPE articulation in UKA. The available evidence for oxidized zirconia and ceramic coatings demonstrate these as being viable alternatives, particularly for patients with suspected metal hypersensitivity; however, cost-effectiveness for broader population is unknown. In recent years, there has been an increased interest in PEEK polymer for large joint application, including in the knees. Current evidence does not support CoCr-PEEK or CoCr-CFR PEEK articulation as a promising candidate for UKA.

References

1. Newman J, Pydisetty RV, Ackroyd C. Unicompartmental or total knee replacement: the 15-year results of a prospective randomised controlled trial. J Bone Joint Surg Br. 2009;91(1):52–7. https://doi.org/10.1302/0301-620X.91B1.20899. 91-B/1/52 [pii].
2. van der List JP, Kleeblad LJ, Zuiderbaan HA, Pearle AD. Mid-term outcomes of metal-backed unicompartmental knee arthroplasty show superiority to all-polyethylene unicompartmental and total knee arthroplasty. HSS J. 2017;13(3):232–40. https://doi.org/10.1007/s11420-017-9557-5. 9557 [pii].
3. American Joint Replacement Registry. Fourth annual report on hip and knee arthroplasty data. Rosemont; 2017.
4. Australian Orthopaedic Association National Joint Replacement Registry. 2016 Annual Report. Adelaide; 2016.
5. National Joint Registry for England W, Northern Ireland and the Isle of Man. 14th Annual Report. Hemel Hempstead; 2017.
6. Murray DW, Liddle AD, Judge A, Pandit H. Bias and unicompartmental knee arthroplasty. Bone Joint J. 2017;99-B(1):12–5. https://doi.org/10.1302/0301-620X.99B1.BJJ-2016-0515.R1. 99-B/1/12 [pii].
7. Psychoyios V, Crawford RW, O'Connor JJ, Murray DW. Wear of congruent meniscal bearings in unicompartmental knee arthroplasty: a retrieval study of 16 specimens. J Bone Joint Surg Br. 1998;80(6):976–82.
8. Smith TO, Hing CB, Davies L, Donell ST. Fixed versus mobile bearing unicompartmental knee replacement: a meta-analysis. Orthop Traumatol Surg Res. 2009;95(8):599–605. https://doi.org/10.1016/j.otsr.2009.10.006. S1877-0568(09)00173-X [pii].
9. Li MG, Yao F, Joss B, Ioppolo J, Nivbrant B, Wood D. Mobile vs. fixed bearing unicondylar knee arthroplasty: a randomized study on short term clinical outcomes and knee kinematics. Knee. 2006;13(5):365–70. https://doi.org/10.1016/j.knee.2006.05.003. S0968-0160(06)00082-2 [pii].
10. Emerson RH Jr, Hansborough T, Reitman RD, Rosenfeldt W, Higgins LL. Comparison of a mobile with a fixed-bearing unicompartmental knee implant. Clin Orthop Relat Res. 2002;404:62–70.

11. Gleeson RE, Evans R, Ackroyd CE, Webb J, Newman JH. Fixed or mobile bearing unicompartmental knee replacement? A comparative cohort study. Knee. 2004;11(5):379–84. https://doi.org/10.1016/j.knee.2004.06.006. S0968-0160(04)00132-2 [pii].
12. Peersman G, Stuyts B, Vandenlangenbergh T, Cartier P, Fennema P. Fixed- versus mobile-bearing UKA: a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2015;23(11):3296–305. https://doi.org/10.1007/s00167-014-3131-1. 10.1007/s00167-014-3131-1 [pii]
13. Ko YB, Gujarathi MR, Oh KJ. Outcome of unicompartmental knee arthroplasty: a systematic review of comparative studies between fixed and mobile bearings focusing on complications. Knee Surg Relat Res. 2015;27(3):141–8. https://doi.org/10.5792/ksrr.2015.27.3.141.
14. Varadarajan KM, Oral E, Muratoglu OK, Freiberg AA. Why all tibial polyethylene bearings are not the same. Tech Orthop. 2018;33(1):17–24.
15. Burton A, Williams S, Brockett CL, Fisher J. In vitro comparison of fixed- and mobile meniscal-bearing unicondylar knee arthroplasties: effect of design, kinematics, and condylar liftoff. J Arthroplast. 2012;27(8):1452–9. https://doi.org/10.1016/j.arth.2012.02.011. S0883-5403(12)00121-0 [pii].
16. Kretzer JP, Jakubowitz E, Reinders J, Lietz E, Moradi B, Hofmann K, et al. Wear analysis of unicondylar mobile bearing and fixed bearing knee systems: a knee simulator study. Acta Biomater. 2011;7(2):710–5. https://doi.org/10.1016/j.actbio.2010.09.031. S1742-7061(10)00441-1 [pii].
17. Brockett CL, Jennings LM, Fisher J. The wear of fixed and mobile bearing unicompartmental knee replacements. Proc Inst Mech Eng H. 2011;225(5):511–9. https://doi.org/10.1177/2041303310393824.
18. Becker R, Mauer C, Starke C, Brosz M, Zantop T, Lohmann CH, et al. Anteroposterior and rotational stability in fixed and mobile bearing unicondylar knee arthroplasty: a cadaveric study using the robotic force sensor system. Knee Surg Sports Traumatol Arthrosc. 2013;21(11):2427–32.https://doi.org/10.1007/s00167-012-2157-5.
19. Pandit H, Jenkins C, Beard DJ, Price AJ, Gill HS, Dodd CA, et al. Mobile bearing dislocation in lateral unicompartmental knee replacement. Knee. 2010;17(6):392–7. https://doi.org/10.1016/j.knee.2009.10.007. S0968-0160(09)00208-7 [pii].
20. Simpson DJ, Kendrick BK, O'Connor JJ, Dodd C, Murray DW. Lateral mobile bearings in partial knee replacement: flat or domed? 56th Annual Meeting of the Orthopaedic Research Society; New Orleans; 2010.
21. Streit MR, Walker T, Bruckner T, Merle C, Kretzer JP, Clarius M, et al. Mobile-bearing lateral unicompartmental knee replacement with the Oxford domed tibial component: an independent series. J Bone Joint Surg Br. 2012;94(10):1356–61. https://doi.org/10.1302/0301-620X.94B10.29119. 94-B/10/1356 [pii].
22. Newman SDS, Altuntas A, Alsop H, Cobb JP. Up to 10 year follow-up of the Oxford domed lateral partial knee replacement from an independent Centre. Knee. 2017; https://doi.org/10.1016/j.knee.2017.05.001. S0968-0160(17)30103-5 [pii].
23. Saenz CL, McGrath MS, Marker DR, Seyler TM, Mont MA, Bonutti PM. Early failure of a unicompartmental knee arthroplasty design with an all-polyethylene tibial component. Knee. 2010;17(1):53–6. https://doi.org/10.1016/j.knee.2009.05.007. S0968-0160(09)00106-9 [pii].
24. Scott CE, Eaton MJ, Nutton RW, Wade FA, Evans SL, Pankaj P. Metal-backed versus all-polyethylene unicompartmental knee arthroplasty: proximal tibial strain in an experimentally validated finite element model. Bone Joint Res. 2017;6(1):22–30. https://doi.org/10.1302/2046-3758.61.BJR-2016-0142.R1. 6/1/22 [pii].
25. Walker PS, Parakh DS, Chaudhary ME, Wei CS. Comparison of interface stresses and strains for onlay and inlay unicompartmental tibial components. J Knee Surg. 2011;24(2):109–15.
26. Bray RL, White P, Howells N, Robinson JR, Porteous AJ, Murray JR. Minimum 20-year survivorship of the St Georg Sled medial unicompartmental knee replacement. BASK Annual Spring Meeting 2017; Southport, England; 2017.
27. Lustig S, Paillot JL, Servien E, Henry J, Ait Si Selmi T, Neyret P. Cemented all polyethylene tibial insert unicompartmental knee arthroplasty: a long term follow-up study. Orthop Traumatol Surg Res. 2009;95(1):12–21. https://doi.org/10.1016/j.otsr.2008.04.001. S1877-0568(08)00011-X [pii].
28. Manzotti A, Cerveri P, Pullen C, Confalonieri N. A flat all-polyethylene tibial component in medial unicompartmental knee arthroplasty: a long-term study. Knee. 2014;21(Suppl 1):S20–5. https://doi.org/10.1016/S0968-0160(14)50005-1. S0968-0160(14)50005-1 [pii].
29. Hawi N, Plutat J, Kendoff D, Suero EM, Cross MB, Gehrke T, et al. Midterm results after unicompartmental knee replacement with all-polyethylene tibial component: a single surgeon experience. Arch Orthop Trauma Surg. 2016;136(9):1303–7. https://doi.org/10.1007/s00402-016-2515-8. 10.1007/s00402-016-2515-8 [pii].
30. Forster-Horvath C, Artz N, Hassaballa MA, Robinson JR, Porteous AJ, Murray JR, et al. Survivorship and clinical outcome of the minimally invasive uniglide medial fixed bearing, all-polyethylene tibia, unicompartmental knee arthroplasty at a mean follow-up of 7.3years. Knee. 2016;23(6):981–6. https://doi.org/10.1016/j.knee.2016.07.003. S0968-0160(16)30104-1 [pii].
31. Furnes O, Espehaug B, Lie SA, Vollset SE, Engesaeter LB, Havelin LI. Failure mechanisms after unicompartmental and tricompartmental primary knee replacement with cement. J Bone Joint Surg Am. 2007;89(3):519–25. https://doi.org/10.2106/JBJS.F.00210. 89/3/519 [pii].
32. Hutt JR, Farhadnia P, Masse V, LaVigne M, Vendittoli PA. A randomised trial of all-polyethylene and metal-backed tibial components in unicompartmental arthroplasty of the knee. Bone Joint J.

2015;97-B(6):786–92. https://doi.org/10.1302/0301-620X.97B6.35433. 97-B/6/786 [pii].
33. The New Zealand Joint Registry. Eighteen Year Report January 1999 to December 2016. Wellington, New Zealand; 2017.
34. Campi S, Pandit HG, Dodd CAF, Murray DW. Cementless fixation in medial unicompartmental knee arthroplasty: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2017;25(3):736–45. https://doi.org/10.1007/s00167-016-4244-5. 10.1007/s00167-016-4244-5 [pii].
35. Akan B, Karaguven D, Guclu B, Yildirim T, Kaya A, Armangil M, et al. Cemented versus uncemented Oxford unicompartmental knee arthroplasty: is there a difference? Adv Orthop. 2013;2013:245915. https://doi.org/10.1155/2013/245915.
36. Yildirim G, Gopalakrishnan A, Davignon RA, Parker JW, Chawla H, Pearle AD. Comparative fixation and subsidence profiles of cementless unicompartmental knee arthroplasty implants. J Arthroplast. 2016;31(9):2019–24. https://doi.org/10.1016/j.arth.2016.02.034. S0883-5403(16)00177-7 [pii].
37. van der List JP, Sheng DL, Kleeblad LJ, Chawla H, Pearle AD. Outcomes of cementless unicompartmental and total knee arthroplasty: a systematic review. Knee. 2017;24(3):497–507. https://doi.org/10.1016/j.knee.2016.10.010. S0968-0160(16)30176-4 [pii].
38. Schlueter-Brust K, Kugland K, Stein G, Henckel J, Christ H, Eysel P, et al. Ten year survivorship after cemented and uncemented medial Uniglide(R) unicompartmental knee arthroplasties. Knee. 2014;21(5):964–70. https://doi.org/10.1016/j.knee.2014.03.009. S0968-0160(14)00066-0 [pii].
39. Panzram B, Bertlich I, Reiner T, Walker T, Hagmann S, Gotterbarm T. Cementless Oxford medial unicompartmental knee replacement: an independent series with a 5-year-follow-up. Arch Orthop Trauma Surg. 2017;137(7):1011–7. https://doi.org/10.1007/s00402-017-2696-9. 10.1007/s00402-017-2696-9 [pii].
40. Pandit H, Liddle AD, Kendrick BJ, Jenkins C, Price AJ, Gill HS, et al. Improved fixation in cementless unicompartmental knee replacement: five-year results of a randomized controlled trial. J Bone Joint Surg Am. 2013;95(15):1365–72. https://doi.org/10.2106/JBJS.L.01005. 1719859 [pii].
41. Kendrick BJ, Kaptein BL, Valstar ER, Gill HS, Jackson WF, Dodd CA, et al. Cemented versus cementless Oxford unicompartmental knee arthroplasty using radiostereometric analysis: a randomised controlled trial. Bone Joint J. 2015;97-B(2):185–91. https://doi.org/10.1302/0301-620X.97B2.34331. 97-B/2/185 [pii].
42. Seeger JB, Haas D, Jager S, Rohner E, Tohtz S, Clarius M. Extended sagittal saw cut significantly reduces fracture load in cementless unicompartmental knee arthroplasty compared to cemented tibia plateaus: an experimental cadaver study. Knee Surg Sports Traumatol Arthrosc. 2012;20(6):1087–91. https://doi.org/10.1007/s00167-011-1698-3.
43. O'Donnell T, Neil MJ. The Repicci II(R) unicondylar knee arthroplasty: 9-year survivorship and function. Clin Orthop Relat Res. 2010;468(11):3094–102. https://doi.org/10.1007/s11999-010-1474-6.
44. Romanowski MR, Repicci JA. Minimally invasive unicondylar arthroplasty: eight-year follow-up. J Knee Surg. 2002;15(1):17–22.
45. Jacofsky DJ, Allen M. Robotics in arthroplasty: a comprehensivereview.JArthroplast.2016;31(10):2353–63. https://doi.org/10.1016/j.arth.2016.05.026. S0883-5403(16)30164-4 [pii].
46. Sassoon A, Nam D, Nunley R, Barrack R. Systematic review of patient-specific instrumentation in total knee arthroplasty: new but not improved. Clin Orthop Relat Res. 2015;473(1):151–8. https://doi.org/10.1007/s11999-014-3804-6.
47. Carpenter DP, Holmberg RR, Quartulli MJ, Barnes CL. Tibial plateau coverage in UKA: a comparison of patient specific and off-the-shelf implants. J Arthroplast. 2014;29(9):1694–8. https://doi.org/10.1016/j.arth.2014.03.026. S0883-5403(14)00198-3 [pii].
48. Demange MK, Von Keudell A, Probst C, Yoshioka H, Gomoll AH. Patient-specific implants for lateral unicompartmental knee arthroplasty. Int Orthop. 2015;39(8):1519–26. https://doi.org/10.1007/s00264-015-2678-x.
49. Pearle AD, van der List JP, Lee L, Coon TM, Borus TA, Roche MW. Survivorship and patient satisfaction of robotic-assisted medial unicompartmental knee arthroplasty at a minimum two-year follow-up. Knee. 2017;24(2):419–28. https://doi.org/10.1016/j.knee.2016.12.001. S0968-0160(16)30242-3 [pii].
50. Sinha R, Burkhardt J, Martin G, Mack D, Dauphine R, Levine M et al. Customized, individually made unicondylar knee replacement: a prospective, multicenter study of 2-year clinical outcomes. In: Proceedings of the 2014 Harvard Arthroplasty Course, Cambridge. Oct 7–10, 2014.
51. Atsui K, Tateishi H, Futani H, Maruo S. Ceramic unicompartmental knee arthroplasty for spontaneous osteonecrosis of the knee joint. Bull Hosp Jt Dis. 1997;56(4):233–6.
52. Affatato S, Spinelli M, Lopomo N, Grupp TM, Marcacci M, Toni A. Can the method of fixation influence the wear behaviour of ZrN coated unicompartmental mobile knee prostheses? Clin Biomech (Bristol, Avon). 2011;26(2):152–8. https://doi.org/10.1016/j.clinbiomech.2010.09.010. S0268-0033(10)00258-5 [pii].
53. Malikian R, Maruthainar K, Stammers J, Wilding CP, Blunn GW. Four station knee simulator wear testing comparing titanium niobium nitride with cobalt chrome. J Bioeng Biomed Sci. 2013;3(3):1–5.
54. Thienpont E. Titanium niobium nitride knee implants are not inferior to chrome cobalt components for primary total knee arthroplasty. Arch Orthop Trauma Surg. 2015;135(12):1749–54. https://doi.org/10.1007/s00402-015-2320-9. 10.1007/s00402-015-2320-9 [pii].
55. Varadarajan KM, Holtzman DJ, Li G, Lange J, Haas SB, Rubash HE, et al. Implant designs of total

knee arthroplasty. In: Mont MA, Tanzer M, editors. Orthopaedic knowledge update hip and knee reconstruction 5. Rosemont: American Academy of Orthopaedic Surgeons; 2016. p. 113–30.
56. Grupp TM, Utzschneider S, Schroder C, Schwiesau J, Fritz B, Maas A, et al. Biotribology of alternative bearing materials for unicompartmental knee arthroplasty. Acta Biomater. 2010;6(9):3601–10. https://doi.org/10.1016/j.actbio.2010.04.003. S1742-7061(10)00181-9 [pii].
57. Brockett CL, Carbone S, Fisher J, Jennings LM. PEEK and CFR-PEEK as alternative bearing materials to UHMWPE in a fixed bearing total knee replacement: an experimental wear study. Wear. 2017;374–375:86–91. https://doi.org/10.1016/j.wear.2016.12.010. S0043-1648(16)30749-9 [pii].
58. Chaudhary M, Walker PS. Analysis of an early intervention distal femoral resurfacing implant for medial osteoarthritis. J Biomech. 2016; https://doi.org/10.1016/j.jbiomech.2016.09.039. S0021-9290(16)31053-3 [pii].
59. Haider H, Walker P, Weisenburger J, Garvin K. Wear of unicompartmental knee replacements: standard and reversed material couples. Bone Joint J Orthop Proc Suppl. 2017;99-B(Supp 4):6.
60. Chaudhary ME, Walker PS. Analysis of an early intervention tibial component for medial osteoarthritis. J Biomech Eng. 2014;136(6):061008. https://doi.org/10.1115/1.4027467. 1864205 [pii]
61. Bodycad. Park City, UT, USA. https://bodycad.com/en/home. Accessed 20 Nov 2017.

15 The Kinematics of the Three Compartments of the Native and Partially Implanted Knee

Francesco Zambianchi, Shinichiro Nakamura, Francesco Fiacchi, Shuichi Matsuda, and Fabio Catani

Introduction

The biomechanics of the human knee joint has been a subject of speculation since the past century [1]. Different theories as to how the tibia, the femur, and the patella articulate with respect to each other have developed as a result of research involving cadavers and living subjects. Different methods have been applied in order to study the functional kinematics of the human knee, taking into account how muscle activation, movement, and loading condition affect joint motion and bone's position.

The first radiological study was performed by Zuppinger [2], who reported that the femur rolled back across the tibia during flexion as a result of the so-called rigid four-bar link mechanism, provided by the two cruciate ligaments. In the 1970s, Frankel [3] introduced the concept of the instant center of rotation, emphasizing as one link (rigid body) rotates around the other, there is at any given moment in time a point with zero velocity and that point is called the "instant center of rotation." The preliminary findings by Frankel were carried out by considering "true lateral" radiographs of the knee in subjects lying on one side at different intervals in the range of motion from extension to flexion. Basically, the knee motion was reduced from a 3D reality to a 2D projection. In the early1980s, Grood and Suntay introduced a joint-coordinate system providing a geometric description of the 3D rotational and translational motion between two rigid bodies, applied to the knee joint. With this model, the described joint motion became independent of the order in which the component rotations and translation occurred [4].

In more recent times, technological progress allowed the use of advanced tools to examine the kinematic behavior of the knee joint, including in vitro studies with MRI on cadaveric specimens [5, 6]; in vivo analyses using 2D video-fluoroscopy with shape-matching techniques, based on CT models [7–9]; in vivo semi-dynamic roentgen stereophotogrammetric analysis [10]; and open dual-coil MRIs [11, 12]. These approaches have revealed a more comprehensive three-dimensional insight in the morphology and kinematic pattern of the normal knee in loading and unloading conditions.

Video-fluoroscopy allows to follow real-time in vivo knee motion, with the intrinsic drawback of delivering two-dimensional images from a three-dimensional reality. Three-dimensional bone models are usually derived from preliminary CTs and subsequently overimposed to 2D

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fluoroscopic images with iterative shape-matching technique [7]. This method for knee kinematics study uses different acquisition procedures and joint contact computations to describe findings, making it sometimes difficult to compare results of one study to another. Determination of tibiofemoral contact conditions from CT models assumes uniform cartilage thickness on both knee compartments. MR-based surface models including cartilage are superior for computing surface interactions, but suffering from less accurate bony definition and leading to inaccurate kinematics measurements [13]. Therefore, best approach might consist in model registration using CT-derived bone models with surface interrogations performed using MR-derived articular surfaces [7].

Based on the published data, the human knee joint kinematics consist of a progressive femoral external rotation relative to the tibia with knee flexion and greater posterior displacement of the lateral femoral condyle with respect to the medial condyle. However, different approaches for in vivo kinematics assessment seem to discover different kinematic patterns. Cadaveric in vitro studies and in vivo studies on native, osteoarthritic, and replaced knees demonstrate a significant interindividual and activity-dependent variability. Rotational and translational motion patterns represent the expression of the equilibrium between external forces and the articular reactions determined by muscular action, body inertia, and soft tissue constraint.

Functional In Vivo Kinematics of the Native Knee

In vivo knee kinematics studies have provided clinically insightful information and spurred further complementary investigations. Research topics of current interest include exploration of knee kinematics over the full flexion range and development of techniques for generating and reporting data to provide enhanced physiologic insight. Knee motion can be divided into three arcs based on the flexion degrees: the screw-home arc, the functional active arc, and the passive deep-flexion arc [9, 14] (Fig. 15.1).

The Screw-Home Arc

The screw-home arc is the movement of knee motion between full extension (0°) and approximately 20° of flexion. Moro-Oka et al. described knee kinematics of six healthy male subjects during three activities (kneel, squat, and stair climb) using video-fluoroscopy model registration techniques.

Johal et al. instead described the weight-bearing knees in healthy subjects with interventional MRI. Both authors demonstrated a sharp external rotation of the femur relative to the tibia from 0° to 20° of flexion during the screw-home arc [9, 12].

In the lateral compartment, the femur displaces posteriorly, producing an average 10 mm of displacement, starting its motion from the anterior portion of the tibial plateau. Medially, the kinematic behavior of the femoral contact point shows a slight forward translation averaging approximately 2 mm [12].

The screw-home mechanism is determined by the profound asymmetry between the shapes of the medial and lateral femoral condyles articulating with the tibia, which are composed by a larger distal and smaller posterior circular arc medially and a single circular sagittal facet on the lateral side [5]. The screw-home mechanism functioning is guaranteed by an intact anterior cruciate ligament, as demonstrated by Yamaguchi et al. [15].

Functional Active Arc

The functional active arc is the movement of the knee between 20° and 120° of flexion and is highly influenced by the neuromuscular control. During this range of knee flexion, the femur exhibits a relatively constant external rotation, up to 20° with respect to the tibia with the majority of this motion occurring earlier in the flexion range and around a medially positioned axis.

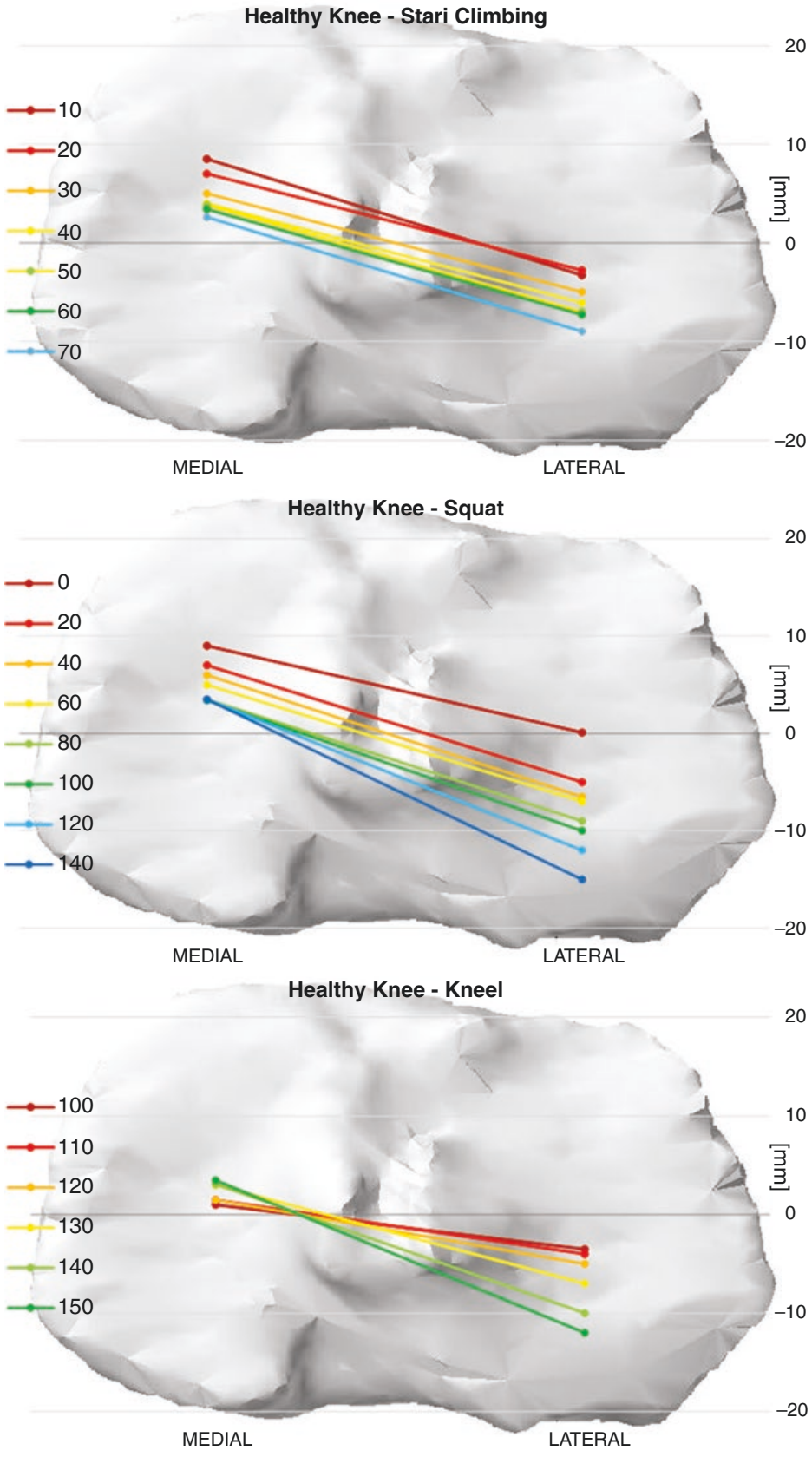

Fig. 15.1 Average contact locations overimposed on a right tibial surface model of a representative healthy knee. Average contact locations are shown for 10° flexion increment for each motor task. (Image data based on Moro-Oka et al. [9])

During the functional active arc of motion, the position of the femoral contact points is posteriorly directed. In the lateral compartment, the femur continues its backward-directed translation, producing approximately 15 mm of displacement. Medially instead, the contact point position remains almost constant, with little posterior translation (about 2–3 mm) during this arc of knee flexion [12].

Passive Deep-Flexion Arc

In the arc of 120–140° of joint flexion, tibiofemoral motion is usually passive, as a result of external forces (usually body weight), allowing extra degrees of flexion.

In the literature, some authors have described knee kinematics of healthy subjects during full flexion in a lunge using 3D-to-2D model registration techniques or interventional MRI [12, 16]. The femur exhibits additional 15° of external rotation relative to the tibia over the entire activity of deep flexion, up to over 30° external rotation in full flexion. From 120° to 140° flexion, the medial and lateral tibiofemoral contact points demonstrate a narrow posterior displacement on the tibial plateau surface, with a larger translation of the lateral condyle compared to the medial. The medial tibiofemoral contact point translates posteriorly but remains centered in the medial compartment. The lateral tibiofemoral contact point instead is posteriorly directed, up to the edge of the tibial surface in full flexion [16].

The Influence of Activity on Healthy Knee Kinematics

Although the kinematic pattern of the healthy knee can be simplified as described above, in the literature, different authors have underlined that kinematic behaviors change with different activities. In particular, Hamai et al. demonstrated that healthy knee kinematics varied between squat and kneel. The greatest femoral external rotation and the most posterior tibiofemoral lateral contact were observed with squatting, but the maximum flexion angle and the range of femoral external rotation from 100° to maximum flexion were greater in kneeling. Medial contact was described in the same central area of the medial plateau for both activities, while the lateral femoral condyle showed a larger posterior displacement in squat activity, up to the edge of the tibial surface [16]. Comparison of stair climb and squat activities instead revealed small kinematic differences in the middle range of flexion, with the femur showing greater external rotation for all flexion angles during squatting [9].

In Vivo Kinematics of the Knee with Unicompartmental Knee Osteoarthritis

Few studies have described the kinematics of knees with unicompartmental osteoarthritis. Knees with medial osteoarthritis have shown somewhat similar kinematic patterns to those of the normal knee, such as a gradually increasing femoral external rotation with flexion for squatting and kneeling and gradually decreasing with extension for stair climbing [17] (Fig. 15.2). Nevertheless, some differences were reported between medial osteoarthritic and healthy knees. Compared to the healthy knee in extension, the femur in the osteoarthritic joint is placed at reduced values of external rotation, with this condition being maintained during the whole range of motion. Moreover, in knees with medial arthritis, the natural screw-home mechanism has not been described [17].

In the literature, the role of the anterior cruciate ligament (ACL) and its presence or absence in the determination of osteoarthritic knee kinematics has not been completely investigated.

Fiacchi et al. have described the kinematic behavior of knees with medial osteoarthritis and intact ACL during three activities of daily living, including weight-bearing and open chain motor task(s).

They reported different values of knee axial rotation on the horizontal plane in each of the three activities, with the greatest external rotation of the femur relative to the tibia during weight-

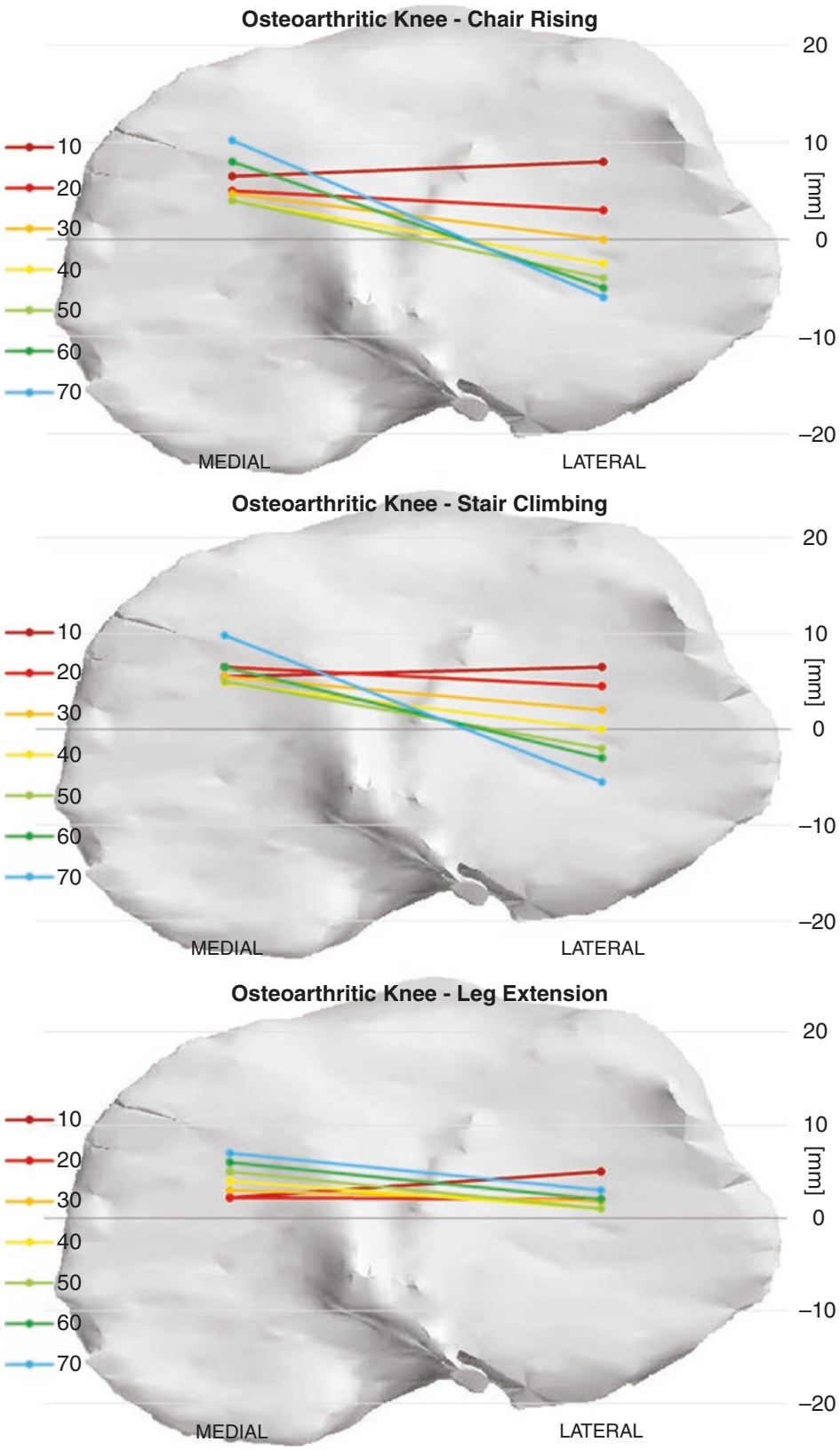

Fig. 15.2 Average contact locations overimposed on a right tibial surface model of a representative knee with medial osteoarthritis. Average contact locations are shown for 10° flexion increment for each motor task. (Image data based on Fiacchi et al. [18])

bearing (stair climbing and chair rising) and reduced average values of femoral external rotation during open chain motor task(s) (leg extension) [18]. The data describing the stair-climbing task were eventually compared with those by Moro-Oka et al. in healthy joints during the same motor tasks and analyzed with the same methodology. From 10° to 75° of knee flexion, an overall 9° femoral external rotation was reported both in healthy and osteoarthritic knees [9]. However, at

every degree of knee flexion, the axial rotation curve was shifted of about 10° internal rotation compared to the axial rotation of the healthy joint. This finding has already been noted by Matsui et al., who evaluated the femorotibial rotation using CT and reported that the femur tended to locate in a relative internal rotation position in knees with severe osteoarthritis compared to normal joints [19], and by Hamai et al. in their video-fluoroscopic analysis of the kinematics of the osteoarthritic knee [17]. Moreover, in the series reported by Fiacchi et al., the natural screw-home mechanism, occurring between 0° and 20° of healthy knee flexion, was not observed, presumably because the examined patients could not reach full extension [18]. This functional limitation is probably attributable to cartilage degeneration, osteophytes, and menisci disease in the medial compartment of unicompartmental arthritic knees. The reduction of the sharp internal rotation of the femur relative to the tibia in the last degrees of extension in the osteoarthritic joint has already been described by Nagao et al., who investigated normal and arthritic knees with ultrasound finding that the screw-home mechanism proportionally decreased with the progression of medial compartment osteoarthritis [20]. For what concern the anterior-posterior motion of the arthritic knee in weight-bearing motor tasks, the medial femoral condyle describes reduced motion from 10° to approximately 50° of knee flexion and an average 5 mm anterior translation from mid- to full-knee flexion, upon different activities. On the other hand, in open chain motor task(s), the medial condyle reports a little but progressive anterior translation throughout the whole range of motion. As described by Hamai et al., the lack of posterior translation of the medial condyle may be caused by soft tissue contracture and osteophyte formation with cartilage-bone erosion in the medial compartment and may be related to the cartilage wear pattern on the tibial plateau [17]. These findings are confirmed by the description of the kinematic behavior of early-stage osteoarthritic knees by Matsuki et al., who demonstrated reduced values of displacement on the medial side [21]. Moreover, the anterior translation of the medial femoral condyle in flexion – and its backward movement with extension – can be assumed as responsible for cartilage and meniscus damage due to increased shear forces on the articular surfaces. According to literature, the femoral condyle translation on the medial tibial plateau seems to be strictly dependent on ACL integrity. As reported by Moschella et al. in their study of tibial plateau wear patterns, cartilage erosion on arthritic knees with intact cruciates occurred in the central to medial region of the medial plateau. Instead, osteoarthritic knees with ruptured anterior cruciate ligament showed larger posterior wear [22] and tended to show more posterior contact during weight-bearing activities as reported by Hamai et al. and Yamaguchi et al. in their video-fluoroscopy analyses [15, 17].

On the lateral side, the osteoarthritic knee is characterized by a posterior motion of the femoral condyle, averaging 10 mm, upon different activities. This contributes to create a medial pivot type of axial rotation pattern, in which the femur externally rotates relative to the tibia as flexion progresses. The translation of the lateral femoral condyle occurs with a progressive and remarkable posterior motion for weight-bearing activities and a small relative motion during leg extension/flexion task. The described findings are comparable to those presented by Moro-Oka et al. and Lu in healthy knees [9, 23], but with the remarkable difference of significant anterior shift of the lateral contact points as reported by Matsuki et al. [21]. The relative motion of the lateral condyle on the tibial plateau seems to be independent from osteoarthritic degeneration. Not even the ACL integrity seems to be a factor with major influence on the translation of the lateral femoral condyle. In fact, as described by Dennis et al. comparing healthy with ACL-deficient knees, subjects with or without functional cruciate ligament report similar posterior motion patterns [24]. Relevant findings reported in literature include the kinematic differences showed between weight-bearing activities (chair rising and stair climbing) and open chain motor task(s), with smaller magnitude values for femoral axial rotation and medial and lateral

translations reported by the leg extension motion [18]. These findings are consistent with those of Lu et al. who compared the motion pattern of eight knees in conditions of load and unload [23].

In Vivo Knee Kinematics of Medial Unicompartmental Knee Arthroplasty

The clinical and functional outcomes of unicompartmental knee arthroplasty (UKA) have improved through the years since their introduction. Advanced designs, materials, and surgical techniques have played a role in improving outcomes, as the development of more specific indications for their use [25]. UKA also preserves native structures, such as cruciate ligaments or patellofemoral joint, leading closer to a more natural knee kinematics [26]. Current consensus regarding UKA indications suggests that the ACL should be intact and fully maintained to achieve greater implant survivorship [27, 28] and close-to-normal knee kinematics [29] (Fig. 15.3).

Component position, alignment, and ligament tension are thought to be crucial for better clinical outcome and durability. In addition, the study of knee kinematics has been addressed to for years and is considered to be related with postoperative knee functioning. Recent kinematic studies have shown that medial pivot kinematic patterns result in significantly better patient-reported outcome and larger flexion angles after TKA [30]. Preservation of knee kinematics after UKA is one of the key factors for better outcomes, and high discrepancies between pre- and postoperative knee kinematics may be the cause of knee pain and discomfort.

In the literature, different studies have investigated UKA-replaced-knee kinematics during diverse activities, describing various methods for motion analysis. In particular, it has been shown that knees with accurately placed implants exhibit stable kinematics, consistent with knees having intact and functioning cruciate ligaments. The patterns of tibiofemoral displacement in partially implanted knees are usually more similar to natural joints than what commonly has been reported in total knee arthroplasty [29, 31–33].

Three-dimensional-to-2D video-fluoroscopy studies on patients implanted with UKA reveal similar kinematic features compared to healthy knees [9], in particular for what concern patterns of axial rotation and femoral condyle contact point posterior translation, with progressive femoral external rotation and posterior lateral condylar translation with knee flexion [33]. Navigation has demonstrated to be a useful tool for accurate implant positioning to predict pre-disease alignment and recreating it with high accuracy [34, 35]. Simulator studies can mainly investigate the wear rate of the polyethylene, which informs the effects of the kinematics and femoral liftoff in several implant designs. Cadaver studies have depicted knee kinematics in detail with a dynamic knee rig, in which comparison with a native knee and contact mechanics can be obtained. Finite element analysis (FEA) can simulate knee kinematics as well as contact forces and contact stresses to the component and bone in detail. Recent technology can involve many factors such as cartilage, ligament, and muscles. In the present paragraph, different methods for partially implanted knee kinematics study have been described.

3D-to-2D Video-Fluoroscopy

Patterns of medial UKA knee axial rotation show progressive femoral external rotation relative to the tibia with increasing flexion, with no significant differences upon activity. In particular, in extension, the femur starts its motion from a neutral rotation, reaching about an average 7° of external rotation in mid-flexion. Noticeable remark of axial rotation pattern includes the suppression of the natural knee screw-home movement. This finding is likely to be explained by the modification of joint surface, conformity, and stiffness of the medial compartment induced by medial UKA.

On the medial side, the translation of the femoral condyles' contact points is characterized by

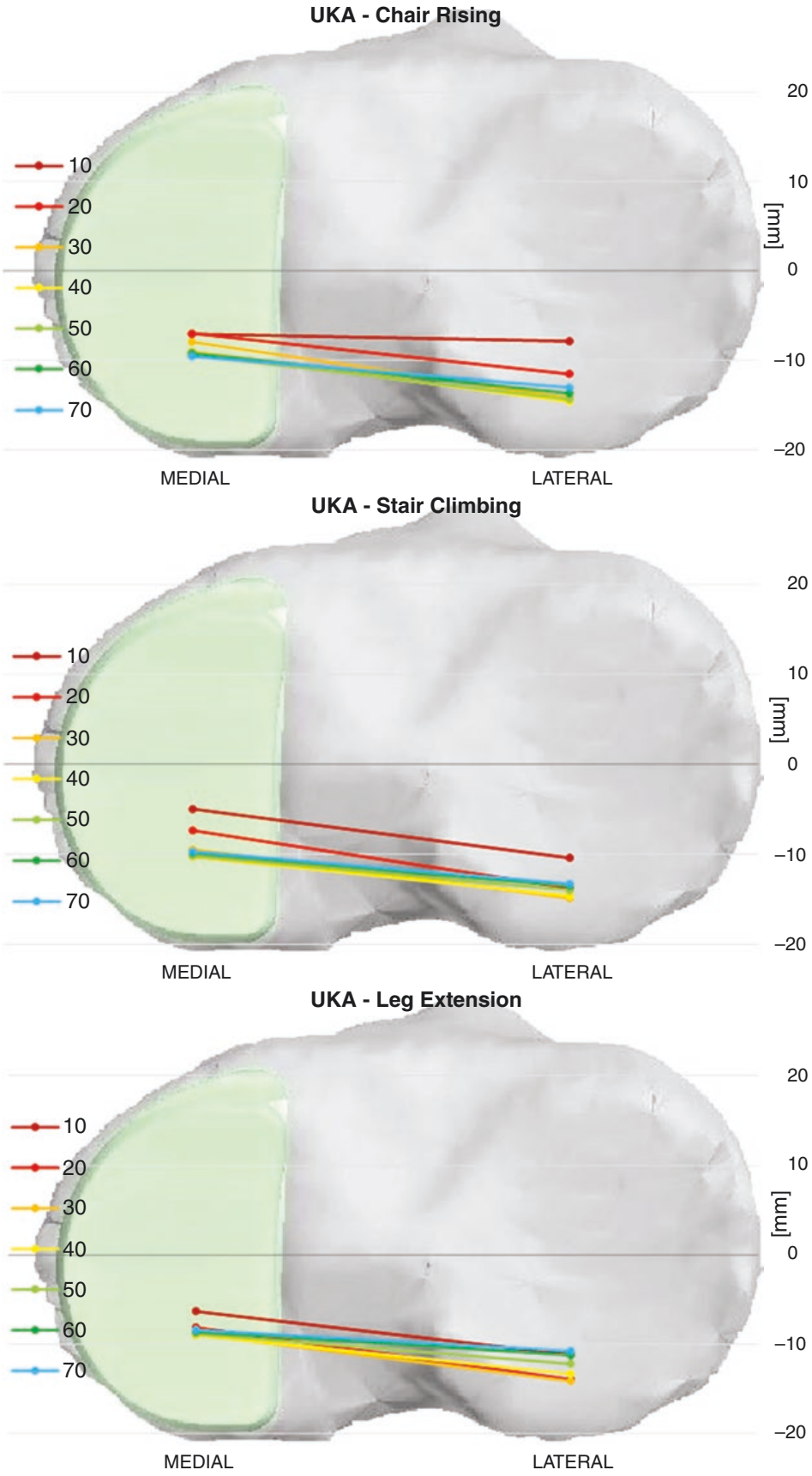

Fig. 15.3 Average contact locations overimposed on a right tibial surface model of a representative knee with medial unicompartmental knee arthroplasty. Average contact locations are shown for 10° flexion increment for each motor task

reduced values of translation from extension to mid-flexion, with the maintenance of a constant position in the central area of the tibial baseplate. From 50° to 60° of knee flexion, the kinematic behavior of the replaced knee demonstrates differences according to authors: some series report a medial contact point showing a slight anterior translation, averaging 4 mm, while others have described a minimal contact point posterior displacement of approximately 5 mm [33]. These differences can be explained by the absence of the menisci and of congruent articular surface, being replaced by the polyethylene insert flat surface.

On the lateral side, the femoral contact point shows a progressive and constant posterior translation with increasing degrees of knee motion, up to 20 mm of displacement in mid- to full flexion. Such kinematic characteristic is similar to that reported by the healthy and osteoarthritic knees, with the significant difference of the anterior shift of the kinematic curves of both contact points in the replaced knee compared to the healthy joint. This feature can be explained by the rather flat design of the tibial insert in most fixed-bearing UKA designs, allowing for less constraint of both condyles.

Navigation in UKA

Navigation has been introduced to improve accuracy in implant positioning and postoperative alignment in UKA as well as TKA. In several clinical studies, the accuracy of UKA implantations in relation to the coronal mechanical axis in a navigation group was significantly superior to that of conventional group, although clinical results, including ROM and Knee Society score, were equally good in both the groups [34, 35].

Current navigation systems provide the surgeon with a set of surgical parameters (cut orientation, component dimensions, valgus angle) that should assure appropriate component alignment and potentially joint kinematics similar to that of the intact knee. Casino et al. computed knee laxities and the 3D motions of the knee with a navigation system, evaluating the pattern and amount of tibial axial rotation and the anterior-posterior displacements in the medial and lateral compartments during the range of motion [36]. Kinematic tests were performed before and after surgery and included varus/valgus stress at 0 and 30° and passive range of motion. Varus/valgus laxity at extension was significantly reduced from 7.7° to 4.0° after UKA. Concerning the axial rotation, the amount of axial rotation during the passive ROM was similar in osteoarthritic knees (17.9°) and knees after UKA (15.8°). Similar patterns of tibial rotation were seen between before and after UKA. The transepicondylar line projection moved posteriorly during flexion (from 10° to 90° of flexion) in all UKA patients both before and after replacement. During flexion, the medial compartment displaced posteriorly approximately 9 mm, while the lateral compartment showed an average posterior translation of 18.3 mm. These results demonstrate that proposed intraoperative kinematics evaluations by a navigation system provide additional information on the functional outcome of the reconstruction permitting to restore knee kinematics during surgery.

Simulator Studies

Simulator studies have been conducted mainly to examine polyethylene inserts' wear in TKA and UKA. Recent improvement of the simulator and surrounding equipment has enabled to investigate the amount of quadriceps force, the strain on the surface of the tibial metaphysis, and the effect of variations in kinematic inputs and femoral condylar liftoff, although different loading conditions and the output of the data were detected among the studies.

Burton et al. investigated the effects of kinematics and femoral liftoff on the wear of fixed and mobile versions of a UKA design, in which axial load, flexion angle, anterior-posterior displacement, and internal/external tibial rotation were controlled [37]. High- and intermediate-kinematic input conditions, which consisted of an anterior-posterior displacement of 0–10 mm for high kinematics and 0–5 mm for intermediate

kinematics, were used for testing. Femoral condylar liftoff was tested by introducing an adduction/abduction rotation torque. Wear was reduced with the fixed-bearing UKA compared with the mobile-bearing UKA. Reducing anterior-posterior displacement demonstrated to reduce wear of the medial mobile UKA bearings; however, this led to increased wear in the fixed-bearing UKA system. Femoral condylar liftoff caused an increase in medial UKA bearing wear in both fixed- and mobile-bearing designs.

Small et al. evaluated the independent effects of slope, resection, rotation, and medial-lateral shift on strain response of the proximal tibia [38]. An electrodynamic axial-torsional material testing machine was used for mechanical testing. To quantify biomechanical response to loading, a grid of rectangular rosette strain gages was affixed to the tibia. Digital image correlation and strain gage analysis was conducted in static loading to evaluate strain distribution as a result of component alignment. Minimal distal resection and most lateral positioning, neutral component rotation, and 3°of slope (from mechanical axis) exhibited the most balanced strain response to loading following UKA.

Ettinger et al. investigated the differences in the quadriceps force and the medial contact pressure in vitro before and after UKA with two prosthesis systems, representing the mobile-bearing and fixed-bearing designs [39]. Designs were tested in sequences under isokinetic extension in an in vitro simulator, simulating muscular traction power using hydraulic cylinders. The articulation and pressure distribution between the femoral and tibial component was displayed using a pressure-sensitive film. Area and peak contact pressures were evaluated, and the center of pressure as the geometric center of the loaded pressure area was used. Implantation of both designs resulted in significant increase in the necessary maximum quadriceps force. In addition, maximum extension force was significantly higher in the mobile design (1701 N) than the fixed design (1585 N). A mean peak pressure of 14.1 MPa was detected across the flexion-extension cycle in the fixed-bearing group, compared with 5.8 MPa in the mobile-bearing group. With the fixed inlay, this was concentrated to a relatively constant mean value of 0.4 cm^2, whereas a minimum of 1.0 cm^2 across the whole tibial tray surface was detected in the mobile-bearing group. According to these findings, the mean pressure was 6.7 MPa for the fixed-bearing design and 1.0 MPa for the mobile design. The mobile design showed significantly increased quadriceps extension force compared with the fixed-bearing inlay in deep flexion. Although the fixed design showed higher maximum peak pressures concentrated on a smaller area, the pressure introduction in deep flexion was lower, compared to mobile-bearing inserts.

Cadaver Studies

Cadaver studies were conducted to examine in detail medial UKA kinematics, contact mechanics, and ligament tension. However, this condition does not represent the actual in vivo knee environment, due to smaller axial load and muscle forces and limited motion tasks.

Cassidy et al. quantified tibiofemoral position and alignment through a range of passive knee flexion after performing a balanced and overstuffed fixed-bearing medial UKA in a controlled cadaveric biomechanical model [40]. The appropriate-sized polyethylene was then inserted based on surgical judgment to replicate a balanced knee. A 1 mm thicker polythene component was then inserted to simulate the effects of an overstuffed knee. Measurements were recorded for the intact knee, the balanced knee, and the overstuffed knee. Following UKA, the tibia was externally rotated (3.6° at 15° flexion) and in 0.9° valgus relative to the native knee close to extension. In flexion, UKA implant determined a medial (1.8 mm at 45° flexion) and anterior (1.1 mm at 60°, 75°, and 90°flexion) translation of the knee. The tibia was translated distally through the entire range of flexion (2.4 mm at 30° and 45°flexion) after UKA. Compared to the balanced UKA, overstuffing further increased 0.7° valgus in full extension and distal translation of the tibia from full extension (0.8 mm) to 45°flexion (0.6 mm). Alterations in tibiofemoral kine-

matics following UKA might have implications for prosthesis failure and progression of osteoarthritis in the remaining compartment. Overstuffing should be avoided as it further increased valgus and did not improve the remaining kinematics.

Heyse et al. also examined effects of improper balancing on knee kinematics, ligament strain, and joint contact stress in mobile-bearing medial UKAs [41]. Three inlay thicknesses were tested to simulate optimal balancing as well as under- (1 mm thinner) and overstuffing (1 mm thicker) of the medial compartment relative to the optimal thickness. Under-stuffing of the medial compartment leads to close-to-native knee kinematics. Subjectively balanced and overstuffed mobile-bearing UKA knees were in more valgus. Lateral peak contact stress was higher from mid- to deep flexion following UKA in all three tested states; however, these results were not significant. Peak strain in the superficial medial collateral ligament was significantly higher in mobile-bearing UKA, regardless of the inlay thickness mainly in mid-flexion. Inlay thickness had no significant impact on measured quadriceps force during squatting. Overstuffing should be avoided as it results in the largest kinematic changes relative to the native condition and induces higher strains in the superficial medial collateral ligament. Based on the kinematic findings, it is advisable to use thinner inlays, as long as this is not compromising stability or risking inlay luxation.

Peersman et al. investigated whether mobile-bearing UKA preserves natural knee kinematics [42]. Three motion patterns, passive flexion-extension (0–110° flexion), open chain extension (5–70° flexion), and squatting (30–100° flexion), were performed pre- and post-implantation of a medial mobile-bearing UKA and compared in terms of rotational and translational knee joint kinematics in the different anatomical planes, respectively. In the axial plane, internal rotation of the tibia before and after UKA was consistent, regardless of motion task, with no significant differences. In anteroposterior translations during open chain activities, the femoral medial condyle center tended to be more posterior following UKA relative to the native knee in mid-flexion and above. The kinematics of the unloaded knee following mobile-bearing UKA closely resembled those of the native knee, while relative medial overstuffing with UKA results in the joint being more valgus.

Finite Element Analysis

Finite element analysis (FEA) can predict knee kinematics, contact pressure on polyethylene, and stress distribution on the tibia in detail after UKA, although validation of the analysis is required. So far, various methodologies have been reported, in which various bony and soft tissue structures such as articular cartilage, meniscus, ligaments, and joint capsule are included in the finite element models.

Kwon et al. conducted several studies using FEA concerning comparison of fixed- and mobile-bearing and importance of joint line preservation. In comparison the study of fixed- and mobile-bearing, the effects of polyethylene insert contact pressure, and stress in opposite compartments for fixed- and mobile-bearing were investigated using high kinematics displacement and rotation inputs [43]. The mobile-bearing polyethylene insert had lower contact pressure than the fixed-bearing polyethylene insert. With the mobile-bearing UKA, lower stress on the opposite compartment reduced the overall risk of progressive arthritis in the knee. The fixed-bearing UKA increases the overall risk of progressive osteoarthritic degeneration in the knee due to higher stress on the opposite compartment. However, the polyethylene insert of mobile-bearing showed pronounced backside stress at the inferior surface.

Concerning the importance of joint line preservation, the effects of the joint line on the contact stresses in polyethylene inserts, articular cartilage, and lateral meniscus using the FEA were evaluated [44]. The model for joint line was modeled as the orthogonal projection line from the medial tibial plateau to the anatomical axis. The joint line was shifted from −6 to +6 mm in 2 mm intervals, and the seven models were analyzed and compared under gait-loading conditions. The contact stresses in the PE insert, articular carti-

lage, and lateral meniscus matched were more variable from the original joint line model with increasing the difference of joint line level. On the +6 mm joint line, the contact stress was greater on the insert than on the articular cartilage, whereas the reverse occurred on the −6 mm joint line.

Innocenti et al. investigated the biomechanical effects of different varus/valgus alignment positions of tibial components in UKA [45]. In particular, the stress distribution in the proximal tibia and in the polyethylene tibial insert, the strains in both collaterals and cruciate ligaments, and the load distribution between the medial and the lateral compartments have been evaluated, using a validated FEA, comparing the differently aligned configurations. Both neutral mechanical and 3° of varus alignment induce lower stress distributions than valgus or a higher varus alignment for which higher values, up to 40%, are achieved for the polyethylene stress. When a UKA is implanted, a mismatch in the stiffness of the joint is introduced, changing the load distribution from medial to lateral for all configurations compared to the native. However, slight differences are noticeable among the different conditions with a maximum of 190 N and 90 N for the lateral and the medial side, respectively. Neutral mechanical or 3° of varus alignment presents similar biomechanical outputs on the bone, collateral ligament strain, and polyethylene insert. A 6° varus alignment or changes in valgus alignment were always associated with more detrimental effects.

Kia et al. determined how nonconforming, fixed-bearing medial UKA affects tibiofemoral kinematics and tension in the medial collateral ligament and the anterior cruciate ligament during passive knee flexion [31]. Fixed-bearing medial UKA could not maintain the medial pivoting that occurred in the intact knee from 0° to 30° of passive flexion. Increasing or decreasing tibial insert thickness following medial UKA also failed to restore the medial pivoting behavior of the intact knee despite modulating medial collateral ligament and anterior cruciate ligament forces. Reduced anterior-posterior constraint in nonconforming medial UKA relative to the intact knee leads to abnormal condylar translations regardless of insert thickness even with intact cruciate and collateral ligaments. This finding suggests that the conformity of the medial compartment as driven by the medial meniscus and articular morphology plays an important role in controlling anterior-posterior condylar translations in the intact tibiofemoral joint during passive flexion.

In conclusion, literature confirms that UKA knee kinematics is similar to the unicompartmental osteoarthritic knee kinematic patterns. Modern technologies and soft tissue-sparing surgical procedures, with respect of the ligaments' tightness, should permit to maintain the same preoperative knee kinematic features.

References

1. Weber WE, Weber E. Mechanics of the human walking apparatus. Translated by Maquet P and Furlong R Berlin etc: Springer 75; 1992 (Original Publication: Mechanik der menschlichen Gehwerkzeuge. Gottingen, 1836).
2. Zuppinger H. Die aktive flexion im unbelasteten Kniegelenk: Züricher Habil Schr. Bergmann: Wiesbaden; 1994. p. 703–63.
3. Frankel VH, Burstein AH, Brooks DB. Biomechanics as determined by analysis of the instant centers of motion. J Bone Joint Surg. 1971;53-A:945–77.
4. Grood ES, Suntay WJ. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. J Biomech Eng. 1983;105:136–44.
5. Iwaki H, Pinskerova V, Freeman MAR. Tibiofemoral movement 1: the shapes and relative movements of the femur and the tibia in the unloaded cadaver knee. J Bone Joint Surg. 2000;82-B:1189–95.
6. Eckhoff DE, Hogan C, DiMatteo L, et al. Difference between the epicondylar and cylindrical axis of the knee. Clin Orthop. 2007;461:238–44.
7. Banks SA, Hodge WA. Accurate measurement of three-dimensional knee replacement kinematics using single-plane fluoroscopy. IEEE Trans Biomed Eng. 1996;43:638–49.
8. Komistek RD, Dennis DA, Mahfouz M. In vivo fluoroscopic analysis of the normal human knee. Clin Orthop Relat Res. 2003;410:69–81.
9. Moro-Oka T, Hamai S, Miura H, Shimoto T, Higaki H, Fregly BJ, Iwamoto Y, Banks SA. Dynamic activity dependence of in vivo normal knee kinematics. J Orthop Res. 2008;26:428–34.
10. Karrholm J, Brandsson S, Freeman MAR. Tibiofemoral movement: changes of axial rotation caused by forced rotation at the weight bear-

ing knee studied by RSA. J Bone Joint Surg. 2000;82-B:1201–3.
11. Nakagawa S, Kadoya Y, Todo S, Kobayashi A, Sakamoto H, Freeman MAR, Yamano Y. Tibiofemoral movement: full flexion in the living knee studied by MRI. J Bone Joint Surg. 2000;82-B:1199–200.
12. Johal P, Williams A, Wragg P, Hunt D, Gedroyc W. Tibio-femoral movement in the living knee. A study of weight bearing and non-weight bearing knee kinematics using 'interventional' MRI. J Biomech. 2005;38:269–76.
13. Moro-Oka TA, Hamai S, Miura H, Shimoto T, Higaki H, Fregly BJ, Iwamoto Y, Banks SA. Can magnetic resonance imaging-derived bone models be used for accurate motion measurement with single-plane three-dimensional shape registration? J Orthop Res. 2007;25(7):867–72.
14. Williams A, Phillips C. Functional in vivo kinematics analysis of the normal knee. Chapter 5. Total knee arthroplasty – a guide to get better performance. Springer: Berlin/Heidelberg; 2005.
15. Yamaguchi S, Gamada K, Sasho T, Kato H, Sonoda M, Banks SA. In vivo kinematics of anterior cruciate ligament deficient knees during pivot and squat activities. Clin Biomech (Bristol, Avon). 2009;24(1):71–6. https://doi.org/10.1016/j.clinbiomech.2008.08.007.
16. Hamai S, Moro-Oka TA, Dunbar NJ, Miura H, Iwamoto Y, Banks SA. In vivo healthy knee kinematics during dynamic full flexion. Biomed Res Int. 2013:717546. https://doi.org/10.1155/2013/717546.
17. Hamai S, Moro-Oka T, Miura H, Shimoto T, Higaki H, Fregly BJ, et al. Knee kinematics in medial osteoarthritis during in vivo weight-bearing activities. J Orthop Res. 2009;27:1555–61.
18. Fiacchi F, Zambianchi F, Digennaro V, Ricchiuto I, Mugnai R, Catani F. In vivo kinematics of medial unicompartmental osteoarthritic knees during activities of daily living. Knee. 2014;21(Suppl 1):S10–4. https://doi.org/10.1016/S0968-0160(14)50003-8.
19. Matsui Y, Kadoya Y, Uehara K, Kobayashi A, Takaoka K. Rotational deformity in varus osteoarthritis of the knee: analysis with computed tomography. Clin Orthop. 2005;433:147–51.
20. Nagao N, Tachibana T, Mizuno K. The rotational angle in osteoarthritic knees. Int Orthop. 1998;22:282–7.
21. Matsuki K, Matsuki KO, Kenmoku T, Yamaguchi S, Sasho T, Banks SA. In vivo kinematics of early-stage osteoarthritic knees during pivot and squat activities. Gait Posture. 2017;58:214–9. https://doi.org/10.1016/j.gaitpost.2017.07.116.
22. Moschella D, Blasi A, Leardini A, Ensini A, Catani F. Wear patterns on tibial plateau from varus osteoarthritic knees. Clin Biomech. 2006;21:152–8.
23. Lu T, Tsai T, Kuo M, Hsu HC, Chen HL. In vivo three-dimensional kinematics of the normal knee during active extension under unloaded and loaded conditions using single-plane fluoroscopy. Med Eng Phys. 2008;30:1004–12.
24. Dennis D, Mahfouz M, Komistek R, Hoff W. In vivo determination of normal and anterior cruciate ligament-deficient knee kinematics. J Biomech. 2005;38:241–53.
25. Jamali AA, Scott RD, Rubash HE, Freiberg AA. Unicompartmental knee arthroplasty: past, present, and future. Am J Orthop. 2009;38(1):17–23.
26. Heyse TJ, El-Zayat BF, De Corte R, Chevalier Y, Scheys L, Innocenti B, Fuchs-Winkelmann S, Labey L. UKA closely preserves natural knee kinematics in vitro. Knee Surg Sports Traumatol Arthrosc. 2014;22(8):1902–10.
27. Deschamps G, Lapeyre B. Rupture of the anterior cruciate ligament: a frequently unrecognized cause of failure of unicompartmental knee prostheses. Rev Chir Orthop Reparatrice Appar Mot. 1987;73(7):544–51.
28. Hernigou P, Deschamps G. Posterior slope of the tibial implant and the outcome of unicompartmental knee arthroplasty. J Bone Joint Surg. 2004;86-A(3):506–11.
29. Argenson JN, Komistek RD, Aubaniac JM, et al. In vivo determination of knee kinematics for subjects implanted with a unicompartmental arthroplasty. J Arthroplast. 2002;17(8):1049–54.
30. Nishio Y, Onodera T, Kasahara Y, Takahashi D, Iwasaki N, Majima T. Intraoperative medial pivot affects deep knee flexion angle and patient-reported outcomes after total knee arthroplasty. J Arthroplast. 2014;29(4):702–6.
31. Kia M, Warth LC, Lipman JD, et al. Fixed-bearing medial unicompartmental knee arthroplasty restores neither the medial pivoting behavior nor the ligament forces of the intact knee in passive flexion. J Orthop Res. 2017; https://doi.org/10.1002/jor.23838.
32. Mochizuki T, Sato T, Tanifuji O, et al. In vivo pre- and postoperative three-dimensional knee kinematics in unicompartmental knee arthroplasty. J Orthop Sci. 2013;18(1):54–60.
33. Watanabe T, Abbasi AZ, Conditt MA, Christopher J, Kreuzer S, Otto JK, Banks SA. In vivo kinematics of a robot-assisted uni- and multi-compartmental knee arthroplasty. J Orthop Sci. 2014;19(4):552–7. https://doi.org/10.1007/s00776-014-0578-3.
34. Grant AL, Doma KD, Hazratwala K. Determination of the accuracy of navigated kinematic unicompartmental knee arthroplasty: a 2-year follow-up. J Arthroplast. 2017;32(5):1443–52. https://doi.org/10.1016/j.arth.2016.11.036.
35. Zhang Z, Zhu W, Zhu L, Du Y. Superior alignment but no difference in clinical outcome after minimally invasive computer-assisted unicompartmental knee arthroplasty (MICA-UKA). Knee Surg Sports Traumatol Arthrosc. 2016;24(11):3419–24.
36. Casino D, Martelli S, Zaffagnini S, Lopomo N, Iacono F, Bignozzi S, Visani A, Marcacci M. Knee stability before and after total and unicondylar knee replacement: in vivo kinematic evaluation utilizing navigation. J Orthop Res. 2009;27(2):202–7.
37. Burton A, Williams S, Brockett CL, Fisher J. In vitro comparison of fixed- and mobile meniscal-bearing unicondylar knee arthroplasties: effect of design, kinematics, and condylar liftoff. J Arthroplast. 2012;27(8):1452–9. https://doi.org/10.1016/j.arth.2012.02.011.

38. Small SR, Berend ME, Rogge RD, Archer DB, Kingman AL, Ritter MA. Tibial loading after UKA: evaluation of tibial slope, resection depth, medial shift and component rotation. J Arthroplast. 2013;28(9 Suppl):179–83. https://doi.org/10.1016/j.arth.2013.01.004.
39. Ettinger M, Zoch JM, Becher C, Hurschler C, Stukenborg-Colsman C, Claassen L, Ostermeier S, Calliess T. In vitro kinematics of fixed versus mobile bearing in unicondylar knee arthroplasty. Arch Orthop Trauma Surg. 2015;135(6):871–7. https://doi.org/10.1007/s00402-015-2214-x.
40. Cassidy KA, Tucker SM, Rajak Y, Kia M, Imhauser CW, Westrich GH, Heyse TJ. Kinematics of passive flexion following balanced and overstuffed fixed bearing unicondylar knee arthroplasty. Knee. 2015;22(6):542–6. https://doi.org/10.1016/j.knee.2015.07.014.
41. Heyse TJ, Slane J, Peersman G, Dworschak P, Fuchs-Winkelmann S, Scheys L. Balancing mobile-bearing unicondylar knee arthroplasty in vitro. Knee Surg Sports Traumatol Arthrosc. 2017;25(12):3733–40. https://doi.org/10.1007/s00167-016-4241-8.
42. Peersman G, Slane J, Vuylsteke P, Fuchs-Winkelmann S, Dworschak P, Heyse T, Scheys L. Kinematics of mobile-bearing unicompartmental knee arthroplasty compared to native: results from an in vitro study. Arch Orthop Trauma Surg. 2017;137(11):1557–63. https://doi.org/10.1007/s00402-017-2794-8.
43. Kwon OR, Kang KT, Son J, Kwon SK, Jo SB, Suh DS, Choi YJ, Kim HJ, Koh YG. Biomechanical comparison of fixed- and mobile-bearing for unicomparmental knee arthroplasty using finite element analysis. J Orthop Res. 2014;32(2):338–45. https://doi.org/10.1002/jor.22499.
44. Kwon OR, Kang KT, Son J, Suh DS, Baek C, Koh YG. Importance of joint line preservation in unicompartmental knee arthroplasty: finite element analysis. J Orthop Res. 2017;35(2):347–52. https://doi.org/10.1002/jor.23279.
45. Innocenti B, Pianigiani S, Ramundo G, Thienpont E. Biomechanical effects of different varus and valgus alignments in medial unicompartmental knee arthroplasty. J Arthroplast. 2016;31(12):2685–91. https://doi.org/10.1016/j.arth.2016.07.006.