Unicompartmental Knee Arthroplasty
US and Global Perspectives

David A. Crawford, MD[a,*], Keith R. Berend, MD[a],
Emmanuel Thienpont, MD, MBA, PhD[b]

KEYWORDS
• Unicondylar • Unicompartmental • Knee arthroplasty • Global • Survival

KEY POINTS

- With expanded indications, UKA can be considered in young, active, and obese patients.
- UKA has shown to have improved knee range of motion, kinematics, functional recovery, and decreased medical complications compared with TKA.
- UKA has higher rates of revision and decreased survivorship compared with TKA, which may be due to a lower surgeon threshold for revision of a painful UKA than TKA.
- With current implants, there is no significant difference in function or survival between mobile or fixed-bearing implants, nor between cemented and cementless.
- Aseptic loosening is the most common early indication for revision of UKA, whereas arthritic progression is the most common mid- to late-term indication.

INTRODUCTION

Debate continues regarding the optimal surgical treatment for isolated medial compartment osteoarthritis (OA) of the knee. Although high tibial osteotomy is an option, most patients are treated with either a unicompartmental knee arthroplasty (UKA) or total knee arthroplasty (TKA). UKA has been around since the 1950s; however, initial designs were fraught with complications.[1] As component designs and instrumentation have evolved, the survivorship of UKA improved greatly.[2–5] UKA has many advantages over TKA, including improved knee kinematics, range of motions, and functional outcomes.[6–10] Furthermore, medical complications with UKA are significantly less than TKA.[11–13]

US and global use of UKA has varied over the years. In the United States, there was a steady increase in UKA use from 2002 to 2008, after which there has been a decline.[14] Data from the 2018 Australian National Joint Replacement Registry demonstrate that partial knee replacement represented 8.6% of primary knee arthroplasties in 2017, which was down from 16.9% in 2003.[15] A similar incidence of use of UKA in 2017 was reported from the National Joint Registry of England and Wales (NJREW) at 8.9%, which has remained consistent over the past decade.[16] UKA is not performed by all arthroplasty surgeons, and a small percentage of surgeons perform most procedures.[17] Surgeons tend to be pretty rigid on their impression of UKA, with a handful of zealots as well as vocal detractors. This article presents US and global perspective on UKA.

INDICATIONS FOR MEDIAL UNICOMPARTMENTAL KNEE ARTHROPLASTY

The classic restrictive inclusion criteria of Kozinn and Soctt[18] have been greatly expanded with modern research demonstrating successful outcomes with UKA in younger patients,[19] obese patients,[12] patients with patellofemoral

[a] JIS Orthopedics, 7277 Smith's Mill Road, Suite 200, New Albany, OH 43054, USA; [b] Cliniques universitaires Saint Luc, Avenue Hippocrate 10, Brussels 1200, Belgium
* Corresponding author.
E-mail address: crawfordda@joint-surgeons.com

Orthop Clin N Am ■ (2019) ■–■
https://doi.org/10.1016/j.ocl.2019.11.010

disease,[20] and those who are very active.[21] However, proper patient selection is still vital to ensuring a successful outcome with UKA. Medial UKA could be considered in all patients with anteromedial OA (**Fig. 1**) with correctable deformity (**Fig. 2**), intact knee ligaments, and preserved knee range of motion with less than 15° flexion contracture.

UKA should be avoided in patients with inflammatory arthropathy and used cautiously in those who have previously undergone a high tibial osteotomy. Patients should have full thickness cartilage loss and/or avascular necrosis, because those with partial thickness loss have inconsistent pain relief and 6 times higher revision rate.[22] Studies have estimated that between 25% and 48% of patients presenting with knee OA are candidates for UKA.[23,24]

UNICOMPARTMENTAL KNEE ARTHROPLASTY VERSUS TOTAL KNEE ARTHROPLASTY: FUNCTION

Although TKA achieves excellent outcomes on a range of measures, there remains a portion of patients who are not completely satisfied with their outcome and suffer continued impaired functional activity[25] and persistent postsurgical pain.[26,27] In a multicenter study, Nam and colleagues[26] reported that, although 90% of patients after TKA had overall satisfaction with the functioning of their knee, only 66% felt that their knee was "normal," with nearly half conveying residual symptoms and functional problems. The persistence of symptoms lends itself for other implant concepts that can improve functional outcomes with a more normal feeling knee.

Fig. 1. Computed tomography scan demonstrating anteromedial osteoarthritis.

UKA allows for more closely matched knee kinematics of the native knee due to its cruciate-preserving nature, and its intact contralateral compartment and patellofemoral anatomy.[6–8] This results in a more normal gait, as well as reduced perioperative trauma, greater range of motion, and faster rehabilitation.[9,10] In a series of 23 patients with a UKA in 1 knee and a TKA in the contralateral knee, patients more often reported the UKA as feeling normal.[28] In a 10-year minimum propensity matched analysis of 519 UKA to 519 TKA, Burn and colleagues[29] found that UKA was associated with better Oxford Knee Scores and EQ-5D. UKA was also associated with an increased likelihood of successful outcome and chance of obtaining minimally clinically important improvements in Oxford Knee Scores and EQ-5D.

UNICOMPARTMENTAL KNEE ARTHROPLASTY VERSUS TOTAL KNEE ARTHROPLASTY: PERIOPERATIVE COMPLICATIONS

UKA is a less-invasive procedure than TKA, and as such the risk profiles of these surgeries differ as shown in both US and global research publications. In a 2:1 matched cohort study of obese patients undergoing TKA versus UKA in the United States, the UKA cohort had significantly less blood loss ($P = .004$) as well as a lower infection rate (0% vs 0.5%, $P = .016$). Furthermore, the risk of manipulation was significantly higher in the TKA group (6.5%) compared with the UKA group (0.5%) ($P<.001$).[12] Another US study by Hansen and colleagues[13] compared complications and outcomes between UKA and TKA by analyzing a 5% Medicare sample from 2004 to 2012. Compared with TKA, UKA was found to have significantly lower wound complications, pulmonary embolisms, infection, myocardial infarction, readmission, and death.

In analysis of the NJREW, Liddle and colleagues[30] found that the average length of stay, rate of medical complications, such as thromboembolism, myocardial infarction, stroke, and rate of readmission, were all higher for TKA than for UKA. Furthermore, 30-day and 8-year mortality was lower with UKA than with TKA, at hazard ratios of 0.23 and 0.85. Hunt and colleagues,[31] in an analysis of 467,779 primary knee replacements from the same registry, found that UKA was associated with substantially lower 45-day mortality than

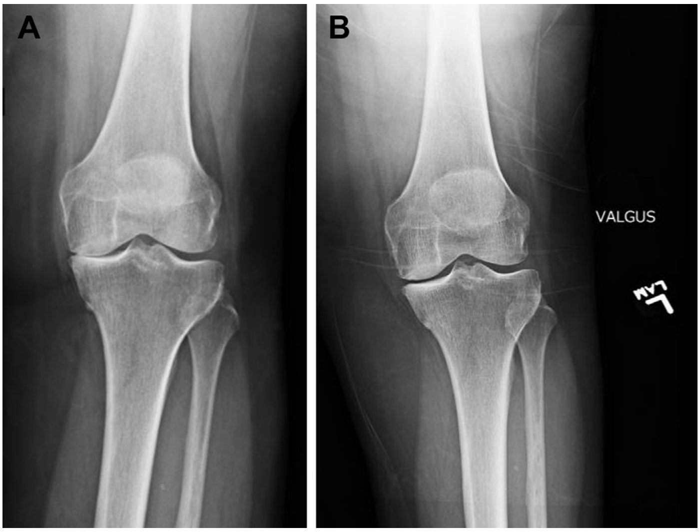

Fig. 2. (*A*) Standing anteroposterior radiograph demonstrating medial joint space loss. (*B*) Valgus stress radiograph demonstrating correctable alignment and preservation of lateral joint space.

TKA, at a hazard ratio 0.32 ($P<.0005$). There is global consensus, by way of studies out of India, England, Canada, and the United States, that UKA has a shorter length of stay and decreased rate of readmission compared with TKA.[13,31–33]

UNICOMPARTMENTAL KNEE ARTHROPLASTY VERSUS TOTAL KNEE ARTHROPLASTY: SURVIVAL

Surgeons must balance the improved function and lower medical complications of UKA with the consistently reported lower survival compared with TKA. For example, the Australian Orthopedic Association National Joint Replacement Registry report found the 10-year survival rates with TKA and UKA in primary OA were 94.4% and 84.7%, respectively.[15] This disparity is also reflected in the NJREW and Swedish Knee Arthroplasty Register annual reports.[16,34] The 15th annual NJR report noted that the 14-year cumulative revision rate for TKA was 6%, whereas that for UKA was 16.9%.[16] In a study evaluating the survivorship of UKA versus TKA over an 8-year period in US Medicare patients, Hansen and colleagues[13] reported the 7-year survivorship of UKA to be 80.9% versus 95.7% for TKA. A systematic review of cumulative data from 6 national registries and clinical studies found that the overall 10-year revision rate for TKA was 6.2% compared with 16.5% for UKA.[35] Liddle and colleagues[36] used propensity matching to adjust for confounding baseline patient demographics to compare 25,334 UKAs and 75,996 TKAs from the NJREW. At 8-year follow-up they found that UKA had worse implant survival in terms of both revision and revision/reoperation than TKA.

Some have suggested that the discrepancy in revision rates between UKA and TKA may be due a lower surgeon threshold to revise a painful UKA. In their analysis of the New Zealand Joint Registry, which includes outcome data, Goodfellow and colleagues[37] found a significantly greater percentage of patients reporting good or excellent results after UKA than TKA and fewer patients reporting poor or fair outcomes. Although both groups had an increase in revision rates with lower outcome scores, patients with UKA had a 6 times greater revision rate than those with TKA for the same score category of Oxford Knee Score of less than 20. Analysis of the Norwegian Arthroplasty Register found that UKA is more than 11 times more likely to be revised for pain than TKA, at a relative risk of 11.3 ($P<.001$).[38]

Ultimately, the choice between UKA and TKA according to available literature is still a choice between function and survivorship.[39] Better preoperative analysis of the patient's disease process leading to arthritis progression,[39] and better understanding of pain after knee arthroplasty[40] could reduce the number of necessary revisions to TKA.

CEMENTED VERSUS CEMENTLESS UNICOMPARTMENTAL KNEE ARTHROPLASTY

Although most UKA designs use cemented fixation,[41] the minimally invasive nature of the procedure can make the insertion and extrusion of cement challenging.[41–43] Cementation errors can lead to failure of fixation and aseptic loosening, which is the leading cause of revisions in UKA.[2,42,44,45] Extruded cement can break off and become a loose body creating third body wear on both the replaced surface as well as normal articular cartilage in the unresurfaced portions of the knee. Cementless UKA could be a way of reducing these failures and achieving more durable long-term fixation. Cementless UKA has consequently become increasingly popular in recent years.[42]

Early data from the Finish Arthroplasty Registry found that the 5-year survival of the cementless Oxford UKA was 92.3% compared with 88.9% for the cemented Oxford UKA.[46] In the 2018 NJREW report, cementless UKA knees had a slightly higher 10-year survival at 87.3% comparted with cemented knees at 85.1%.[16] In a comparison of cemented versus cementless Oxford Partial Knee, Pandit and colleagues[44] found significantly more radiolucencies in the cemented group at 20/30 knees versus 2/27 knees in the cementless ($P<.001$). Furthermore, there were 9 complete radiolucencies in cemented knees, as opposed to none in the cementless group ($P = .01$) [Pandit].[44] These findings were further supported by Kendrick and colleagues,[47] who noted significantly less tibial radiolucencies in cementless UKA compared with cemented UKA at 2 years ($P = .02$).

Some rare complications have been reported for cementless UKA, including early subsidence of the tibial component into a valgus position.[48] A cadaveric study has also suggested that cementless implants may be more susceptible to periprosthetic tibial plateau fracture (PTPF) [Seeger],[49] although this may be due to implantation errors known to dispose toward PTPF, such as a deep posterior cortical cut in the tibia and perforating the posterior cortex perforation during keel preparation.[42] Overall, cementless UKA is a promising technology, although more research is required and cemented fixation remains the gold standard.

FIXED VERSUS MOBILE UNICOMPARTMENTAL KNEE ARTHROPLASTY

Fixed bearing (FB) (Fig. 3) and mobile bearing (MB) (Fig. 4) are the 2 main design concepts in UKA.[50–52] Although the theoretic advantages of MB prostheses over FB designs have made it increasingly popular,[53] advances in polyethene manufacturing have significantly decreased the wear in the FB design.[54] With polyethene wear no longer a major issue with FB designs, the

Fig. 3. Radiograph of a fixed-bearing medial UKA.

Fig. 4. Radiograph of a mobile-bearing medial UKA.

choice of design for UKA therefore remains controversial.[55]

Several meta-analyses have compared FB with MB designs. Peersman and colleagues[56] reviewed 44 comparative and noncomparative studies, involving 9463 knees. After stratification by age and follow-up time, there were no major differences in survival rates between FB and MB implants. However, the mean time to revision was shorter for MB knees, at 2.5 ± 1.8 years and 6.7 ± 2.5 years, respectively ($P<.001$).[56] In another meta-analysis comparing FB and MB UKA, Cheng and colleagues[53] examined 9 studies, involving 915 knees. They also found no significant differences between the implants in terms of clinical outcome scores, range of motion, or revision rates. Similar to Peersman and colleagues,[56] they found the time to revision was significantly sooner in MB (5.0 vs 6.3 years for FB implants, $P = .016$), with early failures in MB patients due to bearing dislocations; later failures in the FB group were more commonly due to polyethylene wear. Smith and colleagues[52] identified 5 studies comparing FB and MB implants for medial and lateral UKA, involving a total of 165 and 159 knees, respectively. There were no significant differences between the implant types in medical UKA in terms of clinical outcome, and no differences in complication rates.

In summary, any decision between FB and MB designs in UKA is hampered by a lack of robust and well-designed studies, and an evidence base limited to observational studies and small, randomized controlled trials. Nevertheless, it seems that there are no major differences between the 2 implant types.

FAILURE ANALYSIS OF UNICOMPARTMENTAL KNEE ARTHROPLASTY

Aseptic Loosening

The most common cause of early UKA failure is aseptic loosening, representing 28% to 59.2% of all UKA revisions.[2,57–59] This trend has been shown in multiple international registries, including Sweden, England/Wales, Australia, and Italy,[57–59] along with US institutional case series.[60–62] However, the overall incidence of aseptic loosening in large reports is low with rates reported between 1.5% and 2.7% in mid-term follow-up.[57,63] There are specific UKA designs that have much higher reported incidences of aseptic loosening. In a randomized trial between all-polyethylene and metal-backed tibial trays, the all-polyethylene design had a 37% incidence of aseptic loosening.[64] This may be attributed to the more focal tibial loading seen in these designs.[65] Surgeons must be cautious of interpreting all radiolucencies as aseptic loosening, which is discussed below.

Arthritic Progression

With appropriately selected patients and proper surgical technique, the risk of arthritic progression following UKA (Fig. 5) is low. At minimum 10-year follow-up, Emerson and colleagues[66] found an incidence of 4.2% for revision due to lateral progression. Progression of arthritis, however, is the most common reason for mid-term (5–10 year) and long-term (>10 year) failure in UKA.[2] In a meta-analysis Van der List and colleagues[2] showed that 40% of revisions at greater

Fig. 5. Radiograph demonstrating lateral arthritic disease progression.

than 10 years were for progression of arthritis. In the Australian Orthopedic Association National Joint Replacement Registry, 43.7% of UKA failures were for disease progression.[15] The NJREW 2018 report noted that 32.3% of UKA revisions were for arthritic progression.[16] The most significant predictor of progression of OA is the arthritic grade of the lateral compartment at the time of surgery.[44] This emphasizes the importance of proper patient selection. If full thickness lateral disease is identified intraoperatively, TKA should be performed instead of UKA.

Pain

Residual medial tibial pain can persist for up to 1-year after UKA. More chronic persistent pain is the cause of 8% of early failures and 10% of late failures after UKA.[2] Even in well-aligned UKA, the proximal medial tibial stress is increased up to 50% of the native bone.[67] Surgeons should be cautious about revising a UKA for unexplained pain because results are significantly worse than when a cause of pain can be identified.[68]

Radiolucent Lines

Radiolucencies can be an indication of component loosening; however, "physiologic" tibial radiolucencies (Fig. 6) are well-defined, nonprogressive radiolucencies that can be seen in up to 62% of UKA with the Oxford UKA.[69,70] These physiologic radiolucencies do not correlate with clinical outcome or component failure.[70] Surgeons who are relatively unfamiliar with radiolucencies may attribute medial knee pain to the presence of a radiolucent line, and convert the UKA to a TKA for aseptic loosening. This is often unnecessary, as a fine, well-defined radiolucent line may be present at the bone-cement interface even in well-functioning cemented UKAs.[71]

Other Failure Modes

Bearing dislocation is a unique complication to the MB designs, with incidence reported between 2% and 3%.[37,72] The cause of bearing dislocation is multifactorial, but advances in the Oxford instrumentation have reduced the risk.[73] It is critical to ensure there is no remaining posterior femoral osteophyte at the time of surgery, which can lead to impingement of the bearing resulting in anterior dislocation. If components are properly aligned, bearing often dislocation can be managed by removing any impingement and replacing a new bearing.

Medial tibia collapse (Fig. 7) or fracture is a rare complication after UKA, representing only

Fig. 6. Radiograph demonstrating physiologic tibial radiolucencies.

Fig. 7. Radiograph demonstrating medial tibial collapse.

2% of revisions for failed UKA.[2] These fractures can be related to component alignment as well as surgical technique. Coronal alignment in greater than 6° of varus or any valgus alignment significantly increases the load to the proximal medial tibia.[74] Treatment of these fractures can include open reduction internal fixation or revision to a TKA depending on the stability of component and size of the fracture.

Periprosthetic joint infection (PJI) after UKA is quite uncommon, with incidence reported between 0% and 1%.[5,57,75] Furthermore, PJI after UKA is significantly lower than TKA.[76] Unlike in a TKA, however, with a PJI in an UKA there is native cartilage remaining. Therefore, in these cases of chronic PJI after UKA, a 1- or 2-stage revision to a TKA should be performed to remove the damaged native cartilage from the infection.

REVISION OF UNICOMPARTMENTAL KNEE ARTHROPLASTY TO TOTAL KNEE ARTHROPLASTY

Revision of UKA to TKA (Uni to Total) has been stated to be a relatively easy procedure and might offer advantages over revision of primary TKA.[77,78] However, revision of UKA to TKA are typically more challenging than a primary TKA and approximately 50% of patients will have significant bone defects, and stemmed implants and/or augments are required in 33% of cases.[77–81] The mode by which the UKA fails influences the complexity of the revision,[60] but most UKA revisions can be successfully completed using primary components (**Fig. 8**).[82] Revision for tibial collapse poses the highest complexity (**Fig. 9**) as these cases will more frequently require augments and constraint.[60,82]

Using data from the New Zealand Joint Registry from 1999 to 2008, Pearse and colleagues[83] examined 4284 UKAs, of which 236 required revision, and compared those revisions with 34,369 primary TKAs. The authors found that the revision rate for Uni to Total was 4 times higher than that for primary TKA, at rates of 1.97 and 0.48 per 100 component years, respectively ($P<.05$). The mean Oxford Knee Score was also significantly worse in the Uni to Total group than in the primary TKA group, at 30.02 versus 37.16 ($P<.01$).[83] Contrary to these findings, Lombardi and colleagues[78] reported on 184 UKA to TKA revisions. At 6-year minimum follow-up, 4.1% of knees required re-revision. This rate was similar to the institution's revision rate of primary TKA's and much lower than their re-revision rate of failed TKA. The mean Knee Society Clinical score in the UKA to TKA revision group was 83.4.

UNICOMPARTMENTAL KNEE ARTHROPLASTY OUTCOME RELATED TO HOSPITAL AND SURGEON VOLUME

If surgeons choose to perform UKA, this should be a dedicated portion of their practice because surgeon experience influences the risk of failures. Liddle and colleagues[84] found that the revision rate following UKA dropped steeply until the annual volume reached 10 cases and plateaued at 30 cases per year. Furthermore, they found that case load more strongly affected risk of revision in UKA than TKA, indicating that UKA is possibly a more technically demanding surgery. Baker and colleagues[17] suggested that 13 surgeries per year should be the minimum threshold for performing UKA in their registry analysis of 23,400 UKAs from the New Zealand Registry and NJREW. Data from the Norwegian Arthroplasty Register suggest that the risk of UKA revision is lower in hospitals that perform more than 40 procedures a year than in those that carry out less than 10 per year, at a risk ratio adjusted for age, diagnosis, and sex of 0.59 ($P = .01$). The main reasons for

Fig. 8. Postoperative radiograph with primary components after a revision to a TKA from a previous UKA.

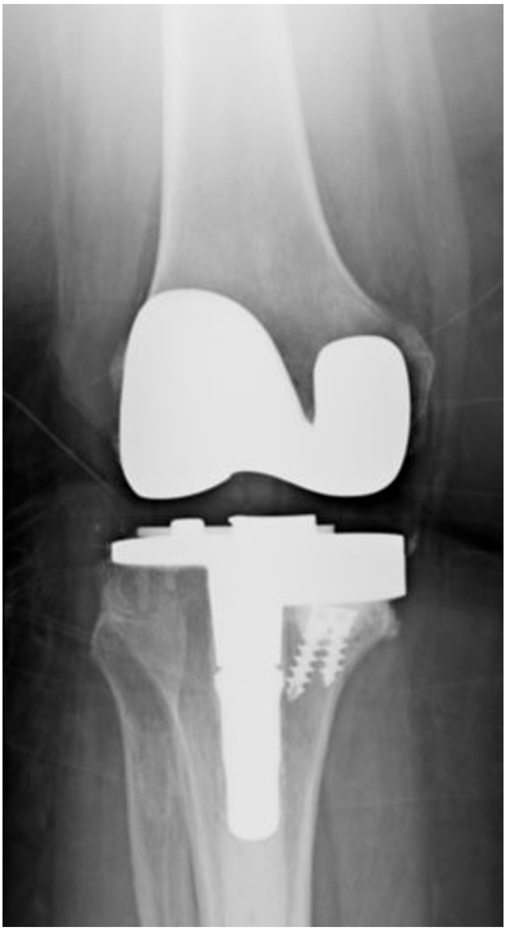

Fig. 9. Postoperative radiograph after revision for a failed UKA due to medial collapse that required a tibial augment and stem.

failure in low-volume hospitals are dislocation, instability, malalignment, and fractures.[85]

Because it might be difficult for surgeons to increase the referrals to their practice, 1 option to increase UKA volume is to more closely evaluate the indications for UKA as noted previously.[36]

COMPONENT POSITIONING AND ENABLING TECHNOLOGY

Correct component positioning is critical to the success and survival of UKA.[74,86] For example, lowering the medial joint space greater than 2 mm compared with the lateral joint space has been associated with more tibial aseptic loosening.[86] In MB designs, studies have found increased rates of bearing dislocation associated with excessive varus or valgus positioning of the tibial component, elevation of the medial joint, inadequate posterior slope, and internal rotation of the tibial component.[87] Excessive varus alignment decreases the contact area of the femoral component on the tibia, thus increasing contact stress and potentially leading to increased wear.[88] Malpositioning errors are more commonly seen in low-volume surgeons[85,89] and during the learning curve of the procedure.[90] Technologies to improve alignment accuracy may therefore benefit UKA even more than they have done for TKA.[91] Current enabling technologies for UKA include patient-specific instruments (PSI), computer navigation and robotic-assisted surgery.

PSI involves the manufacturing of instruments based on computed tomography or MRI to match the individual patient's anatomy. PSI has been shown in some studies to enhance implant alignment,[92,93] which should, theoretically, improve surgical outcomes and reduce the risk of revision. In a sawbones model, PSI technology allowed inexperienced trainee surgeons to have equivalent tibial saw cuts as high-volume experienced surgeons.[94]

Computer navigation can further enhance the accuracy of component positioning with a significant reduction in outliers.[95–98] Suda and colleagues[95] found 100% accuracy within 3° of target alignment with the use of an accelerometer-based portable navigation system, compared with 76.5% coronal and 88.2% sagittal accuracy with conventional instruments. At 5-year minimum follow-up, Chowdhry and colleagues[99] reported a 97.6% survival rate of 252 UKA performed with computer navigation. This survival rate rivals that of TKA.

Robotic technology has been at the forefront of debate in arthroplasty for the past few years. One challenge with interpreting the literature on robotic-assisted UKA is that many of the studies are funded by industry with design surgeons writing the articles.[100] Although there is little argument whether robotics improves component positioning,[92,101–103] the question remains whether this technology improves patient outcomes to justify the cost. As discussed throughout this paper, component positioning is likely more critical to the survival of UKA compared with TKA, and thus this procedure may benefit more greatly from the increased accuracy. With robotics, the surgeon receives continuous, real-time feedback on knee kinematics, range of motion, and implant placement during the procedure with extremely accurate bony resection. In a matched prospective cohort study of robotic assisted versus conventional instrumentation, Kayani and colleagues[104] found that the robotic-arm assisted group had significantly reduced postoperative pain, decreased opiate requirements, shorter time to straight leg raise, decreased therapy sessions, and reduced hospital stay. These early clinical improvements may be related to decreased periarticular soft tissue damage from confines of the stereotactic boundaries with robotic-assisted UKA. At present, however, there have been no studies to show that robotic-assisted improves UKA mid- to long-term UKA survivorship.[103,105] However, robotic technology offers lower-volume surgeons to achieve high levels of accuracy with implant positioning.

DISCLOSURES

Dr K.R. Berend is a paid consultant for Zimmer Biomet, has minority interest in SPR Therapeutics, Elutibone, Joint Development Corporation. Dr E. Thienpont is a paid consultant for ConvaTec, KCI, Lima, Medacta, and Zimmer Biomet, and receives royalties from Zimmer Biomet.

REFERENCES

1. Kurtz SM. The origins and adaptations of UHMWPE for knee replacement, biomaterials handbook. New York: Marcel Dekker; 1995. Chapter 7.
2. Van der List JP, McDonald LS, Pearle AD. Systematic review of medial versus lateral survivorship in unicompartmental knee arthroplasty. Knee 2015;22(6):454–60.
3. 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.
4. Murray DW, Goodfellow JW, O'Connor JJ. The Oxford medial unicompartmental arthroplasty: a ten-year survival study. J Bone Joint Surg Br 1998;80(6):983–9.
5. Berger RA, Meneghini RM, Jacobs JJ, et al. Results of unicompartmental knee arthroplasty at a minimum of ten years of follow-up. J Bone Joint Surg Am 2005;87(5):999–1006.
6. Akizuki S, Mueller JK, Horiuchi H, et al. In vivo determination of kinematics for subjects having a Zimmer unicompartmental high flex knee system. J Arthroplasty 2009;24:963–71.
7. Heyse TJ, El-Zayat BF, De Corte R, et al. UKA closely preserves natural knee kinematics in vitro. Knee Surg Sports Traumatol Arthrosc 2014;22:1902–10.
8. Jenny JY, Boeri C. Unicompartmental knee prosthesis implantation with a non-image-based navigation system: rationale, technique, case-control comparative study with a conventional instrumented implantation. Knee Surg Sports Traumatol Arthrosc 2003;11:40–5.
9. Engh GA. Orthopaedic crossfire—can we justify unicondylar arthroplasty as a temporizing procedure? in the affirmative. J Arthroplasty 2002;17:54–5.
10. Robertsson O, Borgquist L, Knutson K, et al. Use of unicompartmental instead of tricompartmental prostheses for unicompartmental arthrosis in the knee is a cost-effective alternative. 15,437 primary tricompartmental prostheses were compared with 10,624 primary medial or lateral unicompartmental prostheses. Acta Orthop Scand 1999;70:170–5.
11. Finkelstein EA, Khavjou OA, Thompson H, et al. Obesity and severe obesity forecasts through 2030. Am J Prev Med 2012;42(6):563–70.
12. Lum ZC, Crawford DA, Lombardi AV Jr, et al. Early comparative outcomes of unicompartmental and total knee arthroplasty in severely obese patients. Knee 2018;25(1):161–6.
13. Hansen EN, Ong KL, Lau E, et al. Unicondylar knee arthroplasty has fewer complications but higher revision rates than total knee arthroplasty in a study of large United States databases. J Arthroplasty 2019;34(8):1617–25.
14. Hansen EN, Ong KL, Lau E, et al. Unicondylar knee arthroplasty in the U.S. patient population: prevalence and epidemiology. Am J Orthop (Belle Mead NJ) 2018;47(12). https://doi.org/10.12788/ajo.2018.0113.
15. Australian Orthopaedic Association National Joint Replacement Registry, annual report. Available at: https://aoanjrr.sahmri.com/.
16. National Joint Registry for England, Wales and Northern Ireland. 15th annual report. Hemel Hempstead (England): NJR; 2018.
17. Baker P, Jameson S, Critchley R, et al. 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 2013;95(8):702–9.
18. Kozinn SC, Scott R. Unicondylar knee arthroplasty. J Bone Joint Surg Am 1989;71:145–50.
19. Greco NJ, Lombardi AV Jr, Price AJ, et al. Medial mobile-bearing unicompartmental knee arthroplasty in young patients aged less than or equal to 50 years. J Arthroplasty 2018;33(8):2435–9.
20. Berend KR, Lombardi AV Jr, Morris MJ, et al. Does preoperative patellofemoral joint state affect medial unicompartmental arthroplasty survival? Orthopedics 2011;34(9):e494–6.
21. Crawford DA, Adams JB, Lombardi AV Jr, et al. Activity level does not affect survivorship of unicondylar knee arthroplasty at 5-year minimum follow-up. J Arthroplasty 2019;34(7):1364–8.
22. Maier MW, Kuhs F, Streit MR, et al. Unicompartmental knee arthroplasty in patients with full

versus partial thickness cartilage loss (PTCL): equal in clinical outcome but with higher reoperation rate for patients with PTCL. Arch Orthop Trauma Surg 2015;135(8):1169–75.
23. Shakespeare D, Jeffcote B. Unicondylar arthroplasty of the knee—cheap at half the price? Knee 2003;10:357–61.
24. Willis-Owen CA, Brust K, Alsop H, et al. Unicondylar knee arthroplasty in the UK National Health Service: an analysis of candidacy, outcome and cost efficacy. Knee 2009;16:473–8.
25. Noble PC, Gordon MJ, Weiss JM, et al. Does total knee replacement restore normal knee function? Clin Orthop Relat Res 2005;(431):157–65.
26. Nam D, Nunley RM, Barrack RL. Patient dissatisfaction following total knee replacement: a growing concern? Bone Joint J 2014;96-B:96–100.
27. Nashi N, Hong CC, Krishna L. Residual knee pain and functional outcome following total knee arthroplasty in osteoarthritic patients. Knee Surg Sports Traumatol Arthrosc 2015;23:1841–7.
28. Laurencin CT, Zelicof SB, Scott RD, et al. Unicompartmental versus total knee arthroplasty in the same patient: a comparative study. Clin Orthop Relat Res 1991;273:151–6.
29. Burn E, Sanchez-Santos MT, Pandit HG, et al. Ten-year patient-reported outcomes following total and minimally invasive unicompartmental knee arthroplasty: a propensity score-matched cohort analysis. Knee Surg Sports Traumatol Arthrosc 2018;26(5):1455–64.
30. Liddle AD, Judge A, Pandit H, et al. Adverse outcomes after total and unicompartmental knee replacement in 101 330 matched patients: a study of data from the National Joint Registry for England and Wales. Lancet 2014;18:1437–45.
31. Hunt LP, Ben-Shlomo Y, Clark EM, et al, National Joint Registry for England and Wales. 45-day mortality after 467,779 knee replacements for osteoarthritis from the National Joint Registry for England and Wales: an observational study. Lancet 2014; 384:1429–36.
32. Kulshrestha V, Datta B, Kumar S, et al. Outcome of unicondylar knee arthroplasty vs total knee arthroplasty for early medial compartment arthritis: a randomized study. J Arthroplasty 2017;32(5): 1460–9.
33. Drager J, Hart A, Khalil JA, et al. Shorter hospital stay and lower 30-day readmission after unicondylar knee arthroplasty compared to total knee arthroplasty. J Arthroplasty 2016;31(2):356–61.
34. Swedish knee arthroplasty register-annual report. Available at: http://www.myknee.se/en/.
35. Labek G, Thaler M, Janda W, et al. Revision rates after total joint replacement: cumulative results from worldwide joint register datasets. J Bone Joint Surg Br 2011;93:293–7.
36. Liddle AD, Pandit H, Judge A, et al. 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:793–801.
37. Goodfellow JW, O'Connor JJ, Murray DW. A critique of revision rate as an outcome measure: re-interpretation of knee joint registry data. J Bone Joint Surg Br 2010;92:1628–31.
38. Furnes O, Espehaug B, Lie S, et al. Failure mechanisms after unicompartmental and tricompartmental primary knee replacement with cement. J Bone Joint Surg Am 2007;89:519–25.
39. Thienpont E, Baldini A. Unicompartmental knee arthroplasty: function versus survivorship, do we have a clue? Knee 2014;S1:S1–2.
40. Grosu I, Lavand'homme P, Thienpont E. Pain after knee arthroplasty: an unresolved issue. Knee Surg Sports Traumatol Arthrosc 2014;22:1744–58.
41. Akan B, Karaguven D, Guclu B, et al. Cemented versus uncemented Oxford unicompartmental knee arthroplasty: is there a difference? Adv Orthop 2013;2013:245915.
42. Liddle AD, Pandit H, Murray DW, et al. Cementless unicondylar knee arthroplasty. Orthop Clin North Am 2013;44:261–9.
43. Baker P, Jameson S, Deehan D, et al. Mid-term equivalent survival of medial and lateral unicondylar knee replacement: an analysis of data from a National Joint Registry. J Bone Joint Surg Br 2012;94:1641–8.
44. Pandit H, Liddle AD, Kendrick BJ, et al. Improved fixation in cementless unicompartmental knee replacement: five-year results of a randomized controlled trial. J Bone Joint Surg Am 2013;95: 1365–72.
45. Pandit HG, Campi S, Hamilton TW, et al. Five-year experience of cementless Oxford unicompartmental knee replacement. Knee Surg Sports Traumatol Arthrosc 2017;25(3):694–702.
46. Knifsund J, Reito A, Haapakoski J, et al. Short-term survival of cementless Oxford unicondylar knee arthroplasty based on the Finnish Arthroplasty Register. Knee 2019;26(3):768–73.
47. Kendrick BJ, Kaptein BL, Valstar ER, et al. Cemented versus cementless Oxford unicompartmental knee arthroplasty using radiostereometric analysis: a randomised controlled trial. Bone Joint J 2015;97-B:185–91.
48. Liddle AD, Pandit HG, Jenkins C, et al. Valgus subsidence of the tibial component in cementless Oxford unicompartmental knee replacement. Bone Joint J 2014;96-B:345–9.
49. Seeger JB, Haas D, Jäger S, et al. Extended sagittal saw cut significantly reduces fracture load in cementless unicompartmental knee

arthroplasty compared to cemented tibia plateaus: an experimental cadaver study. Knee Surg Sports Traumatol Arthrosc 2012;20(6):1087–91.
50. Bonutti P, Dethmers D. Contemporary unicompartmental knee arthroplasty: fixed vs mobile bearing. J Arthroplasty 2008;23:24–7.
51. Emerson RJ, Hansborough T, Reitman R, et al. Comparison of a mobile with a fixed-bearing unicompartmental knee implant. Clin Orthop Relat Res 2002;404:62–70.
52. Smith T, Hing C, Davies L, et al. Fixed versus mobile bearing unicompartmental knee replacement: a meta-analysis. Orthop Traumatol Surg Res 2009;95:599–605.
53. Cheng M, Chen D, Guo Y, et al. Comparison of fixed- and mobile-bearing total knee arthroplasty with a mean five-year follow-up: a meta-analysis. Exp Ther Med 2013;6(1):45–51.
54. Winnock de Grave P, Barbier J, Luyckx T, et al. Outcomes of a fixed-bearing, medial, cemented unicondylar knee arthroplasty design: survival analysis and functional score of 460 cases. J Arthroplasty 2018;33(9):2792–9.
55. Li M, Yao F, Joss B, et al. Mobile vs. fixed bearing unicondylar knee arthroplasty: a randomized study on short term clinical outcomes and knee kinematics. Knee 2006;13:365–70.
56. Peersman G, Stuyts B, Vandenlangenbergh T, et al. Fixed- versus mobile-bearing UKA: a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc 2015;23(11):3296–305.
57. Bordini B, Stea S, Falcioni S, et al. Unicompartmental knee arthroplasty: 11-year experience from 3929 implants in RIPO register. Knee 2014;21:1275–9.
58. Lewold S, Robertsson O, Knutson K, et al. Revision of unicompartmental knee arthroplasty: outcome in 1,135 cases from the Swedish Knee Arthroplasty study. Acta Orthop Scand 1998;69:469–74.
59. Baker PN, Petheram T, Avery PJ, et al. Revision for unexplained pain following unicompartmental and total knee replacement. J Bone Joint Surg Am 2012;94:e126.
60. Berend KR, George J, Lombardi AV Jr. Unicompartmental knee arthroplasty to total knee arthroplasty conversion: assuring a primary outcome. Orthopedics 2009;32(9):684.
61. Sierra RJ, Kassel CA, Wetters NG, et al. Revision of unicompartmental arthroplasty to total knee arthroplasty: not always a slam dunk! J Arthroplasty 2013;28(8 Suppl):128.
62. Fehring TK, Odum SM, Masonis JL, et al. Early failures in unicondylar arthroplasty. Orthopedics 2010;33(1):11.
63. Bergeson AG, Berend KR, Lombardi AV Jr, et al. Medial mobile bearing unicompartmental knee arthroplasty: early survivorship and analysis of failures in 1000 consecutive cases. J Arthroplasty 2013;28(9 Suppl):172–5.
64. Hutt JR, Farhadnia P, Massé V, et al. A randomised trial of all-polyethylene and metal-backed tibial components in unicompartmental arthroplasty of the knee. Bone Joint J 2015;97-B(6):786–92.
65. Small SR, Berend ME, Ritter MA, et al. A comparison in proximal tibial strain between metal-backed and all-polyethylene anatomic graduated component total knee arthroplasty tibial components. J Arthroplasty 2010;25(5):820–5.
66. Emerson RH, Alnachoukati O, Barrington J, et al. 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.
67. Simpson DJ, Price AJ, Gulati A, et al. Elevated proximal tibial strains following unicompartmental knee replacement—a possible cause of pain. Med Eng Phys 2009;31:752–7.
68. Kerens B, Boonen B, Schotanus MG, et al. Revision from unicompartmental to total knee replacement: the clinical outcome depends on reason for revision. Bone Joint J 2013;95-B(9):1204–8.
69. Tibrewal SB, Grant KA, Goodfellow JW. The radiolucent line beneath the tibial components of the Oxford meniscal knee. J Bone Joint Surg Br 1984;66-B:523–8.
70. Voss F, Sheinkop MB, Galante JO, et al. Miller-Galante unicompartmental knee arthroplasty at 2- to 5-year follow-up evaluations. J Arthroplasty 1995;10:764–71.
71. Ecker ML, Lotke PA, Windsor RE, et al. Long-term results after total condylar knee arthroplasty. Significance of radiolucent lines. Clin Orthop Relat Res 1987;(216):151–8.
72. Kim SJ, Postigo R, Koo S, et al. Causes of revision following Oxford phase 3 unicompartmental knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2014;22:1895–901.
73. Koh IJ, Kim JH, Jang SW, et al. Are the Oxford(®) medial unicompartmental knee arthroplasty new instruments reducing the bearing dislocation risk while improving components relationships? A case control study. Orthop Traumatol Surg Res 2016;102(2):183–7.
74. Innocenti B, Pianigiani S, Ramundo G, et al. Biomechanical effects of different varus and valgus alignments in medial unicompartmental knee arthroplasty. J Arthroplasty 2016;31(12):2685–91.
75. Epinette JA, Brunschweiler B, Mertl P, et al. Unicompartmental knee arthroplasty modes of

failure: wear is not the main reason for failure: a multicentre study of 418 failed knees. Orthop Traumatol Surg Res 2012;98:S124–30.
76. Bolognesi MP, Greiner MA, Attarian DE, et al. Unicompartmental knee arthroplasty and total knee arthroplasty among Medicare beneficiaries, 2000 to 2009. J Bone Joint Surg Am 2013;95(22):e174.
77. Craik JD, El Shafie SA, Singh VK, et al. Revision of unicompartmental knee arthroplasty versus primary total knee arthroplasty. J Arthroplasty 2014;30(4):592–4.
78. Lombardi AV Jr, Kolich MT, Berend KR, et al. Revision of unicompartmental knee arthroplasty to total knee arthroplasty: is it as good as a primary result? J Arthroplasty 2018;33(7S):S105–8.
79. Barrett WP, Scott RD. Revision of failed unicondylar unicompartmental knee arthroplasty. J Bone Joint Surg Am 1987;69:1328–35.
80. Chou DT, Swamy GN, Lewis JR, et al. Revision of failed unicompartmental knee replacement to total knee replacement. Knee 2012;19:356–9.
81. Wynn Jones H, Chan W, Harrison T, et al. Revision of medial Oxford unicompartmental knee replacement to a total knee replacement: similar to a primary? Knee 2012;19:339–43.
82. Khan Z, Nawaz SZ, Kahane S, et al. Conversion of unicompartmental knee arthroplasty to total knee arthroplasty: the challenges and need for augments. Acta Orthop Belg 2013;79(6):699–705.
83. Pearse AJ, Hooper GJ, Rothwell A, et al. Survival and functional outcome after revision of a unicompartmental to a total knee replacement: the New Zealand National Joint Registry. J Bone Joint Surg Br 2010;92:508–12.
84. Liddle AD, Pandit H, Judge A, et al. Effect of surgical caseload on revision rate following total and unicompartmental knee replacement. J Bone Joint Surg Am 2016;98(1):1–8.
85. Badawy M, Espehaug B, Indrekvam K, et al. Higher revision risk for unicompartmental knee arthroplasty in low-volume hospitals. Acta Orthop 2014;85:342–7.
86. Chatellard R, Sauleau V, Colmar M, et al. Medial unicompartmental knee arthroplasty: does tibial component position influence clinical outcomes and arthroplasty survival? Orthop Traumatol Surg Res 2013;99:S219–25.
87. Gulati A, Weston-Simons S, Evans D, et al. Radiographic evaluation of factors affecting bearing dislocation in the domed lateral Oxford unicompartmental knee replacement. Knee 2014;21:1254–7.
88. Diezi C, Wirth S, Meyer DC, et al. Effect of femoral to tibial varus mismatch on the contact area of unicondylar knee prostheses. Knee 2010;17(5):350–5.
89. Mercier N, Wimsey S, Saragaglia D. Long-term clinical results of the Oxford medial unicompartmental knee arthroplasty. Int Orthop 2010;34:1137–43.
90. Hamilton WG, Ammeen D, Engh CA Jr, et al. Learning curve with minimally invasive unicompartmental knee arthroplasty. J Arthroplasty 2010;25:735–40.
91. Robertsson O, Knutson K, Lewold S, et al. The routine of surgical management reduces failure after unicompartmental knee arthroplasty. J Bone Joint Surg Br 2001;83:45–9.
92. Bell SW, Stoddard J, Bennett C, et al. Accuracy and early outcomes in medial unicompartmental knee arthroplasty performed using patient specific instrumentation. Knee 2014;21(Suppl 1):S33–6.
93. Demange MK, Von Keudell A, Probst C, et al. Patient-specific implants for lateral unicompartmental knee arthroplasty. Int Orthop 2015;39:1519–26.
94. Jones GG, Logishetty K, Clarke S, et al. Do patient-specific instruments (PSI) for UKA allow non-expert surgeons to achieve the same saw cut accuracy as expert surgeons? Arch Orthop Trauma Surg 2018;138(11):1601–8.
95. Suda Y, Takayama K, Ishida K, et al. Improved implant alignment accuracy with an accelerometer-based portable navigation system in medial unicompartmental knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2019. https://doi.org/10.1007/s00167-019-05669-y.
96. Weber P, Crispin A, Schmidutz F, et al. Improved accuracy in computer-assisted unicondylar knee arthroplasty: a meta-analysis. Knee Surg Sports Traumatol Arthrosc 2013;21:2453–61.
97. Nair R, Tripathy G, Deysine GR. Computer navigation systems in unicompartmental knee arthroplasty: a systematic review. Am J Orthop (Belle Mead NJ) 2014;43:256–61.
98. Cobb J, Henckel J, Gomes P, et al. Hands-on robotic unicompartmental knee replacement: a prospective, randomised controlled study of the acrobot system. J Bone Joint Surg Br 2006;88:188–97.
99. Chowdhry M, Khakha RS, Norris M, et al. Improved survival of computer-assisted unicompartmental knee arthroplasty: 252 cases with a minimum follow-up of 5 years. J Arthroplasty 2017;32(4):1132–6.
100. Cavinatto L, Bronson MJ, Chen DD, et al. Robotic-assisted versus standard unicompartmental knee arthroplasty-evaluation of manuscript conflict of interests, funding, scientific quality and bibliometrics. Int Orthop 2019;43(8):1865–71.
101. Citak M, Suero EM, Citak M, et al. Unicompartmental knee arthroplasty: is robotic technology

more accurate than conventional technique? Knee 2013;20(4):268–71.
102. Lonner JH, John TK, Conditt MA. Robotic arm-assisted UKA improves tibial component alignment: a pilot study. Clin Orthop Relat Res 2010;468(1):141–6.
103. Batailler C, White N, Ranaldi FM, et al. Improved implant position and lower revision rate with robotic-assisted unicompartmental knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2019;27(4):1232–40.
104. Kayani B, Konan S, Tahmassebi J, et al. An assessment of early functional rehabilitation and hospital discharge in conventional versus robotic-arm assisted unicompartmental knee arthroplasty: a prospective cohort study. Bone Joint J 2019;101-B(1):24–33.
105. Gilmour A, MacLean AD, Rowe PJ, et al. Robotic-arm-assisted vs conventional unicompartmental knee arthroplasty. The 2-year clinical outcomes of a randomized controlled trial. J Arthroplasty 2018;33(7S):S109–15.