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Minimal invasive techniques in unicompartamental knee arthroplasty (UKA) have been available for over a decade and are based on three principles: minimization of the joint damage, minimal interference with patient's lifestyle, and no interference with consequential future treatment options as popularized by John Repicci [1]. The introduction of minimally invasive techniques to UKA has led to renewed interest in UKA. Further, growth rates have tripled compared to the rate of total knee replacement (TKR) over the past decade [2], fueled by the introduction of new technology like mobile-bearing UKA, haptic guidance system, and custom UKA with 3D printed single-use instruments.

The concept of unicompartamental TKR is an attractive alternative to tibial osteotomy or TKR for unicompartamental osteoarthritis [3, 4]. Compared with osteotomy and TKR, unicompartamental arthroplasty has a higher initial success rate and fewer early complications [5]. Additionally, recovery is quicker and more patients going home than patients who have received a TKA but a lower postoperative morbidity [6]. A randomized prospective study comparing patients with unicompartamental osteoarthritis who had received either a UKA or TKR for 15 years showed a survival rate of 89 % for UKA and 79 % for TKR. Further, patients who received the UKA had better range of motion, were more satisfied, and were more active, with a comparable functioning score. The failure rate at

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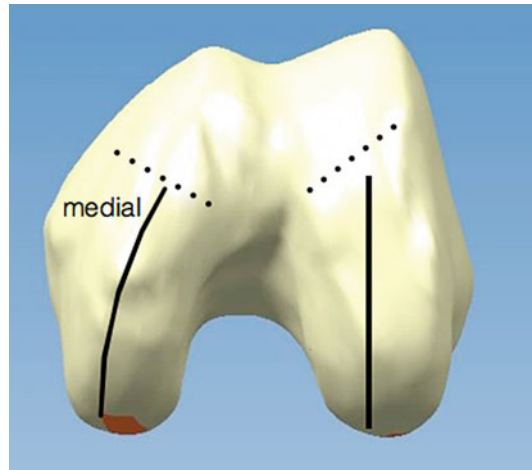
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15 years of UKA was not higher than that seen with TKR [7].

## Patient Selection

The widespread use of arthroscopic treatment for osteoarthritis of the knee without large mechanical relevant meniscal tears has been questioned [8–10] and is not recommended. Osteotomy remains the procedure of choice for young, athletic, active patients with unicompartmental osteoarthritis who want to return to high impact sport activities. Internal derangement and its treatment in the younger subpopulation are not contraindications to osteotomy and may need an arthroscopic procedure before or after the osteotomy is performed. However, additional studies are needed to clarify the effectiveness of knee arthroscopy in this population. Subluxation and extreme angular deformity are contraindications to both osteotomy and unicompartmental replacement.

What are the potential benefits of custom unicompartmental arthroplasty? The geometry of the articulating surfaces of the knee is rather complex, and it is unclear whether or not an off-the-shelf (OTS) implant designed for the medial tibiofemoral joint in varying sizes while simultaneously flipping a left medial UKA to use for the lateral tibiofemoral joint of the right knee or vice versa is sufficient. The knee has three compartments with three different J-curves on the femoral side and two tibial surfaces with a more teardrop-shaped and concave medial plateau and a rounder but convex lateral plateau. On the femoral side, the medial and lateral condyles are different: comparing the medial to the lateral J-curves, the posterior radius is similar, but the anterior radius is much larger for the lateral condyle [11]. The average anterior medial radius is 37.5 mm ( $\pm 3.3$  mm) and 43.4 mm ( $\pm 4.2$  mm) for the lateral condyle. Furthermore, the posterior lateral condyle is narrower and the anterior condyle is longer and straighter. The medial condyle is slightly externally rotated and more curved (Fig. 1). Therefore, the question has to be raised whether it makes sense to use one OTS femoral component with different magnifications and use it for both the



**Fig. 1** Medial and lateral femoral condyles have different geometries. The medial condyle is more curved and the lateral condyle straighter and longer. The anterior radius of the lateral J-curve is twice compared to the medial anterior radius

medial and for the lateral condyle while ignoring the different geometries of both the femoral and tibial compartments.

Besides the shortcomings of not matching the geometries of OTS implants, the wide range of sizes is insufficient: we compared the femoral and tibial dimensions of 48 knee computer tomography (CT) scans and studied how many components would fit within 2 mm. We selected the widest femoral component of OTS UKA available in the USA and compared its width to the widths of the medial and lateral condyles. For the medial condyle, 67 % did not fit within 2 mm in males and 8 % did not fit within 2 mm in females. For the lateral condyle, 88 % did not fit within 2 mm for males and 21 % did not fit within 2 mm for females [12]. While all female tibial (medial and lateral tibial plateau) knee dimensions fell within  $\pm 2$  mm of the range of available components, males are not as lucky: taking the longest and widest tibial component, 8 % had anteroposterior (AP) dimensions that were 2 mm longer and 13 % had wider dimensions ( $>2$  mm) on the medial side. On the lateral tibial plateau, 5 % had longer ( $>2$  mm) plateaus, but 29 % had wider dimensions ( $>2$  mm) [12]. Even if OTS UKA improves their design for the tibial component and optimizes the geometry of the tibial implant OTS,



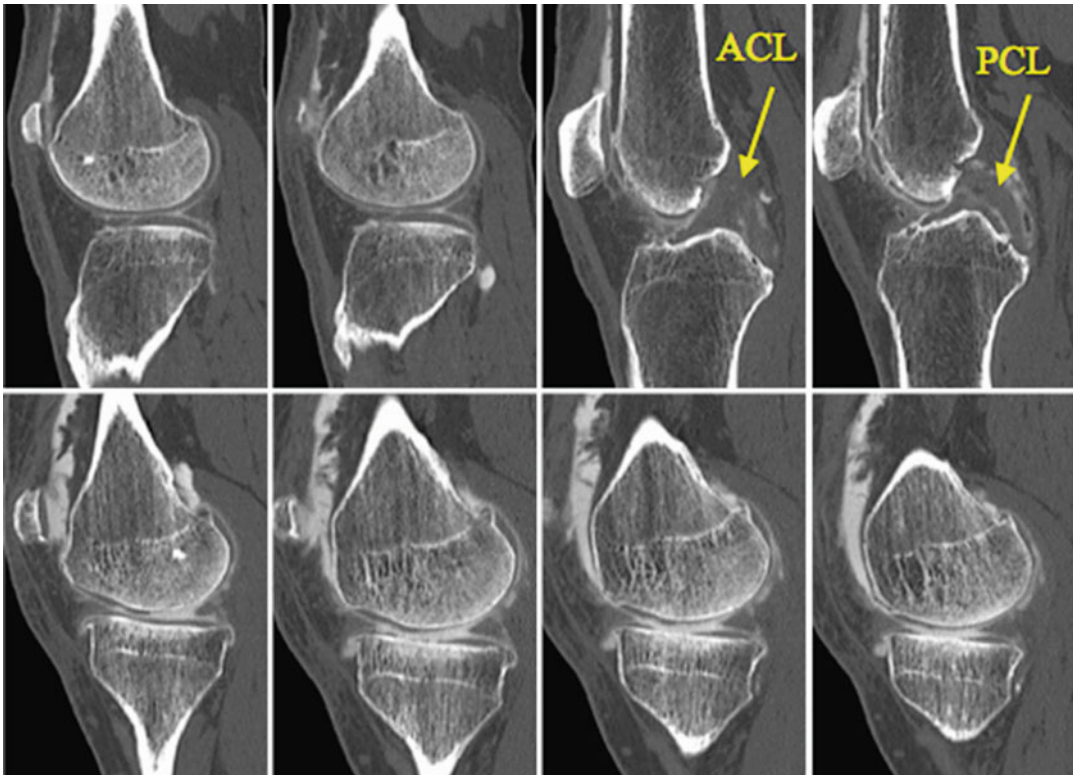
**Fig. 2** Standard screening X-rays: AP standing in extension and 45° flexion (Rosenberg), standing lateral and skyline views

tibial implants would not cover more than 76 % of the cortical rim [13]. Other authors have described the mismatch of implants and tibial anatomy and suggested that surgeons should be aware of the fact that some implants fit better than others [14, 15]. These shortcomings are addressed with custom-designed implants, not only for each patient but also designed for each individual compartment of the knee, whether it is for the femoral or tibial side.

The ideal candidate for custom unicompartmental replacement is the unicompartmental osteoarthritic patient with intact cruciate and collateral ligaments, preserved range of motion, and a correctable deformity, but no inflammatory arthritis. There is no difference on patient selection criteria when deciding to use an off-the-shelf (OTS) or a custom UKA. Whether age, weight, and activity should be considered as part of the selection, criteria for UKA have been a reoccurring controversial topic in the literature for decades. The strict narrow indications discussed 20 years ago [3] have been softened and widened. Most surgeons make their final decision on whether to use a UKA or a TKA at the time of surgery after arthrotomy [3]. However, authors question this practice given the limited access to the contralateral side with the use of minimal invasive techniques through a minimal invasive medial approach: it is difficult to judge the

integrity of the lateral tibial plateau, and the same is true for the medial compartment through a minimal invasive lateral approach. The practice of judging the contralateral compartment intraoperatively is not recommended in the case of a custom implant: from a cost perspective, it makes no sense to produce several different custom implants like a partial and a total knee replacement and discard the unused implant at the time of surgery.

So how can you optimize the selection process of patients qualifying for UKA and make sure that the correct implant is picked? There are two important steps in the selection process of custom implants. The first step is a general screening for uni-, bi-, or tri-compartmental osteoarthritis with a series of standard X-rays (Fig. 2). Standing posteroanterior bilateral knee views in extension and flexion (Rosenberg views) are good screening tools for unicompartmental medial or lateral osteoarthritis. The standing lateral X-ray helps to identify an anteromedial wear pattern. Furthermore, it is helpful in predicting whether the anterior cruciate ligament (ACL) is intact [16]. Skyline views may demonstrate patellofemoral (PF) osteoarthritis since PF eburnated bone is generally considered a contraindication to UKA, but could be addressed with a custom bicompartamental knee arthroplasty (BKA). There is one exception: in varus knees with bare

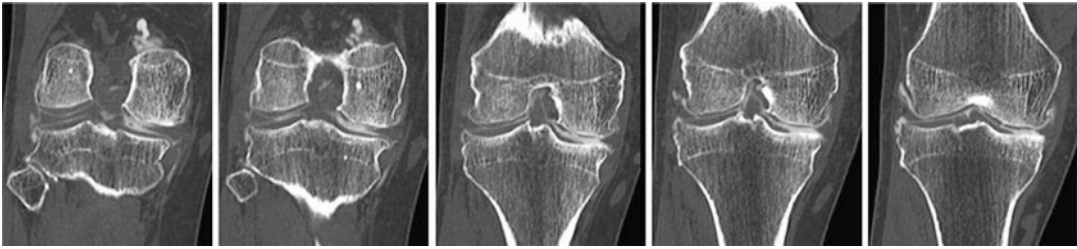


**Fig. 3** CT arthrogram sagittal cuts demonstrating medial tibiofemoral bare bone, anteromedial wear pattern, intact ACL, PCL, and intact lateral femorotibial compartment

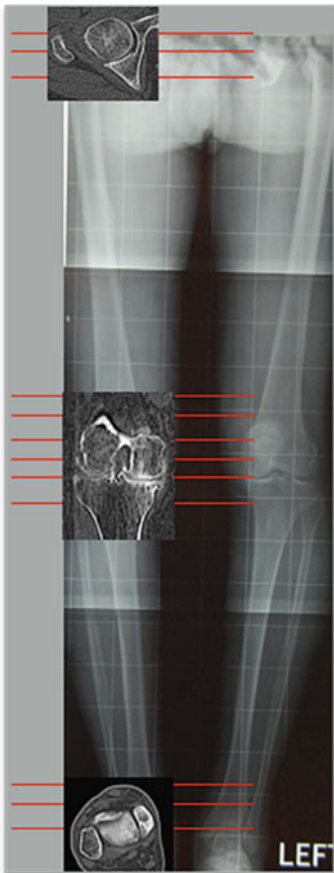
bone in the medial tibiofemoral joint and bare bone in the lateral PF joint, the author would not recommend BKA but TKA. With the correction of the varus deformity, the Q angle is increased affecting PF tracking, and sometimes these knees have some form of distal trochlear dysplasia with a bump toward the lateral condyle, which is not addressed with a custom BKA. Interestingly, most patients with isolated PF Osteoarthritis (OA) on plain skyline views may be candidates for patellofemoral arthroplasty (PFA) but have tibiofemoral arthritic changes that are detected in the second part of the screening process: all custom UKA or custom BKA are CT based and can be combined with an arthrogram to map the cartilage in all three compartments. The integrity of both the ACL and posterior cruciate ligament (PCL) can be verified, too. This study (Fig. 3) allows for the identification of small defects or even fissures in the contralateral compartment

that would not be detected with plain stress X-rays and potentially could lead to progression of osteoarthritis of the contralateral compartment, which is known to be a frequent failure mechanism in UKA (Fig. 4). The use of a CT arthrogram avoids additional tests or even procedures, such as magnetic resonance imaging or diagnostic knee arthroscopies.

Custom UKA is derived from a preoperative CT scan using a special protocol, including some slices of the hip and ankle to include the mechanical axis of both femur and tibia into the design process (Fig. 5). While the neutral axis in UKA is not restored, the femoral component is designed perpendicular to the femoral mechanical axis. The tibial component, with the use of the custom 3D printed instrumentation, is placed perpendicular to the tibial mechanical axis. The implants and the individualized 3D printed nylon instruments are delivered sterilized in one small container (Fig. 6).



**Fig. 4** Coronal view of same patient with medial OA, lateral compartment intact



**Fig. 5** Special protocol includes a few slices of the hip and ankle to align femoral and tibial components along the mechanical axis

## Surgical Technique

For the lateral UKA, the author prefers a slightly different positioning of the knee. The medial UKA is positioned in 90° of knee flexion, but for

the lateral UKA, 70° of flexion diminishes the tension of the patella using a lateral para-patellar approach and allows the patella to be moved medial to facilitate exposure to the lateral femoral-patellar compartment. For medial UKA, a short medial minimal invasive approach is recommended. The length of the incision varies depending on the size of the knee, the muscularity, and how easily the patella can be moved. It is more important to protect the wound edges from maceration and to gain sufficient access to the joint without any struggle to expose the knee.

For the medial approach, it is important to avoid any release of the medial collateral ligament (MCL). The author uses a narrow Z-retractor around the medial tibia to remove the osteophytes without getting into the MCL. This allows the Z-retractor to be positioned around the tibia to protect the MCL, while the tibia is cut, without release of the semimembranosus tendon insertion (Fig. 7).

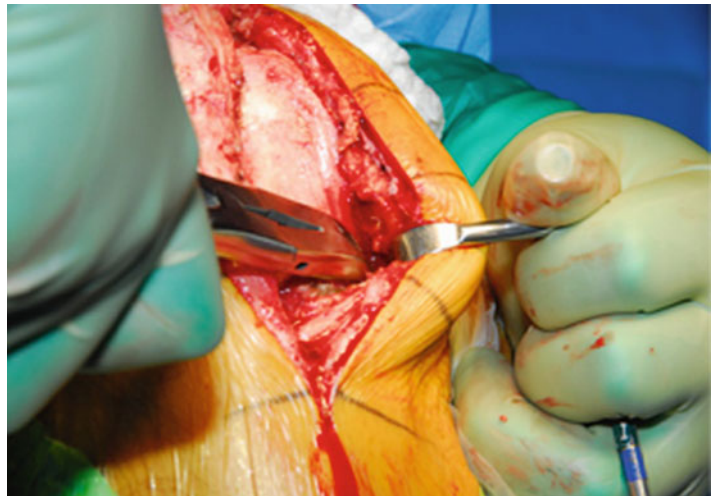
It is easier to cut the femur first to gain more space for the tibial cut. After the linea terminalis is marked the femoral condylar cartilage is removed including the top of the notch (Fig. 8). The medial osteophytes are completely taken off. Care needs to be taken to avoid incomplete osteophyte removal, since the femoral cutting block would be seated slightly more medial and ultimately would move the femoral component 1 or 2 mm more medial in relation to the center of the medial tibial component during range of motion. This may lead to increased shear forces and should be avoided. The femoral cutting block is then placed and pinned and the planned amount of bone is removed off the posterior condyle (Fig. 9). The cartilage needs to be removed before the accurate





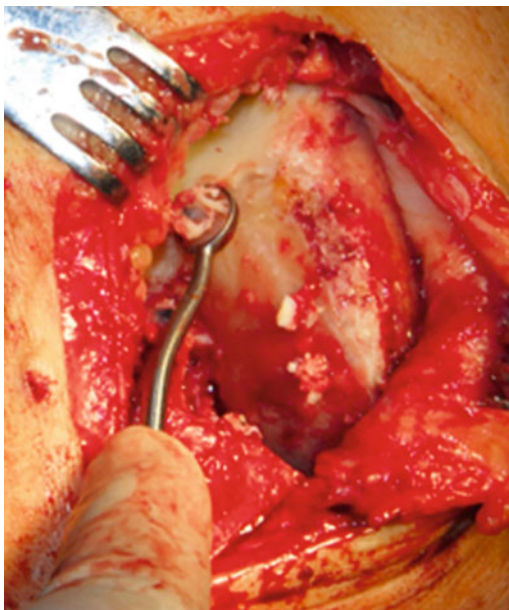
**Fig. 6** Single-use instrumentation and custom implants, including three polyethylene inserts, two 6 mm and one 8 mm, are delivered to the OR in one box

**Fig. 7** MIS unicompartmental approach protecting MCL with a narrow Z-retractor

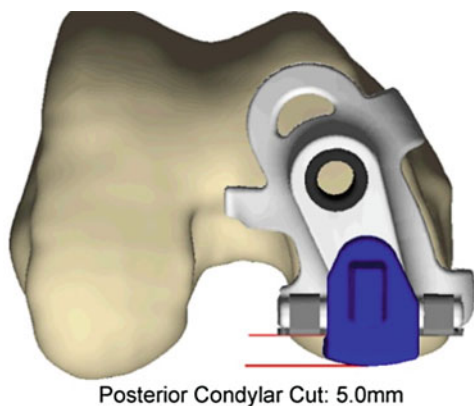


amount of bony resection is measured, including the saw thickness. The femoral cutting block should be moved 1–2 mm more anteriorly to resect 1–2 mm additional bone to match the planned resection thickness and to avoid flexion tightness. Enough space is now created to remove the cartilage of the anterior two-thirds of the tibia,

specifically toward the tibial eminentia. This step is important since this system is the only UKA on the market where the soft tissue balancing is done prior to resecting the tibia. Incomplete removal of the cartilage would either result in a varus/valgus positioning of the tibial component or not enough tibial resection. This is done with special



**Fig. 8** Removal of articular cartilage



**Fig. 9** The femoral cutting block is placed on femoral condyle. The planned amount of bone excluding the cartilage needs to be measured to verify correct amount of resected bone and match planned amount. If not enough bone resection, the femoral cutting block is moved more anteriorly until total planned amount is resected of the posterior condyle to place femoral component “anatomically”

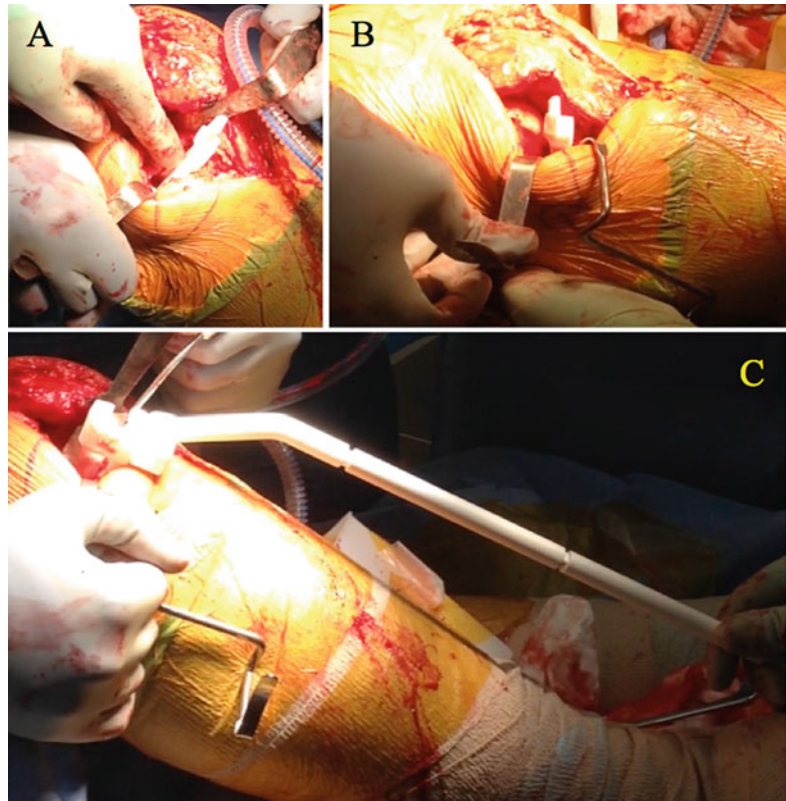
balancing chips (Fig. 10), which are custom fitted to the tibial surface and come in four thicknesses with 1-mm increments. In flexion, the balancing chips are placed on the tibia (Fig. 10a) and its custom fit is verified. If there are some additional

osteophytes, they need to be removed. The knee is brought into slight flexion of about  $10^\circ$  starting with the thinnest balancing chip (Fig. 10a) to find the optimal tension of the medial and lateral collateral ligament (Fig. 10b). The majority of knees are balanced with opening between 1–2 mm on the medial side and 2–3 mm on the lateral side using the B or C balancing chip. If the thinnest A chip is used and the knee is not opening at all, incomplete cartilage or osteophyte removal may be the reason and should be readdressed, before cutting the tibia. If the D balancing chip is necessary to balance the knee or if it is still too loose, MCL insufficiency should be considered which cannot be treated with a UKA. Care should be taken to avoid overstuffing of the compartment, which will result in overcorrection. The opening under varus or valgus stress will match the opening after the implants are placed using the default plastic thickness of 6 mm. Figures 11 and 12 show 3-foot films of a varus and valgus knee pre- and post-op with slight under-correction of the deformity.

The tibial cutting block is now connected to the balancing chip in extension, and the alignment is verified using the extramedullary rod (Fig. 10c). While some surgeons try to match the individual slope, the author prefers to avoid a tibial slope of more than  $7^\circ$  on the medial side to reduce the strain on the ACL [17]. The slope of the lateral tibial component is matched individually (Fig. 10c). The tibial cutting block is pinned. One pin is in general enough to achieve sufficient fixation. The medial pin in medial UKA should not be used. It would create an additional stress riser of the medial tibial plateau [18, 19] and has been described in cases with tibial plateau fractures following medial UKA. First, the horizontal cut is made. The MCL needs to be protected and undercutting of the eminentia should be avoided. The author leaves the saw blade in situ to protect the posterior cortex from the sagittal cut, since a cut into the posterior cortex may increase the risk of a tibial plateau fracture [20].

After the tibia is cut, the geometry of the resected bone is compared to the geometry of the tibial implant. Insufficient resection or malrotation can be recognized and corrected.

**Fig. 10** Balancing the knee: first (a) verify anatomic placement of balancing chip in flexion. Bring knee in 10° of flexion (b) and open compartment with valgus or varus stress. If too much opening, increase thickness of balancing chip. Try to avoid using the thinnest chip and verify first if all cartilage of the tibial plateau and osteophytes have been removed, since the thinnest chip removes the most tibial bone stock. Also be careful not to use the D chip, since laxity is most likely an insufficiency of the collateral ligament and will result in overcorrection. After selecting the best thickness of the balancing chip, attach the tibial cutting block including alignment rod and verify varus-valgus alignment and slope (c)



After resecting reminiscent meniscal tissue, removing osteophytes from the posterior condyle, the final preparation of the tibial plateau is completed using the drill bit and the puncher for the tibial keel. On the femoral side, the anterior trough is prepared to create space for the anterior tapered femoral component (Fig. 13). The transition to the posterior condyle is smoothed, and multiple drill holes are placed to allow better cement penetration into the femoral condyle. After trialing, the bony surfaces are washed and the components are cemented, starting with the tibia. Mixing the bone cement under vacuum increases the fatigue properties [21]. Both the implants and bony surfaces should be covered with bone cement, and a small suction tip is used to apply a vacuum to the bone [22]. It has been shown that a cement mantle of more than 3 mm improves the fixation and shear strength of the bond but should be less than 5 mm to avoid

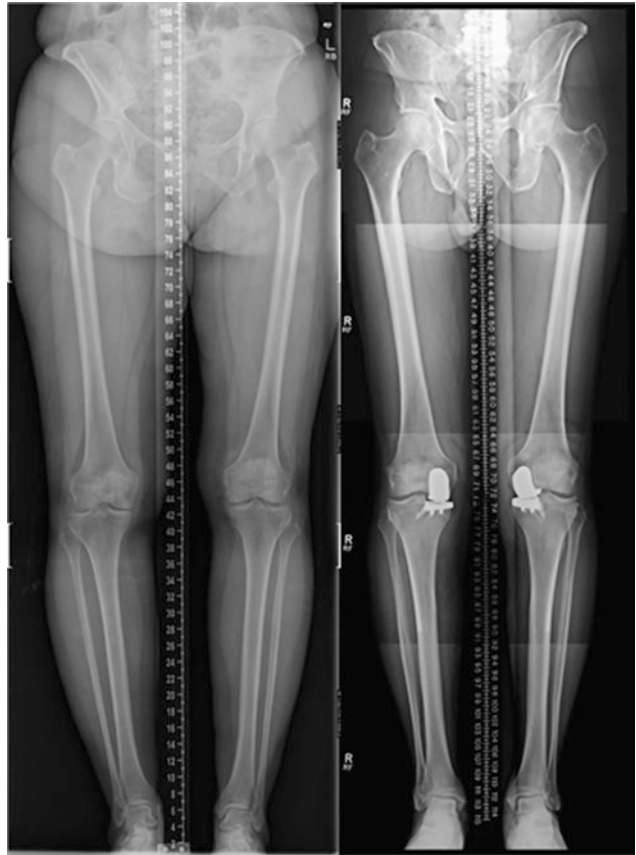
thermal necrosis [23]. Medium viscosity cement achieves deeper bone penetration than high-viscosity bone cement [24]. Using a trial insert will allow access to any posterior extruded cement. Others prefer to insert the original PE before cementing the femoral component (Fig. 14). Wound closure is performed in standard fashion and most surgeons prefer periarticular injections prior to closure.

## Results

Radiographs demonstrate good fit of the components for medial or lateral UKA and BKA in both planes (Figs. 15, 16, 17, and 18). In a prospective multicenter study of 120 patients (110 medial and 10 lateral), 118 UKA patients improved from baseline scores across all collected scores: average KSS, KSS function, scaled



**Fig. 11** Overcorrection of deformity should be avoided for medial OA



WOMAC, and VAS pain scores. At the 2-year follow-up, 99 % reported satisfaction and 89 % reported that the movement of their knee felt natural, and scores compared favorably to published scores of OTS UKA [25].

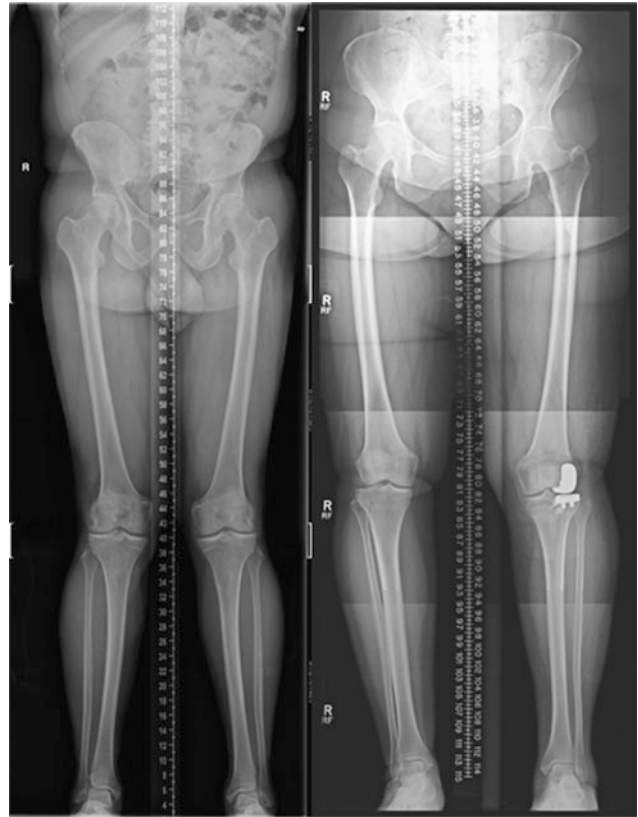
Early results of lateral custom UKA are encouraging: In a prospective comparison between 33 custom UKA and 20 OTS UKA, survivorship was 97 % for the custom UKA with a mean follow-up of 37 months versus 85 % with a mean of 32 months in the OTS UKA group [26] on the lateral side.

Early results of custom bicompartamental knee arthroplasty are also encouraging and do not reproduce the reported early high failure rates of OTS bicompartamental knee replacements (BKA) [27, 28]. Thirty-one patients with 34 bicompartamental osteoarthritis were treated

with 26 medial and 8 lateral custom BKA and prospectively followed. Patient satisfaction, pain assessment, and survival analysis were conducted with a mean of 30-month follow-up. There were no revisions; 91 % rated their results good or excellent and 97 % indicated that they would have the surgery again.

One study compared the knee kinematics during walking between custom bicompartamental knee replacement (BKA to TKA and healthy controls). There were no significant differences in walking speed, peak knee extensor moment, peak knee power absorption, and knee peak knee power production between custom BKA and healthy controls. TKR showed slower walking speed, less peak knee extensor moment, and less peak knee power absorption and production [29].

**Fig. 12** Slight under-correction is recommended for a lateral UKA



**Fig. 13** Final preparation of tibial and femoral condyle. An anterior trough is created to gain space for the anterior tapered design of the femoral component

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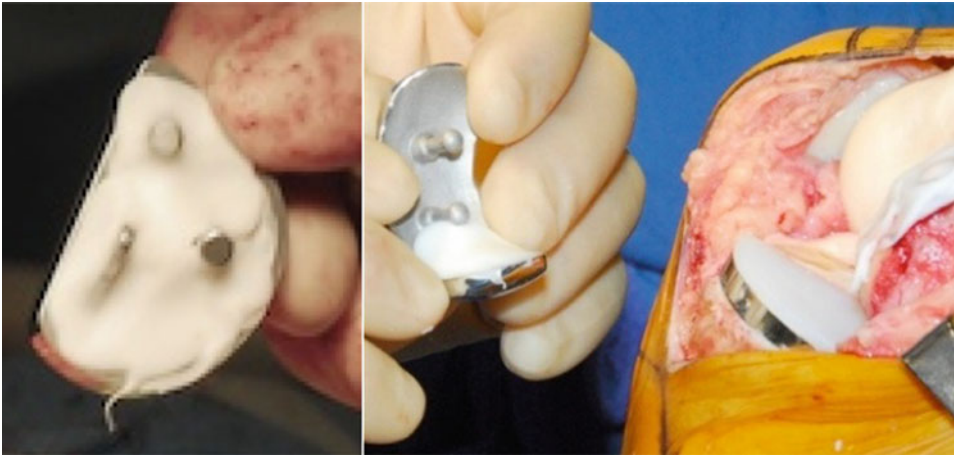
## Postoperative Rehabilitation

Perioperative multimodal pain management in combination with periarticular infiltration of local anesthetics can facilitate a quick recovery with good pain control. In general, patients are allowed to bear weight as tolerated and to walk with an assistive device within the first day. Rehabilitation is less painful and quicker than with TKR.

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## Summary

Custom uni- or bicompartamental knee replacements offer an attractive alternative to OTS implants using a minimal medial or lateral approach to the knee. Given the increased numbers of patients in need of joint replacement,



**Fig. 14** Cementing of components

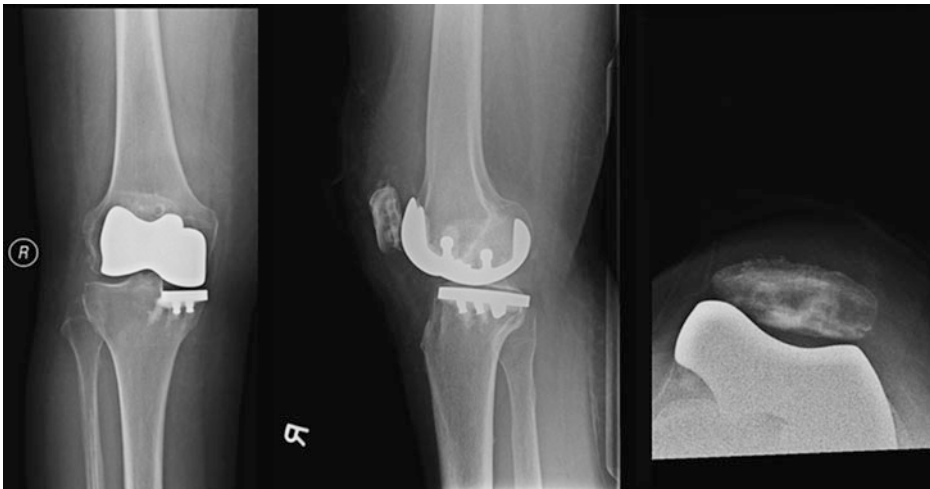
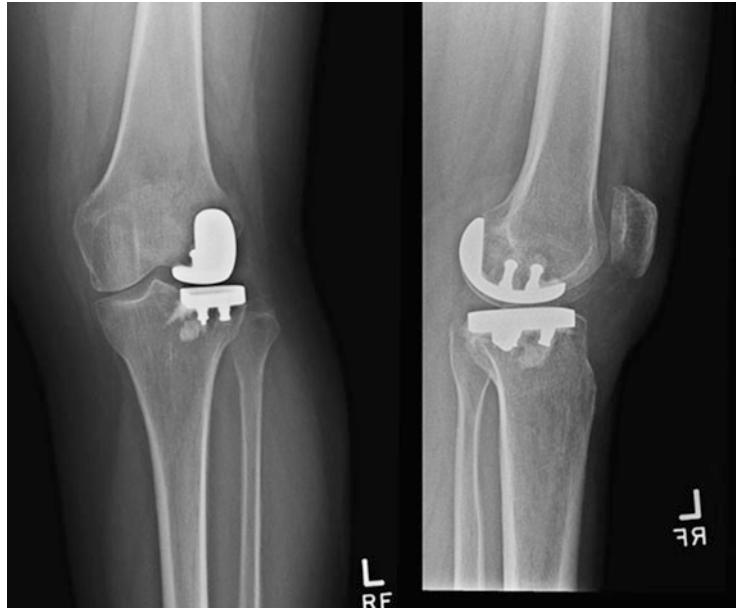
**Fig. 15** AP and lateral view of a medial UKA with slight under-correction



UKA is an important treatment with clinical results that are similar to those of TKA at 10 and 15 years. Custom UKA and BKA offer a bone-sparing alternative along with preservation of both cruciate ligaments. It is feasible to consider UKA and BKA as the first prosthetic treatment for osteoarthritis in middle-aged patients. Custom partial knee replacements

address the anatomic differences between the medial and lateral tibiofemoral geometries and have been a helpful addition to surgeon's armamentarium in the last decade. Long-term studies are needed to demonstrate that custom anatomic implants outpace the results of OTS UKA implants, which are designed exclusively for the medial tibiofemoral joint.

**Fig. 16** Radiographic example of a lateral UKA demonstrating good fit and under-correction



**Fig. 17** Medial custom BKA with good patella tracking





**Fig. 18** Lateral custom BKA with good patella tracking

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