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Unicompartmental Knee Arthroplasty: The Past, Current Controversies and Future Perspectives

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Abstract

Unicompartmental knee arthroplasty (UKA) is a bone conserving and ligament-sparing procedure that reliably restores normal knee kinematics and function for arthritis limited either to the medial or the lateral compartment of the knee. Although there is enough evidence to demonstrate that the UKA offers good medium to long-term success given the correct patient selection, prosthesis design and implantation technique, there are several reports to suggest inferior survival rates in comparison with the total knee arthroplasty (TKA). Furthermore, it is a specialized procedure which works well in the hands of the experienced operator and therefore different authors' tend to draw different conclusions based on the same evidence, and as a result, there is great variability in the usage of the UKA. The aim of this current concepts review is to present to the readers the history of the UKA especially with reference to implant design, discuss current controversies and outline the future perspectives of this novel procedure.

Keywords

Unicompartmental knee arthroplasty (UKA), Osteoarthritis (OA), Implant design, History, Outcomes, Future

Introduction

Isolated medial compartment osteoarthritis (OA) has been reported to be present in 85% of the knees presenting with clinical OA[1]. This discovery revolutionized knee arthroplasty surgery through the development of the Unicompartmental knee arthroplasty (UKA)[2]. Initial enthusiasm has given way to more limited use following concerns over long-term survival[2,3]. The Australian registry's annual report in 2016 indicated that over 46,000 UKAs have been implanted since 1999, with a ten and fifteen-year cumulative revision rate of 14.6% and 21.0%, respectively[3]. This compares unfavorably with the 5.5% and 6.5% rates for TKA. Also, the UK national joint registry (NJR) in 2016 described that over 784,000 TKAs and 75,000 UKAs have been implanted since 2003, with a twelve-year cumulative revision rate of 3.87% and 15.0%, respectively[4]. These may explain the reason that the number of UKAs performed in 2012 was 49% less than those implanted in 2003 in Australia. Contrary to this, many groups have independently reported excellent results with 91% survival rate at 20 years using the Oxford UKA[5]. High volume centers seem to produce better results following UKA. Robertson supported this claim by showing that surgeons performing at least 24 UKAs per year achieved a survival of 93% at 9 years[6].

Before we identify possible future directions, it is important to revisit the past, to understand the concepts behind the implant's design and the lessons learned along the way. The aim of this article is to review the evolution, current controversies, and future directions of UKA.

The History of the UKA

In 1954, Macintosh performed the first Unicompartmental inter-positional replacement whilst operating on an arthritic knee with a severe valgus deformity[7]. He noticed that the deformity could be passively corrected by tightening the medial ligament to its natural tension. The prosthesis was held in position by the intrinsic soft tissue constraints of the knee. Later, the acrylic prosthesis was abandoned due to dissatisfaction with the results in hip arthroplasty despite Macintosh's good results in 72% of the 122 patients (defined as improved gait with at least 60° of flexion)[7].

In the 1960s, McKeever's tibial plateau prosthesis was designed by measuring 40 different sized tibiae and effectively placed on the tibial plateau. There is a constant direction of stress applied to the tibial plateau but the stress applied to the distal femur is varied. As a result, either one or both plateaus can be replaced[8]. Springer studied 26 McKeever prostheses with an average patient age of 44 years. Half were revised at an average of eight years after the operation; however, the authors noted that the revisions were easy[9]. This concept of interposition replacement has a modern-day equivalent in the Uni-spacer Knee System (Zimmer Inc., Warsaw, Indiana), which is a highly polished cobalt-chrome interposition replacement. However, Bailie in 2008 reported 44% implant revision rate within two years after the operation with an unpredictable relief of pain[10]. In 1968, Gunston developed the polycentric knee prosthesis, which involved replacement of both the medial and lateral compartments of the knee[11]. By doing this, he was able to resurface the condyles while preserving the cruciate ligaments in an attempt to duplicate knee kinematics more accurately.

The first modular UKAs were developed in the late 1960's and early 70's. These included the St Georg Sled, the Marmor knee, the Liverpool knee, the Manchester knee and Insall's Unicondylar knee. The first of these was the St Georg Sled, designed by Buchholz and first used in 1969[12]. It comprised of a biconvex metal sled and a flat ultra-high-density polyethylene tibial component. Studies of these prostheses showed promising results with Engelbrecht reporting that of the 226 prostheses implanted, 85% of patients were pain-free[13]. MacKinnon later found 79% of patients had good or excellent function[12]. Also, Ackroyd found good or excellent results for 77.9% of medial St Georg replacements when compared with 75.1% of the kinematic TKA[14]. The Manchester knee was first used in 1971, designed by Shaw & Chatterjee as a polycentric TKA for use in rheumatoid arthritis[15]. As an implant, it consisted of two unicondylar prostheses and had the advantage of being able to be used either as a total or unicompartmental arthroplasty. The Marmor modular knee was first used in 1972. There was no groove in the polyethylene component, thus allowing for rotation and preventing stress[16]. The results of this prosthesis were much debated, with Insall and Walter[17] reporting poor results (42% fair or poor), as did Laskin[18] whilst other authors reported good results [16]. In 1972, Cavendish & White developed the Liverpool knee arthroplasty[19]. The Liverpool knee was also a polycentric TKA with the flexibility of being used for UKA. A specific stereotactic jig system was developed especially for the Mark II Liverpool knee prosthesis introduced in 1974[19]. Walker[20] found promising results for the Liverpool knee: 96.9% of patients had reduced pain with 71.1% of those being pain-free or only causing minimal pain, and 77.3% of patient satisfaction. Walker, Ranawat & Insall's Unicondylar knee[21] was first used in 1976 and was designed to be an anatomical replacement allowing 120° of flexion. It consisted of a Vitallium femoral component, which mimicked the shape of the femoral condyles. The tibial component was made of high-density polyethylene shaped to the coronal curve of the femoral component[22]. Insall compared this prosthesis against the Duocondylar, Geometric, and Guepar prostheses and found their Unicondylar prosthesis gave good results[23].

The Oxford UKA heralded the biggest advance in modern day UKA. Goodfellow and O'Connor[24] noted the components should be shaped appropriately to allow distracting, sliding and rolling forces. Moreover, the prosthesis should apply only compressive forces to the tibial bone and the surviving soft tissue should be maximally retained and restored to natural tension. The first issue they faced in the design of the prosthesis was maximizing the contact area between the two components of the prosthesis. The most effective design for this would ideally be a ball and socket joint. However, if two of these were used either side of the joint then only one axis of motion would be possible or the mechanics of the ligaments would not allow this. On the other hand, if the prosthesis were made with two articular surfaces then the pressure would not be so widely distributed, resulting in greater wear of the surfaces. However, the joint would be more kinematically functional, and compressive stress would be transmitted through the joint. The use of a closely fitting unconstrained washer trapped by its shape between the rounded femoral component and the flat tibial component enables the maximum contact surface area whilst enabling a full range of movement[24]. The Oxford UKA consisted of a femoral component with spherical articular surfaces and a flat tibial component. In between two components, an unconstrained high-density polyethylene "meniscal" bearing was inserted that conformed to the metal components and was retained only by its shape and soft tissue tension[25]. This was first used in 1982 with adjustments made in 1987. The anterior lip of the meniscal bearing was also lowered to prevent it catching on the femur in extension[26]. The phase 3 Oxford UKA was introduced in 1998. It included a larger range of sizes and the instrumentation was designed so that the procedure could be performed using a minimally invasive approach[27]. The current annual report from the NJR in the UK showed that greater than 66% of the UKAs were Oxford[4]. However, the Zimmer Uni and the Sigma HP appear to be gaining in popularity as well[4]. A timeline of the key events is shown in Table 1.

Current Perspective

Data from the UK's NJR[4], shows that 75,719 UKAs have been performed between 2003 and 2015. Of these, fixed bearing type was used in 31.3% and mobile bearing type was used in 67.6% of the cases. Average patient age was 64 years (range: 18 – 97 years). 5-year survival rate was 93.56% and 10-year survival rate was 88.06%, which were lower than those of TKA (5-year survival rate: 97.86% (cemented) / 97.11% (uncemented), 10-year survival rate: 96.63% (cemented) / 95.81% (uncemented)). Also, results based on the Finnish arthroplasty register between 1980 & 2003 found no cost benefit of UKA over TKA due to its poorer long-term survival[28]. However, with the development of new prostheses using newer materials with improved wear properties and with closer attention to the accurate alignment of the prosthesis, the survival of UKAs will hopefully be maximised[29].

There are a number of current controversies regarding the use of UKAs as follows;

Is anterior cruciate ligament (ACL) deficiency a contraindication to UKA?

Isolated ACL injury increases the risk of developing OA tenfold[30]. A successful UKA requires both the cruciates to be preserved, although an intact ACL was only introduced as criteria in 1985[31]. UKAs performed in ACL-deficient knees have been noted to lead to disappointing results. Goodfellow found a 21.4% revision rate for the Oxford UKA within two years in the ACL-deficient knee[32]. Engh noted increased failure rates when both mobile-bearing and fixed-bearing UKAs were implanted in an ACL-deficient knee[33]. Tinius evaluated the midterm outcome of twenty-seven knees that underwent simultaneous ACL reconstruction and UKA and reported good functional results with no revision surgery at a mean follow-up of fifty-three months[34]. The Oxford Group compared outcomes following a combined ACL reconstruction (ACLR) and Oxford UKA with Oxford UKAs performed with an intact ACL[35]. The ACLR + UKA group were significantly better than the patients with an intact ACL. This could be partly explained by work by Trompeter who showed that patients with macroscopically normal ACLs in arthritic knees actually showed significant signs of histological degeneration[36]. Citak demonstrated that with respect to the Lachman and the pivot shift tests, single-bundle ACL reconstruction restored kinematics in the UKA knee to magnitudes similar to those in the ACL-intact knee[37]. An in-vivo kinematic study by Pandit demonstrated that normal knee kinematics is achieved in the ACL deficient arthritic knee, following ACL reconstruction and UKA[38].

Are UKAs performed best in old, thin and sedentary patients with no evidence of patellofemoral arthritis?

Kozinn and Scott suggested that patients who weighed more than 82kg, were younger than 60, extremely active, performed heavy labor, had chondrocalcinosis, or had any exposed bone in the patellofemoral joint, had increased rates of failure following UKA[39]. The Oxford Group challenged these contraindications and reviewed 1,000 Oxford UKAs at a mean follow-up of 5.6 years[40]. As a result, the clinical and functional outcome and survival of patients with each of the potential contraindications were similar to or better than those without each contraindication. Berend and Lombardi compared the failure rate of mobile-bearing, medial UKA in patients with and without radiographic evidence of patellofemoral degenerative changes using 638 knees. At 70 months, Kaplan-Meier analysis predicted 97.9% survival in knees with patellofemoral disease and 93.8% survival in those without it[41]. Kang assessed functional outcome in UKAs with and without the patellofemoral disease. At a mean of 3.4 years, the 195 knees showed no statistically significant difference between them[42]. These results support that patellofemoral involvement is not an absolute contra-indication to medial UKA. Heyse investigated the outcomes of UKA and patellofemoral arthroplasty in nine patients with bicompartmental OA[43]. After an average follow-up of 11.8 years, no surgical revisions were required and the Knee Society scores and WOMAC scores increased significantly. On the contrary, Morrison compared functional outcomes of bicompartmental knee arthroplasty (BKA) and TKA in patients with medial and patellofemoral OA, and the BKA group had less pain and significantly better function for the first 3 months after surgery, while it did not continue beyond 3 months[44].

Cemented vs. Uncemented Prosthesis

The majority of UKAs performed are cemented and is certainly the preferred method currently. However, Epinette reported good 5 to 13-year survival rates following a hydroxyapatite-coated uncemented UKA[45]. Lindstrand compared the medium term results of UKAs using cement with those without using cement. There were no differences in revision rates or other complications. However, authors reported that the cemented UKAs had a higher frequency of complete pain relief[46]. Campi conducted a systematic review of uncemented UKas (1,199 knees) and reported that clinical outcome, failures, reoperation rate, and survival were similar to those reported for cemented implants with a lower incidence of radiolucent lines[47].

Fixed vs. Mobile Bearing

The design rationale behind the mobile bearing was to improve knee kinematics, lower contact stresses and reduce polyethylene wear. Li performed an RCT of 56 knees in 48 patients wherein these knees were randomized to a fixed bearing (Miller/Galante) or a mobile bearing (Oxford) UKA. At two years, the mobile bearing UKAs had better knee kinematics, less radiolucency but equal Knee Society, WOMAC, and SF-36 scores[48]. Manson performed a retrieval analysis to investigate different wear modes in UKAs. Fixed bearing designs demonstrated increased articular surface wear, delamination and surface deformation. However, mobile bearing designs also underwent backside wear. When this was combined with articular wear, this actually resulted in higher overall damage score than the fixed bearing designs[49]. A knee simulator study performed by Kretzer described that there was no difference in kinematics and that the mobile-bearing designs showed increased in-vitro wear[50]. Despite this, a survivorship rate of 93% at 15 years for mobile bearings and 90% at 10 years for fixed bearings has been reported[51]. Fixed-bearing unicompartmental designs are not fully conforming, and this results in higher contact stresses at the articulating surfaces and a higher wear penetration rate[52]. On the other hand, there is no risk of bearing dislocation and an easier surgical technique is claimed[53]. Indeed, Paratte performed a retrospective review of 187 UKAs with a minimum 15-year follow-up and noted that more early complications were noted in the mobile-bearing group and no difference in survivorship[54]. Furthermore, very small differences were found between the two designs on gait analysis[55]. With respect to patients' perceptions of UKAs, Bhatarcharya noted that 83.5% of patients with fixed bearing UKAs were satisfied compared with 93.9% of those with mobile-bearing UKAs[56].

Lateral vs. medial UKA

Lateral UKA is performed ten times less frequently than its medial counterpart[57]. This can explain the less abundant literature of lateral UKAs when compared with the medial UKA. Marmor presented the first study to focus on lateral UKA in 1984; almost a decade after the first series regarding the medial UKA was published[58]. Radiostereometric studies indicate that internal tibial rotation in flexion leads to an increased posterior lateral condylar translation[59]. Thus the kinematics of the lateral compartment differs significantly to the medial side. As a result, a lateral UKA is often considered to be technically more demanding than medial UKA[60]. Historically, many comparative studies have shown significantly worse results for the lateral UKA, when compared with the medial UKAs. In 1981, Scott reported on 88 medial and 12 lateral UKAs[61]. The lateral procedure showed more failures (17%) than the medial UKA (1.1%). Gunther demonstrated 82% survival at 5-year follow-up with a lateral UKA[62]. 10% of their revisions were due to dislocation of the bearing, which contrasted significantly with the medial side (1%). This issue with the bearing dislocation led to the development of a domed lateral UKA. A recent series of 265 domed mobile bearing lateral UKAs demonstrated 92% survival at 8 years follow-up, with a dislocation rate of as little as 1.5%[63]. Therefore, a lateral UKA is still a worthy option in the patient with isolated lateral compartmental arthritis, but the careful patient selection and accurate surgical implantation are paramount.

Is revision of failed UKA easy?

One of the major advantages of a UKA is the relative bone conserving nature of the procedure. However, numerous national joint registries have documented increased revision rates for UKAs when compared with TKAs. The Oxford Group published the results of the first 1,000 minimally invasive phase 3 Oxford UKAs[64]. At a mean follow-up of 5.5 years, there was a 2.9% rate of implant related revisions. The most common reason for revision was a progression of arthritis in the lateral compartment, followed by dislocation of the bearing. If only implant-related re-operations were considered failures, the ten-year survival rate was 96%. However, Wynn-Jones noted that of the 80 Oxford UKAs revised to a TKA, the median tibial component thickness was 15mm. Thus, tibial bone defects were common at the time of UKA revision, often requiring revision components and a thicker polyethylene insert[65]. Chou commented on their UKA revisions and felt that

'Two-thirds of the revisions were technically difficult and required additional constructs'[66] and the clinical outcome after UKA revision was inferior to that of a primary TKA[66]. Pearse examined the New Zealand registry comparing revised UKAs to primary TKAs[67]. The re-revision rate for UKAs converted to a TKA was four times higher than the revision rate for primary TKAs and their clinical scores were significantly worse. The re-revision rate for UKAs revised to a further UKA was 13 times higher than the revision rate of a primary TKA[67]. Australian registry data has shown that there is an almost 30% cumulative re-revision rate at three years for UKAs revised to another UKA and that the re-revision rates for UKAs revised to a TKAs and primary TKAs were similar[68]. Järvenpää found that UKAs revised to a TKA showed significantly poorer clinical outcomes than primary TKAs in an 8-17 year follow-up study[69]. Despite the cost of a TKA revision being more than a UKA revision, a theoretical cost-benefit analysis showed that the money saved by lower implant prices and shorter hospital stay with UKA as compared with a TKA did not cover the costs of the extra revisions[28]. Most registry data also shows increased revision rate for UKAs when compared with TKAs. Despite the fact that UKAs outperformed TKAs with respect to functional scores on the New Zealand registry, the revision rate was three times as high[70]. However, if analyzing knees with a very poor outcome (OKS < 20 points), only about 12% of TKAs were revised compared with about 63% of UKAs with similar scores. This emphasizes the different thresholds for revision surgery with the two procedures.

Future Perspectives

It is difficult to imagine which concepts will enable a UKA to survive for up to 30 years. Improvements in polyethylene properties and kinematics of new UKA designs may help to improve longevity and functional outcome. A modern technological advance in computer-assisted design and imaging has led to the phenomenon of patient-specific knee implants. Van Den Heever demonstrated that a patient-specific UKA had lower contact stresses and more uniform stress distribution at the tibiofemoral joint than a conventional implant[71]. Steklov showed that patient-specific implants allowed for matching of the coronal femoral curvature, subsequently decreasing contact stress and point loading across the joint[72]. Koeck looked at the radiographic results of 32 patient-specific fixed bearing UKAs[73]. They noted restoration of limb axis, avoidance of implant malposition and enhancement of tibial coverage. A study by Konyves looked into long-term outcomes following a computer-assisted navigated UKA and found better implant positioning compared with a conventional UKA, while there was no difference in survivorship at nine years[74]. On the contrary, Weber found that navigation did not lead to better positioning of the implant[75]. Roche detailed the use of a robotic-arm-assisted UKA with CT guidance to enhance alignment of UKA. The robot is said to be "semiactive"; that is, the surgeon still retains control, but is assisted by robotic guidance[76]. Pearle reported that in the first ten patients treated with the MAKO system (MAKO Surgical Corp., FL, USA), all patients were within 1.6° of the mechanical axis[77]. Furthermore, Plate showed that soft tissue balancing was accurate up to 0.53 mm compared with the operative plan and 83 % of the cases were within 1 mm throughout ROM in 52 patients undergoing UKA using the MAKO system[78]. Also, Cobb[79] and Lonner[80] have shown that robotic-assisted surgery has increased accuracy in mechanical axis compared with manual UKA using Acrobot (Acrobot Co. Ltd, UK) and the MAKO system.

Conclusions

Over the last 50 years, the UKA has developed from a prosthesis that has limited use into an effective bone preserving the surgical option for unicompartmental OA. Despite being initially disregarded, the UKA is in the middle of a renaissance and there are a plethora of exciting future directions to pursue, with the ultimate goal of improved longevity and optimal function but the careful patient selection and precision in surgical technique remain the key to a successful outcome.

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Table 1

A timeline of the key events in the development of unicompartmental knee arthroplasty

Material used	**Year**	**Inventor**	**Name**
Acrylic	1954	MacIntosh	
	1960s	McKeever	
Vitallium	1964	MacIntosh	
Vitallium	1968	Gunston	Polycentric Knee Prosthesis
	1969		St Georg Sled
Stainless Steel High-density polyethylene	1971	Shaw and Chatterjee	Manchester

	1972	Cavendish and White	Liverpool
Polyethylene	1972	Marmor	Marmor Modular
	1974	Cavendish and White	Mark II Liverpool
Vitallium	1976	Insall, Walker and Ranawat	Insall's
Cobalt-chrome	1982	Goodfellow and O'Connor	Oxford