8 The Mobile Bearing in Unicompartmental Knee Arthroplasty

Nicholas J. Greco, Kojo A. Marfo, and Keith R. Berend

Introduction

Mobile-bearing unicompartmental knee arthroplasty (UKA) was conceived by John Goodfellow and John O'Connor in the release of the "Oxford Knee" in 1974. Prior to its inception, UKA consisted of the St Georg design released in 1969 and the Marmor released in 1972 [1]. Both of these unicompartmental devices displayed a rounded femoral articular surface articulating with a flat all-polyethylene tibial component. These designs fluctuated between all-polyethylene and metal-backed tibial components as issues were seen with wear and distortion of the polyethylene component [2]. With the release of the Oxford Knee, the design was comprised of a mobile polyethylene bearing that was instead fully congruent with the femoral and tibial components, and that was also unconstrained in its ability to pursue motion [3]. These modifications were meant to maximize bearing contact area and decrease stress at the implant interface addressing problems with the previous unicompartmental devices. While the first implant was meant to be used bicompartmentally for total joint arthroplasty, the current mobile-bearing implant is used primarily in the medial compartment. It was believed that through retention of the cruciate ligaments and preservation of bone in uninvolved compartments, patient functional results would be improved. Early clinical outcome scores supported this hypothesis [4].

In the original implant design, termed Phase 1, the superior surface of the bearing was concave to articulate with the spherical metallic femoral component, while the inferior surface was flat to interface with the flat metallic tibial component. This articular geometry has not changed in more recent updates to the prosthesis but instead has remained constant since inception. The femoral articulation with the meniscal bearing allows flexion and extension, while the tibial articulation with the bearing enables translational movement. This geometry allows the bearing to move freely through the knee range of motion in an effort to reproduce natural kinematics dictated by the soft tissue structures around the knee. Furthermore, polyethylene contact area is maximized, and the prosthesis is subjected to primarily compressive forces, which is intended to limit polyethylene wear and risk of component loosening [5]. The femoral component was applied through a series of three inclined bone cuts made with cutting blocks in order to fit the three facets of the component and single central peg, while the tibial component was applied with a keel slot through the tibial surface.

Early failures consisted of bearing dislocation and wear in the contralateral compartment. Anecdotally, it was observed that a higher rate of these failures occurred in patients with a

N. J. Greco (✉) · K. A. Marfo · K. R. Berend
Joint Implant Surgeons, Inc, Athens, OH, USA

T. L. Gerlinger (ed.), *Unicompartmental Knee Arthroplasty*,
https://doi.org/10.1007/978-3-030-27411-5_8

defective anterior cruciate ligament (ACL) [4]. Therefore, in 1982, the implant began to be used for the treatment of unicompartmental disease.

History

Updated Phase 2 components followed in 1987 with the specific use for unicompartmental arthritis. The link between ACL function and implant survival facilitated an understanding of the phenomenon of anteromedial osteoarthritis [6]. With functional cruciate and collateral ligaments, the degenerative process was localized to the anteromedial portion of the tibial articular surface and the posterior cartilage was preserved. This corresponded with cartilage wear on the distal part of the medial femoral condyle. In the Phase 2 design, the articular surface of the femoral component remained spherical to mate with the congruent polyethylene bearing; however, preparation of the femur was altered. The posterior femur was cut at an inclined angle, and the distal femur was prepared with a spherical bone-mill. While the posterior femur resection was replaced with an equal thickness of the femoral implant, the distal femur bone milling process enabled incremental bone resection in order to balance the extension gap with the flexion gap. This was intended to allow restoration of the medial collateral ligament tension to improve knee kinematics and limit risk of bearing dislocation. As with the Phase 1 prosthesis, the Phase 2 prosthesis was implanted through a traditional medial parapatellar arthrotomy similar to that employed for total knee arthroplasty (TKA), and the patella was routinely dislocated. There remained a single size femoral component that had to be fit to each patient regardless of boney anatomy, and the tibial plateau was universal. With an updated surgical technique that allowed balancing of the flexion and extension gaps, there was an improvement noticed in the knee kinematics and a decrease in the observed rate of bearing dislocations [7].

Murray, Goodfellow, and O'Connor studied 143 consecutive knees between 1982 and 1992 treated with a mix of Phase 1 and 2 implants. Mean follow-up in the study was 7.6 years with a maximum of 13 years, and based on the data from this study, the authors projected a 10-year survival rate of 98% with the use of a mobile-bearing implant [8]. In contrast to this designer series, Vorlat et al. reported on outcomes of an independent series of 149 operations performed in Belgium between 1988 and 1996 utilizing Phase 2 implants. Mean follow-up was 10.5 years in this study, and the estimated 10-year survival rate was 84% [9]. In another smaller independent study from a private hospital in Sweden, Svard and colleagues reported a10-year survival rate of 94% with primarily Phase 2 implants. This study was composed of 124 knees treated with Phase 1 and 2 implants over a mean follow-up period of 12.5 years (range 10–15 years) [10].

With an increasing knowledge of the disease-specific indications and shortcoming of prior mobile-bearing designs, the Phase 3 implant was released in 1998 for application in the medial compartment [11]. The instrumentation was created in order to allow implantation through a minimally invasive approach that did not require subluxation of the patella. The femoral component was now available in 5 parametric sizes, and the tibial plateau was right and left specific. The mobile-bearing was changed from a universal design with symmetric medial and lateral edges to an anatomic design with elongated medial wings that more closely mimics the "D" shape of the medial condyle in the transverse plane and has unique parts for left and right knees. Improvements in the femoral design, effectively a "Phase 4" and marketed as the Oxford Twin Peg, were initially introduced in 2003 in the United Kingdom and later implemented worldwide [12] (Fig. 8.1). These changes consisted of a more rotund undersurface to match the femoral bone cut, a twin-peg design to improve fixation and stability, and 15° of femoral articular surface was added to increase contact in deep flexion. The polyethylene bearing general articular surface remained unchanged, but alterations were made in order to limit the risk of impingement through range of motion. Function and time of recovery were improved with this new method [13].

The first mobile-bearing UKA design was cleared by the US Food and Drug Administration

Fig. 8.1 The current design of the mobile-bearing Oxford, marketed as the Oxford Twin Peg Partial Knee, was initially introduced in 2003 in the United Kingdom and later implemented worldwide. An explanted device is shown. Improvements in the femoral design, effectively a "Phase 4," consist of a more rotund undersurface to match the femoral bone cut, a twin-peg design to improve fixation and stability, and an additional 15° of femoral articular surface to increase contact in deep flexion

for use in the United States in April 2004 with a physician training requirement prior to use. In June 2004, the FDA Orthopaedic Advisory Panel recommended the reclassification of mobile-bearing knee systems for general use; however, the FDA has not currently accepted this recommendation. It follows that less than 8% of all knee arthroplasties in the United States are unicompartmental procedures [14].

The mobile-bearing implant has also been investigated for use in the lateral compartment; however, the revision rate has been projected as high as 15% at 5 years postoperatively [15]. The primary reason for this high failure rate is a high propensity for dislocation of the mobile bearing. This is believed to be the result of unique kinematics in the lateral compartment as the posterior femoral condyle translates a greater amount posteriorly in flexion compared to the medial femoral condyle. However, adjustments to the mobile-bearing design to maintain a full congruous spherical femoral articulation with a biconcave tibial plateau reduced the dislocation rate to 1.7% at 4 years in a new cohort of 101 patients [16]. Nevertheless, due to this kinematic difference in the lateral compartment, a fixed-bearing implant has become the preferred type of lateral UKA implant [17].

Design Rationale

The Oxford mobile-bearing UKA consists of a dual articulation between polyethylene insert and metallic femoral and tibial components. The conformity between the spherical femoral component and concave polyethylene bearing surface has been a design feature of the Oxford Partial Knee System present since its inception. Finite-element analysis predicts reduced contact stress due to an articular conforming design that distributes forces over a larger surface area. Ten-year in vivo measurements have demonstrated linear wear rates of 0.02 mm/year [18]. Therefore, revisions for wear in long-term studies remain uncommon [19]. However, impingement on retained osteophytes or cement particles remains a cause of not only bearing dislocation but also polyethylene wear [20]. Kendrick et al. studied the impact of impingement on the polyethylene bearing as it related to wear rate. In a retrieval study of 47 Phase 1 and 2 bearings, the wear rate was 0.07 mm/year in the 31 bearings that demonstrated signs of impingement compared to 0.01 mm/year in those that did not [21]. Moreover, the bearings demonstrating impingement affecting the articular surface had a penetration rate 2.5 times higher than those demonstrating extra-articular impingement. In general, the mobile-bearing design is believed to lessen the rate of polyethylene wear compared to fixed bearing designs in exchange for the risk of bearing dislocation [22].

This implant conformity and mobile-bearing design are also meant to decrease stress at the

bone-cement interface. This has resulted in a small probability of aseptic component loosening, which has been estimated as low as 0.2% in some independent studies [23]. This is believed to be an even smaller issue with the use of cementless components, which have been used in European countries since its release in 2004. In a randomized compared trial, fixation of cementless components was observed to be improved compared to cemented components as per lower amount of radiolucent lines [24]. Currently, cementless components are under investigation in the United States, but are not currently approved for general use at the time of this writing.

Microplasty Instrumentation

The Microplasty instrumentation platform was subsequently introduced, designed to streamline the surgical procedure, and make it more efficient overall. The specific changes included a sizing spoon-stylus combination to decrease the need to recut the tibial plateau, an intramedullary femoral alignment guide, and a guide for reducing impingement. The spoon-based stylus references the posterior femoral condyle and removes 6.5 (3 "G-clamp") to 7.5 mm (4 "G-clamp") of tibial bone. The accuracy afforded by the spoons decreases the need for another resection of the tibial plateau as well as increases the likelihood of implanting smaller bearings (3 and 4 mm bearings). Femoral alignment in the Microplasty platform is performed via an intramedullary rod, whereas the Phase 3 instrumentation required visualization and adjustment of 6 separate variables. Removal of impinging osteophytes with Phase 3 instruments involved using an osteotome and then repeatedly checking for impingement in full-knee extension. The Microplasty guide for removing anterior osteophytes allows this step to be done once with no need to recheck impingement-free ROM.

We previously reported that the use of the new Microplasty instrumentation results in more accurate and reproducible femoral component placement [25]. In another prior study, we analyzed whether the new Microplasty instrumentation improved efficiency and reduced operative time compared to the Phase 3 instrumentation [26]. Patients in both groups were matched for gender, age, body mass index, preoperative ROM, and Knee Society pain and clinical scores. Operative time was defined as the time from skin incision until the final dressing was applied. Both groups were compared, and statistical significance was defined as $p < 0.05$. The mean operative time was significantly shorter with the Microplasty instrumentation (49 minutes) compared to the Phase 3 (58 minutes). Additionally, the standard deviation was significantly lower in the Microplasty group (14 minutes) versus the Phase 3 (17 minutes). The minimum and maximum operative times were also less in the Microplasty group compared with the Phase 3 (24–88 minutes versus 30–126 minutes).

The efficiencies of the Microplasty instrumentation resulted in an average of 9 minutes less per surgical case compared to Phase 3 instrumentation. This correlates to a 15% reduction in the time it takes to implant the Oxford mobile-bearing UKA. This 15% reduction in operating time should translate into the ability to perform more surgeries, decreased infection, decreased tourniquet use, and overall better experience for surgeon and patient alike.

Indications

Beginning in 1989, the classic article by Kozinn and Scott detailed contraindications to unicondylar arthroplasty procedures including both disease- and patient-specific criteria [27]. They stated that patients exceeding an age of 60 years, weight of 180 pounds, or those extremely physically active heavy laborers were contraindicated for the procedure given an increased risk for mechanical loosening based on their anecdotal evidence. Disease-specific criteria, which included chondrocalcinosis on preoperative imaging or at the time of surgery and exposed subchondral bone within the patellofemoral joint, were identified as factors portending worse outcome. These principles stemmed from an unpublished study of 100 consecutive unicom-

partmental arthroplasty procedures performed by the authors with 10-year follow-up in which 13 failures from mechanical loosening were attributed to either surgical inadequacy, or patient-specific or disease-specific factors as categorized above. Other authors have echoed this sentiment when indicating patients for the procedure [28].

These historical patient indications severely restrict the number of patients considered as appropriate candidates for unicompartmental arthroplasty. One retrospective study of TKA cases declared that 21% of the cases may have been eligible for UKA based on disease-specific criteria, which included intact lateral cartilage, an intact ACL, no patellofemoral arthritis, ROM greater than 90°, and varus deformity less than 10° [29]. Multiple investigations have aimed to refine appropriate indications for a unicompartmental arthroplasty with a mobile-bearing implant. In a prospective cohort of 1000 Oxford partial knee arthroplasties, Pandit et al. showed that the Oxford Phase 3 implant revision rate at 10-years was relatively similar for patients with one contraindication based on the Kozinn and Scott criteria as compared to those satisfying all criteria (2.4% vs. 4.0%) [30]. The projected survival free of component revision from life-table analysis was higher in the contraindicated patients as compared to the ideal patients (97.0% vs. 93.6%). The causes of failure were different between these two groups as those ideal patients developed a higher rate of lateral compartment osteoarthritic progression, while the contraindicated patients suffered more mobile-bearing dislocations requiring revision surgery. This cohort of patients was comprised of 68% for whom the Kozinn and Scott principles would have contraindicated them for unicompartmental knee arthroplasty. In the updated study of this cohort, cumulative 15-year survival rate was not statistically different between those highly active male patients older than 60 years with weight greater than 180 pounds as compared with those patients without any of these contraindications (92.7% vs. 89.9%) [31]. Furthermore, clinical outcomes as measured by Knee Society objective score, Oxford Knee score, and Tegner activity scale were similar or better in the Kozinn and Scott contraindicated patients. Further studies have demonstrated that age and activity do not compromise results of mobile-bearing unicompartmental arthroplasty, and these patients may be able to successfully attain a high level of activity postoperatively [31–33].

In contrast, Goodfellow and colleagues believed that treatment with a mobile-bearing unicompartmental arthroplasty should instead be applied in patients demonstrating the appropriate pathoanatomy independent of patient-specific factors. The specific applications included anteromedial osteoarthritis and spontaneous medial osteonecrosis of the knee. Anteromedial osteoarthritis (AMOA) is defined by medial compartment bone-on-bone joint space narrowing with intact posterior cartilage. In addition, the lateral compartment should contain full-thickness cartilage and both the anterior cruciate and medial collateral ligaments should be functional. This pathoanatomy manifests specific clinical signs and symptoms. Varus deformity is most noted in full extension due to the pattern of wear on the anterior portion of the tibial plateau and the inferior articular surface of the femoral condyle [34]. This deformity is not fixed and can be corrected with a valgus stress at roughly 20° of flexion relaxing the posterior capsule. This is possible because joint space contact in flexion retains normal cartilage, therefore maintaining normal tension on the medial collateral ligament (MCL) and keeping its length constant. It is believed that the presence of functional cruciate ligaments correlates with the disease pattern observed as they maintain normal femoral roll-back in flexion.

Hence, unicompartmental arthroplasty should not be offered in cases with an impaired ACL. In some cases, the ACL may fail secondarily after the advent of anteromedial disease, causing a progressive erosion of the posterior cartilage and therefore a fixed varus deformity. In other instances where the medial compartment disease develops secondary to ACL rupture, the posterior cartilage is usually affected first due to anterior subluxation of the tibia. Still attempts have been made to reconstruct the torn ACL while performing unicompartmental arthroplasty with promising short-term results [35].

There has also been some confusion when it comes to application of unicompartmental arthroplasty in patients with anteromedial osteoarthritis who demonstrate arthritic changes in the patellofemoral joint. In a cohort of 677 patients, the Oxford group found that there was no relationship between implant survival at 15 years postoperatively and the presence of anterior knee pain preoperatively, nor with the degree of cartilage loss within the patellofemoral joint intraoperatively [36]. The authors did document difficulty with stair descent in those patients treated with medial mobile-bearing unicompartmental arthroplasty demonstrating intraoperative evidence of full-thickness cartilage loss on the lateral aspect of the patella. Similarly, in a retrospective review of 100 consecutive Oxford medial unicompartmental arthroplasties with a minimum 8-year follow-up, patients with grade 3 change in the central and lateral aspect of the patellofemoral joint were found to have lower mean satisfaction with pain and function compared to the remainder of the cohort [37]. Stair climbing ability was also significantly decreased in those patients with central and lateral lesions observed intraoperatively in the patellofemoral joint. For this reason, severe damage to the lateral side of the patellofemoral joint with bone loss and grooving is defined as a contraindication to the procedure; however, less severe damage to the lateral articulation, medial patellofemoral disease, and anterior knee pain should not be considered contraindications.

Rheumatoid arthritis is another contraindication to medial unicompartmental arthroplasty as the inflammatory process primarily affects the synovium, resulting in tricompartmental disease. Therefore, in patients with this underlying diagnosis, it is recommended that total knee arthroplasty be performed as there is a risk of rheumatoid progression when a unicompartmental arthroplasty is performed [38].

Based on these principles, a strict preoperative clinical evaluation should be implemented in order to determine the ideal candidate for medial mobile-bearing UKA [39]. Clinically the patient should have varus malalignment in extension that corrects in flexion. Flexion contracture should not exceed approximately 15° and total range of motion should be greater than 100°. The ACL should be competent on clinical exam. Imaging should demonstrate significant loss of medial compartment joint space in either the anteroposterior weight-bearing view or the posteroanterior 45-degree flexion view. Lateral radiographs should display bony erosion of the anterior portion of the medial tibial plateau in contrast to an ACL-deficient knee in which the femoral condyle will be articulating with the posterior portion of the plateau, causing posterior erosion. A valgus stress view taken at 20-degrees of knee flexion should also be taken to confirm full-thickness cartilage within the lateral compartment and demonstrate a correctable deformity through a competent MCL. The patellofemoral joint should be imaged in order to exclude patients with significant bone-on-bone arthritis of the lateral patellar facet. Otherwise, moderate lateral facet disease or advanced diseased of the medial patellofemoral compartment should not preclude the use of UKA.

These criteria were elucidated in a radiographic decision aid, which was developed by a collaboration of joint arthroplasty surgeons after review of current literature [40]. In a retrospective review of over 500 patients, those meeting the radiographic standards irrespective of patient factors such as age and weight displayed a 5-year implant survival rate of 99% compared to 93% in those patients failing to meet these standards. Furthermore, functional outcomes measured by knee flexion, Knee Society score function component, and University of California Los Angeles activity score were significantly higher in those patients meeting the radiological criteria.

Osteonecrosis

Spontaneous osteonecrosis of the knee (SPONK) that is focal and localized to the medial femoral condyle or the medial tibial plateau is also an indication for mobile-bearing UKA [41]. In the early stages of disease, SPONK may only be detected on MRI prior to subchondral collapse, while also ruling out secondary osteonecrosis, which frequently involves both condyles [42].

As the disease progresses, some patients may demonstrate subchondral collapse in conjunction with joint space narrowing as the osteonecrosis is accompanied by a degenerative process. In all forms of the disease, the pathoanatomy resembles anteromedial osteoarthritis in that it is limited to the medial compartment and both the ACL and MCL are functionally intact. This should not be confused with secondary osteonecrosis, which occurs frequently in younger patients after corticosteroid, renal, or systemic disease [43]. This entity is often bilateral and involves both compartments, thus making unicompartmental arthroplasty futile. More recently, osteonecrosis in the postoperative knee (ONPK) has been described following arthroscopic surgery and is similarly focal in extent and localized to the medial femoral condyle in most cases [44, 45]. Outcomes and survival of UKA for SPONK or ONPK localized to the medial compartment have been encouraging [46, 47]. Furthermore, the success appears to be independent of the size of the osteonecrosis lesion as we have found a survival rate of 94.6% at 5 years in a cohort of 64 patients with mean lesion width amassing 64% of the medial femoral condyle width. Only one patient suffered from aseptic loosening of the femoral component in this cohort [48].

Surgical Principles and Technique

Before beginning surgery, there are a number of items that should be available to successfully perform the operation. Radiographs should be available demonstrating the classic pattern of AMOA with correction of the varus deformity with valgus stress (Fig. 8.2). The operation can be performed supine on a regular operating table or the leg can be held over the side of the bed in a hanging leg holder. We prefer to use the hanging leg holder with the hip flexed 30° and a tourniquet applied to the proximal thigh. There should be enough abduction for the operative leg to flex between 90° and 135° without impingement on the operative table (Fig. 8.3). The contralateral leg is placed on a well-padded foam leg holder, and the bottom of the bed is dropped perpendicular to the floor. A stiff, narrow reciprocating saw, a 12-mm wide oscillating saw, and a double-armed vertical toothbrush saw are utilized during the operation.

The goals of the operation are to relieve pain and restore function through resurfacing of the medial compartment. The surgical principles and technique employed to achieve these goals stem from the relevant disease pathoanatomy. The technical aims of the operation are to restore native MCL tension through a series of bone cuts and to attain stable fixation of the components. As a result of the MCL being of normal length in anteromedial osteoarthritis and osteonecrosis, there is no deformity to correct in UKA procedures [6]. Thus, no medial release should be carried out. After making the skin incision (Fig. 8.4) and subsequent arthrotomy, the subperiosteal tissue sleeve that is created during exposure should only be performed to improve visualization of the anteromedial tibia and care should be taken not to affect the MCL.

The tibial cut will affect the balance in both extension and flexion, as with total knee arthroplasty, while the distal femur and posterior femoral cuts will affect only the extension or flexion gap, respectively. Using a resection guide, the depth of tibial resection should be as conservative as possible to allow placement of the smallest implant bearing. A standard depth of resection is made with instrumentation for the Oxford Partial Knee System (Fig. 8.5). A conservative tibial resection will ensure that the implant is resting on robust proximal tibial metaphyseal bone with a larger cortical rim [49]. The vertical limb of the tibial resection should be flush with the medial intercondylar tibial spine to maximize the size of the tibial component that can be applied. Larger tibial components allow greater contact area and thus decrease contact stress within the proximal tibia [50]. Additionally, the angulation of the vertical saw cut in the sagittal plane should match that of the desired tibial slope that has been set into the tibial resection guide (Fig. 8.6). Inadvertently cutting further through the posterior cortex increases the risk of medial tibial plateau fracture [51]. A standard amount of

posterior femoral bone is resected corresponding to the thickness of the posterior aspect of the femoral component (Figs. 8.7 and 8.8). Osteophytes should be resected from the medial aspects of the femur and tibia prior to determining the gap balance as they will tend to distract the collateral ligaments. The flexion gap is now established first. Accounting for inclination in the posterior femoral and tibial resections with the Oxford Partial Knee System, trialing of the flexion gap is performed at 110° because this is the point at which the gap is rectangular. As

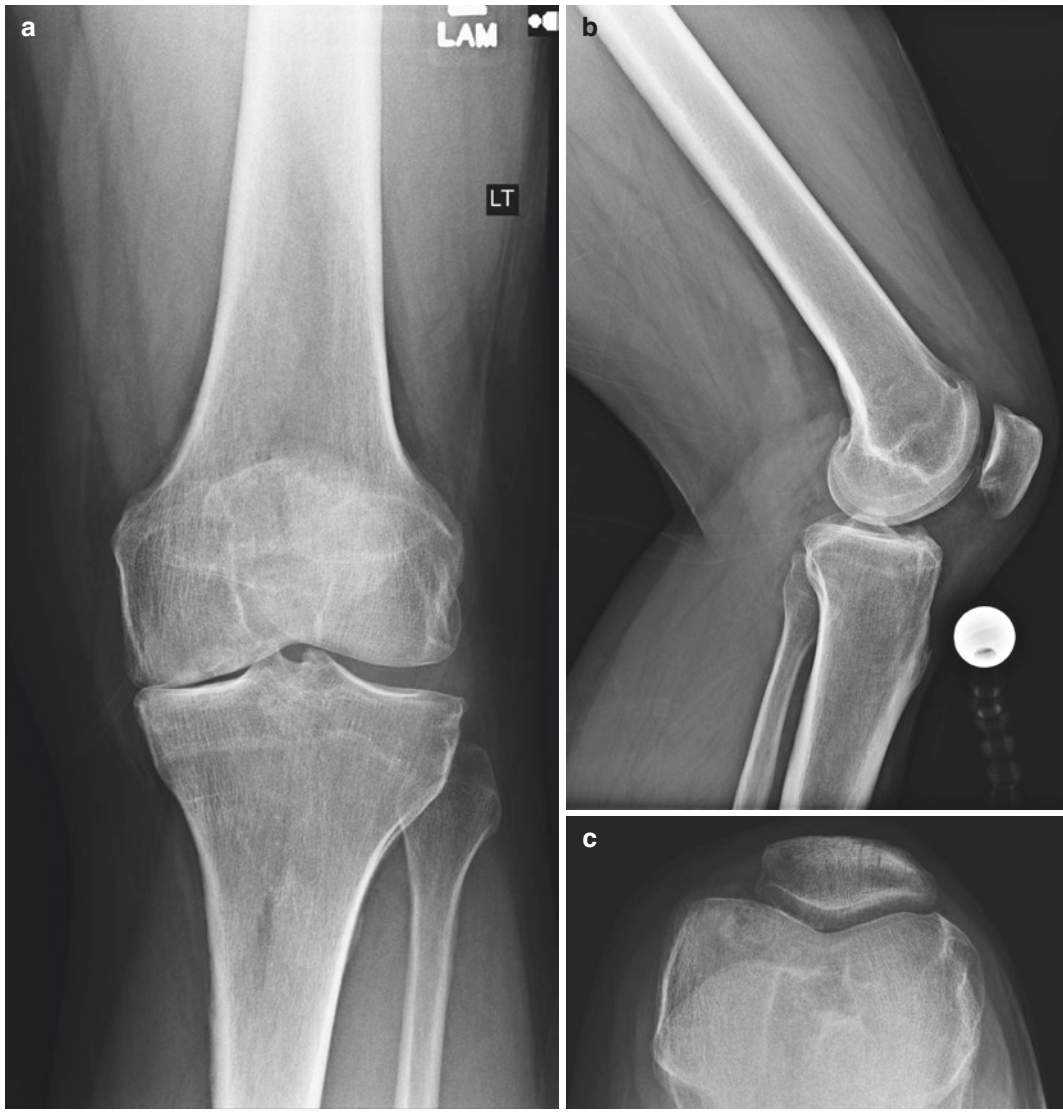

Fig. 8.2 A 43-year-old male patient with a BMI of 27.1 kg/m^2 presented complaining of severe medial pain and swelling of the left knee with progressive worsening over the past 14 months. Previous treatments of arthroscopy, physical therapy, corticosteroid injection, nonsteroidal anti-inflammatories, self-directed home care, and pain medication have not relieved his pain. Radiographs were obtained including standing anteroposterior (**a**), lateral (**b**), merchant patellar (**c**), posteroanterior weight bearing in 45° of flexion (**d**), and valgus stress test (**e**) views, which demonstrate severe joint space narrowing, sclerosis, and osteophyte and cyst formation. The valgus stress test (**e**) revealed restoration of normal limb alignment without collapse of the lateral compartment and an intact medial collateral ligament

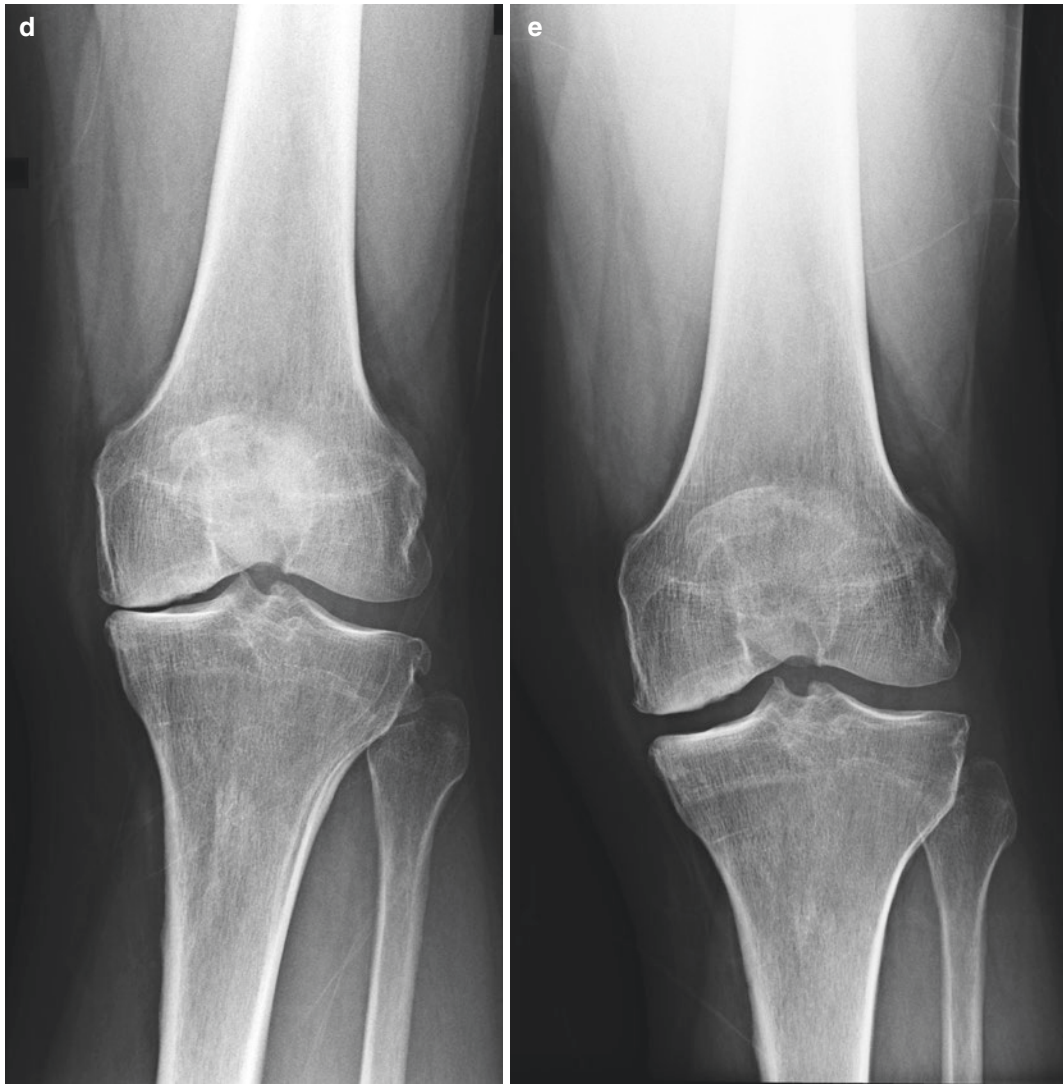

Fig. 8.2 (continued)

the wear pattern in anteromedial osteoarthritis does not affect the middle to posterior tibia or the posterior femur, and given that the depth of tibial resection and amount of posterior femoral resection are standardized with instrumentation, the flexion gap should simply restore the native tension within the collateral ligament using the smallest polyethylene bearing thickness. Overtensioning the ligament with a larger bearing, and thus overloading the lateral compartment, should be avoided. With the flexion gap established, an appropriate amount of bone is resected from the distal femur in order to balance the extension gap. In anteromedial osteoarthritis, the extension gap is primarily affected by the disease process causing decreased tension within the MCL near full extension. Hence, the amount of distal femoral bone that is resected will depend upon the degree of disease. With more significant cartilage and bone erosion, there is less tension within the medial compartment in extension and less bone will be resected to restore normal MCL tension. The extension gap is trialed at 20° because

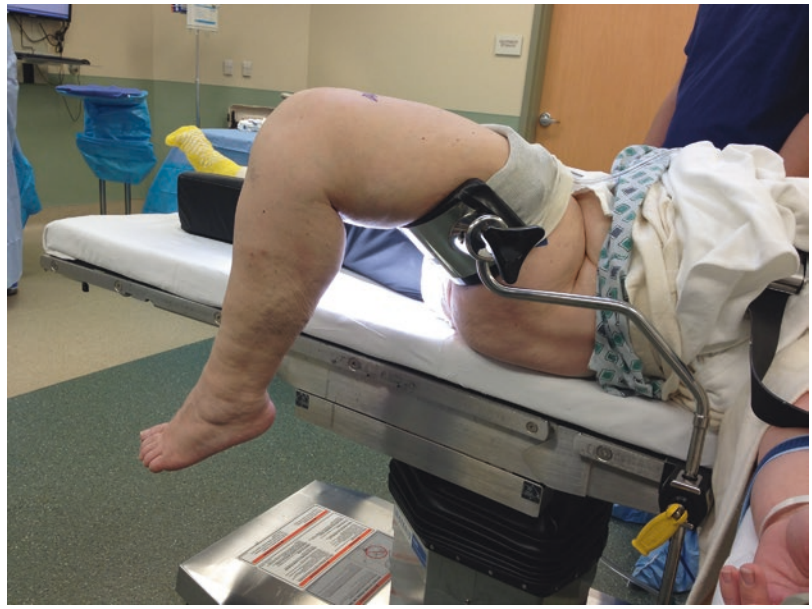

Fig. 8.3 The patient is positioned with the operative extremity in the hanging leg holder. A tourniquet is placed on the upper thigh. The hip is flexed approximately 30° and abducted to allow at 90–135° of knee flexion without impingement on the operative table

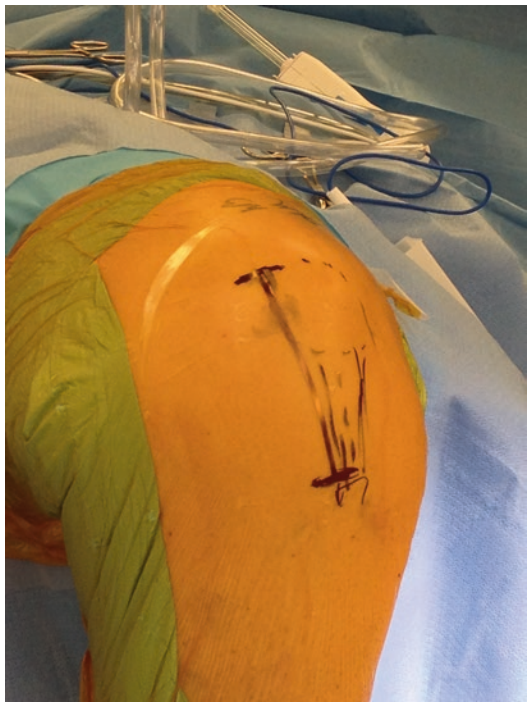

Fig. 8.4 Planned incision is marked on a left knee

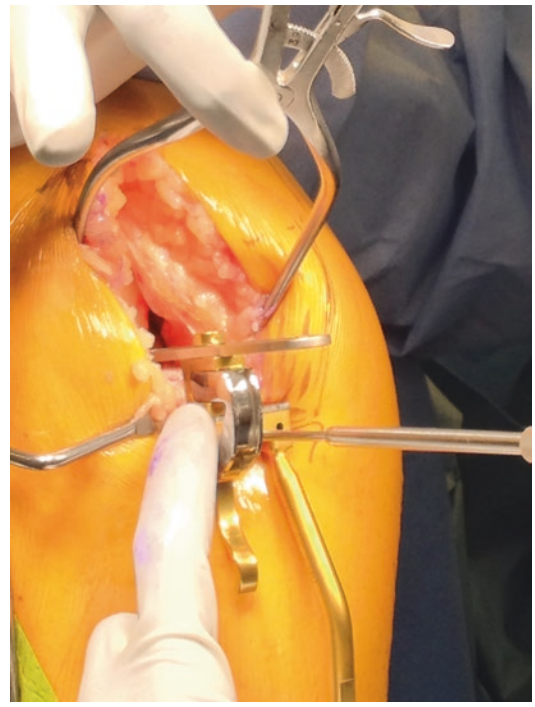

Fig. 8.5 Oxford Microplasty spoon and tibial resection guide linked by the G-clamp. Drill is securing the tibial resection guide to the medial proximal tibia

the posterior capsule is typically shortened, which creates excessive strain near full extension. Flexing the knee 20° relaxes the posterior capsule, allowing the tension in the medial compartment to be controlled by the MCL and cruciate ligaments alone. The MCL tension at 20° should now match the tension at 110° with the appropriately selected bearing (Fig. 8.9).

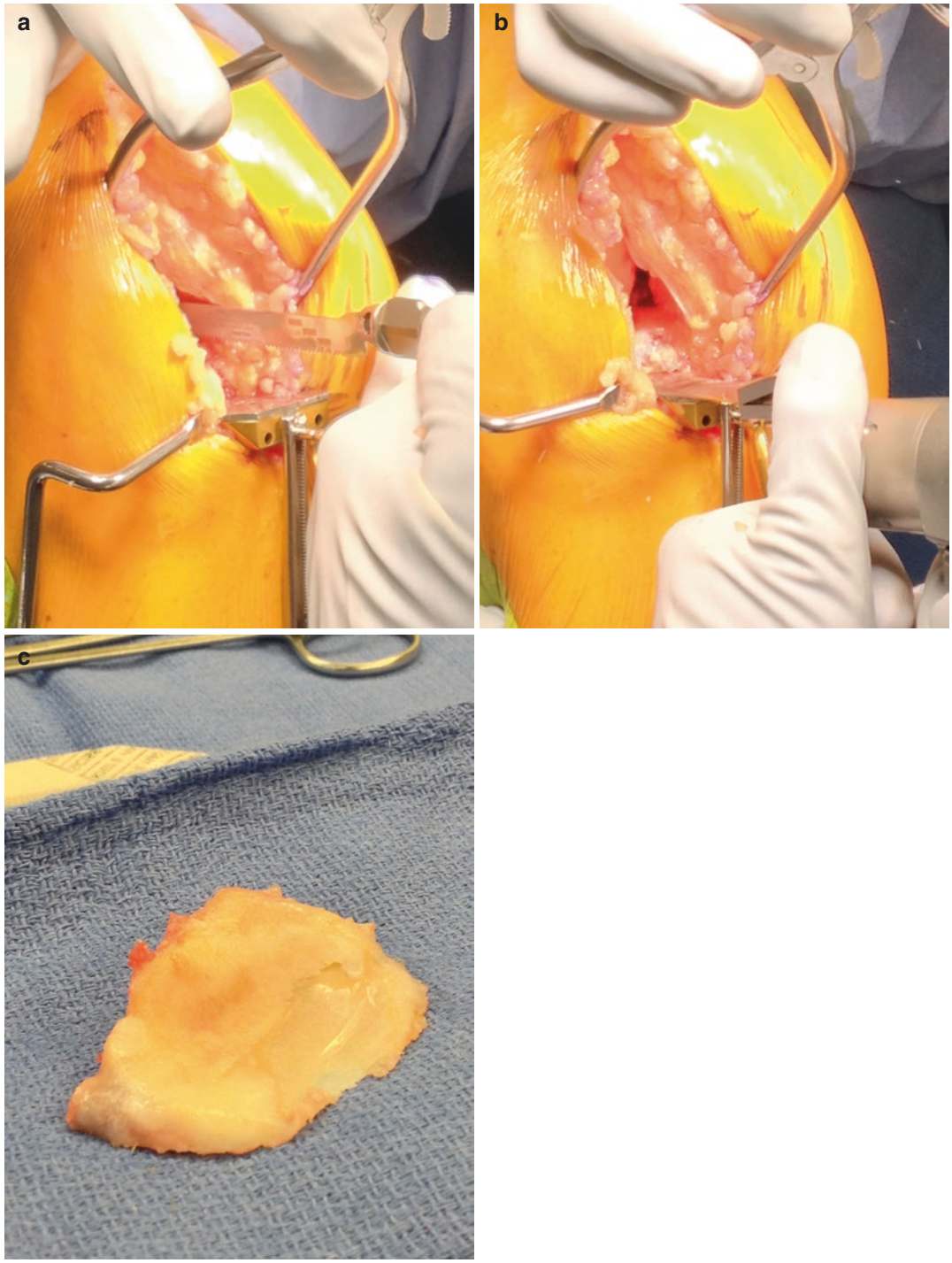

Fig. 8.6 (**a**) Intraoperative photograph demonstrating the vertical saw cut on the tibia. The saw should be in line with the flexion axis of the knee and should be adjacent to the lateral aspect of the medial femoral condyle and medial edge of the ACL on the tibia. (**b**) Horizontal cut of the proximal tibia. (**c**) Excised tibial bone from the left knee demonstrating classic anteromedial arthritis with preserved posterior cartilage

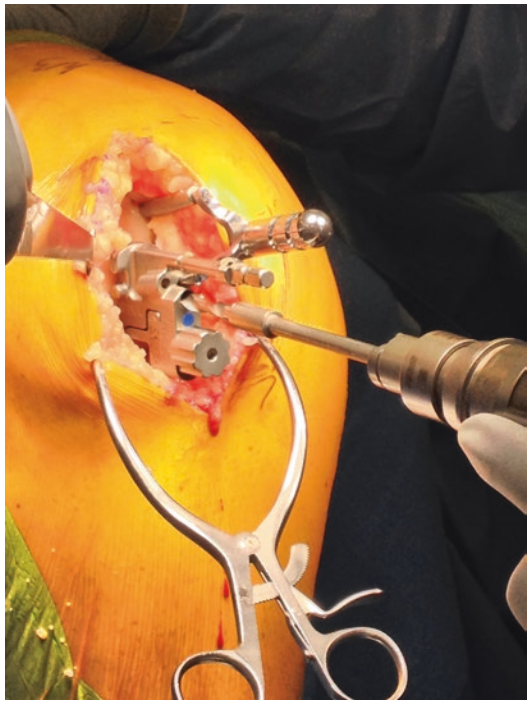

Fig. 8.7 Intraoperative photograph demonstrating the Oxford Microplasty flexion gap spacer coupled to the intramedullary rod by the linkage bar. The 4-mm hole has already been drilled, and now the 6-mm hole is being drilled in the center of distal medial femoral condyle

Appropriate MCL and cruciate ligament tension are crucial to restore kinematic motion and to ensure stability of the mobile bearing. Excessively tensioning the MCL risks overloading the lateral compartment, which could lead to arthritic progression, a primary reason for failure of unicompartmental arthroplasty procedures. Conversely, failure to restore tension will create inappropriate laxity within the medial compartment and put the bearing at risk of dislocation.

After the knee is balanced, the keel is cut for the tibia, and the Oxford Microplasty 2-in-1 anterior mill and posterior osteophyte resection tool is placed (Fig. 8.10). This device removes anterior as well as posterior osteophytes, which could cause impingement in extension and high flexion, respectively. These obstructions can cause bearing impingement and may lead to dislocation. Testing with a mobile-bearing trial will allow the surgeon to determine if any impediments remain and need to be addressed prior to implantation of the final components.

While cementless components are available in Europe, bone cement is required for fixation currently in the United States. Small 2-mm drill holes should be made in the femur and tibia for cement interdigitation prior to implantation. When implanting components, efforts should be made to extrude cement from posterior to anterior when impacting the tibial prosthesis into place and only a small amount of cement should be placed on the posterior aspect of the femoral prosthesis. These efforts limit the amount of cement that can extrude posteriorly, which can be very difficult to remove. Stable fixation of the components is ensured by placing the knee at 45° with the mobile-bearing inserted while allowing the cement to cure (Fig. 8.11). This position may prevent inappropriate rocking of components that can occur at greater degrees of extension or flexion. Errors in cementation or failure to remove excess cement have been linked to pain, premature loosening, and rapid bearing wear [21, 52].

Surgical Pearls

There are a number of surgical pearls that help make the Oxford mobile-bearing UKA more successful (Fig. 8.12). If in between two sizes, it is generally recommended to use the smaller size bearing so that the knee is not too tight or overcorrected. Tibial plateau fractures occur more often when the vertical saw cut goes below the desired resection level, so the surgeon should avoid raising his or her hand during this cut. We also recommend only drilling one hole to secure the tibial resection guide. If possible, avoid placing the drill hole where the keel will ultimately be cut, and use gentle impaction blows when inserting the tibial component. The MCL should never be released during the procedure, and retractors should always be used during all bony resection steps. If the MCL is transected, the procedure

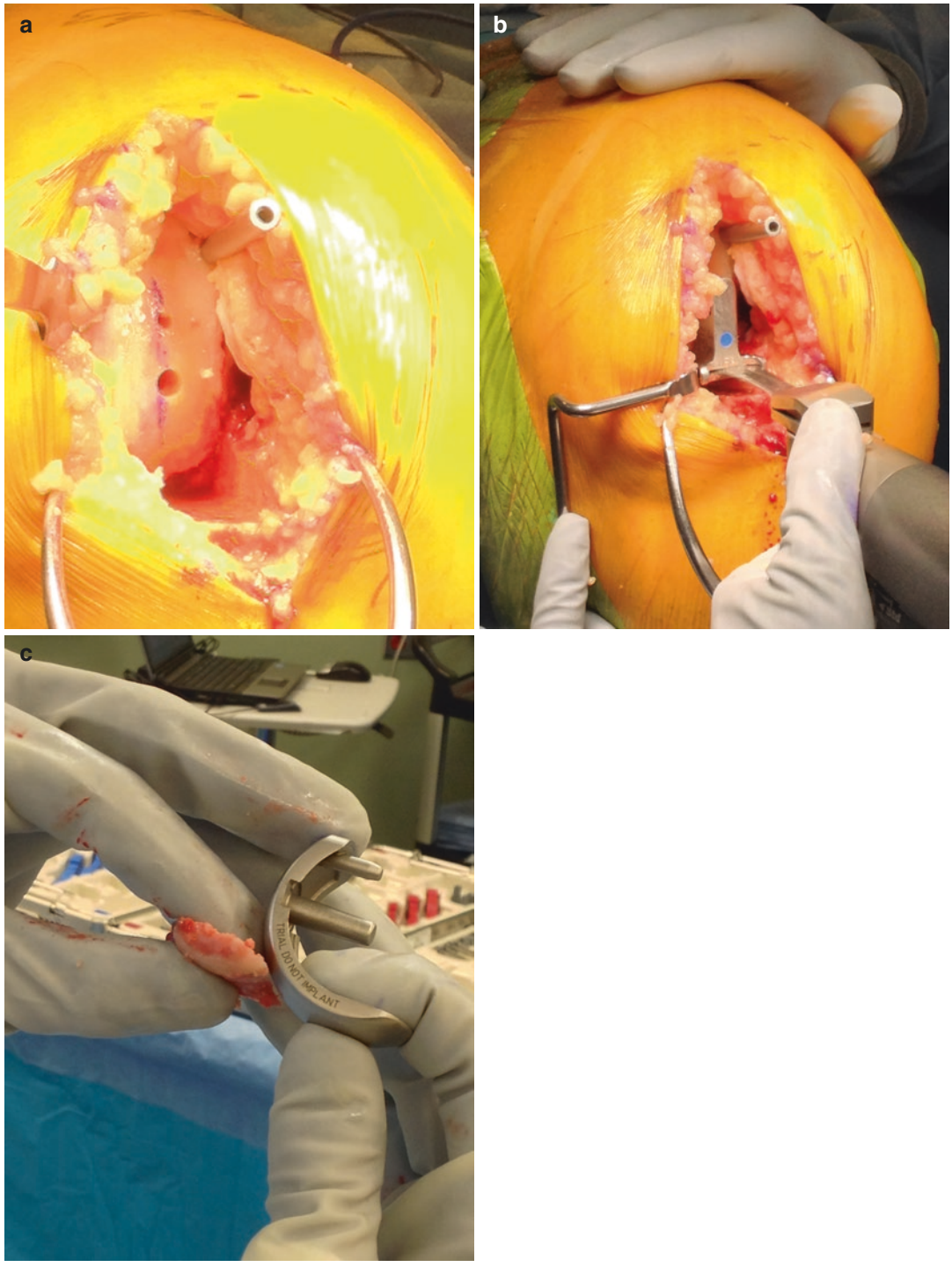

Fig. 8.8 (**a**) 4- and 6-mm holes have been drilled in the center of the distal medial condyle. (**b**) Posterior femoral condyle resection guide is inserted and the cut is made while the MCL is protected with a retractor. (**c**) Photograph demonstrating that the removed bone is of the same size as the posterior aspect of the implant

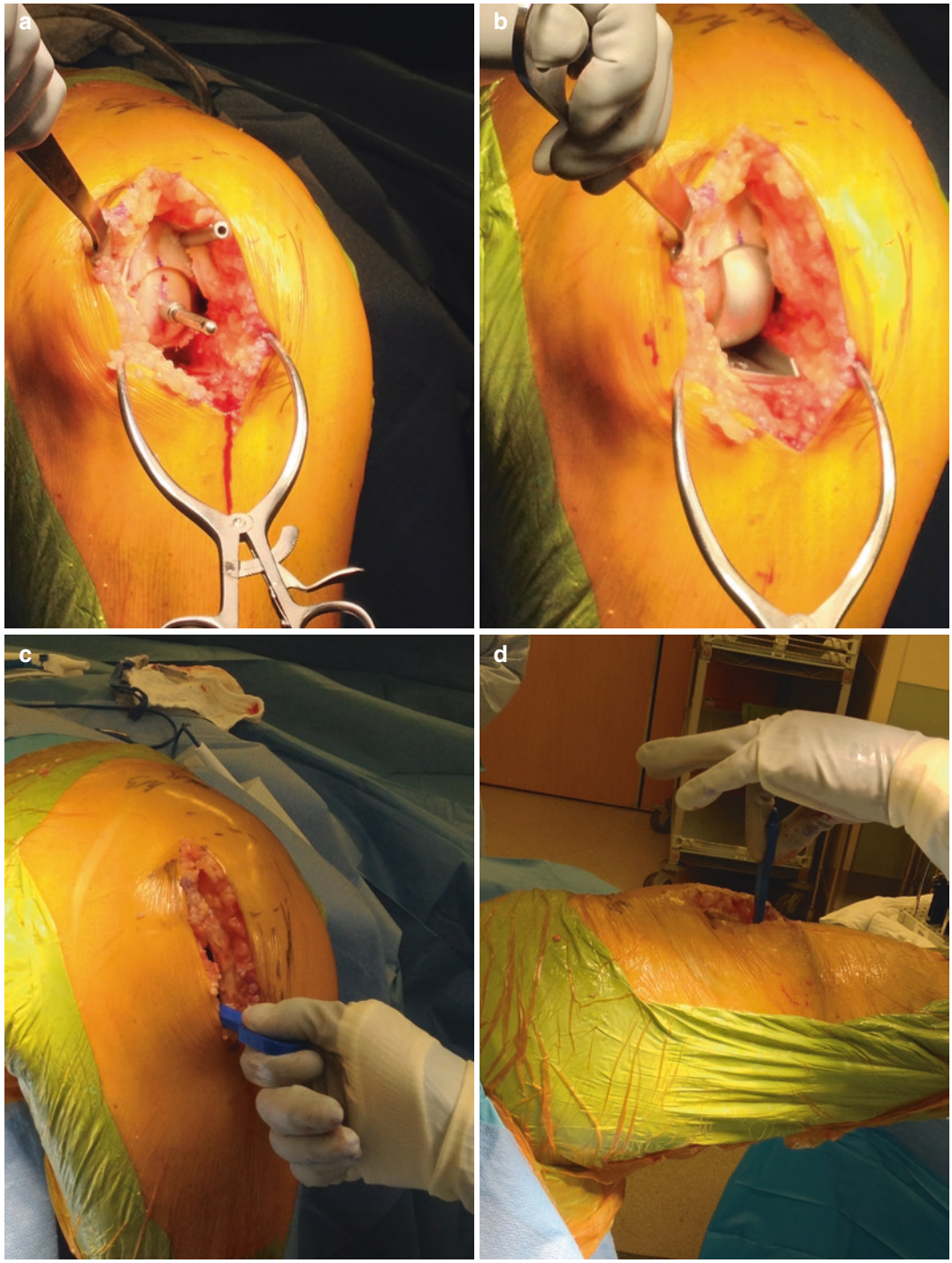

Fig. 8.9 (**a**) Zero spigot inserted into the 6-mm pilot hole. After incrementally milling the distal femur to try and match the gaps, (**b**) trials are reinserted, and the (**c**) flexion gap and the (**d**) extension gap are checked to make sure they are equal

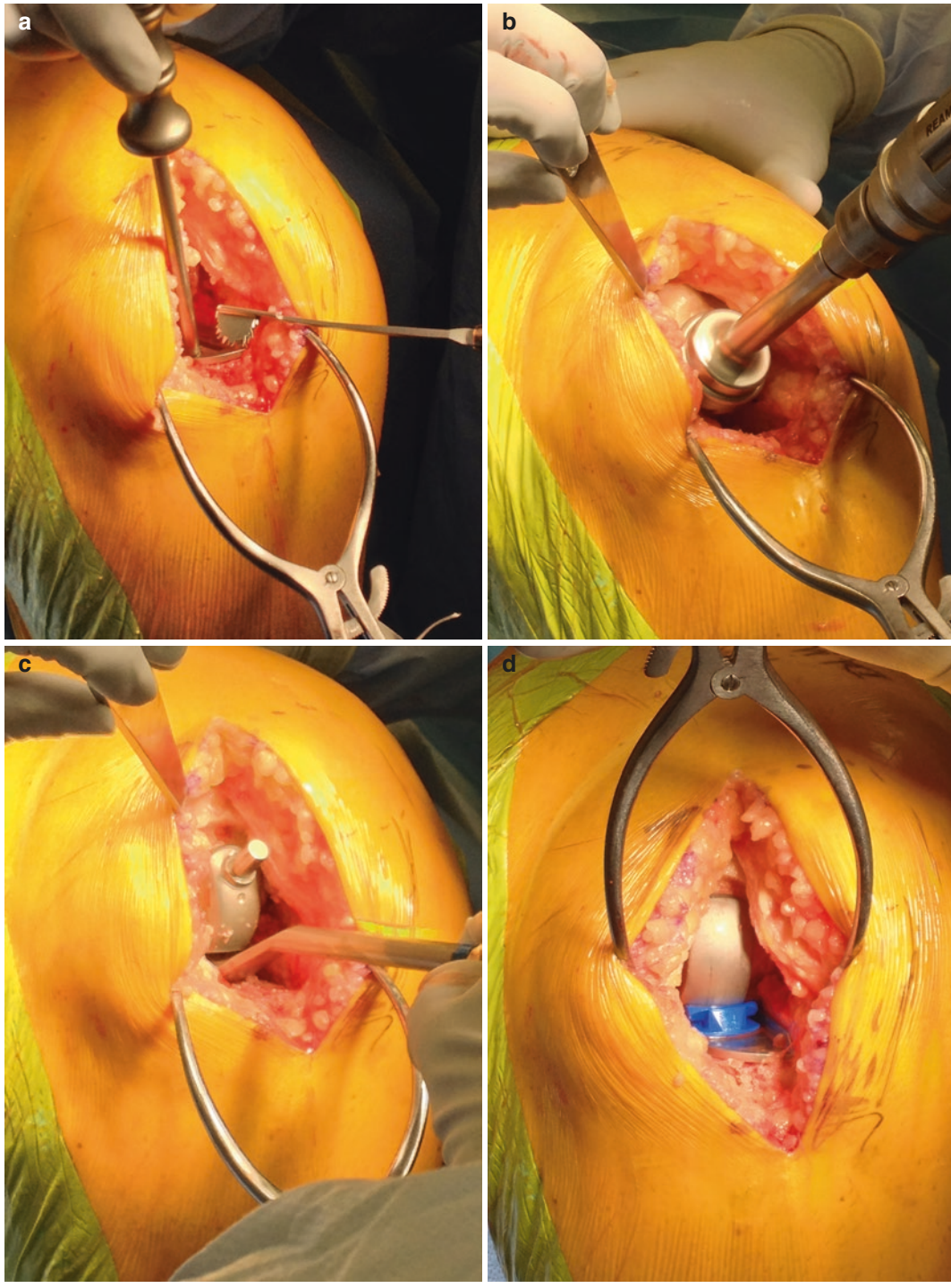

Fig. 8.10 (**a**) After stabilizing the tibial base plate template with the tibial nail, the toothbrush saw is used to prepare the keel slot. (**b**) The 2-in-1 anterior mill guide and (**c**) posterior osteophyte resection guide are used to remove potentially impinging osteophytes. (**d**) Trial components and bearings are inserted and taken through a full range of motion to make sure motion is smooth throughout

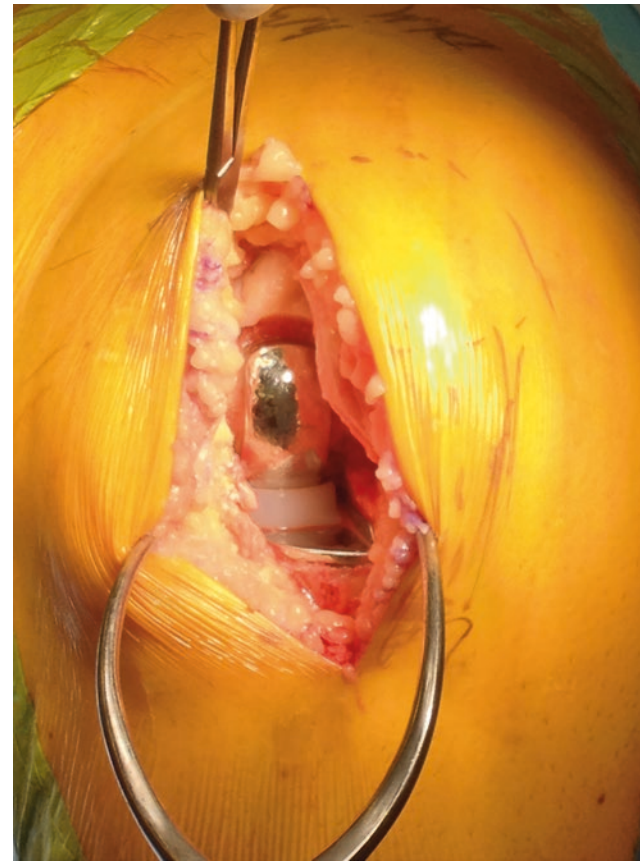

Fig. 8.11 Final components are cemented into place, and the anatomic meniscal bearing is inserted

should be converted to a TKA with the appropriate amount of constraint. Finally, the goal of the tibial resection is 7° of posterior slope, which is usually built into the resection guide. Avoid additional slope, which is a known cause of posterior collapse and failure. Before anesthesia is reversed and the patient is taken out of the operating room, good-quality postoperative radiographs should be reviewed.

Complications

Bearing Dislocation

Dislocation of the mobile bearing is a shortcoming that is unique to this type of unicompartmental arthroplasty. It has been estimated to occur in nearly 0.58% of cases using the Phase 3 prosthesis [53]. Primary dislocations are usually the result of technical error during the procedure. This stems from inadequate tensioning of the collateral ligament or failure to remove sources of impingement such as osteophytes or retained cement particles.

Meticulous surgical technique is crucial in preventing bearing dislocation events. Care should be taken to not release the medial collateral ligament or cause damage to it while using the saw. The femoral component should be aligned centrally in relation to the tibial cut surface. As the mobile bearing follows the movement of the femur, alignment of the femoral component excessively medial or lateral will allow the bearing to track too far or close to the tibial sidewall, which could increase risk of impingement and dislocation [54]. Tension in the collateral ligaments should be equal when tested at 20° and 110° of flexion. The trial bearing should gap open roughly 1–2 mm when tested with the

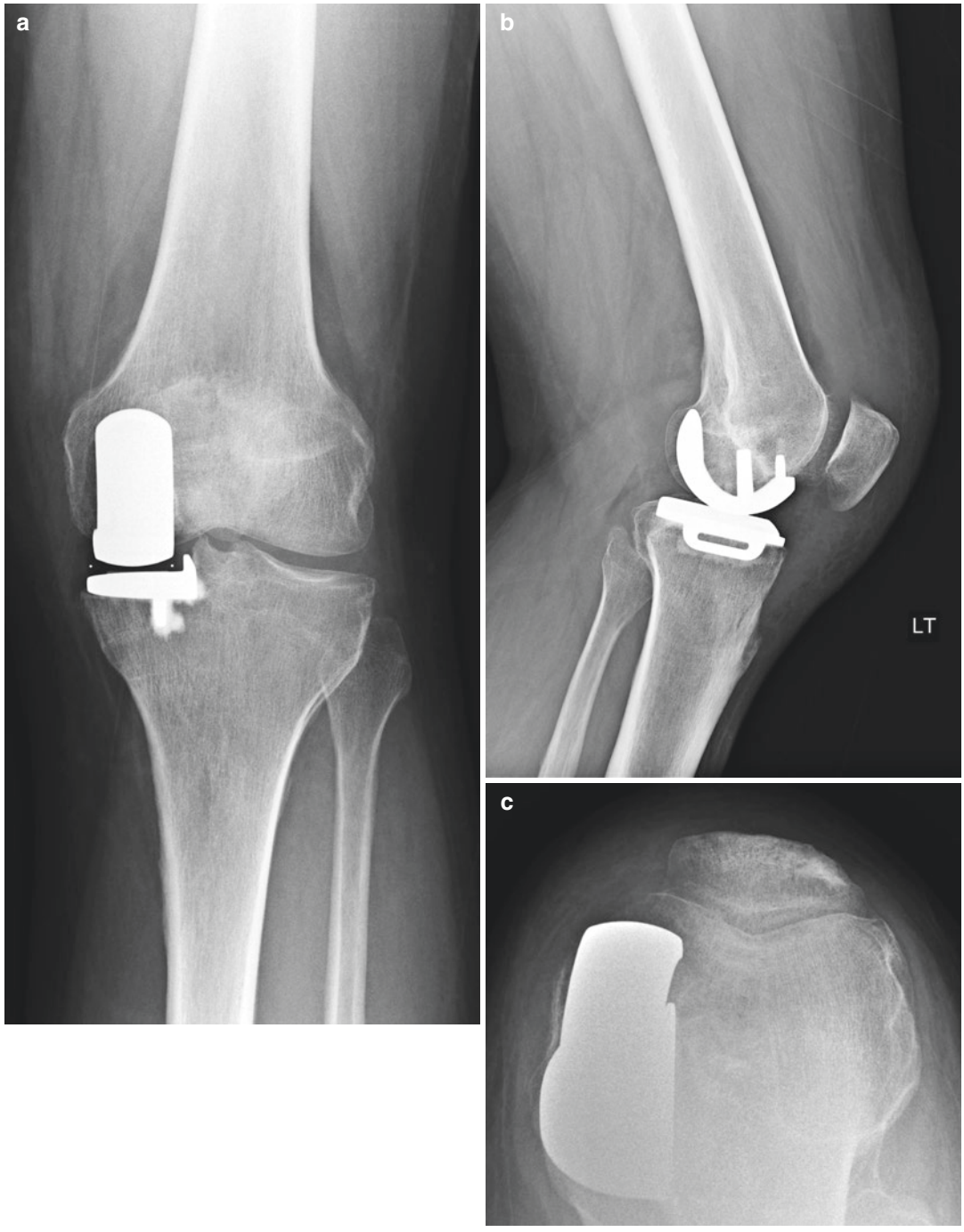

Fig. 8.12 The patient shown previously (Fig. 8.2) was treated at an ambulatory surgery center with outpatient cemented medial unicompartmental arthroplasty of the left knee with a mobile-bearing device. The twin-peg femoral component was size large, the anatomic meniscal bearing was 3 mm thick, and the medial tibial tray was a size D. Postoperative radiographs, including standing anteroposterior (**a**), lateral (**b**), and merchant patellar (**c**) views reveal well-fixed components in satisfactory position and alignment

insertion instrument throughout range of motion. Increased movement of the bearing will allow the possibility for dislocation; however, care must be taken not to make the bearing excessively large in which case inappropriate load is transferred to the lateral compartment, increasing risk of lateral arthritic progression [55]. Osteophytes must be removed from the anterior and posterior femoral condyle using the anti-impingement tools as these can contact the bearing inappropriately. Residual meniscal tissue may also have the same effect. Final trial of the bearing will help to confirm that there is no residual impingement. Finally, steadfast excision of excess cement particulate should be performed as this is another source of impingement.

In cases of dislocation, the diagnosis is usually made with a radiograph demonstrating direct contact between the femoral and tibial components, while the radiopaque marker within the polyethylene is identified in either the anterior or posterior aspects of the knee.

Closed reduction of the bearing is difficult and only successful in rare cases. Surgical intervention consisting of an arthrotomy is usually required. During this procedure, the cause of the dislocation must be identified. Inspection of the MCL, gap balance, and sources of impingement should be performed. These sources should be addressed prior to placement of new mobile bearing.

Arthritic Progression in Lateral Compartment

Progression of lateral compartment arthritic disease remains one of the most common reasons for failure following medial mobile-bearing UKA. In the study with the longest follow-up, the reoperation rate for lateral compartment progression was found to be 2.3% at 20 years [56]. In a 15-year study by the Oxford group, the rate was similarly found to be 2.5% [57].

Causes include inappropriate surgical indications or technical surgical error. Preoperative evaluation must confirm a diagnosis of either anteromedial osteoarthritis or osteonecrosis of the medial femoral condyle. In both cases, the ACL should be intact, and the deformity should be flexible. Valgus stress radiograph should help to confirm the presence of full-thickness cartilage in the lateral compartment. It has been shown that a higher rate of success is seen when these criteria are met [35, 40]. Furthermore, during intraoperative examination, there should be no full-thickness lesions in the lateral compartment. If any lesions are appreciated, then UKA should be aborted and TKA should be performed. Unicompartmental arthroplasty should also not be performed in patients with a history of rheumatoid arthritis even if radiographs more closely resemble those of anteromedial arthritis. In these cases, progressive disease in the lateral and patellofemoral compartments is more likely. Flaws in surgical technique also represent a key reason for arthritic progression. Overcorrection of the varus deformity transfers the weight-bearing load to the unaffected lateral compartment, which may cause accelerated cartilage wear. Therefore, it is recommended that the prosthesis be left in slight varus deformity and a bearing size should be selected to restore native tension on the MCL. If the MCL is released inadvertently, then a larger bearing size may be selected to tension the ligament, which may allow overcorrection of the deformity.

If symptomatic lateral compartment arthritis is diagnosed, then addition of a lateral TKA or conversion to a TKA should be considered. Addition of lateral unicompartmental arthroplasty has demonstrated successful results at mid-term follow-up [58]. Furthermore, conversion of a UKA to a TKA may be a less complicated operation with lower risk compared to revision of a TKA to a TKA [59].

Aseptic Loosening

Aseptic loosening of components can occur either early due to improper fixation or years later due to causes intrinsic to the components. Inadequate initial fixation may result from inability to secure cement within the tibial keel or femoral peg holes. Later causes of loosening may relate to

technical error or intrinsic flaws of the components. The tibial component size should be maximized in order to obtain optimal cortical contact without overhang. Cortical bone provides more robust support of the tibial baseplate to prevent abnormal settling that can occur in cancellous bone. The femoral component should be aligned centrally with the tibial baseplate in order to centralize the weight-bearing stress. This should prevent misaligned stress concentration that could enable tilting of the tibial baseplate over time [60]. Finally, the updated twin-peg design may add rotational stability to the femoral component, which has lessened the concern for aseptic loosening of the femoral component as compared to the single-peg design [61].

Diagnosis of component loosening should be made on successive radiographs taken with the same rotation of the leg as judged by overlap of the tibia and fibula. There should be clear evidence of change in position of components on the radiographs in order to diagnose aseptic loosening. Stable radiolucent lines at the bone-cement interface are a normal finding and should not be misinterpreted as component loosening [62]. These physiologic radiolucencies are well-defined lines that are stable on successive imaging and may represent suboptimal cement fixation from a layer of fibrocartilage in between the bone-implant interface [63]. This contrasts with pathologic radiolucencies, which are thick, poorly defined areas representing large amounts of soft tissue within the bone-implant interface [64].

Early cases of loosening may be treated with revision unicompartmental arthroplasty if the bone is relatively well preserved and the prime issue was cement technique. Causes diagnosed after long-term follow-up usually require conversion to total knee arthroplasty given the degree of bone loss that typically results.

Unexplained Pain

Unexplained pain located anteromedially remains a cause for concern of some patients following mobile-bearing medial unicompartmental arthroplasty. The pain is ordinarily situated on the tibial side of the joint and experienced within the first 6–12 months following the surgical procedure. In few cases, the pain has been shown to linger longer than this time interval. In all instances, this pain is correlated with poorer patient functional outcome scores [65].

Unexplained medial knee pain has several potential etiologies. Soft tissue irritation from medial tibial component overhang or impingement on retained osteophytes or cement debris may be attributable to technical error during the surgery [66]. Similarly, overstuffing the medial compartment with consequent lengthening of the MCL may inflame and irritate the ligament substance. Poor cementation of components and early aseptic loosening may be another cause that can be related to surgical technique. Benign soft tissue irritation such as pes anserine bursitis is yet another source that has been linked to this clinical presentation.

Once these other sources of pain have been excluded, then a diagnosis of medial tibial bone overload must be considered. Strain in the proximal medial tibia bone beneath the tibial component increases following unicompartmental arthroplasty, as demonstrated in various studies. One study employing finite analysis proclaimed that this strain increases on average by 40% following the unicompartmental arthroplasty [49]. Different explanations for these changes have been demonstrated and hypothesized. Tibial components with decreasing implant stiffness such as all-polyethylene designs cause an increase in cortical strain and cancellous bone structural damage [67]. Surgical factors have also been implicated. During preparation of the tibia, the potential causes include a deep vertical saw cut beyond the boundary of the horizontal cut, a medially placed vertical saw cut, deeper tibial resections, and excessive varus malalignment [49]. Placement of the component relatively medial as well as tibial tray overhang of 3 mm or greater has also proven to cause increases in tibial strain [68]. Efforts should be made during the surgical procedure to avoid miscalculations associated with tibial preparation and component placement. Updated Microplasty instrumentation

has also been developed in order to safeguard against these mistakes and make tibial preparation more standardized.

Most authors anecdotally proclaim that unexplained anteromedial pain that may be attributable to proximal tibial strain peaks within 6–12 months following the unicompartmental arthroplasty. It is believed that as the proximal tibial bone remodels, the pain settles spontaneously within 1–2 years of surgery. During this time period, the characteristics of the patient's pain should be monitored, and activity should be limited as needed. Without clear evidence of another source of the pain, patients should be reassured that symptoms will gradually improve as the bone remodels. Early revision surgery should be avoided as the pain will usually improve. Unindicated revision arthroplasty for unexplained pain is believed to be a reason for the higher early revision rate of UKA compared to TKA in large registry studies [69].

Long-Term Outcomes

Over the last decade, several small independent studies with long-term follow-up have been published demonstrating successful results with use of the updated Phase 3 implant. Keys et al. studied 40 prospective patients treated with Phase 2 and 3 implants at a small district hospital in the United Kingdom [70]. The author performed roughly 8 mobile-bearing unicompartmental arthroplasties per year. At a mean follow-up of 7.5 years, there were no component failures or revision surgeries required. Emerson and Higgins studied 55 consecutive patients treated with Phase 2 and 3 implants at a private hospital in the United States [71]. Patients were followed for a mean of 11.8 years postoperatively and the 10-year survival rate was 85%. In their updated series including only Phase 3 components implanted between 2004 and 2006, the authors reported on 213 knees with a mean follow-up of 10 years [72]. Using life-table analysis, the projected survivorship was 88% at 10 years. The revision rate was just over 9%, with nearly half of the revisions being attributed to lateral compartment arthritic progression. Only one bearing dislocation was witnessed in this cohort. Lisowski reported on 129 consecutive patients with an average age of 72 years treated with Phase 3 implants at a single center in Amsterdam [73]. Mean follow-up was over 11 years, and the projected 15-year all-cause revision rate was 90.6%. Most of the revisions were due to lateral compartment arthritic progression, with none due to bearing wear or aseptic loosening of components. Of interest, radiolucency below the tibial component was observed in 27% of cases without signs of component loosening.

As previously presented above, Pandit et al. reported on the first 1000 Phase 3 Oxford partial knee replacements between 1998 and 2009 [57]. The operations were performed by two surgeons utilizing a minimally invasive approach, which did not require dislocation of the patella. Mean follow-up was 5.6 years (range 1–11 years) and 547 of the cohort were followed for at least 5 years postoperatively. Of note, the authors excluded 97 patients from the final analysis who did not meet the now accepted criteria for medial unicompartmental arthroplasty, which included a fragmented ACL, lateral compartment near full-thickness defect, uncorrectable varus deformity, and patients treated with concurrent ACL reconstruction. Patients demonstrated significant improvement in the Oxford Knee score of 17 points, increase in flexion of 13°, and 94% were pleased with the outcome of the operation. Reoperation requiring component revision occurred in 2.9% with 20 of these 29 revisions due to arthritic progression in the lateral compartment and 4 due to bearing dislocation. Only 5 septic revisions were reported. Comparatively, in the 97 patients excluded from the analysis, the survival rate was estimated to be 88% at 8 years, while in patients meeting the current indication, 10-year survival rate was 95.6%. The overall survival rate of the study cohort was 95%.

A similar multicenter study was partaken in the United States to document the first 825 Phase 3 unicompartmental arthroplasties performed by 5 surgeons nationwide [74]. The average fol-

low-up for these cases was 9.7 years, and Knee Society overall and function scores had increased from 49 to 90 and 55 to 77, respectively, between pre- and postoperative time points. The projected 10-year implant survival rate was 90%, and survival free of any revision procedure was 85%. There were a total of 93 revision procedures, with 22 of these for lateral compartment progression and 31 for aseptic component loosening. Only 5 bearing dislocations were reported. It was observed that 14.8% of patients with a bearing thickness between 5 and 7 mm required revisions compared to 10.5% in patients with a thinner bearing between 3 and 4 mm. It is theorized that a use of larger tibial bearing may be due to technical error in which the surgeon either overstuffed the medial compartment leading to lateral compartment overload or the surgeon resected an excessive amount of tibial bone that forces the tibia to rest on weaker metaphyseal bone.

Price and Svard presented the longest patient follow-up in the mobile-bearing literature to date [56]. They reported on a consecutive series of 682 knees treated with mobile-bearing unicompartmental arthroplasties between 1983 and 2005 with a median patient follow-up of 5.9 years ranging from 0.5 to 22 years postoperatively. The data were collected from three surgeons operating at three different hospitals in Sweden. While 142 patients (172 knees) died during the follow-up period, no others were lost to follow-up. The mean age at the time of index surgery was 69 years and 55% of patients were females. Implants in the study include 125 Phase 1, 271 Phase 2, and 286 Phase 3 implants. The 16-year cumulative all-cause revision rate was 91% in 100 knees. This rate was maintained at 91% in the 16 knees that were still available for follow-up at 20 years. Interestingly, 31 of the 34 failures requiring component revision occurred less than 10 years postoperatively. This included 8 conversions to total knee arthroplasty for lateral compartment arthritic progression with the majority clustered around 5 years postoperatively, and 6 cases of aseptic loosening occurring between 5 and 8 years. Revision for bearing wear was a minor cause of complication with only a few reported cases. The high number of early failures may be due to inappropriate patient indications or poor surgical technique, causing overloading of the lateral compartment.

Comparison to Total Knee Arthroplasty

While cohort studies of mobile-bearing unicompartmental arthroplasty have demonstrated good results with estimated 10-year implant survival rates greater than 90%, registry studies continue to question the durability of unicompartmental arthroplasty compared to total knee arthroplasty. The Finnish arthroplasty registry presents long-term data extending over a 27-year span from 1985 to 2011 [75]. A study was published from this registry data examining differences between 4712 unicompartmental arthroplasties as compared to 83,511 total knee arthroplasties. The mean patient age was lower in the unicompartmental group (63.5 vs. 69.5 years); however, mean follow-up was roughly 6 years for both groups. Kaplan-Meier analysis was adjusted for age and gender differences between the groups, but unicompartmental arthroplasty was still projected to have lower 5-, 10-, and 15-year survivorship relative to total knee arthroplasty (89% vs. 96%, 81% vs. 93%, 70% vs. 88%). Similarly, in a German registry study of 20,946 unicondylar knee arthroplasties, the 5-year survival rate free of one component exchange or complete revision was estimated at 87.8% [76]. This patient cohort was comparable to the Finnish cohort in that mean patient age was 64 years and 60% of patients were female. Younger age, diabetes, obesity, and lower surgical volume hospitals were associated with higher risk of failure.

Despite lower implant survival rates in registry studies, larger registry studies do not account for differences in patient indications, surgeon technique, and implant use that may dramatically affect the rate of revision surgery. First, the proper pathoanatomy must be identified as explained by Goodfellow, as higher rates of failure of mobile-bearing implant have been reported in patients not meeting these criteria. In many of these studies, outcomes of mobile-bearing and

fixed bearing components are not differentiated. Mobile-bearing UKA implants theoretically have a lower rate of wear. Surgical technique is important to avoid overcorrection of deformity as lateral arthritic progression is an important reason for failure and conversion to TKA. Finally, there may be differences in surgeon threshold for conversion from a UKA to a TKA as compared to the revision of a primary TKA given that the conversion procedure is typically less technically demanding.

These theories have been supported in smaller studies directly comparing unicompartmental arthroplasty to total knee arthroplasty [77]. In a systemic review and meta-analysis evaluating randomly controlled trials of UKA versus TKA, the UKA patients demonstrated a trend toward higher patient outcome scores and flexion and a lower rate of short-term complications, which included aseptic loosening, arthritic progression, bearing dislocation, deep venous thrombosis, and infection. Despite these findings, there was a higher overall revision rate following UKA as compared to TKA. More recently when examining the National Joint Registry of England and Wales, UKA again has been shown to produce significantly higher patient outcomes, higher patient satisfaction, and lower complications or readmissions compared to TKA [78].

Surgeon Volume

There has been a focus in examining unicompartmental arthroplasty outcomes as they relate to surgeon experience with the procedure. Applying the historical Kozinn and Scott criteria unnecessarily lowers the number of patients indicated for unicompartmental arthroplasty. It is believed that only 5% of patients with medial compartment osteoarthritis may fit these patient-specific standards, whereas as many as 50% may be appropriate candidates for the operation based on the pathoanatomic criteria laid out by Goodfellow and colleagues [70, 79]. This excessive exclusion of candidates adversely affects patients and surgeons as it limits the number of unicompartmental operations performed and hence decreases surgeon comfort with the procedure while overtreating a large portion of patients [80].

Research has demonstrated a clear linear relationship with number of unicompartmental arthroplasties performed annually by a given surgeon and the consequent implant survival rate, as performing less than 10 procedures per year was shown to significantly decrease survival compared to greater than 30 per year in the National Joint Registry for England and Wales [81]. This relationship between surgeon caseload and outcomes was also shown to be stronger in unicompartmental arthroplasty as compared to total knee arthroplasty in this same study. These findings have also been replicated specifically with use of a mobile-bearing prosthesis. Examination of over 23,000 cemented Oxford partial knee arthroplasties in the National Joint Registry for England and Wales over an 8-year study period from 2003 to 2010 demonstrated that risk of revision of one or both components was 30% in hospital centers performing less than 100 procedures per year as compared to centers performing greater than 200 per year [82]. Furthermore, risk of revision was twice as high for surgeons performing less than 100 procedures annually as compared to those performing more than 100 per year. This dependence between surgeon volume and survival of cemented Oxford partial knee arthroplasties was similarly corroborated in the Nordic Arthroplasty Register Association database studied between 2000 and 2012 [83]. The authors also showed that the risk of revision for unexplained pain was 40–50% higher when the index surgeon performed less than 11 Oxford medial unicompartmental procedures per year compared to those surgeons performing more than 11 per year. This discovery further illustrates the subjective nature when determining the need for revision of a unicompartmental replacement. One potential explanation is that surgeons less familiar with the procedure may have greater haste in converting to a TKA in cases of unexplained pain.

Conclusion

Medial mobile-bearing unicompartmental arthroplasty represents a proven treatment to relieve pain and restore function in patients diagnosed with anteromedial osteoarthritis or focal spontaneous osteonecrosis of the knee in the medial compartment. Current indications for the procedure are centered on disease-specific clinical criteria and are independent of patient age, body habitus, and activity level. The Oxford partial knee is currently the most commonly used mobile-bearing medial unicompartmental arthroplasty device worldwide. The spherical femoral component and conformity with the mobile polyethylene bearing have been designed to limit the contact stress on the polyethylene and decrease forces at the implant interfaces to improve longevity of the prosthesis. Surgical principles are aimed at resurfacing the medial compartment and re-creating native tension on the medial collateral ligament in an effort to restore knee kinematics and relieve pain from the arthritic or osteonecrotic process. The technical principles are important in order to limit risk of complications related to bearing dislocation, lateral compartment stress overload, proximal medial tibial strain, and component loosening. With the improved Microplasty instrumentation, the procedure is more reproducible and efficient. This decreases operative time, which is beneficial to the patient and surgeon. Long-term outcomes from various clinical settings have demonstrated 10-year survival rates ranging from 85% to 95%. Surgeon caseload and experience with UKA have correlated to improved survival and clinical outcomes of this treatment.

References

1. Marmor L. Unicompartmental and total knee arthroplasty. Clin Orthop Relat Res. 1985;192:75–81.
2. Palmer SH, Morrison PJ, Ross AS. Early catastrophic tibial component wear after unicompartmental knee arthroplasty. Clin Orthop Relat Res. 1998;350:143–8.
3. Goodfellow J, O'Connor J. The mechanics of the knee and prosthesis design. J Bone Joint Surg Br. 1978;60-B:358–69.
4. Goodfellow JW, Kershaw CJ, Benson MK, O'Connor JJ. The Oxford knee for unicompartmental osteoarthritis. The first 103 cases. J Bone Joint Surg Br. 1988;70-B:692–701.
5. O'Connor JJ, Goodfellow JW. Theory and practice of meniscal knee replacement: design against wear. Proc Inst Mech Eng [H]. 1996;210:217–22.
6. White SH, Ludkowski PF, Goodfellow JW. Anteromedial osteoarthritis of the knee. J Bone Joint Surg Br. 1991;73(4):582–6.
7. Price AJ, O'Connor JJ, Murray DW, Dodd CA, Goodfellow JW. A history of Oxford unicompartmental knee arthroplasty. Orthopedics. 2007;30(Suppl):7–10.
8. Murray DW, Goodfellow JW, O'Connor JJ. The Oxford medial unicompartmental arthroplasty: a ten-year survival study. J Bone Joint Surg Br. 1998;80-B:983–9.
9. Vorlat P, Putzeys G, Cottenie D, Van Isacker T, Pouliart N, Handelberg F, Casteleyn PP, Gheysen F, Verdonk R. The Oxford unicompartmental knee prosthesis: an independent 10-year survival analysis. Knee Surg Sports Traumatol Arthrosc. 2006;14:40–5.
10. Svard 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.
11. Keys GW. Reduced invasive approach for Oxford II medial unicompartmental knee replacement - preliminary study. Knee. 1999;6:193–6.
12. White SH, Roberts S, Jones PW. The twin peg Oxford partial knee replacement: the first 100 cases. Knee. 2012;19(1):36–40.
13. Price AJ, Webb J, Topf H, Dodd CA, Goodfellow JW, Murray DW, Oxford Hip and Knee Group. Rapid recovery after Oxford unicompartmental arthroplasty through a short incision. J Arthroplast. 2001;16(8):970–6.
14. Riddle DL, Jiranek WA, McGlynn FJ. Yearly incidence of unicompartmental knee arthroplasty in the United States. J Arthroplasty. 2008;23(3):408–12.
15. Walker T, Zahn N, Bruckner T, Streit MR, Mohr G, Aldinger PR, Clarious M, Gotterbarm T. Mid-term results of lateral unicondylar mobile bearing knee arthroplasty. Bone Joint J. 2018;100-B(1):42–9.
16. Streit MR, Walker T, Bruckner T, Merle C, Kretzer JP, Carius M, Aldinger PR, Gotterbarm T. Mobile-bearing lateral unicompartmental knee replacement with the Oxford domed tibial component. J Bone Joint Surg Br. 2012;94-B:1356–61.
17. Forster MC, Bauze AJ, Keene GC. Lateral unicompartmental knee replacement: fixed or mobile bearing? Knee Surg Sports Traumatol Arthrosc. 2007;15(9):1107–11.
18. Price AJ, Short A, Kellett C, Beard D, Gill H, Pandit H, Dodd CA, Murray DW. Ten-year in vivo wear measurement of a fully congruent mobile bearing unicompartmental knee arthroplasty. J Bone Joint Surg Br. 2005;87(11):1493–7.

19. 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.
20. 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.
21. Kendrick BJ, Longino D, Pandit H, 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.
22. 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.
23. 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.
24. Pandit H, Liddle AD, Kendrick BJ, Jenkins C, Price AJ, Gill HS, Dodd CA, Murray DW. 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.
25. Hurst JM, Berend KR, Adams JB, Lombardi AV Jr. Radiographic comparison of mobile-bearing partial knee single-peg versus twin-peg design. J Arthroplast. 2015;30(3):475–8.
26. Berend KR, Hurst JM, Morris MJ, Adams JB, Lombardi AV Jr. New instrumentation reduces operative time in medial unicompartmental knee arthroplasty using the Oxford mobile bearing design. Reconstruct Rev. 2015;5(4):19–22.
27. Kozinn SC, Scott R. Unicondylar knee arthroplasty. J Bone Joint Surg Am. 1989;71:145–50.
28. Thornhill TS. Unicompartmental knee arthroplasty. Clin Orthop Relat Res. 1986;205:121–31.
29. Arno S, Maffei D, Walker PS, Schwarzkopf R, Desai P, Steiner GC. Retrospective analysis of total knee arthroplasty cases for visual, histological, and clinical eligibility of unicompartmental knee arthroplasties. J Arthroplasty. 2011;26(8):1396–403.
30. Pandit H, Jenkins C, Gill HS, Smith G, Price AJ, Dodd CA, Murray DW. Unnecessary contraindications for mobile-bearing unicompartmental knee replacement. J Bone Joint Surg Br. 2011;93(5):622–8.
31. Hamilton TW, Pandit HG, Jenkins C, Mellon SJ, Dodd CAF, Murray DW. Evidence-based indications for mobile-bearing unicompartmental knee arthroplasty in a consecutive cohort of thousand knees. J Arthroplast. 2017;32(6):1779–85.
32. 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.
33. Greco NJ, Lombardi AV Jr, Price AJ, Berend ME, Berend KR. Medial mobile-bearing unicompartmental knee arthroplasty in young patients aged less than or equal to 50 years. J Arthroplasty. 2018;33(8):2435–9.
34. Harman MK, Markovich GD, Banks SA, Hodge WA. Wear patterns on the tibial plateaus from varus and valgus osteoarthritic knees. Clin Orthop Relat Res. 1998;352:149–58.
35. Mancuso F, Dodd CA, Murray DW, Pandit H. Medial unicompartmental knee arthroplasty in the ACL-deficient knee. J Orthop Traumatol. 2016;17(3):267–75.
36. Hamilton TW, Pandit HG, Maurer DG, Ostlere SJ, Jenkins C, Mellon SJ, Dodd CAF, Murray DW. 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.
37. 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.
38. Robertsson O, Lewold S, Goodman S, Lidgren L. Knee arthroplasty in rheumatoid arthritis: a report from the Swedish knee arthroplasty register on 4,381 primary operations 1985-1995. Acta Ortho Scand. 1997;68(6):543–53.
39. Jackson WF, Berend KR, Spruijt S. 40 years of the Oxford Knee. Bone Joint J. 2016;98-B(10 Supple B):1–2.
40. 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 Supple B):3–10.
41. Marmor L. Unicompartmental arthroplasty for osteonecrosis of the knee joint. Clin Orthop Relat Res. 1993;294:247–53.
42. Ahlbäck S, Bauer GC, Bohne WH. Spontaneous osteonecrosis of the knee. Arthritis Rheum. 1968;11(6):705–33.
43. Mont MA, Baumgarten KM, Rifai A, Bluemke DA, Jones LC, Hungerford DS. Atraumatic osteonecrosis of the knee. J Bone Joint Surg Am. 2000;82(9):1279–90.
44. Brahme SK, Fox JM, Ferkel RD, Friedman MJ, Flannigan BD, Resnick DL. Osteonecrosis of the knee after arthroscopic surgery: diagnosis with MR imaging. Radiology. 1991;178(3):851–3.
45. Pruès-Latour V, Bonvin JC, Fritschy D. Nine cases of osteonecrosis in elderly patients following arthroscopic meniscectomy. Knee Surg Sports Traumatol Arthrosc. 1998;6(3):142–7.
46. 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.
47. Chalmers BP, Mehrotra KG, Sierra RJ, Pagnano MW, Taunton MJ, Abdel MP. Reliable outcomes and survivorship of unicompartmental knee arthroplasty for

isolated compartment osteonecrosis. Bone Joint J. 2018;100-B(4):450–4.
48. Greco NJ, Lombardi AV, Hurst JM, Morris MJ, Berend KR. Medial unicompartmental knee arthroplasty for focal femoral osteonecrosis. J Bone Joint Surg Am. 2019;101(12):1077–84.
49. Simpson DJ, Price AJ, Gulati A, Murray DW, Gill HS. Elevated proximal tibial strains following unicompartmental knee replacement--a possible cause of pain. Med Eng Phys. 2009;31(7):752–7.
50. Pegg EC, Walter J, Mellon SJ, Pandit HG, Murray DW, D'Lima DD, Fregly BJ, Gill HS. Evaluation of factors affecting tibial bone strain after unicompartmental knee replacement. J Orthop Res. 2013;31(5):821–8.
51. Pandit H, Murray DW, Dodd CA, Deo S, Waite J, Goodfellow J, Gibbons CL. Medial tibial plateau fracture and the Oxford unicompartmental knee. Orthopedics. 2007;30(5 Suppl):28–31.
52. Dervin GF, Carruthers C, Feibel RJ, Giachino AA, Kim PR, Thurston PR. Initial experience with the oxford unicompartmental knee arthroplasty. J Arthroplast. 2011;26(2):192–7.
53. Mohammad HR, Strickland L, Hamilton TW, Murray DW. Long-term outcomes of over 8,000 medial Oxford phase 3 unicompartmental knees-a systematic review. Acta Orthop. 2017;89(1):101–7.
54. Chatellard R, Sauleau V, Colmar M, Robert H, Raynaud G. Brilhault J; Sociétéd'Orthopédie et de Traumatologie de l'Ouest (SOO).Medial unicompartmental knee arthroplasty: does tibial component position influence clinical outcomes and arthroplasty survival? Orthop Traumatol Surg Res. 2013;99(4 Suppl):S219–25.
55. Gulati A, Weston-Simons S, Evans D, Jenkins C, Gray H, Dodd CA, Pandit H, Murray DW. Radiographic evaluation of factors affecting bearing dislocation in the domed lateral Oxford unicompartmental knee replacement. Knee. 2014;21(6):1254–7.
56. 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.
57. 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.
58. Pandit H, Mancuso F, Jenkins C, Jackson WFM, Price AJ, Dodd CAF, Murray DW. Lateral unicompartmental knee replacement for the treatment of arthritis progression after medial unicompartmental-replacement. Knee Surg Sports Traumatol Arthrosc. 2017;25(3):669–74.
59. Leta TH, Lygre SH, Skredderstuen A, Hallan G, Gjertsen JE, Rokne B, Furnes O. Outcomes of unicompartmental knee arthroplasty after aseptic revision to total knee arthroplasty: a comparative study of 768 TKAs and 578 UKAs revised to TKAs from the Norwegian Arthroplasty register (1994 to 2011). J Bone Joint Surg Am. 2016;98-A:431–40.
60. Liddle AD, Pandit HG, Jenkins C, Lobenhoffer P, Jackson WF, Dodd CA, Murray DW. Valgus subsidence of the tibial component in cementless Oxford unicompartmental knee replacement. Bone Joint J. 2014;96-B(3):345–9.
61. Lum ZC, Lombardi AV, Hurst JM, Morris MJ, Adams JB, Berend KR, et al. Bone Joint J. 2016;98-B(10 Supple B):28–33.
62. 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.
63. Kendrick BJ, James AR, Pandit H, Gill HS, Price AJ, Blunn GW, Murray DW. Histology of the bone-cement interface in retrieved Oxford unicompartmental knee replacements. Knee. 2012;19(6):918–22.
64. Mukherjee K, Pandit H, Dodd CA, Ostlere S, Murray DW. The Oxford unicompartmental knee arthroplasty: a radiological perspective. Clin Radiol. 2008;63(10):1169–76.
65. Edmondson MC, Isaac D, Wijeratna M, Brink S, Gibb P, Skinner P. Oxford unicompartmental knee arthroplasty: medial pain and functional outcome in the medium term. J Orthop Surg Res. 2011;6(52):1–7.
66. Murray D, Simpson D, Dodd C, Gill H, Beard D, Pandit H, Chau R. An acceptable limit of tibial component overhang in the Oxford unicompartmental knee arthroplasty. British Association for Surgery of the Knee, free paper session, 'Technical Aspects of UKA', Bournemouth. 2008.
67. Scott CE, Eaton MJ, Nutton RW, Wade FA, Pankaj P, Evans SL. Proximal tibial strain in medial unicompartmental knee replacements: a biomechanical study of implant design. Bone Joint J. 2013;95-B(10):1339–47.
68. 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.
69. Tregonning R, Rothwell A, Hobbs T, Hartnett N. Early failure of the Oxford Phase 3 cemented medial unicompartmental knee joint arthroplasty.An audit of the NZ Joint Registry over six years. J Bone Joint Surg Br. 2009;91-B(Supp II):339.
70. Keys GW, Ul-Abiddin Z, Toh EM. Analysis of first forty Oxford medial unicompartmental knee replacement from a small district hospital in UK. Knee. 2004;11(5):375–7.
71. Emerson RH Jr, 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.
72. Emerson RH, Alnachoukati O, Barrington J, Ennin K. The results of Oxford unicompartmental knee arthroplasty in the United States: a mean ten-year survival analysis. Bone Joint J. 2016;98-B(10 Supple B):34–40.
73. Lisowski LA, Meijer LI, van den Bekerom MP, Pilot P, Lisowski AE. Ten- to 15-year results of the Oxford

Phase III mobile unicompartmental knee arthroplasty: a prospective study from a non-designer group. Bone Joint J. 2016;98 B(10 Supple B):41–7.
74. Alnachoukati OK, Barrington JW, Berend KR, Kolczun MC, Emerson RH, Lombardi AV Jr, Mauerhan DR. Eight hundred twenty-five medial mobile-bearing unicompartmental knee arthroplasties: the first 10-year US multi-center survival analysis. J Arthroplast. 2018;33(3):677–83.
75. Niinimäki T, Eskelinen A, Mäkelä 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. 2013;472(5):1496–501.
76. Jeschke E, Gehrke T, Günster C, Hassenpflug J, Malzahn J, Niethard FU, Schräder P, Zacher J, Halder A. Five-year survival of 20,946 unicondylar knee replacements and patient risk factors for failure: an analysis of German insurance data. J Bone Joint Surg Am. 2016;98(20):1691–8.
77. Arirachakaran A, Choowit P, Putananon C, Muangsiri S, Kongtharvonskul J. Is unicompartmental knee arthroplasty (UKA) superior to total knee arthroplasty (TKA)? A systematic review and meta-analysis of randomized controlled trial. Eur J Orthop Surg Traumatol. 2015;25(5):799–806.
78. 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.
79. 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.
80. Stern SH, Becker MW, Insall JN. Unicondylar knee arthroplasty: an evaluation of selection criteria. Clin Orthop Relat Res. 1993;286:143–8.
81. Liddle AD, Pandit H, Judge A, Murray DW. Effect of surgical caseload on revision rate following total and unicompartmental knee replacement. J Bone Joint Surg Am. 2016;98(1):1–8.
82. Baker P, Jameson S, Critchley R, Reed M, Gregg P, Deehand D. Center and surgeon volume influence the revision rate following unicondylar knee replacement: an analysis of 23,400 medial cemented unicondylar knee replacements. J Bone Joint Surg Am. 2017;95(8):702–9.
83. Badawy M, Fenstad AM, Bartz-Johannessen CA, Indrekvam K, Havelin LI, Robertsson O, W-Dahl A, Eskelinen A, Mäkelä K, Pedersen AB, Schrøder HM, Furnes O. Hospital volume and the risk of revision in Oxford unicompartmental knee arthroplasty in the Nordic countries -an observational study of 14,496 cases. BMC Musculoskelet Disord. 2017;18(1):388.