Unicompartmental knee arthroplasty: state of the art

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ABSTRACT

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Received 17 November 2016 Revised 12 December 2016 Accepted 13 December 2016 The popularity of unicompartmental knee arthroplasty (UKA) for the treatment of isolated compartment osteoarthritis of the knee has risen over the past 2 decades. Currently, UKA covers 10% of all knee arthroplasties worldwide. Although indications have been extended, results have proven that patient selection plays a critical role in the success of UKA. From the current perspective, age, body mass index, patellofemoral osteoarthritis, anterior cruciate ligament deficiency and chondrocalcinosis are no longer absolute contraindications for UKA. Motivated by the desire to improve survivorship rates, patient-reported outcomes and reduce complications, there have been many technological advances in the field of UKA over the recent years. The aim of this review was to evaluate the current indications, surgical techniques, modes of failure and survivorship results of UKA, by assessing a thorough review of modern literature. Several studies show that innovations in implant design, fixation methods and surgical techniques have led to good-to-excellent longterm survivorship, functional outcomes and less complications. Until now, resurgence of interest of cementless designs is noted according to large national registries to address problems associated with cementation. The future perspective on the usage of UKA, in particular the cementless design, looks promising. Furthermore, there is a growing interest in robotic-assisted techniques in order to optimise result by controlled soft-tissue balancing and reproduce alignment in UKA. Future advances in robotics, most likely in the field of planning and setup, will be valuable in optimising patient-specific UKA.

INTRODUCTION

Clinical problem: prevalence and social impact

Knee osteoarthritis (OA) is highly prevalent worldwide. It is the leading cause of musculoskeletal disability and associated with activity limitation, working disability, reduced quality of life and increased healthcare costs.^{1 2} Partial or total joint replacement of the affected knee is a surgical intervention to treat the disease when conservative stratfails. Both procedures are commonly egy performed in developed countries and the number is expected to increase dramatically in the upcoming decade.^{2 3} Unicompartmental knee arthroplasty (UKA) has gained popularity recently because several studies have shown that it is less invasive and has a reduced operative time, larger postoperative range of motion (ROM), improved pain relief, earlier return to daily activities and sports, and cost reduction in comparison to total knee arthroplasty (TKA).⁴⁻⁸ National and annual registries show similar usage with an increasing incidence over the past 10 years, currently ranging from 5% to 11% globally in 2014.9-14

The aim of this review is to provide an overview of different aspects concerning UKA in terms of diagnostics, indications, patient selection, surgical techniques, clinical outcomes and geographical differences.

Historical perspective of UKA and its upswing

The concept of replacement of a single compartment of the knee joint originated in the 1950s, when McKeever¹⁵ and MacIntosh introduced the metallic tibial plateau. In 1972, the first contemporary UKA, resurfacing both the femur and tibia of a single knee compartment, was performed by Marmor.¹⁶ Despite the theoretical advantages of this design, the survivorship rates were disappointing with more than 30% of patients undergoing revision surgery within 10 years.¹⁷ Tibial loosening, subsidence and accelerated polyethylene wear were the dominant reasons for implant failure.¹⁸ In 1976, Insall and Walker¹⁹ reported similar disappointing results at 2-4-year follow-up, finding good-toexcellent results in only 11 out of 24 UKAs and a 28% conversion rate to TKA. The reasons for these dissatisfying results were malposition of the implant, insufficient correction of the leg alignment and removal of the patella due to patellofemoral osteoarthritis (PFOA).²⁰ Subsequently, Laskin²¹ reported outcomes using the Marmor knee (Richards Manufacturing Company) with pain relief in only 65% of the patients and a 26% failure rate at a 2-year follow-up.²¹ Following these disappointing results, interest for UKA further decreased and UKA was discouraged.²⁰ ²¹

In 1989, Kozinn and Scott²² sought to improve these outcomes by proposing the use of strict inclusion criteria. As a result, better results were reported in the literature. Berger et al^{23} applied these criteria and showed a survival rate of 98% at 10-year follow-up, using the Miller-Galante prosthesis (Zimmer, Warsaw, Indiana, USA). Clinically, outcomes were graded excellent in 78% of patients and good in 20% of patients.²³ Simultaneously, Murray et al^{24} reported on 143 knees treated with a medial Oxford mobile-bearing UKA, revealing a survivorship of 97% with a mean follow-up of 10 years. The use of mini-invasive techniques was advocated to reduce tissue damage and improve the ease of revision surgery.²⁵ However, the results have been variable regarding the accuracy and reproducibility of this approach compared with standard techniques.²⁵

Throughout the 1980s and 1990s, UKA usage continued, however, in varying degrees with corresponding results. Over the course of the years, surgeons sought to better understand the biomechanics and modes of failure of these devices to improve on the original UKA designs. In addition, special instrumentation was designed and better patient selection

To cite: Kleeblad LJ, Zuiderbaan HA, Hooper GJ, *et al. JISAKOS* Published Online First: [*please include* Day Month Year] doi:10.1136/jisakos-2016-000102

BMJ



criteria were developed, all of which laid the groundwork for the eventual revival of UKA.

Main articles: reviews, state of the art and current concepts

Over the past decades, several reviews have been published about UKA. As time has progressed, reviews moved from patient selection criteria to surgical techniques and modes of failure. Recently, many authors emphasise different fixation methods, prostheses designs and new technologies (eg, robot-assisted surgery) as is shown in box 1.

CURRENT STATE OF THE ART Diagnostics

Physical and radiographic evaluation remains the cornerstone in the diagnostic process of knee OA and is particularly important to assess whether a knee with unicompartmental OA (medial or lateral) would be indicated for UKA. Evaluation of the presence of unicompartmental knee OA through medical history, physical examination and imaging is essential and all contribute to precise patient selection. Furthermore, it provides valuable information in surgical decision-making after diagnostic criteria are met.

Physical examination

To assess whether or not a patient is indicated for UKA depends on many factors. On physical examination, it is important to evaluate the location of the pain over the joint line (medial or lateral), ROM, leg deformity, state of the anterior cruciate

Box 1 Key articles on unicompartmental knee arthroplasty (UKA)

- ▶ Insall and Walker¹⁹ introduced the first unicompartmental knee arthroplasty in the 1970s.
- ▶ In 1989. Kozinn and Scott²² described the strict patient selection criteria for UKA after disappointing results from the past.
- Murray et al²⁴ reported 10-year survivorship of 98%, showing that long-term outcomes of UKA can be achieved in strictly selected patients.
- Pandit et al²⁷ demonstrated the unnecessary contraindications for mobile-bearing UKA, and thereby proposed to expand the indications for UKA.
- Liddle et al²⁸ showed good-to-excellent results at 10-year follow-up of 1000 cementless UKAs after resurgence of interest in the late 1990s.
- ▶ Chatellard et al²⁹ emphasised the high level of accuracy required for optimal position of the tibial component, to restore knee kinematics and prevent implant wear.
- Pearle *et al*³⁰ were the first to demonstrate successful ► robot-assisted UKA placement in a series of 10 patients, showing improvement of the accuracy in regard to component positioning and leg alignment.
- van der List et al³¹ performed a systematic review ► demonstrating high survivorship rates of medial and lateral UKA, combined with high functional outcomes scores.
- ▶ Epinette et al³² identified modes of failure of UKA in a large French multicentre study. They assessed the differences between early, mid-term and late stages of the arthroplasty.
- ► Jacofsky and Allen³³ reviewed the current robotic systems for UKA and comment on future innovations in robotics.

ligament (ACL) and patellofemoral (PF) discomfort. Pain should be isolated to one compartment, either medial or lateral, to be indicated for UKA. Assessing knee stability, the Lachman or anterior drawer test can be used to evaluate the integrity of the ACL clinically. Furthermore, varus and valgus stress tests assess the collateral ligaments and amount of correctability of a leg deformity if present.

Radiographic assessment

Traditionally, knee OA is diagnosed on anteroposterior (AP) and lateral weight-bearing radiographs of the knee. Rosenberg et al's³⁴ views and additional lower leg alignment radiographs are performed as part of the standard radiological work-up of patients with unicompartmental knee OA. This additional 45° posteroanterior flexion weight-bearing radiograph has a high sensitivity and specificity of detecting isolated lateral OA.³⁴ For evaluation of the patella and trochlear surfaces of the femur, an adequate Merchant view may be helpful in determining gross malalignment and presence of PFOA.

The severity of knee OA is classified according to the Kellgren-Lawrence (KL) Grading System³⁵ or Ahlbäck classification³⁶ (table 1). The most limiting aspect of classification based on radiographic imaging is that it detects joint degeneration only in a more advanced stage.³⁷

To overcome this limitation, the clinical utility of MRI becomes more important to assess the early detection of OA in the contralateral compartment. Subtle degenerative changes in the subchondral bone, cartilage, abnormalities in the bone marrow, ligaments, menisci, synovium and joint fluid are all well detected with MRI technology.^{37 38}

The radiographic indications for UKA is unicompartmental knee OA (figure 1), with preservation of the contralateral compartment as shown on weight-bearing and valgus/varus stress radiographs.³⁹ Preoperatively, stress view radiographs could provide information by means of determining correctability of the deformity, ensuring maintenance of the contralateral joint space, and indirectly assessing the integrity of the ACL and medial collateral ligaments.³⁹⁻⁴¹ Advocates of stress radiographs require the deformity to be correctable to neutral, with preservation of the contralateral joint space.²² However, a preoperative MRI is used more often to document the absence of significant degenerative changes in the contralateral or PF compartment.^{37 38}

Indications and contraindications

Kozinn and Scott's²² original inclusion criteria included that the patient had to be older than 60 years at the time of surgery, weigh <82 kg, should not be physically active or performing heavy labour and have movement-related pain. Furthermore, during physical examination, the patient needed to have a preoperatively flexion of the knee of more than 90°, maximum

Table 1 Radiographical grading scales	al grading scales
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Grade	Kellgren-Lawrence	Ahlbäck
1	Doubtful joint space narrowing and osteophyte formation	Joint space narrowing (<3 mm)
2	Definite osteophyte formation with possible joint space narrowing	Joint space obliteration
3	Multiple osteophytes, definite joint space narrowing, sclerosis and possible bony deformity	Minor bone attrition (0–5 mm)
4	Large osteophytes, marked joint space narrowing, severe sclerosis and definite bony deformity	Severe bone attrition (>10 mm)



Figure 1 Preoperative anteroposterior and lateral radiographs showing medial osteoarthritis of the left knee.

flexion contracture of 5°, varus of valgus deformity of $<15^{\circ}$ and passively correctable to neutral. Although strict adherence to these recommendations led to the improvements of the results, the criteria were generated at a time that surgical techniques and implant designs were not yet optimised. Therefore, questions arise whether these criteria should still be used today or can be extended.

Age

Several authors, including the Oxford Group, reassessed age above 60 years as a contraindication for UKA surgery. They demonstrated similar survival rates (97.3%) and functional outcomes at 10-year follow-up compared with patients older than 60 years (95.1%).^{27 42} The fear of early polyethylene wear in younger patients, mostly more active patients at that age, is therefore not supported. Interestingly, a trend of better functional outcomes is seen in this group.⁴³ This may be explained by the fact that younger patients have high activity levels and high functional demands which are met by UKA, including quicker recovery after surgery and wider ROM.^{6 7 42}

Body mass index

A general increase in the number of obese patients has been noted in orthopaedic practice over the past few decades, and this trend is likely to continue. Reticence in performing surgery on these patients is due to a possibly increased risk of perioperative complications and poor survival due to early implant failure secondary to component loosening and/or excessive wear.44 This concern may be particularly relevant with UKA, on account of the potential of point loading at the small area of the bone-implant interface. However, Murray et al⁴⁴ performed a large retrospective study and divided 2438 patients into the specific subgroups (body mass index (BMI) <25, 25-30, 30-35, 35-40, 40-45, >45 kg/m²). They demonstrated that the survival rate of the Oxford UKA does not decrease with increasing BMI, and no statistical differences were found between any of the groups at the 5-year or 10-year follow-up.44 Similar results have been found by other authors and systematic reviews as well.²⁷ ⁴² ⁴⁵ ⁴⁶

Patellofemoral osteoarthritis

The most contentious potential contraindication relates to the state of the PF joint. According to the Kozinn and Scott selection criteria, PFOA was one of the contraindications for UKA. However, in 1986, Goodfellow and O'Connor⁴⁷ performed a

bicompartmental study of the Oxford knee in a series of 125 patients and found no relationship between the state of the PF joint, as seen during surgery, and the outcomes. Therefore, the Oxford Group made the recommendation of ignoring the grade of PFOA when deciding whether or not to implant a UKA.^{27 48}

Current literature confirms this by not showing a relationship between preoperative PFOA and inferior outcomes.²⁷ ⁴² ⁴⁸ Beard *et al*⁴⁸ examined 824 consecutive knees, in which 16% had full-thickness cartilage loss at any location in the PF joint. These patients did not report worse outcomes than those with a normal or near-normal joint surface.⁴⁸ Recent reports suggest that this might be the result of indirect PF joint congruence improvement as a result of medial UKA implantation.⁴⁸ ⁴⁹ By restoring the alignment, the contact forces over the PF joint are lowered.⁴⁹ Despite the lack of level I evidence, these previously mentioned studies all suggest that PFOA does not influence UKA outcomes.²⁷ ⁴² ⁴³ ^{47–50}

Anterior cruciate ligament

From a historical perspective, it was generally accepted that UKA is contraindicated if the ACL is functionally deficient. The first reports highlighted a higher incidence of complications following UKA surgery in ACL-deficient knees, in terms of tibial loosening and a higher revision rate.^{51 52} Mancuso et al⁵³ summarised the evidence in the literature concerning ACL deficiency in UKA surgery; they concluded that combining ACL reconstruction and UKA is the preferred treatment option for patients with ACL deficiency and bone-on-bone medial OA. Simultaneous or staged ACL reconstruction tends to provide superior outcomes, in particular in younger and more active patients. In the elderly, UKA without ACL reconstruction seems to be a reasonable and attractive option if a fixed-bearing design is used, but careful patient selection is necessary.⁵³ The literature shows no statistical difference between survival rates of UKAs implanted in ACL-deficient and ACL-intact knees.⁵⁴ However, a cautious approach is required, since long-term results are lacking.

Chondrocalcinosis

Chondrocalcinosis, deposition of calcium pyrophosphate crystals in fibrocartilage and hyaline cartilage, is commonly seen in knees with OA.55 It is believed that chondrocalcinosis leads to a more aggressive form of OA, potentially leading to accelerated contralateral compartment OA following UKA. Despite the limited number of series, the literature does not support this theoretical disadvantage. Hernigou et al⁵⁵ proved the incorrectness of this theory; only 11% of their patients showed progression of OA of the other compartment, which is equivalent or less than UKA knees without chondrocalcinosis.⁴³ Another report by the Oxford Group showed no significant difference in survival between patients with radiological chondrocalcinosis undergoing medial UKA and controls without chondrocalcinosis. The relevance of histological chondrocalcinosis in patients with UKA remains unclear. Although it is associated with a significantly higher revision rate, these patients report significantly better functional outcomes.⁵⁶

To summarise, over the past two decades the original contraindications to performing UKA surgery have been reassessed by multiple investigators and now the current literature would suggest that age, BMI, PFOA, chondrocalcinosis and ACL integrity are not absolute contraindications for UKA.

Operative treatment

UKA is most frequently performed on the medial tibiofemoral articulation (90%).^{11 31} There are many variables in the surgical technique of UKA, including differences between cemented or uncemented fixation, mobile-bearing or fixed-bearing design, metal backed or all-polyethylene tibial components and conventional or robotic implant positioning (boxes 2–4).

Surgical techniques

Cemented versus cementless

Initially, both cemented and cementless designs were used. However, the cementless designs were less reliable with failure rates up to 20% 10 years after surgery.⁵⁷ Cementation has proven to be an adequate fixation method for UKA and is therefore considered the standard technique. It has shown high survivorship rates and good functional outcomes.^{26 58} The most common cause of failure of the cemented implant is aseptic

Box 2 Validated outcome measures and classifications

- ► Hospital for Special Surgery (HSS) score;
- ► Knee Society Score (KSS);
- ► Oxford Knee Score (OKS);
- Tegner Activity Score;
- Western Ontario and McMaster Universities Arthritis Index (WOMAC).

Box 3 Tips and tricks for successful unicompartmental knee arthroplasty (UKA)

- Patient selection is essential in UKA surgery, in which single knee compartment osteoarthritis and correctable leg deformity are the most important factors.
- Surgical goal is slight undercorrection of the deformity of the long leg axis.
- ▶ (medial UKA: 1-4° varus, lateral UKA: 3-7° valgus).
- In UKA, correct ligament balance is restored by positioning the components accurately and inserting an appropriate thickness of bearing.
- In high functional demand patients, it is recommended to reconstruct the anterior cruciate ligament simultaneously or staged in addition to UKA.

Box 4 Major pitfalls of unicompartmental knee arthroplasty (UKA)

- Osteoarthritis in the contralateral compartment is contraindicated for UKA; therefore, MRI could be useful to assess the chondral surface in case of doubt.
- Overcorrection during medial UKA (MUKA) or lateral UKA is associated with progression of osteoarthritis in the contralateral compartment and therefore should be avoided.
- Residual postoperative axis >8° to 10° varus following MUKA increases the rate of failure from polyethylene wear and loosening.

loosening according to the joint registries and large systematic reviews.¹⁰ ¹¹ ¹³ ³² ⁴³ Errors in cementation, thermal necrosis, misinterpretation of radiolucent lines (RLLs), and formation of fibrocartilage and fibrous tissue at the bone—cement interface could all contribute to loosening of the cemented UKA.⁵⁹ ⁶⁰ As a result, a resurgence of interest in cementless fixation has been noted over the past decade to address these perceived disadvantages of cemented fixation.

Modern advances, such as the use of porous titanium and especially hydroxyapatite coating, are responsible for an improved fixation of the cementless UKA. Osseous stability, either by ingrowth or ongrowth, and press-fit fixation of both components are key elements in cementless fixation. Currently, the Oxford UKA is the most commonly used cementless prosthesis. The possible downside of the press-fit fixation is an increased risk of periprosthetic fractures, particularly on the tibial side in older osteopaenic women.³² ⁶¹ More impaction is required to introduce components with good primary fixation in cementless replacement. Despite early conflicting results, recent evidence shows good results on the effectiveness and safety of cementless UKA in mid-term follow-up with randomised controlled trials and case series.²⁸ ⁶¹ Summarised in a recent systematic review by Campi et al,⁶¹ the cementless technique has many advantages in comparison to cemented UKA, including shorter surgical time, avoidance of cementation errors, lower incidence of RLLs and reliable fixation. Despite these promising results, longer follow-up data are required to assess the long-term advantage of cementless UKA.

Fixed versus mobile bearing

The first available UKAs were fixed-bearing designs, which often had a flat tibial articular surface. These were less conforming as flexion occurred, and therefore led to higher point loading on the surface.⁶² As a result, higher stress within the polyethylene were noted, which increased the risk of component loosening and polyethylene wear.⁴⁰ ⁶² In order to minimise polyethylene wear, Goodfellow and O'Conner⁴⁷ designed a mobile-bearing metal-backed UKA in 1986. The articulating surfaces of the components are congruent over the entire ROM in most mobile-bearing designs. Large contact areas and small contact stresses diminish the likelihood of wear and decouple the forces at the implant bone interface, which should reduce the incidence of aseptic loosening.⁴⁷ Stability of the insert is created by ligamentous tension and, to a much lesser extent, by the components itself. Therefore, it is mandatory to produce equal flexion and extension balance to maintain stability and reduce the risk of bearing dislocation. Impingement of the mobile-bearing insert is another complication inherent to mobile implants and careful assessment intraoperatively of bearing tracking should alleviate this problem.

Bearing dislocation was observed more often in lateral UKAs (11%) with mobile-bearing designs, caused by a more lax lateral compartment in flexion compared with a tighter medial compartment.⁶³ This allows the lateral compartment to be distracted by about 7 mm, compared with 2 mm on the medial side.⁶⁴ To overcome this problem, the Oxford Group developed a new lateral mobile-bearing tibial component. The Domed Lateral Oxford UKA (Biomet UK) has a spherically convex and domed tibial plateau.⁶⁵ Additionally, the biconcave bearing has a 7 mm entrapment anteriorly and posteriorly in order to reduce the likelihood of dislocation. Survival rates of lateral UKA increased up to 92% at a mean follow-up of 4 years and good functional outcomes were reported by Weston-Simons *et al.*⁶⁵ Comparative studies on medial UKAs were performed by Parratte *et al*⁶⁶ and

Whittaker *et al*;⁶⁷ they found equivalent mid-term and long-term functional outcomes and survivorship rates of mobile-bearing versus fixed-bearing implants. The predominant reasons for revision were progression of OA and aseptic loosening in both fixed-bearing and mobile-bearing UKA. Similar findings were reported by the national arthroplasty registries, suggesting no conclusive advantage of one bearing design over another.^{11–13}

All polyethylene versus metal backed

Historically, two fixed-bearing designs have been used for tibial resurfacing when performing a UKA: (1) inlay (all-polyethylene) and (2) onlay (metal-backed). Inlay components are allpolyethylene implants cemented into a carved pocket on the tibial surface, thereby relying on the subchondral bone to support the implant. Onlay components commonly have a metal base plate and are placed on top of a flat tibial cut, supported by a rim of cortical bone.⁶⁸ 69 Walker *et al*⁶⁸ used a biomechanical model to compare inlay versus onlay implants, and showed superior load distribution over the tibial surface for the metal-backed onlay design. It has been suggested that this may be a mechanistic explanation for the improved pain relief demonstrated by the onlay components.⁶⁸ An additional benefit of metal-backed tibial trays is the possibility to apply cementless fixation. However, metal-backed designs allow a less conservative tibial cut when compared with all-polyethylene implants. In order to minimise contact stresses in the tibial component, a polyethylene thickness of 8 mm should be pursued when possible.^{69 70} Taking into account the thickness of the polyethylene and the metal tray itself (3-4 mm), metal-backed designs necessitate a larger tibial cut.⁶⁹ In current practice, metal-backed as well as all-polyethylene tibial implants are being used. The metal-backed design may favour of the renewed interest of cementless fixation.

Surgical technique: conventional versus robot assisted

Conventional manual techniques have been routinely used in UKA surgery with implant position and alignment critical to short-term and long-term outcomes.^{31 51 71} These variables are most often manually controlled with the aid of extramedullary and intramedullary alignment guides. Although national registries reported lower rates, a recent systematic review showed a 10-year survivorship of medial and lateral UKA of 92% and 91%, respectively.^{10–14 31} As is described, the accuracy of implant alignment is an important prognostic factor for long-term implant survival; therefore, tight control is recommended.^{43 51 71}

Over the past decade, there has been a growing interest in surgical quantifiable variables that can be controlled intraoperatively, which include lower leg alignment, soft-tissue balancing, joint line maintenance and component alignment. Technical innovations in UKA surgery have led to the development and usage of computer navigation systems, with the purpose of more accurate and tight control of the aforementioned surgical factors.⁷⁶⁻⁷⁸ Meta-analyses have reported improvement of alignment and surgical cutting accuracy, however, failed to show the superiority of functional outcomes in comparison to conventional techniques.⁷⁶ ⁷⁸ As a result, robot-assisted systems have been developed to control these variables intraoperatively and, in addition, refine and enhance the accuracy of the procedure.³⁰ ⁷⁹ The fundamental goals of robotic-assisted surgery are to be patient-specific, minimally invasive and highly precise. Most importantly, the robotic systems are 'semiactive', meaning that the surgeon retains

ultimate control of the procedure while benefiting from robotic guidance within target zones and surgical field boundaries. Preoperative CT-based planning was essential in earlier systems; however, new technology allows image-free robotic assistance (figure 2).^{30 80 81} Through mapping condylar landmarks and determination of alignment indices, the volume and orientation of bone to be removed is defined. Continuous intraoperative visual feedback provides quantification of soft-tissue balancing and component alignment (figure 3).^{73 79} Compared with conventional UKA, robotic-assisted systems have demonstrated improved surgical accuracy, lower leg and component alignment.^{79 82–84} Another benefit in the use of the robotic system may be a shorter or rapid progression up the learning curve, which can minimise failures related to surgeon workload.³⁰

Cobb et al⁸² performed a randomised control trial to compare conventional techniques with robot-assisted surgery on 27 patients with medial UKA. They found that the robotic-assisted group had a mechanical axis within two degrees of neutral, while only 40% of the conventional group was in that range. Furthermore, they assessed functional outcomes according to the Western Ontario and McMaster Universities Arthritis Index (WOMAC) score and noted a trend towards improvement in performance with increasing accuracy at 6 weeks and 3 months postoperatively.⁸² The optimal alignment for medial UKA is between 1° and 4° varus; this was associated with a better outcome and medium-term to long-term survivorship.^{29 50 72} For lateral UKA, valgus alignment of 3-7° was correlated with the best functional outcomes at 2 years postoperatively.⁸⁵ Pearle et al⁸⁶ reported the preliminary results of a multicentre study of 854 patients and found a survivorship of 98.9% and satisfaction rate of 92% at a minimum 2-year follow-up. Comparing these results to other large conventional UKA cohorts may suggest that robotic-assisted surgery could possibly improve survivorship at short-term follow-up.^{26 58 87}

Drawbacks of robot-assisted surgery are high overall costs and radiation; however, the implementation of image-free robotic assistance has significantly decreased the radiation by eliminating the CT preoperatively. Furthermore, Moschetti *et al*⁸⁸ has shown that robot-assisted UKA is cost-effective compared with conventional UKA when the annual case volume exceeds 94 UKAs per year. Another disadvantage in comparison to conventional techniques is the necessity of pin tracts for the required optical tracking arrays, which is necessary for some robot-assisted systems. They could create a stress riser in the cortical bone when the pins are applied.⁸¹ Nevertheless, prospective clinical studies with longer follow-up are required to assess the additional value of robotic-assisted UKA surgery, despite the promising short-term results.

Survivorship

In 2015, a systematic review was published concerning UKA survivorship rates of medial and lateral UKAs.³¹ The authors showed that the survivorship of medial UKA at 5, 10, 15 and 20 years was 93.9%, 91.7%, 88.9% and 84.7%, respectively. Lateral UKA is considered a technically more challenging surgery than medial UKA, because of differences in anatomy and kinematics, as well as implants designs and lower surgical volume as compared with medial UKA. However, no statistical difference was found between survivorship in medial and lateral UKA.³¹ The reported survivorship rates of lateral UKA at 5, 10 and 15 years were 93.2%, 91.4% and 89.4%, respectively. A notable factor of alterations in survivorship displayed in cohortbased, case-based and registry-based studies is the differences in volume of surgical procedures. It has been shown that the risk



Figure 2 Robot-assisted surgery of unicompartmental knee arthroplasty, preoperative planning of the femur and tibia component position, however being able to adjust these variables intraoperatively.

of revision decreases as both centre and surgeon UKR volume increase.⁸⁹ Overall, registry-based studies report lower survivorship compared with cohort-based studies. The most likely explanation for the dissimilarities between cohort-based and registry-based studies is the fact that cohort studies are often high-volume centres reporting outcomes, whereas registry-based studies also report low-volume centre outcomes. As has been suggested by a few authors, it would be of additional value if registries and registry-based studies separate the survivorship of medial and lateral UKA.^{31 89} Thereby, it would be possible to compare the survivorship of both UKA procedures in highvolume and low-volume centres. In addition, the long-term survivorship of lateral UKA could be assessed based on registry studies, which is difficult because of the small number of knees in cohort studies.

Modes of failure

Several studies have been published on modes of failure after UKA, using different classification systems based on cause or time stages. Over the past two decades, several developments have been made in UKA surgery. The ongoing development of new prosthesis designs and surgical techniques has ensured that the modes of failure have altered as well.

Aseptic loosening

A French multicentre study of 418 failed knees concluded that aseptic loosening was the most common cause of failure in their population, accounting for 44% of all cases.³² Similar findings were shown by van der List *et al*⁴³ and Citak *et al*;⁹⁰ both reported aseptic loosening and progression of OA as the most common modes of failure in medial UKA. Tibial loosening was seen more often than femoral loosening; moreover, it developed significantly earlier (37.7% within 2 years) when compared with femoral loosening. Noteworthy is the fact that aseptic loosening is much more common in medial than lateral UKA.³²

Progression of osteoarthritis

Progression of OA in the contralateral compartment accounts for the second most common cause of failure of UKA. Various studies have reported progression of the underlying disease in up to 36% of the knees.^{32 43 91} To minimise this progression, a high level of accuracy is required for optimal positioning of the components and restoration of the joint line. The restoration of the prosthetic joint space affects load transfers between the two femorotibial compartments. To that end, Khamaisy *et al*⁷⁴ proved a significant improvement of the congruity of the contralateral compartment following medial and lateral UKA implantation. Restoration of the appropriate joint line in the damaged



Figure 3 Robot-assisted surgery of unicompartmental knee arthroplasty, tibial cut using Stryker/MAKO haptic guided robot (MAKO Surgical Corp) with continuous intraoperative visual feedback.



Figure 4 Postoperative anteroposterior and lateral radiographs showing a left unicompartmental knee arthroplasty.

Figure 5 Weight-bearing long leg radiographs preoperative and postoperative to assess leg alignment.

compartment has an influence on survivorship. A joint space height difference <2 mm was significantly associated with shorter medial UKA survival.²⁹ Failures related to a lower position of the prosthetic joint line were due to loosening, whereas failures related to a higher position of the prosthetic joint space were due to early polyethylene wear and progression of OA in the contralateral compartment.²⁹ ⁴⁰ ⁴⁷ ⁶⁶ As Chatellard *et al*²⁹ stated, UKA acts as a wedge that compensates for the joint damage, which restores normal kinematics and blocks the vicious circle of medial femorotibial OA.⁷⁴

Polyethylene wear

As previously mentioned, wear is another mode of failure which is mostly seen in fixed-bearing designs of UKA.⁴³ ⁶⁶ Higher stresses are generated in these types of designs, often in



combination with a metal-backed tibial tray, which allows only a certain polyethylene thickness. Thinner polyethylene is at risk for accelerated wear of the increased contact stresses.⁷⁰ Furthermore, leg alignment and the position of the components influences wear in the knee following medial UKA.⁷¹ Hernigou and Deschamps⁷¹ showed that a varus undercorrection was associated with increased polyethylene wear and recurrence of the deformity. Subsequently, the risk of lateral degeneration was increased in case of valgus overcorrection.⁷¹ In contrast, no significant correlation was found between polyethylene wear and BMI, gender or preoperative diagnosis of the patient.^{69 90}

Pain

Unexplained pain is an important source of failure following UKA surgery. Among 4-23% of the patients with UKA experience pain postoperatively without any obvious reason after the traditional examinations.^{32 43 92} Park *et al*⁹³ recently performed a diagnostic MRI-based study, in order to create a greater insight into the aetiology of the symptomatic patients where physical and traditional radiographs were not aberrant. MRI examination was found to be instrumental in diagnosing these patients. The most common pathologies based on MRIs included loose bodies, osteolysis, tibial loosening, synovitis, stress fractures and infection.⁹³ Baker et al⁹² compared the proportion of UKA and TKA revisions that were performed because of unexplained pain as recorded in the National Joint Registry of England and Wales.⁹ The risk of revision was greater following UKA, and proportionally more unicompartmental implants were revised for unexplained pain. Some potential explanations were suggested by the authors. First, UKA revision is perceived as an easier procedure to revise than a TKA and this is likely to lower the threshold of patient and surgeon to proceed with pain as the only indicator. However, registry-based studies have shown that revising a UKA results in a poorer result than a primary TKA, with survival and patient-reported outcomes similar to revising a TKA.⁹⁴ They conclude that a demonstrable cause for the revision, rather than unexplained pain, should be the reason for conversion to TKA. Second, inexperienced surgeons faced with an unhappy patient with a UKA with no obvious diagnosis are more likely to blame the unresurfaced compartment.⁹² This situation is similar to TKA with an unresurfaced patellar, where the patellar is subsequently resurfaced as it is assumed that the pain must be coming from this articulation. Revision procedures in these patients only result

in 25% satisfaction rates, even in the presence of a 'hot' nuclear bone scan. 92

Aseptic loosening, progression of OA, polyethylene wear, bearing dislocation and unexplained pain are the most common failure modes following UKA surgery. To a much lesser extent, instability, infection, malalignment, fracture and tibial subsidence are reported as a cause of failure in current literature. ³² ⁴³ ⁹⁰

Postoperative imaging evaluation

Postoperatively, standardised knee radiographs are obtained immediately after surgery and repeated after 6 weeks, 6, 12 months and then yearly. They include AP, lateral and long leg radiographs for the postoperative evaluation of the mechanical axis (figures 4 and 5). The clinical importance of frequent radiographs is to monitor the presence of RLLs and progression of OA in the unreplaced compartments. As is described by Goodfellow et $al_{,,52}^{52}$ two types of RLLs exist; physiological radiolucency (≤2 mm, stable and well-defined) is most commonly seen following UKA. Pathological RLLs are >2 mm thick, progressive and poorly defined, hence associated with component loosening or infection.^{52 95} Moreover, correction of the leg alignment can be calculated after surgery. Taking into account the minor varus alignment of the leg ($\leq 7^{\circ}$) is associated with better functional outcomes and medium-term to long-term survivorship of medial UKA compared with neutral or close-to-neutral alignment.72

Postoperative care and rehabilitation

Rehabilitation after UKA surgery is similar to TKA protocols recommending full weight-bearing exercises directly. However, faster rehabilitation was noted after UKA compared with TKA, particularly after introducing new anaesthetic and pain control protocols (ie, Rapid Recovery).⁹⁶ Early mobilisation allows adequate ROM faster and decreases the risk of complications, such as deep vein thrombosis, pulmonary embolism, chest infection and urinary retention. A short length of stay should also help minimise the risk of hospital acquired infection; in addition, patients are more comfortable at home.⁹⁶

Return to sports after UKA

As a consequence of higher patient expectations regarding physical activity after UKA, clinicians are increasingly forced to express an opinion as to what extent participation in sports is

Table 2	Geographical differences in unicompartmental knee arthroplasty based on registry data													
Registry	Year	Total (%)		Bearing type (%)		Fixation (%)		Most common prostheses			Survival (%)	Most common failure modes		
		UKA	PFA	Fixed	Mobile	Cement	Cementless	1	2	3	10 years	1	2	3
New Zealand	2014	8.8	0.8	7.3	92.7	44.1	55.9	Oxford	Zimmer	Oxford 3	88.7	Pain	Aseptic loosening	Infection
Australia	2014	4.2	0.4	51.6	48.4	66.7	33.3	ZUK	Oxford	Oxford 3	85.5	Aseptic loosening	Progression of OA	Pain
UK and Wales	2014	8.1	1.1	40.5	58.7	Not _l	provided	Oxford 3	Zimmer	Sigma HP	87.5	Aseptic loosening	Pain	Dislocation
Sweden	2014	3.5	0.4	6.6	93.4	80.4	19.6	Oxford	Link Sled	ZUK	87.6	Aseptic loosening	Progression of OA	Polyethylene wear
Norway	2015	10.5	0.6	1.0	99.0	66.8	33.2	Oxford 3	Oxford	Link Sled	82.0	Aseptic loosening	Pain	Progression of OA
USA	2014	4.2		No specific details mentioned on UKA in the registry										
Canada	2014	0.6	0.3	No specific details mentioned on UKA in the registry										

Oxford: Oxford cementless UKA, Oxford 3: Oxford partial knee (cemented).

OA, osteoarthritis; PFA, patellofemoral arthroplasty; UKA, unicompartmental knee arthroplasty.

possible after surgery. Furthermore, there is a growing interest in what specific activities are acceptable after knee arthroplasty. Witjes *et al*⁷ recently performed a systematic review on return to sports and physical activity after TKA and UKA. A limited number of seven studies were included, which reported the return to sports following UKA surgery. They concluded that participation in sports seems more likely after UKA than TKA. Return to the type of sport was subdivided by their impact. Return to sports after UKA for low-impact sports was 93%, >100% for intermediate sports and 35% for high-impact sports. Physical activity scores of these patients confirmed these findings. Moreover, time to return to sports was registered at 12 weeks after UKA (91%, concerning low-impact sports).⁷ No difference in the timing of return to sports between patients with UKA and TKA was found by Walton et al.97 However, patients with UKA were significantly more likely to increase or maintain their preoperative level of sports activity after surgery than patients with TKA.9

Geographical differences

The cementless designs of UKA are increasingly being used in Europe, Australia and New Zealand as is shown in table 2, all of which are depending on conventional surgical techniques to align the components. The most commonly used cementless UKA is from the Oxford Group. The advantages of cementless

Table 3 Key issues of patient selection	ction for UKA
Isolated medial or lateral osteoarthritis	Kellgren-Lawrence 3–4
Leg alignment (correctable to neutral)	MUKA: <15° varus, LUKA: <10° valgus
Fixed flexion deformity	<10°
Anterior cruciate ligament	Intact (relative indication)

LUKA, lateral UKA; MUKA, medial UKA; UKA, unicompartmental knee arthroplasty.

fixation have been thoroughly mentioned earlier in this review. Furthermore, a recent systematic review showed good-toexcellent survivorship of different cementless designs.⁹⁸ In 2218 cementless UKA procedures, 62 failures are reported, which can be extrapolated to 5-year, 10-year and 15-year survivorship of cementless UKA of 96.4%, 92.9% and 89.3%, respectively.⁹⁸

Primarily, a broader adoption of robotic technology was impeded in Asia and Europe. There is scepticism regarding the importance of optimising precision in UKA as well as expense, inconvenience, delays and risks associated with preoperative imaging with this technology.⁸¹ In the USA, three robotic systems are FDA-approved for UKA. The Stryker/MAKO haptic guided robot (MAKO Surgical Corp) has the largest market share with 20% for UKA. Since the introduction in 2005, over 50 000 have been performed with nearly 300 robotic systems nationally.^{33 80 84}

A cautious approach is needed when discussing the geographical differences on UKA, because the data are based on national registries. However, not every country has a national registry or the type of arthroplasty is not specified (tables 3 and 4).

Future perspectives

Based on the advantages, and good-to-excellent survivorship and functional outcomes of cementless designs, it is expected that cementless UKA will gain more popularity in the upcoming years.²⁸ ⁹⁸ Therefore, more companies will most likely launch cementless designs in the near future.

Currently, the total usage of UKA ranges from 8% to 11% according to national registries.^{9–14} Over the past two decades, advances in implant design and surgical technique have generated promising survivorship rates, faster recovery and rehabilitation, increased pain relief and good postoperative ROM. As a consequence of these results, an increase in application of UKA is expected. However, orthopaedic surgeons need to be aware

Table 4 Robotic and computer navigation systems used i	n UKA ^{33 76 77 80 84}
Robotic systems	Characteristics
Navio Precision Free-Hand Sculptor (PFS) system (Blue Belt Technologies) Semiactive robotic system	Image-free, no preoperative imaging required Robotic arm under direct control of the surgeon Uses optical-based navigation, creating a virtual model of the osseous knee Ability to adjust component position, alignment and soft-tissue balance during procedure Open platform (allows different implant designs)
Stryker/MAKO haptic guided robot (MAKO Surgical Corp) Semiactive tactile robotic system	Preoperative imaging required (CT scan) Robotic arm under direct control of the surgeon Real-time tactile feedback intraoperatively Ability to adjust component position, alignment and soft-tissue balance during procedure Closed platform (implant specific)
Computer navigation systems	Characteristics
<i>Ci Navigation</i> (Ci-Navigation-System, DePuy I-Orthopaedics, Munich, Germany)	Image-free navigation system Optical tracking unit that detects reflecting marker spheres by an infrared camera Controlled by a draped, touch-screen monitor Implant specific (Presentation, DePuy) Specific fine adjustable cutting devices
Orthopilot (Orthopilot, Aesculap AG, Tuttlingen, Germany)	Image-free system Allows different implant designs Relative motion of four infrared localisers calculate the centre of rotation Bony resection is performed with a classical saw
Stryker navigation (Stryker Navigation, Kalamazoo, Michigan, USA)	Image-free system Allows different implant designs Infrared stereoscopic camera to track skeletal reference frames
Treon plus (Medtronic)	Image-free navigation system Dynamic tracking of the instruments relative to the patient's position allowed hands-free alignment of the resection guides

UKA, unicompartmental knee arthroplasty.

of the possibility of UKA for treating isolated knee OA, though the candidacy for UKA to treat unicompartmental knee OA was large according to Willis *et al.*⁹⁹ Out of 200 consecutive patients, 47.6% was a potential candidate for UKA based on radiographical findings,⁹⁹ hence the conclusion that UKA has to be considered as a treatment option more often in the future.

Robotic-assisted surgery is beginning to change the landscape of orthopaedics. Initially, robotic systems were introduced to improve precision, accuracy and patient's overall outcome and satisfaction rates.^{30 79 83 86} Robotic-assisted surgery has the potential to achieve these goals by enhancing the surgeon' ability to generate reproducible techniques through an individualised surgical approach. Future innovations will most likely continue to improve the planning, setup and workflow during robotic-assisted UKA surgery. These advances will be implemented by means of simplifying the process and minimises the learning curve. Critical domains will possibly include preoperative analysis, intraoperative sensors and robotically controlled instrumentation.⁸⁴ Currently, some sort of imaging modality is necessary in order to perform preoperative planning, depending on the type of robotic system. The next step will be to extend image-free preoperative planning. This may create options to go beyond imaging to appreciate the kinematics of the operative joint before altered by the pathology of arthritis.⁸¹ The preoperative plan will be used to recreate the desired anatomic and kinematic framework. Furthermore, it is difficult to predict the array of technological innovations in the field of implant development.33

Contributors The authors confirm that the manuscript has been read and approved by all the named authors. LJK was the leading author of the manuscript under the supervision of ADP. All authors have contributed to the writing process by means of specific perspectives on surgical techniques, geographical differences and future innovations. Furthermore, the article has been revised by the other authors a couple of times (HAZ, GJH and ADP).

Competing interests None declared.

Provenance and peer review Commissioned; externally peer reviewed.

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J ISAKOS published online January 13, 2017

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