UNICOMPARTMENTAL KNEE ARTHROPLASTY

New Insights in Surgical Results and Knee Kinematics

H.A. Zuiderbaan

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Hendrik Aernout Zuiderbaan

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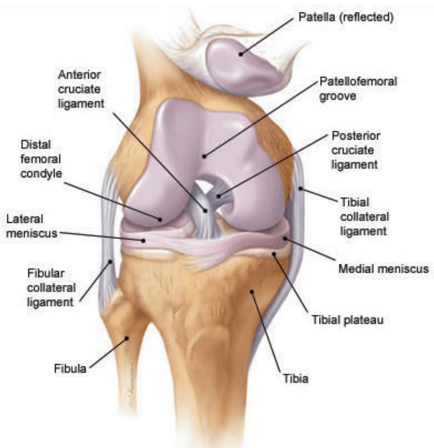
Introduction

The knee is the largest joint of the human body and one of the most complex from an anatomical and biomechanical point of view. The combination of intricate anatomic characteristics and the significant external forces that act on the knee makes that it is vulnerable for various injuries. Anatomically, it can be divided in three separate articulating compartments that permit flexion and extension, as well as internal and external rotation. Thorough knowledge of the anatomy and the associated biomechanical properties of the separate compartments are an essential cornerstone in the diagnosis of the various osseous and ligamentous injuries of the knee and their associated treatments.

Anatomy

The femur, tibia and patella are the osseous structures, which form the tibiofemoral and the patellofemoral articulations of the knee. The tibiofemoral joint can be divided in a medial and lateral compartment. The medial femoral condyle and the concave shaped medial tibial plateau form the medial compartment. In contrast to the medial tibial plateau, the lateral tibial plateau has a convex shape. It articulates with the lateral femoral condyle, which together form the lateral compartment of the knee. The patellofemoral compartment consists of the articulation of the dorsal surface of the patella with the patellofemoral groove of the distal femur, which is displayed in the figure.



Articular cartilage is the highly specialized connective tissue, which covers the articulating surfaces of bones. In the knee, it is found between the previously mentioned articulating surfaces of the various compartments. The primary function of articular cartilage is to transmit load with a low frictional coefficient by providing a smooth lubricated surface. The poorly vascularized properties of articular cartilage make that the tissue has a limited capacity for regeneration and repair. Therefore, preservation of articular cartilage viability is crucial for joint health.

Four strong ligaments provide stability to the knee. They are also known as the primary stabilizers. Their role is to prevent joint incongruence by ensuring normal kinematics and preventing joint dislocation and rotation. Optimal knee joint congruence is essential for the equal load distribution across the articular surfaces of the knee and a well-known influential factor of articular cartilage viability[1, 2]. The primary stabilizers consist of the anterior cruciate ligament (ACL), the posterior cruciate ligament (PCL), the medial collateral ligament (MCL) and the lateral collateral ligament (LCL). The ACL and PCL extend from the femoral notch to the central head of the tibia and provide anterioposterior and rotatory stability[3, 4]. The MCL inserts proximally at the posterior aspect of the medial femoral condyle and distally at the proximal medial side of the tibia. It provides primary restraint to valgus stress of the knee. The LCL prevents varus deviation by connecting the head of the fibula with the lateral femoral condyle. The meniscii, the recent described anterolateral ligament[5-7], the joint capsule and the periarticular muscles are considered as secondary stabilizers of the knee. They also provide stability to the knee. However, in contrast to the primary stabilizers they play a less dominant role in knee stability.

Due to the anatomical differences of the various compartments, the biomechanical properties of both compartments differ. The medial tibial plateau is concave, whereas the lateral plateau is convex. This results in a more distinctive internal rotation of the lateral tibiofemoral compartment during flexion of the knee[8, 9]. Also, both compartments do not bear load equally. During weight bearing in the neutrally aligned knee, 60-70% of the load is transferred over the medial compartment[10-12]. Therefore it is not surprising that degeneration of the of the medial compartment represents 75% of the disease burden and patellofemoral osteoarthritis occurs predominantly on the medial side.

Osteoarthritis

Osteoarthritis (OA), also known as degenerative joint disease, is the degenerative disease of articular cartilage and subchondral bone of articulating joints. It is a leading cause of muscoskeletal disability. Globally, the disease affects millions of people and the incidence and prevalence both increase with aging. Reports from the United States suggest that 85% of the population older than 75 years are affected by OA[13]. More specifically to OA of the knee, Murphey and associates reported that the estimated lifetime risk of symptomatic knee OA is 44.7%[14]. Also, the associated costs of the disease are significant. March and Bachmeier reported that the costs of OA of various Western countries are estimated to be 1-2.5% of the gross national product[15]. Given the current obese epidemic and the aging of our society, the incidence, prevalence and associated costs of OA are all expected to increase the upcoming 15 years[16].

There are several well-known factors that are associated with the risk and progression of the disease. These include age[17], obesity[18, 19], gender (i.e. women are twice as likely to develop OA than men)[20], joint incongruency[2], genetic predisposition[21, 22] and trauma. Whereas OA was first thought to be just "wear and tear" of the articular cartilage, modern insights show that all the various joint tissues are concurrently involved. These include bone, synovial membrane, cartilage, ligaments and the periarticular muscles. Despite the involvement of various tissues, altered mechanical load transmission across the articular cartilage is now believed to play a central role in the development of primary OA[23]. The unbalanced load transmission across the articulating surfaces will be translated in cellular and biochemical perturbation, which will lead to joint degeneration. Thus, OA should be considered as a joint disease with a combination of various systematic (i.e. genetics, gender) and local factors (i.e. biomechanically mediated) which will subsequently affect all various tissues of the joint and not only the AC.

Clinically, OA is characterized by pain, swelling, stiffness and decreased mobility. Moreover, severe OA is characterized by joint deformation. Traditional radiographic findings of knee OA include joint space narrowing, osteophytosis, subchondral cyst formation and sclerosis. Since the knee is a tricompartmental synovial joint, the disease can affect all the various compartments simultaneously. However, a distinct subgroup of patients presents with isolated symptomatic compartment OA. It is estimated that isolated medial compartment OA is seen in 10-29.5% of patients presenting with symptomatic OA, whereas the lateral symptomatic variant is less common with a reported prevalence of 1-7%[24, 25]. Due to the obese epidemic and aging of the western society, the incidence of patients presenting with symptomatic isolated OA is expected to increase the upcoming decade.

Surgical management of isolated compartment OA of the knee

In 1961, Jackson introduced the High Tibial Osteotomy (HTO) as the surgical solution for isolated compartment OA[26]. By correcting the axial alignment of the lower extremity, the diseased compartment of the knee will be off-loaded. In the case of genu varum for instance, load transmission across the diseased medial compartment will be changed to the lateral compartment. This will result in a reduction of symptoms that are associated with OA. Although the early results of this surgical strategy were excellent, the longer follow-up data was disappointing. Many patients developed knee pain and a substantial number of them were revised to a total knee arthoplasty (TKA)[27]. This led to the exploration of alternative strategies to address unicompartmental disease. The unicompartmental knee arthroplasty (UKA) was introduced in the 1970's. In contrast to the TKA, UKA only resurfaces the diseased compartment, while the contralateral compartment is preserved. The initial results of the UKA series were discouraging. Ten-year survivorship results were substantially lower than the alternative surgical methods[28-31]. This led to skepticism about this new form of treatment. In order to optimize the results of UKA, Kozinn and Scott defined the classic inclusion criteria for UKA in their 1989 paper[32]. They included isolated medial or lateral compartment osteoarthritis or osteonecrosis of the knee, the patient's age had to be older than 60 years and the patient's weight had to be less than 82 kg. Furthermore, the angular deformity of the affected lower extremity had to be less than 15 degrees and passively correctable to neutral at the time of surgery. Lastly, the flexion contracture had to be less than 5 degrees and the ideal range of motion 90 degrees. Strict adherence to these criteria led to improved results. Today, these classic criteria are still considered the gold standard for many surgeons. Further improvement of surgical techniques[33] and implant designs have contributed that the modern results of UKA show satisfying long-term results[34-37].

It seems that the modern UKA has several advantages over the TKA. First, since it is a more joint conserving procedure, the physiological properties of the knee are retained[38]. This leads to a better post-operative range of motion and post-operative subjective outcome results[39-41]. Second, less per-operative complications are noted[42]. Third, faster post-operative recovery will lead to a quicker return to work and sport in comparison to TKA[43, 44]. Lastly, in case of a revision, the conversion of a UKA to a TKA is less complicated than the revision of a primary TKA in terms of operative time and blood loss[45]. Together, all these factors have contributed that the UKA has become an attractive surgical treatment for isolated compartment OA and is growing in popularity[46-50].

Despite these advantages and successful results of the modern UKA, there are currently several ambiguities about the implant. Although single center studies show excellent results, the national registries tend to show higher revision rates of the UKA in contrast to TKA[51, 52]. Malposition of the implant, progressive degenerative changes of the contralateral compartment and unexplainable pain are the predominant causes for revision surgery[51-57]. Although Kozinn and Scott's classic inclusion criteria led to improvement of outcome and a decreasing rate of revision, the criteria were generated at a time that implant designs and surgical techniques were not yet perfected. Since then, minimal invasive approaches and improved implant designs have been introduced to the current orthopaedic practice[33, 53]. Moreover, recently there is a renewed interest in the use of robot-navigated assistance during UKA implantation in order to optimize the position of the implant. Multiple studies indicate that robot navigated assisted UKA will lead to a significant better position of the implant and a coronal plane alignment[58-63]. Both are known to be well-known factors of long-term UKA survival[64-66]. With the use of these modern robot-assisted techniques, the implantation and position of the UKA can be performed in a highly controlled manner. Since the robot navigated technique enables us to optimize the position of the implant, the use of this technique furthermore provides the unique opportunity to explore the other two frequent causes of UKA failure; unexplainable pain and progressive degeneration of the contralateral compartment. A better understanding of these two, will not only help us to optimize the results of patients undergoing UKA, but will also help us to identify the potential pre-operative factors which could influence our results. Therefore, in order to optimize the results of patients undergoing UKA, the goal of this thesis is to further investigate these two frequent causes that will lead to early UKA revision. By an extensive analysis of factors, which potentially predict subjective outcome and an evaluation of the alterations of the non-operated compartments following UKA this thesis has the following aims;

- To report a detailed overview of the modern indications, surgical outcomes and global trends in the use of UKA and high tibial osteotomy for isolated medial unicompartmental knee osteoarthritis.
- To identify the various factors that can potentially influence subjective outcome of patients undergoing medial UKA.
- To assess the role of magnetic resonance imaging in the evaluation of symptomatic patients following UKA, where the traditional tests fail to identify the underlying etiology.
- To analyze artificial joint awareness in patients which have undergone UKA and total knee arthroplasty.
- An extensive radiographic evaluation of the congruence alterations from the contralateral compartments following UKA that can potentially influence the osteoarthritic progression of the non-operated compartments.

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2

Modern Indications, Results and Global Trends in the use of Unicompartmental Knee Arthroplasty and High Tibial Osteotomy for the Treatment of Isolated Medial Compartment Osteoarthritis

A Review of Literature

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Abstract

This review evaluates the modern indications, subjective outcome scores and survivorship results of unicompartmental knee arthroplasty (UKA) and high tibial osteotomy (HTO) in the treatment of isolated medial compartment degeneration of the knee. Furthermore, by conducting a thorough review of literature, global trends in the use of both methods were evaluated.

Evaluating various articles, we note that the inclusion criteria for UKA are relatively broad in comparison to HTO, where age and BMI should be respected pre-operatively in order to optimize clinical outcome and survivorship results. Exact thresholds for UKA inclusion have been investigated properly, but a clear definition remains inconclusive. Both methods show good to excellent subjective outcome scores. Expected ten-year survivorship results are in favor of UKA in comparison HTO (90% versus 75% respectively). However, there is a lack of controlled data directly comparing both methods. Therefore it is not possible to draw conclusions at this point, which method is superior.

The broad range of UKA inclusion criteria and good to excellent subjective and survivorships results, have led to an increase among the western practices in the use of UKA, whereas an obvious deteriorating trend is observed in the use of HTO for patients with isolated single compartment OA.

Introduction

There is an increase in the incidence of patients with symptomatic isolated unicompartmental knee osteoarthritis (OA) who are too young and too functional active to be ideal candidates for total knee arthroplasty (TKA). Isolated medial compartment OA occurs in 10-29.5% of all cases, whereas the isolated lateral variant is less common with a reported incidence of 1-7%[1, 2]. In 1961, Jackson introduced the High Tibial Osteotomy (HTO) as a surgical solution for the treatment of single compartment OA[3]. The purpose of this procedure is to expand the life span of the articular cartilage by unloading and redistributing the mechanical forces over the non-affected compartment. Unicompartmental Knee Arthroplasty (UKA) was introduced in the 1970's as an alternative of TKA or HTO in case of single compartment OA. UKA is a joint resurfacing procedure where the affected degenerative compartment is treated by the implantation of prosthesis, while the non-affected compartments of the knee are preserved (figure 1).

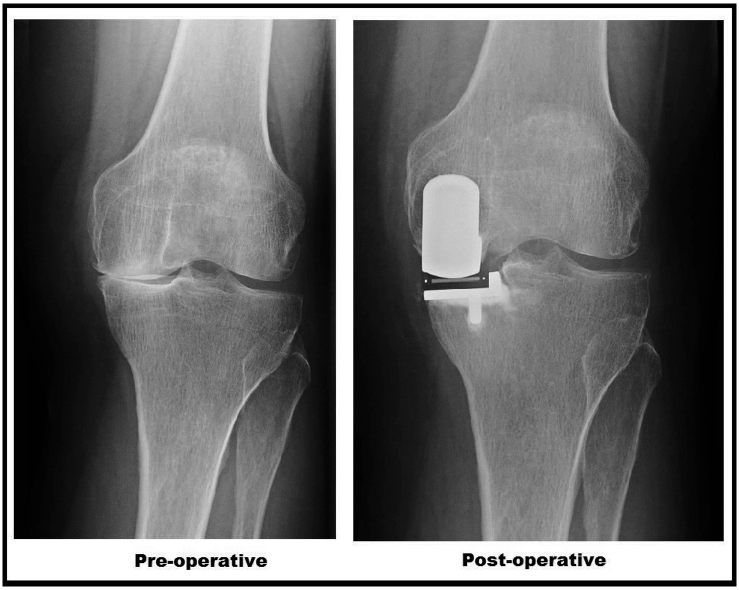

Figure 1. Pre- and six weeks postoperative weight bearing radiographs of a 66-year old female who underwent medial UKA (Oxford UKA, Biomet Inc., Warsaw, IN, USA) by the senior author for symptomatic isolated medial compartment OA.

Since the introduction of both methods, there has been a debate regarding appropriate candidacy for each procedure. The improvement of surgical techniques and implant designs has led surgeons to re-examine the appropriate selection criteria and contraindications for these procedures. Furthermore, due to the growing popularity and use of UKA, the legitimate question arises whether HTO still has a role in clinical practice.

Therefore the purpose of this study is to clarify current ambiguities by reporting an overview of the modern indications and associated results of both methods. Also, we analyzed the reports, which describe the recent trends in use of these two methods among the western practices in the treatment of single compartment OA.

Indications high tibial osteotomy for medial compartment osteoarthritis

Before the introduction of TKA and UKA for the treatment of single compartment osteoarthritis, HTO was the surgical manner to prevent management unilateral OA. By slightly overcorrecting the mechanical axis, the medial compartment will be decompressed which will favor the viability of the tissue and delay progressive compartment degeneration. Multiple techniques have been described to establish this decompression including; open wedge HTO (OWHTO) (figure 2), closed wedge HTO (CWHTO) (figure 3), 'en chevron' and dome osteotomy. The current controlled data is limited and does not prefer one technique to another[4, 5].

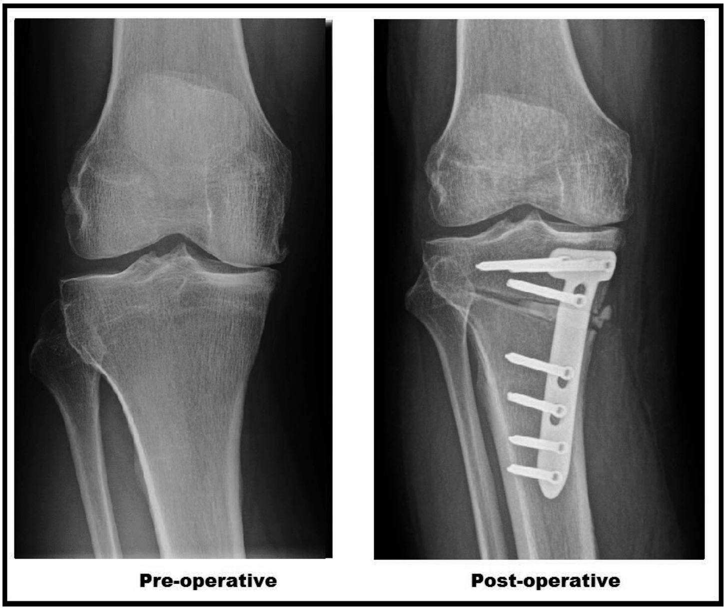

Figure 2. Pre- and three-months postoperative weight bearing radiographs of a 47-year old male who had undergone OWHTO by the senior author for symptomatic isolated medial compartment OA. Based on the pre-operative radiographic measurements of the lower extremity, a 10 degrees correction of the preexisting varus deformity was performed of the proximal tibia. Tricalcium phosphate substitution of the osteotomy was used to promote rapid bone healing. A Tomofix Medial High Tibial plate® was used for fixation.

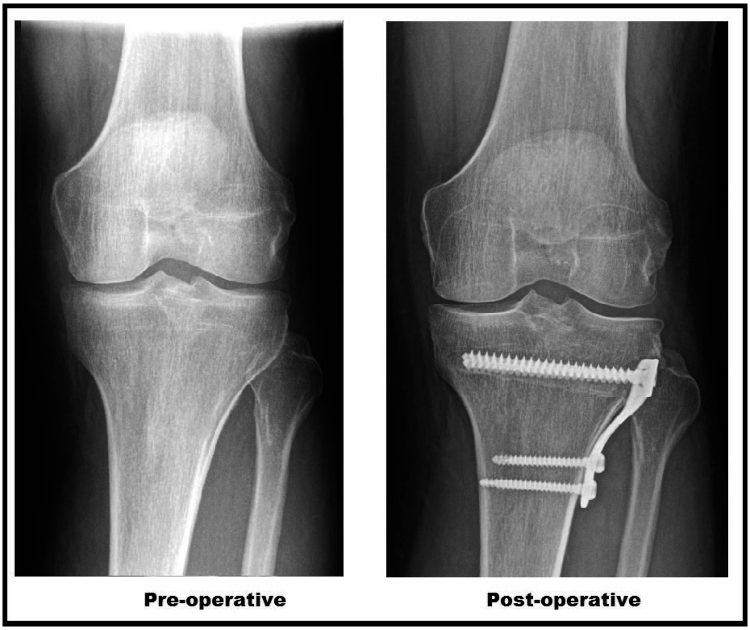

Figure 3. Pre- and three-months postoperative weight bearing radiographs of a 49-year old male who had undergone CWHTO for symptomatic isolated medial compartment OA. First, a midshaft fibular osteotomy was performed. Subsequently, an osteotomy of the proximal tibia was conducted and a wedge was removed according to the pre-operative radiographic measurements. Finally, the gap was closed, leading to a correction of the varus deformity (in this case 8°). Lastly, it was fixated with a plate and screws.

Traditionally HTO is indicated for young and active patients with radiographic single compartment OA[6]. The patient should be younger than 60 years with a normal weight. Furthermore the knee should be stable, have a good range of motion (i.e. flexion > 120˚) and pain should be localized on the tibiofemoral joint line.

Over the last few decades, similar results about the inclusion criteria are reported by numerous reports. These have led to a clear definition of inclusion criteria that should be pursued in order to optimize survivorship and clinical outcome.

To confirm age as a criteria for HTO inclusion, Trieb et al[7] concluded that patients undergoing HTO older than 65 years had a significant higher risk of failure compared to patients younger than 65 (relative risk 1.5, p=0.0461). This finding is in agreement with other studies, suggesting that especially young patients benefit from HTO[8-11].
Moreover, there is a clear relation between the survival of HTO and obesity. Akizuki et al[12] reported in their cohort of 159 CWHTO's that a pre-operative BMI>27.5 kg/m^2 is a significant risk factor of early failure. Using a BMI > 30 kg/m^2 as a threshold, Howells et al[9] found significant inferior KSS and WOMAC scores in the obese group 5 years following HTO.

Radiographically, presence of severe pre-operative compartment degeneration has been associated with early conversion to TKA. Van Raaij et al[13] and Flecher et al[11] both concluded that the best long-term survival grades can be achieved by selecting HTO candidates with mild compartment OA (i.e. Ahlback[14] grade I). However, in this group of patients the legitimate questions arises, if you have to treat them non-operatively instead[15, 16].

In conclusion, current literature supports the strict adherence for inclusion criteria when selecting a potential HTO candidate. Age, BMI and the pre-operative state of OA should be taken into account, in order to optimize clinical outcome and survivorship results in patients who undergo HTO.

Outcome High Tibial Osteotomy for medial compartment osteoarthritis
Multiple mid- to long-term results have been published comparing or describing results of the various surgical HTO techniques. Howells et al[9] noted an overall five year survival of 87% and 79% at 10 years following CWHTO. During the ten years following surgery a significant deterioration trend in clinical outcome scores and survivorship was observed. Others reported similar findings[17-19]. Raaij et al[13] described a probability of survival of 75% over a ten-year post-operative period following CWHTO. Hui et al[8] reported similar percentages. In their series of 455 patients following lateral CWHTO, the overall probability of survival was respectively 95%, 79% and 56% at five, ten and fifteen years following surgery. Niinimäki et al[10] used the Finnish Registry to report the survivorship of HTO at a national level. Using conversion to TKA as a cutoff point, they noted a five-year survivorship of 89% and 73% at ten years. To our knowledge there are currently two reports, which report substantial higher rates of survival. They both originated from Japan, reporting respectively 15 years survivorship results of 90%[12] and 93%[20]. The authors acknowledge that their results are significantly better than other countries. They stated that Japanese lifestyle, culture and body habitus therefore requires further investigation, making it unfortunately not possible at this time to compare western reports with them.

In an attempt to compare different survival rates of the various HTO techniques, Schallberger et al[21] conducted a retrospective study between CWHTO's and OWHTO's. At a median follow-up of 16.5 years, survival rates were comparative with the previous reported studies, showing an obvious deteriorating trend over time. Although numbers were limited, no significant differences were noted between the two used techniques with respect to survival and functional outcome. Recently, a randomized clinical trial by Duivenvoorden et al[5], published the mid-term (average follow-up six years) results comparing both techniques. Their results showed no significant differences in terms of clinical outcomes. Conversion to TKA was higher in the CWHTO group, whereas the OWHTO group had a higher number of complications.

Based on their results, the authors suggested that an OWHTO without autologous bone graft, is the best strategy for medial gonarthritis with a varus malaligment <12˚ treated by HTO.

Summarizing previous mentioned studies about the results following HTO, we note a similar deteriorating trend over time with an expected 10-year survivorship of 75%. With use of modern implants and surgical techniques, there is currently an obvious lack of evidence to prefer one surgical method of HTO to another.

Indications Medial Unicompartmental Knee Arthroplasty

Since the introduction in the 1970's the use of UKA's for the treatment of single compartment osteoarthritis remains a constant subject of debate. Particularly the high failure rates at the time of introduction led to skeptical thoughts about this new form of treatment[22]. Kozinn and Scott[23] defined the classic indications and contraindications. Indications included isolated medial or lateral compartment osteoarthritis or osteonecrosis of the knee, patient's age older than 60 years and weight less than 82 kg. Furthermore, the angular deformity of the affected lower extremity had to be less than 15 degrees and passively correctable to neutral at the time of surgery. Lastly, the flexion contracture had to be less than 5 degrees and the ideal range of motion 90 degrees. The classic contraindications included high activity patients, age younger than 60 years and inflammatory arthritis. Strict adherence led to increased implant survival and lower revision rates. Due to improved surgical techniques, modern implant designs and increasing experience with the procedure, the surgical indications for UKA have expanded. The exact thresholds for UKA inclusion however, remain unanswered in literature.

Traditionally, UKA was not indicated for patients younger than 60 years[23]. However, modern literature proves otherwise. Using the Knee Society Score (KSS), Thompson et al[24] reported that younger patients did better than older patients 2 years following UKA implantation using various type of implants. Analyzing survivorship results, Heyse and co-workers[25] concluded that UKA could be successfully performed in patients younger than 60 years old with reported 15-year survivorship results of 85.6% and excellent outcome scores. Others report similar findings as well[26-28].

Evaluating the influence of weight, Thompson et al[24] showed that obese patients did not have a higher rate of revision, but showed a slower progression of improvement two years following UKA. At a minimum follow-up of seven years (range 7-22), Cavaignac et al[29] concluded that weight did not influence survivorship of UKA. Also others[30-33] found no significant influence of BMI in terms of survival in their reports.
Reports about pre-operative radiogaphical parameters that could potentially influence UKA results are limited. Niinimäki et al[34] found between 113 medial UKA's, that mild degeneration

of the medial compartment on pre-operative radiographs was associated with significantly higher failure rates. They concluded that other choices of treatment should be preferred in the absence of severe isolated compartment OA.

Although the classic indications by Kozinn and Scott[23] have led to good to excellent results following UKA, improvement of implants and surgical techniques[35-38] have led to an expansion of these criteria. Modern reports prove that age or BMI should not be used as exclusion criteria for UKA candidates. Radiographically, there should be significant isolated compartment degeneration, in order to optimize patient reported outcome and survivorship.

Outcomes of Medial Unicompartmental Knee Arthroplasty

Improved implant designs and modern minimal invasive techniques have led to a change in outcome results and a renewed interest in the implant. Over the last decade there have been multiple reports about the various modern UKA implants and their survivorship. Evaluating various reports since the time of introduction of the UKA in the 1970's, we note a constant increase in implant survival over time. Koskinen et al[39] used registry data on 1819 UKA's using the Finnish Arthroplasty Register from 1985 till 2003. Ten year survival data of the Oxford UKA (Biomet Inc., Warsaw, IN, USA) was respectively 81%, the Miller-Galante II UKA (Zimmer Inc, Warsaw, IN, USA) 79%, the Duracon 78% (Howmedica, Rutherford, NJ, USA) and the PCA (Howmedica, Rutherford, NJ, USA) 53%. In patients aged under 60 at the time of index surgery, Heyse et al[25] reported 10 and 15 year follow-up data of 223 patients receiving the Genesis Unicondylar implant (Smith & Nephew, Memphis, TN, USA) between 1993 and 2005. Survivorship of the entire cohort was 93.5% at 10 years and 86.3% at 15 years with a good to excellent KSS. Similar numbers in cohorts younger than 60 years have been reported by Schai et al[26] using the PFC system (Johnson & Johnson, Raynham, MA, USA) and Price et al[27] using the medial Oxford UKA. They both reported excellent survivorship percentages of respectively 93% at 2-6 years follow-up and 91% at 10 years follow-up. The outcome in older patients seems to be satisfying as well. Another multicenter report by Price et al[40] on the medial Oxford UKA, showed a 15-year survival rate of 93%. Berger et al[41] reported similar numbers with the Miller Galante prosthesis with survival rates of 98% at ten years follow-up, 95.7% at 13 years and 92% of patients showing good to excellent Hospital for Special Surgery scores.

Although various modern implants are proven to show good to excellent results, the historical question whether to use a mobile or fixed bearing UKA, remains unanswered. In an attempt to answer this question, Peersman et al[42] recently performed a systematic review. Using 44 papers involving 9463 knees, they noted comparable revision rates between the two type of implants. Another recent study tried to answer the question whether it is the design of the implant or the surgeon's experience which is crucial for the survival of the implant[43]. Retrospectively they concluded that prosthetic component positioning is the keypoint for good survivorship results. Others reported that high volume centers are crucial to obtain satisfying results of UKA and lower revision rates.[44-46].

Based on these previous mentioned studies, we note that if a UKA is frequently being performed, 10-year survivorship percentages of >90% can be expected with good to excellent outcome results.

Medial Unicompartmental Knee Arthroplasty versus High Tibial Osteotomy

Cohorts directly comparing the two treatment modalities are scarce and the majority is retrospective in nature. Stukenborg-Colsman et al[47] used computer randomization between 1988 and 1991 for patients with medial compartment OA to either undergo CWHTO (32 patients) according to a technique reported by Coventry[48], or to undergo UKA (28 patients) using the unicondylar knee sliding prosthesis, Tübingen pattern (Aesculap®, Tuttlingen, Germany). Patients were assessed at 2.5, 4.5 and 7.5 years following surgery. First, more post-operative complications were noted in the HTO group. At 7-10 year follow-up, 71% of the HTO group and 65% of the UKA group reported an excellent KSS. The average range of motion was 103˚ (35˚- 140˚) following UKA and 117˚ (85˚- 135˚) following HTO during that same assessment. Lastly, although differences were not significant, Kaplan-Meier survival analysis was 60% for the osteotomy group and 77% for the UKA group at 10 years. Although their used implant did not show promising results in comparison to other implants, the authors concluded that due to improved implant designs and image guided techniques over time, better long-term successes can be expected from the UKA in comparison to the HTO. The other randomized prospective study, Börjesson et al[49] evaluated pain during walking, range of motion, the British Orthopaedic Association (BOA) score and gait variables at 1 and 5-year follow-up. By drawing lots, patients with moderate medial OA (i.e. Ahlbäck grade I-III) were randomly selected to undergo CWHTO or UKA (Brigham, DePuy). With regards to the BOA score, range of motion, and pain during walking, no significant differences were noted between the two groups at 3 months, 1 year and 5 year following surgery. Gait analysis over time only showed significant differences in favor of UKA 3 months following surgery. At one and five years follow-up no significant differences were noted.

In attempt to clarify current ambiguities, Fu et al[50] conducted a systematic review including all competitive studies. Eleven studies were identified, including 5840 patients (5081 UKA, 759 HTO). While the HTO group did have a significant better range of motion compared to UKA, the UKA groups showed significant better functional results. Walking velocity after both procedures was significantly higher among the UKA group. The authors suggested that this might have been caused by the different post-operative regimes, including a whole leg plaster cast for six weeks in the HTO group, whereas UKA allows immediate post-operative weight-bearing. With respect to survival and complications of both treatments, no significant differences were observed when all data was pooled. Despite these results the authors acknowledge the limitation of available randomized clinical trials and the multiple used techniques and implants. We share the author's assertion that larger prospective controlled trials are needed. These are crucial to give a definitive answer on the current uncertainty in regards to the use of the two treatment strategies for isolated compartment OA.

Current trends in the use of HTO and UKA

Evaluating the national registries and recent reports, we note that there is an obvious global shift in the use of the HTO as well as UKA. Despite the lack of national HTO registries, there are a few reports, which describe the use of TKA, UKA and HTO among the western population over the last two decades. Using data from the Swedish Knee Arthroplasty Register from 1998 till 2007, W-Dahl et al[51] reported a threefold increase in the use of UKA's, while the use of HTO halved during that same period. Niinimäki et al[52] reported similar findings using the Finnish National Hospital Discharge Register. They noted a steadily annual osteotomy decrease of 6.8%, whereas the numbers of implanted UKA's increased sharply after introduction of the Oxford UKA, phase 3 (Biomet Inc., Warsaw, IN, USA). These findings are consistent with several reports from Northern America. From 1985 to 1990, Wright et al[53] reported in their epidemiological analysis an 11 -14% annual osteotomy decrease among the elderly, while a 3-4% decrease per year was noted in patients younger than 65 years. Nwachukwu et al[54] recently compared the UKA and HTO practice patterns between 2007 and 2011, utilizing data from a large US private payer insurance database. They noted an annual growth rate of 4.7% in the utilization of UKA, while the growth rate of HTO declined annually with 3.9%. Furthermore, based on their subgroup analysis, they speculated that there is a demographic shift towards UKA as opposed to the TKA, especially in older women. Bolognesi et al[55] have further investigated this last statement. Evaluating all Medicare beneficiaries who underwent knee arthroplasty in the US from 2000 to 2009, they noted a 1.7-fold increase of the TKA over that period, whereas the use of UKA increased 6.2-fold. Since that they did not observe any substantial changes in patient characteristics over time, they hypothesized that a possible broadening of inclusion criteria may have led to this expansion of UKA implantation.

A possible explanation for the current global shift in favor of UKA is multifactorial. First, where the UKA was considered as a technical demanding procedure, improved surgical techniques, image guidance and robot assistance[56] have made it relatively less difficult for surgeons to implant UKA's. Secondly, are the lower reported perioperative morbidities that are associated with UKA surgery[57]. It is our belief that all these factors have contributed to decreasing global trend in the use of HTO and the increasing use of UKA in the treatment of unicompartmental OA.

Conclusion

In conclusion, current literature suggests the inclusion criteria for HTO have been well investigated and defined, whereas the UKA criteria remain a matter of debate but appear to be expanding. The long-term survivor results of both procedures seems to be in favor of UKA, while both procedures show good to excellent patient satisfaction. The broadening range of inclusion criteria and consistent reports of durable outcomes coupled with excellent patient satisfaction is the likely explanation for the observed shift towards UKA in the treatment of isolated compartment degeneration.

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3

Predictors of Subjective Outcome After Medial Unicompartmental Knee Arthroplasty

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Abstract

Background:

Unexplainable pain following medial unicompartmental knee arthroplasty (UKA) remains a leading cause for revision surgery. Therefore, the aim of this study is to identify the patient-specific variables that may influence subjective outcomes following medial UKA in order to optimize results.

Methods:

Retrospectively, we analyzed 104 consecutive medial UKA patients. The evaluated parameters consisted of; age, BMI, gender, pre-operative radiographic severity of the various knee compartments and pre- and postoperative mechanical axis alignment.

Results:

At an average of 2.3 years follow-up, our data demonstrates that BMI, gender and preoperative severity among the various knee compartments do not influence WOMAC results. Preoperatively, patients younger than 65 years had inferior WOMAC stiffness (4.6 vs. 2.9,p=0.001), pain (9.7 vs. 7.6,p=0.041) and total (37.2 vs. 47.6,p=0.028) scores versus patients aged 65 years or older. Postoperatively, only the difference on the WOMAC stiffness subscale remained significant between both age groups, in favor of patients aged 65 years or older (1.0 versus 1.5,p=0.035). A postoperative varus mechanical axis alignment of 1-4° correlated to significantly superior WOMAC pain, function and total scores compared to a varus of ≤1° or ≥4°.

Conclusion:

Our data suggests that greater pain relief can be expected in patients below 65 years of age, and that a postoperative lower limb alignment of 1-4° varus should be pursued. Taking these factors into consideration will help to maximize clinical outcomes, fulfill patient expectations following medial UKA and subsequently minimize revision rates.

Introduction

Treatment options for isolated medial unicompartmental osteoarthritis (OA) of the knee have long been a subject of debate. Operative techniques for isolated medial compartment OA include high tibial osteotomy (HTO), unicompartmental knee arthroplasty (UKA) and total knee arthroplasty (TKA). Early results of UKA were discouraging, with failure rates of up to 30% reported by Insall et al[1]. In response to these initial results, Kozinn and Scott proposed a set of criteria to define the ideal medial UKA candidate. These criteria included (I) low functional demand, (II) age >60 years, (III) weight <82 kg, (IV) range of motion >90°, (V) minimal pain at rest, (VI) flexion contracture <5° and (VII) a passively correctable angular deformity.

Strict adherence to these guidelines, improved implant designs and advanced surgical techniques have contributed to a resurgence of UKA as a treatment modality – evidenced by satisfying survivorship results, excellent outcome scores and a constant growth trend in the utilization of UKA[2-6]. While various series report similar survivorship results of UKA and TKA[7-9], national registries continue to show higher revision rates following UKA[10-14]. Persistent unexplainable pain continues to be a leading cause of revision surgery[11, 14].

In order to optimize outcomes and minimize the incidence of revision, it is essential to clarify the various patient-specific characteristics that may influence subjective outcomes. Using a large prospective cohort, the purpose of this study was to identify and evaluate the impact of various preoperative patient variables, including radiographic parameters, on the subjective outcomes of patients undergoing medial UKA. This study aims to optimize the outcomes of patients receiving medial UKA by better managing patient expectations and decreasing the risk of subsequent revision.

Methods

This study is based on a prospective cohort of patients assembled for the OA database of the senior author. Following Institutional Review Board approval by our hospital, an electronic registry search was performed for all patients who underwent medial UKA between October 2010 and June 2012. Surgical inclusion criteria for UKA were (I) isolated medial unicompartmental OA, (II) intact anterior cruciate ligament, (III) correctable varus deformity of the medial compartment, and (IV) a fixed flexion-deformity of <10°. The presence of preoperative radiographic Kellgren and Lawrence (KL)[15] grade III-IV OA in the lateral compartment was considered to be a contraindication for UKA. Furthermore patellofemoral related joint symptoms (anterior knee pain with sitting [i.e. “theatre sign”]) were also considered as a contraindication. Patients with any history of trauma, anterior cruciate ligament deficiency or reconstruction, inflammatory arthritis or prior simultaneous bilateral UKA were excluded from the study.

Implant and Surgical Technique

All enrolled patients received the identical cemented fixed bearing RESTORIS® MCK Medial Onlay implant (MAKO Surgical Corporation, Ft. Lauderdale, FL, USA). This tibial onlay implant has a metal base plate and is placed on top of a flat tibial cut, supported by a rim of cortical bone for direct support. A robot-assisted surgical platform[16, 17] (MAKO Tactile Guidance System, MAKO Surgical Corporation, Ft. Lauderdale, FL, USA) was used for preparation of the tibial and femoral surfaces during medial UKA. The goal was a relative undercorrection from the preexisting varus deformity in order to avoid osteoarthritic progression of the lateral compartment. The senior author, who has extensive experience in robot-assisted UKA, performed all surgeries.

Investigated Parameters

The investigated variables were divided in two groups; (I) patient-specific and (II) radiographic. The potential subjective influence was retrospectively analyzed using the database that consisted of the prospectively collected data. Patient-specific variables consisted of age, gender and body mass index (BMI). Patients were classified as young or old based on a cutoff value of 65 years of age. Using the official World Health Organization definition, a cutoff of 30 kg/m^2 was used to classify patients as non-obese or obese.

Radiographic variables included preoperative severity of OA in the medial compartment, lateral compartment, patellofemoral (PF) compartment and mechanical axis alignment. OA severity was classified on the KL scale, using preoperative weight bearing anteroposterior radiographs of the knee[15]. Mechanical axis alignment was measured on weight bearing hip-to-ankle radiographs, using the hip-knee-ankle (HKA) angle[18]. Preoperative HKA angles were subdivided into 3 groups by varus (A: <5°, B: 5-10°, C: >10°) to evaluate their effect on postoperative functional outcomes. Postoperative HKA angles were similarly divided into 3 groups by varus: (I) ≤1°, (II) 1-4°, (III) ≥4°. Radiographs were obtained preoperatively and at 6 weeks postoperatively.

Outcomes

Patients with inadequate follow-up or missing data that were operated between October 2012 and June 2012 were excluded from the study. Patients were asked to complete the Western Ontario and McMaster Universities Arthritis Index (WOMAC) questionnaire as part of the routine work-up, preoperatively and at a minimum of 2.0 years (average 2.3 years, range 2.0 – 3.7 years) following surgery. The WOMAC Index is a broadly used questionnaire used to evaluate physical function and symptoms in patients with OA of the hip or knee. The survey consists of 24 items, subdivided within three domains: pain (5 questions, range 0 – 20), stiffness (2 questions, range 0 – 8) and physical function (17 questions, range 0 – 68). The sum of the three domain scores produces a total score (range 0 – 96). A score of 0 represents the best possible outcome and a score of 96 the worst (Likert Scale). This study evaluated both the total WOMAC score and individual domain scores for each parameter studied, both preoperatively and at two-year follow-up.

Statistical Analysis

Descriptive analyses were reported using means and standard deviations (±) for continuous variables and frequencies and percentages for discrete variables. Inferential statistics of all patient-reported outcome measures were performed using independent sample t-tests (or one-way ANOVA) for differences in continuous variables and Chi-square or Fisher's exact tests for categorical variables. All analyses were performed using SPSS version 21.0 (IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.). A p-value < 0.05 was considered as statistically significant.

Results

Overall, 232 patients underwent medial UKA during between October 2010 and June 2012. Pre- or post-operative WOMAC scores were absent in 72 patients. Standardized radiographic follow-up evaluation (which included long leg alignment films) was unable in 56 patients. As such, 104 medial UKA patients (55 men, 49 women) with both a complete radiographic survey and patient reported outcome measures were available for inclusion in this study. None of these patients underwent revision surgery during the follow-up time. The average age at the time of surgery was 65.0 years (±9.2, range 47.1 – 86.8). Seventy-two patients (69.2%) had a BMI < 30 m^2/kg (average 26.2, range 18.3 – 29.7) and 32 patients (30.8%) had a BMI ≥ 30 m^2/kg (average 33.2, range 30.0 – 39.1). A significant improvement of all WOMAC domains was noted following UKA implantation (figure 1).

The average preoperative mechanical axis alignment was 7.6° (± 3.8°) of varus, which decreased to 2.8° (± 2.2°) of varus postoperatively (p<0.0001). Twenty-three patients had a preoperative varus deformity of <5° (average 3.1°, range 0.1° – 4.6°), 56 a varus deformity of 5-10° (average 7.1°) and 25 a varus deformity of >10° (average 12.9° range 10.1° – 16.0°). Postoperatively, two patients were overcorrected (respectively 3.4° and 1.6° of valgus). Twenty-eight patients had a HKA angle between 0°- ≤1° varus (average 0.6°), 42 a HKA angle between 1° and 4° of varus (average 2.5°) and 32 a varus deformity of ≥4° (average 5.6°, range 4.1°- 8.1) (Table 1). The distribution of osteoarthritic severity by compartment is displayed in Table 2. Radiolucent lines were present in 38% of cases. None of them were identified as pathologic.

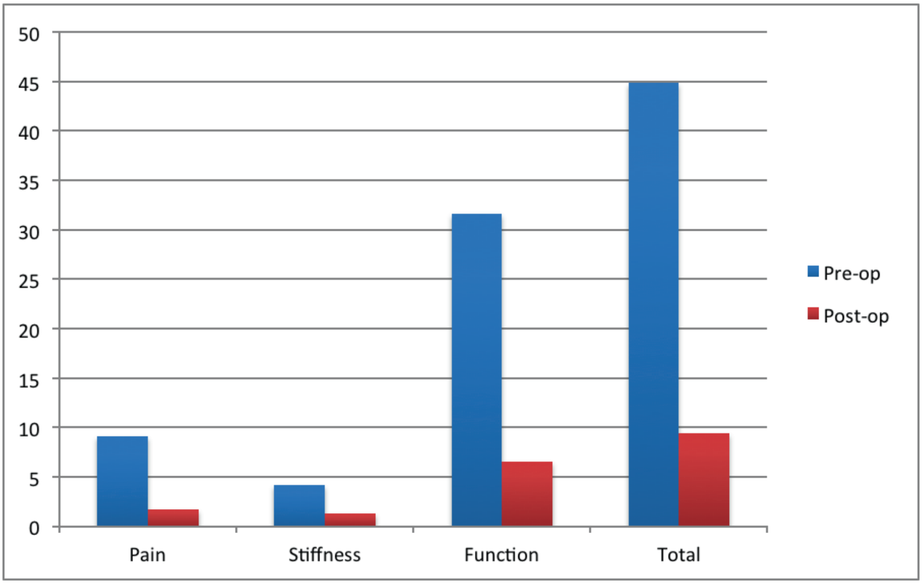

Figure 1. Improvement of the various WOMAC domains following medial UKA at an average of 2.3 years follow-up. All domains showed a significant ($p<0.01$) improvement at the time of follow-up.

Table 1. Distribution of the Preoperative and Direct Postoperative Varus Mechanical Axis Alignment.

HKA angle (varus)		N
Preoperatively	0-5°	23
	5-10°	56
	10-15°	25
Postoperatively	0- < 1°	28
	1-4°	42
	>4°	32

Two patients were overcorrected into valgus. HKA, hip-knee-ankle.

Table 2. Distribution of the Number of Patients With the Measured Kellgren and Lawrence (KL) Grades of the Various Compartments Preoperatively.

	KL Grade				
	0	**1**	**2**	**3**	**4**
Medial Compartment	-	-	30	50	24
Lateral Compartment	51	32	21	-	-
PF compartment	41	49	14	-	-

Preoperative WOMAC Scores

Preoperatively, we noted that patients younger than 65 years old reported significantly more pain (9.7 vs. 7.6 respectively, p=0.041) and stiffness (respectively 4.6 vs. 2.9, p=0.001) than patients older than 65 years. In addition, total preoperative WOMAC scores were significantly inferior among the younger group (37.2 vs. 47.6, p=0.028). No significant differences were noted between groups for the remaining patient-specific or radiographic parameters examined (Table 3 and 5).

Improvement after Medial UKA

Evaluation of improvement following medial UKA revealed significant differences in favor of patients younger than 65 years old versus patients older than 65 years on the WOMAC pain subscale (Δ7.7 versus Δ6.3, p=0.04) and WOMAC total score (Δ36.4 versus Δ29.4, p=0.002). The other investigated parameters did not show significant differences in the magnitude of improvement following medial UKA implantation.

Postoperative WOMAC Scores

Postoperative WOMAC stiffness scores differed significantly in favor of patients older than 65 years (p=0.035). The pre-operative significant WOMAC pain subscale and total subscale differences were absent between young and old patients at an average of 2.3 years following surgery. BMI, gender and the pre-operative severity of OA did not significant influence the WOMAC domains at final follow-up (table 4). Evaluation of radiographic parameters revealed a strong correlation between postoperative mechanical axis alignment and WOMAC scores across multiple domains. Patients with a postoperative HKA between 1-4° reported significantly superior WOMAC scores in the domains of pain, function and total score versus patients with a postoperative HKA angle ≤1° or ≥4° (Table 5).

Table 3. Preoperative WOMAC subscales and WOMAC total scores.

		Number	Pain (95% CI)	Stiffness	Function	WOMAC Total
Age	<65	56	9.7 (8.6- 10.7)	4.6 (4.1- 5.1)	33.3 (29.8- 36.8)	47.6 (42.8- 52.3)
	65+	48	7.6 (5.8- 9.3)	2.9 (2.0- 3.7)	26.9 (21.1- 32.7)	37.2 (29.3- 45.1)
	p-value		**0.041**	**0.001**	0.064	**0.028**
Sex	M	55	8.7 (7.5- 9.9)	4.2 (3.6- 4.9)	29.4 (25.3- 33.6)	42.4 (36.7- 48.1)
	F	49	9.5 (8.2- 10.8)	4.1 (3.4- 4.7)	33.9 (29.5- 38.3)	47.4 (41.4- 53.4)
	p-value		0.39	0.741	0.144	0.235
BMI	<30	72	9.1 (8.0- 10.2)	4.2 (3.7- 4.8)	31.2 (27.6- 34.9)	44.5 (39.5- 49.5)
	30+	32	9.1 (0.8- 7.4)	4.0 (3.1- 4.9)	32.2 (26.6- 37.9)	45.3 (37.6- 53.0)
	p-value		0.981	0.681	0.768	0.869
Medial KL-grade	I-II	30	9.9 (8.3- 11.4)	4.1 (3.3- 4.9)	35.5 (30.4- 40.6)	49.5 (42.5- 56.4)
	III-IV	74	8.7 (7.5- 9.8)	4.2 (3.6- 4.8)	29.4 (25.6- 33.1)	42.1 (37.0- 47.3)
	p-value		0.211	0.832	7.5	0.096
Lateral KL-grade	0	51	9.1 (8.1- 10.1)	3.7 (3.1- 4.3)	31.0 (26.8- 35.1)	43.8 (40.8- 46.7)
	I	32	9.2 (8.1- 10.3)	4.4 (4.0- 4.9)	32.6 (27.6- 37.6)	46.1 (41.9- 50.3)
	II	21	9.0 (8.1- 10.0)	3.4 (2.9- 3.8)	30.8 (28.0- 33.7)	43.2 (39.8- 46.5)
	p-value		*	*	*	*
PF KL-grade	0	41	9.1 (8.2- 10.3)	3.6 (3.0- 4.1)	30.2 (25.0- 35.2)	42.9 (36.8- 49.0)
	I	49	9.1 (8.2- 10.2)	4.4 (3.7- 5.0)	33.6 (27.8- 37.3)	47.0 (41.5- 52.6)
	II	14	8.7 (7.5- 10.0)	4.0 (3.3- 4.6)	30.4 (26.0- 34.1)	43.0 (39.3- 46.8)
	p-value		*	*	*	*

Patients <65 years had inferior WOMAC pain (P-value = 0.041), stiffness (P-value= 0.001) and WOMAC total (P-value = 0.028) scores pre-operatively compared to years. All the preoperative differences between the various preoperative severity classes of osteoarthritis were not significant (*P > .05). BMI, body mass index; KL, Kellgren and Lawrence; WOMAC, Western Ontario and McMaster Universities Arthritis Index.

Table 4. Postoperative WOMAC subscales and WOMAC total scores.

		Number	Pain (95% CI)	Stiffness	Function	WOMAC Total
Age	<65	56	2.0 (1.3- 2.7)	1.5 (1.2- 1.8)	7.6 (5.2- 10.0)	11.1 (7.9- 14.4)
	65+	48	1.3 (0.6- 2.1)	1.0 (0.6- 1.3)	5.6 (3.0- 8.1)	7.9 (4.4- 11.3)
	p-value		0.175	**0.035**	0.261	0.175
Sex	M	55	2.0 (1.3- 2.7)	1.4 (1.0- 1.7)	7.7 (5.3- 10)	11.1 (7.8- 14.3)
	F	49	1.3 (0.6- 2.1)	1.1 (0.7- 1.5)	5.5 (2.9- 8.0)	7.9 (4.3- 11.4)
	p-value		0.165	0.368	0.221	0.195
BMI	<30	72	1.8 (1.1- 2.4)	1.3 (1.0- 1.6)	6.7 (4.5- 8.8)	9.8 (6.8- 12.7)
	30+	32	1.5 (0.6- 2.5)	1.1 (0.6- 1.6)	6.6 (3.4- 9.7)	9.2 (4.9- 13.6)
	p-value		0.684	0.534	0.949	0.836
Medial KL-grade	II	30	1.9 (0.8- 2.9)	1.5 (1.0- 2.0)	7.6 (4.1- 11.2)	11.0 (6.2- 15.9)
	III-IV	74	1.6 (1.0- 2.3)	1.3 (1.0- 1.6)	6.7 (4.6- 8.9)	9.6 (6.8- 12.5)
	p-value		0.686	0.449	0.666	0.618
Lateral KL-grade	0	51	1.6 (1.2-2.0)	1.3 (0.9- 1.7)	5.7 (4.5- 6.8)	8.6 (6.4- 10.6)
	I	32	1.8 (1.4- 2.2)	1.5 (1.2- 1.8)	7.5 (5.5- 9.3)	10.8 (8.8- 12.6)
	II	21	1.8 (1.4- 2.3)	0.9 (1.6- 1.1)	7.0 (6.0- 8.0)	9.7 (8.3- 11.0)
	p-value		*	*	*	*
PF KL-grade	0	41	1.8 (1.4- 2.2)	1.3 (0.9- 1.7)	5.3 (4.5- 6.1)	8.4 (7.1- 9.9)
	I	49	1.5 (1.1- 1.9)	1.3 (0.9- 1.8)	6.7 (5.3- 7.9)	9.5 (8.0- 11.0)
	II	14	2.1 (1.5- 2.5)	1.0 (0.7- 1.4)	9.8 (8.1- 11.7)	12.9 (10.3-14.5)
	p-value		*	*	*	*

Only the post-operative stiffness score remained significant in favor of patients >65 years (P= 0.035). All the postoperative differences between the various preoperative severity classes of osteoarthritis were not significant (*P > .05). BMI, body mass index; KL, Kellgren and Lawrence; PF, patellofemoral; WOMAC, Western Ontario and McMaster Universities Arthritis Index.

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Table 5. WOMAC Scores in the Various Pre-and Post-Operative Alignment Groups.

Pre-Op Varus (SD)	Pain	Stiffness	Function	Total
<5	8.2 (±0.8)	4.3 (±1.8)	29.0 (±7.1)	41.5 (±7.6)
5-10	9.6 (±4.4)	4.4 (±1.6)	31.9 (±12.5)	45.9 (±17.2)
>10	8.7 (±2.6)	3.6 (±1.7)	32.7 (±10.7)	45.0 (±13.6)
P-value	*	*	*	*

Post-Op Varus (SD)	**Pain**	**Stiffness**	**Function**	**Total**
< 1	2.3 (±2.8)	1.2 (±1.4)	7.1 (±9.2)	10.6 (±13.0)
1- <4	1 (±1.5)	1.2 (±1.2)	4.6 (±6.4)	6.8 (±8.5)
> 4	2.1 (±2.7)	1.3 (±1.4)	8.6 (±8.9)	11.9 (±12.5)
P-values				
< 1 vs 1- <4	**0.01**	0.95	**0.04**	**0.03**
< 1 vs > 4	0.77	0.83	0.52	0.68
1- < 4 vs > 4	**0.03**	0.75	**0.03**	**0.04**

A postoperative mechanical axis alignment of 1-4° correlated to significantly superior WOMAC pain, function and total scores compared to a varus of <1° or >4°. None of the preoperative p-values were considered significant between the different groups (*P-value > 0.05). HKA, hip-knee-ankle; SD, standard deviation; WOMAC, Western Ontario and McMaster Universities Arthritis Index.

Discussion

A limited number of articles have been published about the potential factors that can influence subjective outcome of patients undergoing UKA[19, 20]. To our knowledge this is the first cohort study of patients undergoing medial UKA receiving the same medial unicondylar implant using an identical robot-assisted technique where clinical as well as radiographic parameters have been examined.

When considering the potential influence of patient-specific preoperative factors, our data suggests that younger patients reported significantly more pain preoperatively (p=0.041). This supports our opinion that higher baseline physical activity levels in a younger population result in a relatively greater imposition of limitations on daily function stemming from isolated unicompartmental OA. These limitations are exacerbated by the progression of OA as a direct consequence of greater physical activity, creating a self-perpetuating cycle. Furthermore, the data suggest that younger patients benefit from a higher degree of pain relief than patients 65 years of age and older who underwent medial UKA. Post-operatively, these reported pain differences were no longer present (Figure 2 and table 4). Scores in the stiffness domain, however, remained significantly different between both age groups at final follow-up. However, it should be questioned if this difference (WOMAC stiffness score Δ 0.5) is clinically relevant.

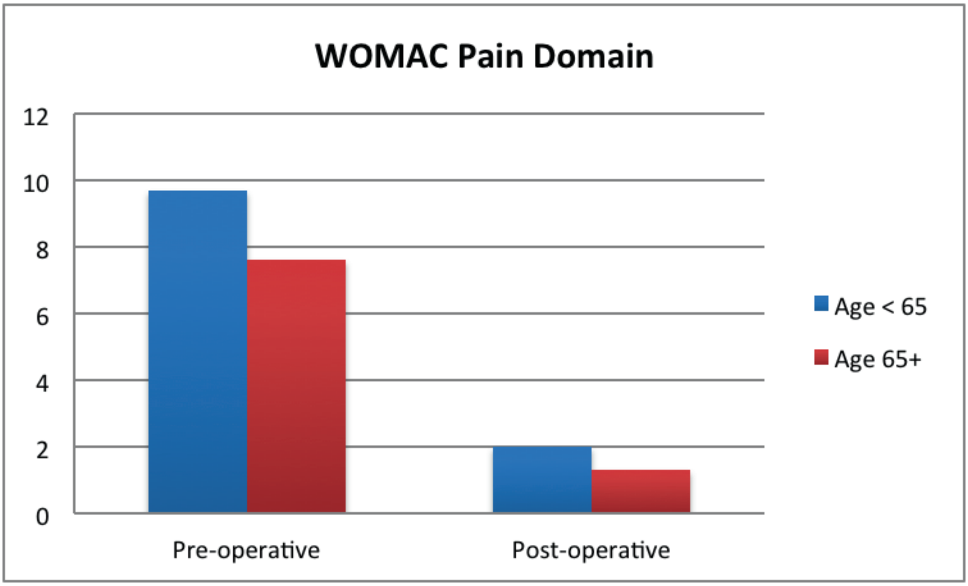

Figure 2. Preoperatively, patients older than 65 years had less pain than patients younger than 65 years (7,6 vs. 9,7, p=0.041). Two years following surgery these differences were absent (1.3 versus 2.0, p=0.175), meaning that younger patients will have a greater relieve of pain following medial UKA.

The optimal range of lower limb alignment following UKA remains a subject of debate. Various authors have stated that varus alignment of >8-10° is associated with accelerated polyethylene wear and implant loosening[21-23]. This has led some to suggest that lower limb alignment following UKA should aim for a neutral angle[24, 25], whereas others opine that mild varus within 6° is preferable[26]. However, the majority of such studies use implant failure as an end-point. In contrast, this study evaluates the potential effect of postoperative lower limb alignment on functional outcomes with successful implants. Our findings suggest that a postoperative varus angle of 1-4° should be pursued when performing medial UKA to optimize subjective results. This corresponds with the results of a recent retrospective report by Vasso et al[27]. Evaluating 125 medial fixed-bearing UKA samples at an average follow-up of 7.6 years (range 3.5-9.3), the authors reported higher IKS knee scores among patients with a mild postoperative varus deformity (i.e. 1-7°) in comparison to patients with a postoperative neutral alignment. Future studies are needed to evaluate the relation and mechanism between lower leg alignment, clinical outcome and revision over a longer follow-up period.

To our knowledge, only two studies have been published evaluating the effect of various factors and their influence on patient-reported outcomes. Thompson et al. performed a similar study in 229 patients who underwent UKA[20]. Using the Knee Society Score (KSS) they noted that patients younger than 60 years had significantly superior KSS scores at 2-year follow-up – suggesting that younger patients are better candidates to undergo UKA. While our data did not display significant differences at final follow-up, the findings suggest that younger patients did benefit from greater pain relief following medial UKA. Thompson et al. also found that patients with a BMI >35 may experience slower postoperative improvement, as significant differences were still present at one year follow-up. Despite these results however, there are some factors in the design of this study that should be taken into account when interpreting the results. The aforementioned study included patients who underwent medial UKA and patients who had undergone lateral UKA. As both compartments differ considerably[28, 29], it can be inaccurate and misleading to draw conclusions about medial UKA's based on lateral UKA results. Secondly, four different implants were used versus a single uniform implant in the present study.

The second study regarding potential factors influencing subjective outcomes was performed by Xing et al, including patients who underwent UKA at an average follow-up of 33 months (range 17 – 66)[19]. The study did not find any significant influence of age, BMI or patellofemoral OA on the final WOMAC scores. However, Xing et al. also combined results of medial and lateral UKA with the same analytical limitations as discussed above. Secondly, all-polyethylene tibial components (n=89) and metal-backed tibial components (n=89) were included. Recent studies have demonstrated that these are functionally nonequivalent, as load across the tibial surface may be better transferred using metal-backed tibial components[30], leading to superior WOMAC scores[31] and lower rates of failure[32].

In our cohort, BMI does not appear to influence subjective outcomes following medial UKA. The literature surrounding this relationship is ambiguous. Using a cohort of 80 knees undergoing medial UKA (minimum follow-up 2 years, cutoff BMI 35 kg/m2), Bonutti et al[33] concluded that UKA should be approached with caution in obese patients in the setting of higher failure rates and inferior outcome scores. Murray et al.[34] found no influence of BMI on implant survival among 2438 medial Oxford UKA subjects, but a significant deteriorating trend of functional outcome scores with increasing BMI. Naal et al.[35] reported findings similar to those of the present study, noting no significant differences in KSS or University of California at Los Angeles (UCLA) activity scores between obese and non-obese patients at two years following medial UKA. The authors concluded that longer follow-up is necessary to determine the impact of obesity on revision rates of medial UKA.

This study has several limitations. Although the data from a prospective arthritis registry was used, the analysis where performed is a retrospective manner. Second, the data reflects the experience of a single surgeon with extensive experience in unicompartmental resurfacing surgery using a robot-assisted arm technique, and results therefore may not be applicable to low-volume centers[36] or to UKA performed without robot-assisted technology. The use of robotic technology, however, offers the advantage of controlling surgical technique[37-39], a crucial variable in determining outcome[40, 41]. At last, although an adequate follow-up was used, this study evaluates the effect on subjective outcomes. Longer follow-up in a multi-center setting is necessary to study the effect of these separate factors on the rate of revision.

In conclusion, our findings suggest that BMI, gender and preoperative osteoarthritic severity of the various knee compartments do not influence subjective outcome in patients undergoing medial UKA. Greater pain relief can be expected in medial UKA candidates below 65 years of age, and a postoperative lower limb alignment of 1-4° varus should be pursued. Taking these factors into consideration is critical, not only towards maximizing clinical outcomes and minimizing revision rates, but also towards appropriately establishing and fulfilling patient expectations following medial UKA. Future studies, however, are required to evaluate the long-term significance of these parameters and their influence on implant longevity.

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Role of magnetic resonance imaging in the diagnosis of the painful unicompartmental knee arthroplasty

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Abstract

Background:
Unicompartmental knee arthroplasty (UKA) is a well established method for the treatment of single compartment arthritis; however, a subset of patients still present with continued pain after their procedure in the setting of a normal radiographic examination. This study investigates the effectiveness of magnetic resonance imaging (MRI) in guiding the diagnosis of the painful unicompartmental knee arthroplasty.

Methods:
An IRB-approved retrospective review identified 300 consecutive UKAs performed over a three years period with 28 cases of symptomatic UKA (nine percent) with normal radiographic images.

Results:
MRI examination was instrumental in finding a diagnosis that went undetected on radiographs. Based on MRI findings, 10 (36%) patients underwent surgery whilst 18 (64%) were treated conservatively.

Conclusion:
This study supports the use of MRI as a valuable imaging modality for managing symptomatic unicompartmental knee arthroplasty.

Introduction

Unicompartmental knee arthroplasty (UKA) is an effective method for treating single compartment arthritis. It provides advantages over total knee arthroplasty (TKA) in terms of kinematics, function, range of movement and recovery time[24,27], whilst reports have shown comparable long-term survivorship[10,28,33,34]. However, the national registries tend to show a higher revision rate of the UKA. A leading cause of revision is unexplainable pain following UKA. Various reports describe that between 4%–23% of patients experience pain post-operatively without any obvious cause[3–5,8,16,19].

There are a variety of etiologies that can contribute to painful UKA, including infection, synovitis, osteolysis, component loosening and further degenerative change in the opposite compartment[2,3,8,31]. Conventional radiographs are the first line of investigation for patients presenting with symptomatic UKA, but these may fail to identify the cause and are ill-suited in rendering accurate images of the peri-prosthetic soft tissues[7,42,46]. The effectiveness of standard radiographs in analyzing component positioning, predicting component loosening, and assessing osteolysis has been called into question[9,29, 30,40,43,48–50]. Magnetic resonance imaging (MRI) is becoming increasingly used in investigating painful TKA due to its accuracy and specificity in diagnosing the etiology of post-operative pain in comparison to radiographic imaging[1,7,21,29–31,36,41–43,48,50]. However, the use of MR imaging in evaluating symptomatic UKA has not been investigated.

The purpose of this study is to assess the role of MRI in the evaluation of patients with symptomatic UKA. We hypothesize that MRI will serve as a useful modality in determining the etiology of the symptoms.

Materials & methods

After approval by the Institutional Review Board, a retrospective review of 300 consecutive UKAs was undertaken. All UKAs were performed over a three years period between January 2008 and January 2011 by two experienced orthopedic surgeons (ADP, ASR). During routine follow-up visits any cases of symptomatic UKA were identified. These patients were initially evaluated by standard anteroposterior (AP), lateral, merchant, and Rosenberg radiographs by both orthopedic surgeons and an experienced musculoskeletal radiologist. If radiographic analysis failed to provide definitive information regarding the etiology of the patient’s post-operative symptoms or if the patient’s symptoms persisted, then the patient underwent MRI. Patients who presented with other obvious causes of pain (e.g. lumbar spine stenosis, hip osteoarthritis, complex regional pain syndrome (CRPS)) were excluded. The final study group consisted of patients presenting with persistent symptoms following UKA who had normal physical examination, negative radiographic imaging, and normal routine postoperative blood work, and an unidentified etiology causing symptoms. Patient notes, radiographs and MR images were reviewed to determine the degree of time to diagnosis from standard AP radiographs, the nature of the patients' symptoms, and any subsequent operative or conservative interventions.

Magnetic resonance imaging was performed using a clinical 1.5 T Surface Coil unit (General Electric Healthcare, Milwaukee, Wis.). Images were obtained with a knee coil with sagittal inversion recovery followed by additional optimized coronal, sagittal and axial fast spin echo sequences (Fast spin echo XL, General Electric Healthcare), which were obtained using a four-channel phased array receive-only shoulder coil (Med Rad phased array, Indianola, Pa), with a repetition time of 3000 to 5000 ms/echo time of 30 to 36 ms, with a wider receiver bandwidth of 62.5 to 100 kHz over the entire frequency direction. Field of view ranged between 17 and 20 cm, and slice thickness was three to four millimeters with no gap; matrix was 512 × 320 to 384 at four to six excitations, yielding a maximum in-plane resolution of 332 μ. Initial coronal fast inversion recovery sequence had a field of view 35 cm, repetition time 17 ms (effective), inversion time 150 ms, receiver bandwidth 62.5 kHz (over the entire frequency range), and slice thickness five millimeters with no interslice gap. Total imaging time ranged between 25 and 40 minutes, depending upon patient size and the need for repetition of pulse sequences due to involuntary motion. MRIs were reviewed by musculoskeletal radiologists for the presence of any effusion, osteoarthritis in adjacent compartments, and synovitis. Osteolysis was also assessed by the fluid signal versus intermediate signal intensity, maximum thickness of the fibrous membrane, presence of stress reaction in the bone, integrity of the articular cartilage in the non-operative compartment and the presence of occult fractures.

Patients with suspected signs of infection on MR images post-operatively had additional tests ordered for workup. Standard serology was ordered, which included erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP). Aspiration of the joint was also performed with the joint aspirate fluid sent for microbiologic culture, synovial fluid white blood cell count and differential. All descriptive statistics (mean, standard deviation [SD], and mean standard error) were performed with SPSS 16.0 (SPSS Inc., Chicago, IL).

Results

Twenty-eight patients were identified with symptomatic UKA. There were 16 females and 12 males, with a mean age of 57 years (range 34–87 years) (Table 1). All surgery was performed using identical techniques through a medial parapatellar incision. Of the 28 patients, 23 had a UKA performed on the medial compartment and five on the lateral. 96% of cases were robotically-assisted UKAs (n = 27 patients). The tibial components used included 16 all-polyethylene and 12 metal-backed implants. Twenty-seven were fixed bearing and one was mobile bearing.

Table 1. Demographic data.

	Mean ± SD (range)
Male:female	12:16
BMI	28.3 ± 6.6 (18.9–42.8)
Mean age (years)	56.1 ± 10.9 (34–79)
UKA	
Medial	23
Lateral	5
Mean follow-up (years)	1.4 ± 0.9 (0.3–2.8)

Radiographic assessment

None of the initial radiographs demonstrated radiolucencies, evidence of fracture, loosening or mechanical failure (Figs. 1 & 2).

Magnetic resonance imaging

The average time between index surgery and MRI was 275 ± 182 days (range 77– 741 days). The average time between the radiograph and MRI evaluation was 48.6 days ± 69.7 days (range 0–335 days). MRI found osteoarthritis in 100% patients (n = 28) with varying degrees of OA in different compartments (Table 2). Other overlapping findings included effusion in 13 patients (46%) (Fig. 3), synovitis in 16 patients (57%), osteolysis in three patients (11%) (Fig. 4), loosening in three patients (11%), a sinus tract in one patient (four percent) (Fig. 5) and a non-displaced proximal tibial fracture in one patient (four percent) (Fig. 6). Signs of infection were found in two patients (seven percent) (Fig. 7). Other findings included the presence of a cyst (seven percent), meniscal tears (18%) and bursitis (eight percent) (Table 2). Radiograph and MRI findings as well as subsequent clinical treatment are listed in Table 3. Based on the clinical presentations and MR findings, 10 patients were advised to undergo operative treatment whilst 18 were recommended for conservative treatment.

Figure 1. Radiographs of a symptomatic right UKA with no overt pathology seen.

Figure 2. Radiographs of a symptomatic right UKA with no overt pathology seen.

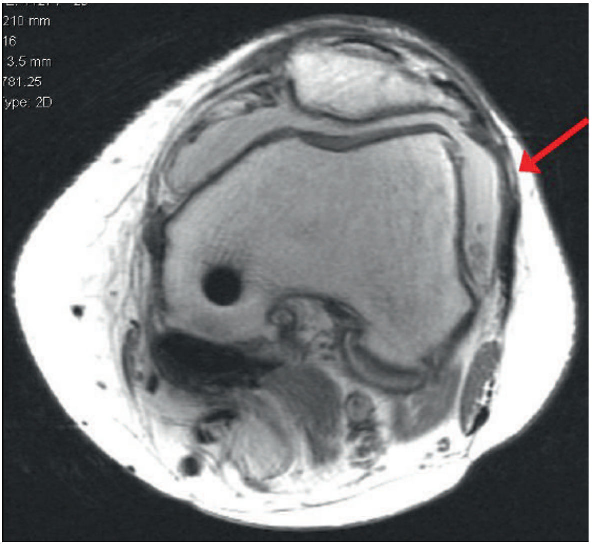

Figure 3. Axial fast spin echomagnetic resonance image of a patient presentingwith effusion and particulate synovial debris. The patient was treated conservatively.

Figure 4. Coronal fast spin echo magnetic resonance image of a patient with osteolysis as indicated by intermediate signal intensity. Patient was revised to a TKR.

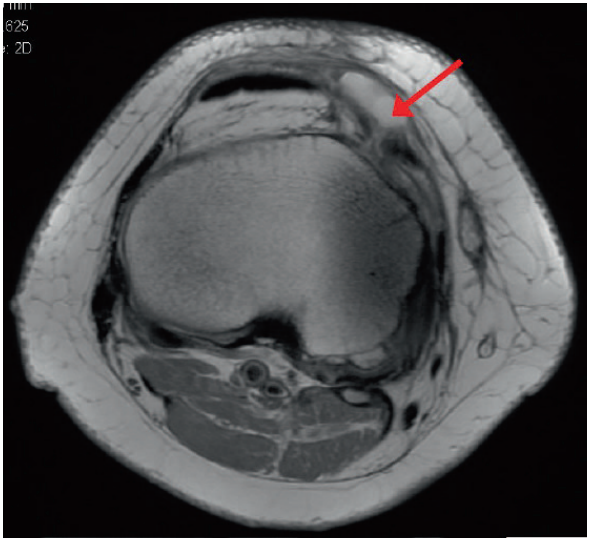

Figure 5. Axial fast spin echo magnetic resonance image of a patient presenting with a sinus tract who was treated conservatively.

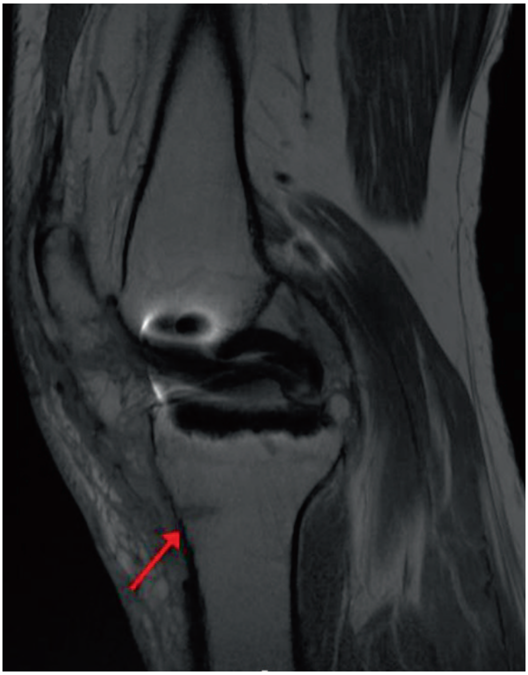

Figure 6. Sagittal fast spin echomagnetic resonance image of a patient presenting with a nondisplaced tibial plateau fracture following a fall. Patient was treated conservatively.

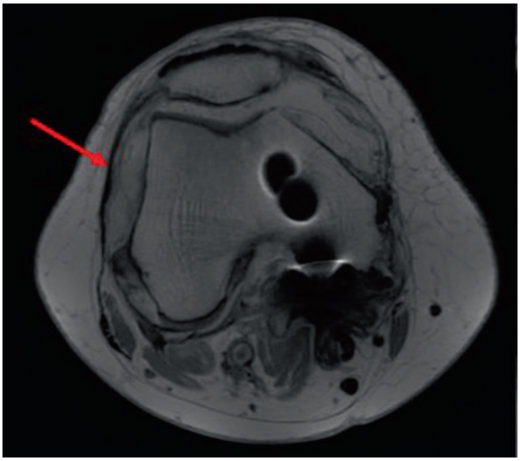

Figure 7. Axial fast spin echo magnetic resonance image shows a slightly lamellated type architecture at the superior aspect of the suprapatellar recess. Findings were suggestive of infection, which was confirmed by OR cultures. Patient was treated with a two stage revision.

Table 2. Incidence of pathology seen on MRI.

Pathology	Incidence (%)
Other compartment arthritis	100%
Superficial wear	4% (n = 1)
Fibrillation	4% (n = 1)
Grade 2	11% (n = 3)
Grade 3	43% (n = 12)
Grade 4	39% (n = 11)
Synovitis	61% (n = 17)
Effusion	68% (n = 19)
Osteolysis	32% (n = 9)
Loosening	11% (n = 3)
Cyst	14% (n = 4)
Presence of stress reaction in bone	14% (n = 4)
Chondromalacia patella	4% (n = 1)
Meniscal tear	14% (n = 4)
Infection	7% (n = 2)

Periprosthetic infection work-up

After MRI detected signs of infection in two patients, blood work was ordered and joint aspiration was performed. ESR was 63 mm/h and 25 mm/h and CRP was 2.8 mg/dL and 5.6 mg/dL. Synovial fluid white blood cell counts were 65,000/µL and 3225/µL, both highly suggestive of infection[44].

Table 3. Patient MRI Findings & Subsequent Treatment

Patient	UKA	MRI Findings	Final Diagnosis	Treatment
1	R med	Mild lateral/PF degenerative joint disease; Meniscus tear	Mild lateral OA	Scope debridement; Sympathetic blocks
2	R lat	Loose body & PF OA	Loose body, PF OA	Knee arthroscopy; Removal of loose body
3	L med	Effusion, mild lateral & PF chondral loss, peripatellar scar	Arthrofibrosis	Manipulation under anesthesia
4	L med	Effusion, tibial loosening, lateral compartment OA	Tibial loosening and progressive arthritis	Revision to onlay UKA
5	L med	Progressive lateral compartment degeneration	Progressive arthritis	Revised to TKR
6	R med	Marrow edema, effusion with fine partculate synovial debris, mild tibial osteolysis	Proximal tibial stress rxn & progressive arthritis	Revised to TKR
7	L med	Progressive lateral & femoral degenerative joint disease	Progressive arthritis	Revised to TKR
8	R med	Tibial component osteolysis and loosening, synovitis	Tibial loosening & progressive arthritis	Revised to TKR
9	L med	Joint effusion, synovitis, lateral meniscal tear, loosening	Infection	Irrigation & debridement with poly exchange
10	R med	Marrow edema, joint effusion, synovitis	Infection	2-Stage Revision
11	R med	Effusion, fine particulate synovial debris	PF OA, reactive synovitis	Conservative treatment
12	R med	Semimembranosus bursitis, lateral meniscus degeneration	Lateral meniscal degeneration	Conservative treatment
13	R med	Effusion, fine particulate synovial debris, meniscus tear	Synovitis	Conservative treatment
14	L lat	Effusion, fine particulate synovial debris	Synovitis	Conservative treatment
15	L med	Popliteal cyst, effusion, fine particulate synovial debris	Synovitis	Conservative treatment
16	R lat	Synovitis, meniscus tear, PF and medial OA	PF & medial OA	Conservative treatment
17	L med	PF OA, medial synovial scar	PF OA	Conservative treatment

18	R lat	Scarred extensor mechanism, PF OA, synovitis	PF OA, reactive synovitis	Conservative treatment
19	R med	Effusion, lateral chondral loss, Hoffa fat pad edema & scar	Hoffa fat pad edema & scar, stress reaction	Conservative treatment
20	R med	Pre-patellar bursitis, PF and lateral OA	PF & lateral OA, reactive bursitis	Conservative treatment
21	L med	Effusion & fine particulate synovial debris, meniscal tear	Meniscus tear, synovitis	Conservative treatment
22	R med	PF OA & synovitis	PF OA & synovitis	Conservative treatment
23	R med	Mild lateral subluxation, patella alta, PF chondromalacia	PF chondromalacia	Conservative treatment
24	L med	Effusion & fine particulate synovial debris, lateral compartment chondral loss, PF OA	PF & lateral OA, synovitis	Conservative treatment
25	L med	Osteolysis, synovitis	Osteolysis, synovitis,	Conservative treatment
26	R med	Effusion & linear synovial debris, healing tibial impaction fx	PF OA, synovitis	Conservative treatment
27	R lat	High grade cartilage wear, large joint line, inner marginal osteophytes	Loose bodies, medial compartment degeneration	Conservative treatment
28	L med	PF OA, synovitis, popliteal cyst	Synovitis	Conservative treatment

Treatment following MRI

Of the 10 patients advised for surgical intervention after MR imaging, two underwent arthroscopic debridement, one underwent manipulation under anesthesia, one underwent revision UKA, four were converted to a TKA, one had an irrigation and debridement with polyexchange, and one underwent a two-stage revision. Seven patients (70%) experienced improvement in pain and function after their second surgical intervention. Of the 18 patients who were treated conservatively, 11 patients (61%) experienced improvement in pain and function. Patients were prescribed anti-inflammatories or physical therapy.

Discussion

In this study, we have found that MRI is an effective imaging technique that provides greater insight into the etiology of the symptomatic patient following UKA. Our data suggests that MRI examination was instrumental in finding a diagnosis that went undetected on radiographs for all 28 symptomatic UKA patients. The pathologies for the 10 patients advised for surgical intervention included loose bodies, osteolysis, tibial loosening, synovitis, stress fractures, and infection. For the 18 patients who were managed conservatively, the pathologic findings included stress fracture, meniscus tear, sinus tract, synovitis, and patellofemoral (PF) OA. Although our numbers are small, our data highlights the usefulness of MRI in the diagnosis of the symptomatic patient following UKA where traditional radiographic evaluation and physical examination do not indicate any pathological explanation.

Management of the symptomatic UKA can be both complex and difficult due to the nature and variety of causative factors. Similar to managing the painful TKA, a systematic approach is required and is comprised of a thorough history, physical examination, laboratory testing, and radiographic imaging[7]. Traditionally, imaging modalities have been limited to plain radiographs, arthrography, and nuclear medicine bone scans[21,42]; however, numerous studies have reported inadequacies in assessing the residual structures of the knee and the surrounding soft tissue, such as ligaments, tendons, and the pseudocapsule[1,42]. MRI is the gold standard in evaluating soft tissue pathology with its diagnostic sensitivity well-documented following numerous orthopedic procedures, including TKA and THA [1,2,6,12,17,21,29,32,37, 39,41–44,48–50].

Although MRI has traditionally not been considered as a diagnostic tool in the setting of arthroplasty due to metallic susceptibility artifact, modern, modified MR imaging techniques allow the amount of artifact around prosthetic implants to be reduced significantly[41]. Heyse et al. showed that with a protocol tailored to reduce metallic susceptibility artifact, MRI can have good reproducibility in the analysis of the bone implant interface at the tibia and patella after TKA and can be helpful in the diagnosis of loosening[14]. More recently, Heyse et al. also showed good reproducibility when analyzing component rotation for femoral and tibial UKA implants, which can provide useful information when evaluating symptomatic UKA[15]. Furthermore, Sofka et al. showed that MRI provided accurate evaluation of periprosthetic structures after TKA when conducted with an appropriate protocol that is available on most commercial MRI units[42]. These findings were also confirmed by Heyse et al. who reported a series of cases where MR examination was a useful addition in the evaluation of symptomatic patients following TKA[13].

Historically, radiographs are used to evaluate prosthesis alignment, positioning, overhang, stress fractures, implant loosening, osteolysis, wear and heterotropic ossifications[18]. Standard radiographs can help detect gross prosthetic malposition, radiolucencies and fractures[26]. However, they have little value in the detection of the more common but subtle osseous abnormalities such as early loosening, minor implant malposition, infection, stress fractures, or early stage OA[7,18,26,46]. Numerous studies have proven that MRI is a valid examination for the early detection of OA[20,22,38]. It is highly sensitive to early morphologic alterations, such as cartilage, bone marrow, and ligament degeneration, which are the earliest structural changes of OA and are not as evident on traditional radiographic examination. These findings are consistent with the results of our study. In multiple patients from our study cohort, we could not diagnose the progression of OA of the non-operated compartment on plain radiographs, whereas MRI was able to detect OA (Table 2 & 3). Furthermore, multiple studies show that components and interfaces are not well visualized on the conventional radiographs[7,30] and component rotation cannot be assessed[15]. Evidence of component loosening is often evaluated by comparing radiographs over time. However, minor changes in the alignment of the X-ray beam to the component can obscure the diagnosis and therefore make the examination unreliable[30].

Radiographic lucencies are a frequent finding on radiographs following arthroplasty and can be indicative of implant loosening. However, multiple studies report that they have low diagnostic value for joint pathology[30,45,46]. In an attempt to answer the question of whether non-pathological radiolucent lines have a relationship with clinical outcome, Gulati et al. studied the incidence and clinical outcome of 161 Oxford UKAs five years following implantation. They found that 30% of UKAs had a complete line, 32% had partial, and 37% had no radiolucent lines. Furthermore, they concluded that the presence of physiological radiolucency under the tibial tray can be ignored since they noted no significant relationship to clinical outcome[11]. None of the patients included in our study showed any signs of radiolucencies, which could have been caused by the relative short follow-up in comparison to the report by Gulati et al.

Fluoroscopy and oblique views are two other additional radiographic examinations in the assessment of the symptomatic UKA. They may enhance plain radiographs but many studies have reported the inaccuracy and insensitivity of this conventional, two-dimensional imaging modality in detecting soft tissue pathology, especially when estimating the degree of periprosthetic osteolysis, a major complication following knee arthroplasty[29,41–43,48–50]. Numerous reports have proven that modifications in MR imaging technique have allowed the MRI to become a valuable addition in the evaluation of osteolysis. In a cadaver study, Walde et al. compared the specificity of radiography, CT and MRI in assessing periacetabular osteolytic lesions. MRI was a significantly more effective tool (95%) in detecting lesions than CT (75%) or radiographs (52%)[49]. The accuracy of MRI in identifying and quantifying osteolysis has also been confirmed intra-operatively[29,48]. Several studies have reported the superior sensitivity and specificity of MRI in assessing the degree of osteolysis around TKA, which is commonly underestimated with radiographs[1,21,29,40,42,43,47,48]. One other study has investigated the use of MRI after medial UKA, but only in terms of safety and the reproducibility of the residual knee anatomy[1].

One of the most challenging complications following knee arthroplasty is treating periprosthetic infections (PPI)[48,49]. In our retrospective cohort, there were two patients where MRI helped confirm infection. In both cases, suspicion of PPI was very low, since both patients presented with atypical symptoms. Physical and radiographic examinations were not aberrant or suggestive for PPI and aspiration resulted in equivocal blood work. Furthermore, both patients presented with a late onset of symptoms, where MR imaging was respectively performed 371 and 225 days following surgery (Table 3). Due to the unclear diagnosis, MRI was obtained which was suggestive for infection and confirmed the diagnosis. The variable presentation of PPI can make diagnosis difficult and there is scant literature to guide the diagnosis of PPI in UKA patients. Radiographic findings indicative of infection are generally found in the later stages of infection. Plodkowski et al. reported the sensitivity and specificity of lamellated hyperintense synovitis in the MRI of knee arthroplasty patients with infection[36]. Comparing 28 patients with a proven infected TKA with 28 patients with a noninfected TKA, they concluded that the presence of lamellated hyperintense synovitis at MR imaging had a high sensitivity (0.85– 0.87) and specificity (0.85–0.87). Similarly in this study, the detection of lamellated synovitis instigated knee aspirations in two patients, which eventually confirmed the suspected infections. MR results influenced the treatment for both patients who both reported an improvement in pain and function at follow-up. Thus, we believe that MRI can be a helpful adjuvant to help diagnose PPI in patients who may have equivocal blood workup or present with atypical symptoms of PPI.

This study is not without limitations. First, this study was limited by its relatively small sample size due to the narrow indication for use of MR imaging. Secondly, time between the obtained radiographs and MR imaging varies due to logistical issues, such as difficulties with obtaining approvals from insurance companies, making sure patients can have a special MRI sequence done, and scheduling the MRI based on the patient's schedule. Thus, in some cases, the time between the two exams is relatively long. Lastly, since this is the first study to report about the use of MRI for the symptomatic UKA patient, the potential influence of metallic artifacts on the diagnosis has not been extensively investigated. The majority of our patients however showed improvement following their treatment based on MR findings.

Although physical examination and traditional radiographs remain the cornerstone in the imaging of postoperative unicompartmental knee arthroplasty, it is to our belief that MRI should be used as a supplemental diagnostic imaging modality for patients experiencing painful UKA. MRI can provide superior evaluation of periprosthetic soft tissues, joint effusion, component integrity, and bony pathology without exposing the patient to additional radiation. The results of our study support the use of high quality MRI for patients presenting with painful UKA. This in conjunction with sound clinical judgment can have a significant impact on operative and conservative treatment decisions, providing a more effective method of managing the symptomatic UKA patient.

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5

Unicompartmental Knee Arthroplasty versus Total Knee Arthroplasty. Which type of artificial joint do patients forget?

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Abstract

Purpose:

During recent years, there has been an intensively growth of interest in the patient's perception of functional outcome. The Forgotten Joint Score (FJS) is a recently introduced score that measures joint awareness of patients that have undergone knee arthroplasy and is less limited by ceiling effects. The aim of this study is to compare the FJS between patients who undergo medial unicompartmental knee arthroplasty (UKA) and patients who undergo total knee arthroplasty (TKA) 1 and 2 years post-operatively.

Methods:

This prospective study compares the FJS at a minimum of one (average 1.5 years, range 1.0-1.9) and a minimum of two years (average 2.5 years, range 2.0-3.6) post-operatively between patients who underwent medial UKA and TKA.

Results:

One-hundred and thirty patients were included. Sixty-five patients underwent medial UKA and 65 patients underwent TKA. At both follow-up points, the FJS was significantly higher in the UKA group (FJS 1 year 73.9±22.8, FJS 2 year 74.3±24.8) in contrast to the TKA group (FJS 1 year 59.3±29.5 (p=0.002), FJS 2 year 59.8±31.5, (p=0.004)). No significant improvement of the FJS was observed between one and two years follow-up of the two cohorts.

Conclusion:

Patients who undergo UKA are more likely to forget their artificial joint in daily life and consequently may be more satisfied.

Introduction

Total knee replacement surgery is the accepted treatment for end-stage arthritis of the knee. In 2008, more than 600,000 cases were performed in the United States [28]. Recently, the utilization of unicompartmental knee arthroplasty (UKA) has dramatically increased for end-stage arthritis of the knee localized to a single compartment [12,18,20]. Less perioperative blood loss, better range of motion, better quadriceps function and a subsequently quicker recovery with a more normal gait [5] following UKA, may all have contributed to the increasing utilization of the implant.

As a result of the reported advantages of UKA, there has been increasing interest in comparing the outcomes of UKA and total knee arthroplasty (TKA), with a particular focus on patients' perception of functional outcome. The outcomes of joint replacement have historically been evaluated based on implant survivorship, physician-assessed clinical outcome measures, complication rates, and radiological parameters. Although these outcomes are critically important to report, they do not provide any information pertaining to patient perception of outcome. Therefore, patient reported outcome (PRO) scores were developed and validated for clinical use. These scores are however limited firstly by ceiling effects [15] particularly in young and active patients, and secondly by the heterogeneity of scores in current use, making it difficult to compare outcomes to previously published data [2,13,14,19,24].

The Forgotten Joint Score (FJS) [3] is a recently validated PRO score which is not limited by a ceiling effect [27]. The rationale thought behind the FJS was to develop an instrument that reflects the ability of a patient to perform activities of daily living (ADL) without any form of interference from their artificial joint replacement. Since the FJS is a relatively new score, prospective data of patients undergoing knee arthroplasty using the FJS is very scarce. Therefore, the aim of this study was to compare the FJS between patients undergoing either medial UKA or TKA in order to evaluate the artificial joint awareness in both groups at one and two years following surgery.

Materials and Methods

This study was based on a prospective cohort of patients assembled for the senior author's surgical arthritis registry. Patients were eligible for this analysis if they were adult participants in the registry and underwent medial UKA or TKA between 2011 and 2013. Patient demographics and clinical data were collected including age, body mass index (BMI) and gender. The surgical indications of patients that underwent medial UKA consisted of: (I) isolated medial compartment OA, (II) an intact anterior cruciate ligament based on clinical and intraoperative assessments, (III) flexion contracture < 10° and (IV) >90° of tibiofemoral flexion. The indications for TKA were (I) symptomatic OA changes of at least 2 compartments of the knee, (II) symptomatic OA of medial or lateral compartment of the knee in patients who did not wish to undergo UKA or in patients with proven anterior cruciate ligament deficiency. Presence of anterior knee pain and pre-operative Kellgren and Lawrence grade III-IV of the lateral or patellofemoral compartments were considered as surgical contraindications for medial UKA and those patients therefore underwent TKA. Patients with a history of complex knee surgery, trauma, inflammatory arthropathy, BMI > 40 kg/m^2, and simultaneous bilateral TKA or UKA were excluded.

All surgeries were performed by the senior author who has extensive experience in computer navigated robotic surgery. For the UKA resurfacing procedure of the femur and tibia, a robotic-arm assisted technique was used which has previously been described [21,23] (MAKO Surgical Corp, Ft. Lauderdale, FL, USA). The goal was an undercorrection of the varus deformity in order to avoid degenerative progression of the lateral compartment. All patients that underwent medial UKA received the RESTORIS® MCK Medial Onlay implant (MAKO Surgical Corporation, Ft. Lauderdale, FL, USA).

All patients who underwent TKA received the Vanguard® Complete Total Knee (Biomet, Warsaw, USA) utilizing patient-specific cutting jigs based on preoperative computed tomography. All procedures were performed under tourniquet control, with patellar resurfacing, and cementation of all implants.

Outcome measurements

All patients were asked to complete the FJS at a minimum of one and two years follow-up. The date of the two year data collection had to be at least 12 months later than the date of the one year data collection. Since the FJS is a questionnaire following arthroplasty, it is not possible to collect pre-operative scores. The FJS consists of 12 questions. It has been devised to evaluate the ability of a patient to forget their artificial joint in daily life. The score is reported on a scale from 0 to 100. A higher score is representative of a more favorable outcome. A detailed description on how the score should be calculated is given in the appendix.

This study was approved by the Institutional Review Board at our hospital (Hospital for Special Surgery, New York, NY, USA. IRB number: 2013-056-CR2)

Statistical Analysis

All analyses were conducted using SAS for Windows 9.3 (SAS Institute Inc., Cary, NC). A priori power analysis was conducted using a two-sample t-test. Sixty-four patients in each group were needed to reach 80% power for detecting a 12-point (standard deviation 24) difference on the FJS scale with a two-sided significance level set at 0.05. Two sample t-tests were used to compare the FJS results between the medial UKA and TKA groups and between male and female subjects. A multiple linear regression analysis was performed to assess the relationship between surgery type and FJS score, controlling for age, sex, BMI, and duration of follow-up. All tests were two sided. A p-value < 0.05 was considered as statistically significant.

Results

One-hundred and thirty patients were able to complete the outcome questionnaires at a minimum of one year follow-up. Both groups consisted of 65 patients (table 1). Two years following surgery, 3 patients were lost to follow-up (1 medial UKA, 2 TKA) because they moved away from the area. There were no significant differences in age, gender distribution and average follow-up at one and two year follow-up between the two cohorts. The average BMI in the medial UKA group (28.6±3.7 kg/m^2) was significantly lower than in the TKA group (30.3±4.7 kg/m^2) (p=0.02) (table 1). During the follow-up none of the included patients were re-operated or underwent revision surgery.

Table 1. Baseline characteristics

	Medial UKA			TKA			
	N	Mean	SD	N	Mean	SD	P-value
Female sex. N(%)	28 (43.1%)			37 (56.9%)			n.s.
Age (years)		66.6	10.5		67.9	8.4	n.s.
BMI (kg/m^2)		28.6	3.7		30.3	4.7	**0.02**
1 year F/U (range)		1.5 (1.0-1.9)	0.4		1.4 (1.0 – 1.9)	0.3	n.s.
2 year F/U (range)		2.4 (2.0- 3.4)	0.7		2.6 (2.0 – 3.6)	0.6	n.s.

Outcome measurements

One year following surgery, the mean FJS in the medial UKA group (73.9±22.8) was significantly higher than the TKA group (59.3±29.5, p=0.002). Two years following surgery the FJS remained significantly higher in the medial UKA group (74.3±24.8) in comparison to the TKA group (59.8±31.5, p=0.004) (figure 1). No significant improvement of the two groups was observed over time when comparing the one and two year FJS data (table 2).

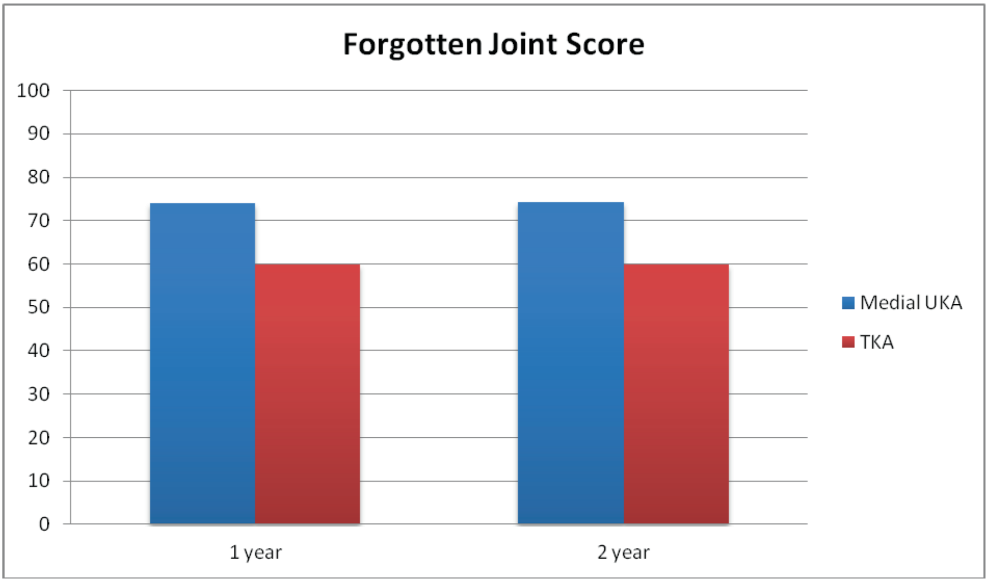

Figure 1. Forgotten Joint Score one and two years following surgery. Note that the medial unicompartmental knee arthroplasty (UKA) group showed significant higher scores at one and two year follow-up (FJS 1 year 73.9±22.8, FJS 2 year 74.3±24.8) in contrast to the total knee arthroplasty (TKA) group (FJS 1 year 59.3±29.5, p=0.002), FJS 2 year 59.8±31.5, p=0.004).

Table 2. Forgotten Joint Score. Note that no significant improvement was observed after one year of surgery for both groups.

FJS	**1 year**	**2 year**	P-value
UKA	73.9	74.3	n.s.
TKA	59.3	59.8	n.s.
P-value	**0.002**	**0.004**	

No significant differences were found in the FJS between men and women in both the medial UKA and TKA groups at one and two years following surgery (Table 3). Multivariate regression analysis showed the FJS in the medial UKA group one year following surgery to be significantly higher than the TKA group (72.2 versus 61.1, p=0.02), after controlling for BMI, age, sex, and follow-up. This significant difference of the FJS remained at two years follow-up in favor of the medial UKA group (72.4 versus 61.2, p=0.01).

Table 3. Forgotten Joint Score by gender

		1 yr	2yr
UKA	**Male**	74.9	76.1
	Female	73.0	72.1
	p-value	n.s.	n.s.
TKA	**Male**	57.7	58.3
	Female	59.1	60.8
	p-value	n.s.	n.s.

Discussion

The most important finding of the present study is that patients who have undergone medial UKA are less aware of their artificial joint than patients who have undergone TKA. The FJS has the ability to distinguish between good and excellent outcomes and is therefore not limited by ceiling effects. There is no consensus in the literature regarding the efficacy of medial UKA compared to TKA with respect to patient satisfaction. The purpose of this study was to compare outcomes of medial UKA and TKA using the FJS at a minimum of one and two years follow-up. We found that patients undergoing medial UKA had a significantly higher FJS compared to patients undergoing TKA at a mean of 1.5 years follow-up. This significant difference remained at 2.4 years as well in favor of patients who had undergone medial UKA. Furthermore our data suggests that no improvement of functional outcome is observed after one year follow-up since we did not note any significant changes when comparing our one and two year data of both cohorts. This last finding corresponds to the work of Pynsent [22] and Fitzgerald [7] who also reported no significant changes in PRO scores beyond one-year follow-up of patients who underwent arthroplasty. However, Giesinger et al [8] and Ko et al [11] noted significant improvement when comparing their two year follow-up data with respectively 1 year and six months follow-up data. Our data might be explained by our average follow-up of 1.5 and 2.4 years following surgery and not 12 and 24 months. Lastly, we did not note a significant influence of gender on joint awareness of patients who had undergone medial UKA or TKA (Table 3).

There is a paucity of outcome studies utilizing the FJS in the literature. To our knowledge there has been only one comparative study between the UKA and TKA using the FJS. Thienpont and associates [25] found no significant differences in the FJS between patients after UKA and patients after TKA at an average of two years following surgery (range 1-3 years). However, in our prospective cohort of patients significantly higher scores are noted for patients that have undergone medial UKA (FJS 1 year 73.9±22.8, FJS 2 year 74.3±24.8) than patients that have undergone TKA (FJS 1 year 59.3±29.5, FJS 2 year 59.8±31.5). Since both difference are significant at both moments of follow-up, our data indicates that this difference is present at one year following implantation and does not improve in the time that will follow.

Comparing the baseline characteristics of both groups, we noted that significant higher BMI in the TKA group (28.6±3.7 vs. 30.3±4.7, p=0.02). The potential influence of BMI on the functional outcome, survivorship and complication rate following arthroplasty has been extensively studied. Most of the published studies have shown that obesity leads to a higher rate of infections [10,17] and inferior implant survival [4,6,9]. No consensus exists however on the influence or relation between obesity and functional outcomes following medial UKA [16,26] or TKA [1]. In a recent systematic review of 9 studies (670 patients), the influence of obesity on the outcome following TKA was evaluated [10]. The Knee Society Score between obese patients, defined as a BMI ≥ 30 kg/m^2, and non-obese patients, defined as a BMI ≤ 30 kg/m^2, differed significantly by 3.23 points in favor of the non-obese group. However, this minimal difference is unlikely to be clinically relevant. Baker et al [1] recently reported the association of BMI and outcome following TKA using data from the National Joint Registry of England and Wales (pre- and postoperative questionnaires; Oxford Knee Score, EQ-5D index and EQ-5D VAS). Patients were divided by BMI in the following groups; non-obese (BMI < 25 kg/m^2), obese (BMI 25-39.9 kg/m^2) and morbidly obese (BMI 40-60 kg/m^2). 13,673 patients were included with an average BMI of 31.0 ± 5.5. They found that the improvements in outcomes between the non-obese and obese patients did not differ significantly. Furthermore the morbidly obese group had significantly lower post-operative scores than the non-obese and obese groups. Murray et al [16] evaluated the effect of BMI on the clinical outcome of 2438 medial Oxford UKA's and found no relation between weight and outcome following medial UKA. In terms of BMI of our two cohorts, we noted a significant pre-operative difference. However, since we excluded patients with a BMI > 40 kg/m^2, we believe that the difference of BMI (i.e. 1.7 kg/m^2) between our two cohorts is too marginal to influence outcome. Furthermore, when we stratified our data for BMI, gender, age and follow-up, the significant FJS differences remained.

With respect to registry data, the Norwegian Arthroplasty Register compared the PRO scores between TKA and UKA [13]. At a minimum follow-up of 2 years (mean, 6.5 years) 972 TKA's and 372 UKA's were compared. The outcome questionnaires being used were the Knee Injury and Osteoarthritis Outcome Score (KOOS), the EQ-5D and the Visual Analog Scale (VAS). The authors found that there were some significant differences in favor of the UKA group. However, the differences were too small to be considered clinically relevant. The National Registry of England and Wales compared the Oxford Knee Score (OKS) and the EQ-5D between 23,393 patients who underwent TKA and 505 patients after UKA (median follow-up 6.6 months) [2]. No differences in both scores were reported. The authors highlighted that these PRO scores are unable to detect top-end differences, and therefore are suboptimal measures in assessing outcomes following knee arthroplasty. Due to the ceiling-effects of the traditional scores we decided to conduct this study using the recently introduced FJS without this limitation.

Despite these results, there are sever several limitations to the present study. First, all procedures were performed by the senior author who has extensive experience in robot assisted UKA implantation and TKA using patient specific guides. Therefore, results may be influenced by the subtleties specific to the respective surgical techniques and may not be duplicable in low-volume centers. Second, the use of the FJS has the advantage of not being influenced by ceiling effects. However, the score can only be used following surgery since it measures the ability of patients to forget their artificial joint in daily life. Since patients undergoing medial UKA were only affected by medial compartment OA and patients undergoing TKA by multicompartmental OA, it might be possible that they both show the same improvement following knee replacement since pre-operative differences might be present. Unfortunately this question cannot be answered with use of the FJS. Therefore, future outcome scores, which are not limited by ceiling effects and are usable pre-operative, are needed to address these questions.

Conclusion

Our data suggests that patients who undergo UKA are better able to ‘forget’ their artificial joint in daily life compared to patients undergoing TKA. We speculate that this observed difference may be due to the fact that a UKA is a more soft-tissue and bone conserving surgical procedure than a TKA. In order to optimize the outcome of patients undergoing knee arthroplasty, this study suggests that – if possible – joint conserving surgical strategies should be pursued.

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Medial Unicompartmental Knee Arthroplasty improves Congruence and Restores Joint Space Width of the Lateral Compartment

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Abstract

Background:
Osteoarthritic progression of the lateral compartment remains a leading indication for medial unicompartmental knee arthroplasty (UKA) revision. Therefore, the purpose of this study is to evaluate the alterations of the lateral compartment congruence and joint space width (JSW) following medial UKA.

Methods:
Retrospectively, lateral compartment congruence and JSW was evaluated in 174 knees (74 females, 85 males, mean age 65.5 years; SD±10.1) preoperatively and six weeks postoperatively, and compared to 41 healthy knees (26 men, 15 women, mean age 33.7 years; SD±6.4). Congruence (CI) was calculated using validated software that evaluates the geometric relationship between surfaces and calculates a congruence index (CI). JSW was measured on three sides (inner, middle, outer) by subdividing the lateral compartment into four quarters.

Results:
The CI of the control group was 0.98 (SD±0.01). The preoperative CI was 0.88 (SD±0.01), which improved significantly to 0.93 (SD±0.03) postoperatively ($p<0.001$). In 82% of knees, CI improved after surgery, while in 18% it decreased. The preoperative significant JSW differences of the inner ($p<0.001$) and outer JSW ($p<0.001$) were absent postoperatively.

Conclusion:
Our data suggests that a well-conducted medial UKA not only resurfaces the medial compartment but also improves congruence and restores the JSW of the lateral compartment.

Introduction

Medial unicompartmental knee arthroplasty (UKA) is a well-accepted surgical treatment for end-stage osteoarthritis (OA) that is located to the medial compartment of the knee. Multiple studies report survival rates of >90-95% at 10 years with good to excellent subjective outcome results[1-5]. Evaluating the various modes of implant failure, osteoarthritic progression of the lateral compartment is one of the dominant reasons for revision surgery[2]. Therefore, optimal cartilage viability of the lateral compartment is essential for medial UKA survival.

Chronic uneven load transmission across the knee is present in OA and plays an important role in the presence and progression of the disease. Lower limb alignment and coronal tibiofemoral subluxation are two important mechanical factors that can influence load distribution over the articular cartilage of the knee[6-8]. Both influence the congruity, leading to an altered distribution of transmitted forces over the affected joint. In the osteoarthritic knee, some regions of the articular cartilage encounter increased peak loads, whereas the forces that are transmitted are reduced in other regions[9, 10]. This chronic altered distribution of forces has a well-recognized influence on cartilage viability[9, 11]. Since congruence plays a central role in the equal distribution of forces over a joint, tibiofemoral joint incongruence can therefore cause progressive OA.

The routine method to evaluate progressive degenerative changes of the knee is to measure the joint space width (JSW) on weight-bearing radiographs. Recent studies have proven that the JSW measurement is highly associated with the volume and compression of cartilage and meniscal extrusion[12, 13]. Therefore, it is considered as a reliable method to evaluate degenerative progression over time. The ease of measuring the JSW, have led that the method has become a frequently used method in the daily orthopedic practice to evaluate osteoarthritic progression.

Since degenerative progression of the lateral compartment remains a dominant reason for revision surgery, it is critically important to evaluate the alterations of the lateral compartment following medial UKA. A better understanding of the indirect changes following medial UKA will help us to optimize the results of the implant. In a recent study, congruence and joint space width alterations of the medial compartment were evaluated following lateral UKA[14]. The study concluded that lateral UKA not only resurfaces the lateral compartment but also improves medial compartment congruence and restores the JSW. However, since the medial and lateral compartment of the knee differ considerably[15-17], it is inaccurate and can be misleading to draw conclusions from the literature based on lateral UKA's when studying results about medial UKA's. Therefore, the purpose of this present study is to evaluate the congruence and joint space width alterations of the lateral compartment of the knee following a medial UKA. Our hypothesis is that implantation of a medial UKA will improve the congruence of the lateral compartment and restore JSW.

Methods and materials

This study is a retrospective review of an IRB-approved surgical database of the senior author. All patients who underwent UKA for isolated medial compartment osteoarthritis by the senior author between January 1, 2008, and June 30, 2011, were included for review. Indications for performing a UKA were the presence of isolated, medial compartment osteoarthritis, a flexion contracture of less than 10°, flexion to greater than 90°, and an intact anterior cruciate ligament based on clinical and intraoperative assessments. Furthermore, the varus deformity had to passively correctable. Contraindications for performing a UKA were the presence of an inflammatory arthropathy, Kellgren Lawrence grade 3-4 changes in the lateral compartment and suspected pain originating from the patellofemoral compartment on preoperative clinical examination. Inclusion criteria for this study were patients who received a UKA for isolated medial compartment OA. Patients without radiographs of adequate quality were excluded. This resulted in an exclusion of 102 patients (116 knees) that had undergone medial UKA. Of the included patients, electronic medical records and charts reviewed for demographic data.

Surgical Procedure

All surgeries were performed by the senior author using a previously described, robotic-arm assisted technique for the preparation of both the femoral and tibial surfaces (MAKO Surgical Corp., Ft. Lauderdale, FL)[18, 19]. Briefly, a preoperative plan was created from a 3-dimensional (3-D) reconstruction of a computed tomography scan of the patient’s hip, knee, and ankle, and computer-assisted design (CAD) models of the implanted components are positioned on 3-D models of the femur and tibia. Standard surgical navigation markers were placed in the femur and tibia, and also mounted on the robotic arm. Virtual modeling of the patient’s knee and intra-operative long leg alignment tracking allowed real-time adjustments to target specific long leg alignment parameters and soft tissue balance. For the medial UKAs, the superficial and deep medial collateral ligaments were preserved and implant position (and thus, the bony resections) were planned to maintain tension of the MCL throughout the range of motion. In accordance with the guidelines set forth by Hernigou et al., the goal was an “undercorrection” of the varus deformities (an overall varus hip-knee-ankle alignment postoperatively), with avoidance of “overcorrection” and potentially hastened wear in the contralateral compartment[20]. The end of the robotic arm was equipped with a burr that was used to resect the bone. While inside the volume of bone to be resected, the robotic arm operated without offering any resistance. As the burr approached the boundary, the robotic arm resisted that surgeon motion and kept the burr only within the accepted volume. Thus, the robotic arm effectively acted as a three-dimensional virtual instrument allowing precise execution of the preoperative plan [18].

Radiographical evaluation

As part of routine follow-up, patients underwent radiographic examination preoperatively and six weeks postoperatively. The radiographic evaluation consisted of standard weight bearing antero-posterior (AP) radiographs of the knee, tunnel view radiographs and hip-to-ankle radiographs. A flexion-board of 40° was used for the tunnel view radiographs to control the flexion angle. Care was taken when obtaining the knee-to-hip radiographs to ensure that each patient stood with their patellae facing forwards in order to minimize rotational variation among the radiographs.

Congruence

The degree of articular congruence was calculated using a specially developed Iterative Closest Point (ICP) based software code (Matlab, MathWorks Inc., Natick, MA, 2012). The ICP algorithm seeks to minimize the sum of the square distances between two clouds of points, and attempts to find the rigid transformation (translation and rotation) that best aligns these two clouds. In our code, the two clouds of points represent the digitized femoral and tibial articular surfaces of the lateral compartment of the knee (figure 1). By measuring the translation and rotation needed for the articular surfaces to be fully congruent, the code calculates the degree of congruence of the lateral compartment and presents it as a Congruence Index (CI). A CI with a value of 1 indicates complete geometric congruence where load is presumably transmitted ideally from the femoral to the tibial articular surfaces. A value of 0 indicates a 100% dislocation of the articular surfaces. This method has been validated in a cadaveric model and used in our previous work[14, 21]. The CI was measured by two independent observers on both the preoperative and postoperative weight bearing tunnel view radiographs. Patients were divided into 2 groups. Group A included knees with increased CI after medial UKA implantation and group B included knees with decreased CI after medial UKA.

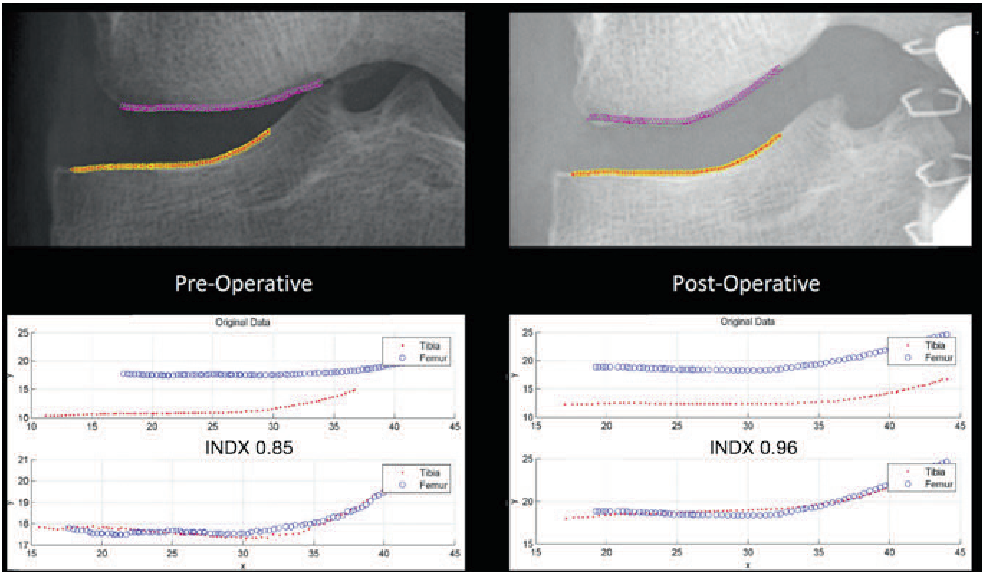

Figure 1. The performed iterative closest point algorithm calculates the congruence index (noted as INDX in the figure) of the lateral compartment pre- and postoperatively following manual digitization of the femoral and tibial surfaces.

Joint Space Width

JSW was measured according to a validated[22] method, by dividing the lateral compartment (i.e. inner, middle, outer) into four quarters (figure 2) on the tunnel view weight bearing radiographs. The tibiofemoral inter-bone distance was measured in millimeters on weight-bearing tunnel radiographs preoperatively, postoperatively and in the control group. For evaluation of knee compartment congruence and joint space width in the normal healthy group, we used weight bearing tunnel view radiographs of both lower extremities of patients younger than 40 years who underwent anterior cruciate ligaments reconstructions or complained about anterior knee pain and had no complaints in the contralateral knee. The CI and JSW were both measured in the contralateral "normal" knees using our specially developed code and considered as normal control value.

Mechanical axis alignment

Preoperatively and six weeks postoperatively, the mechanical axis alignment of the lower extremity was measured on the AP hip-to-ankle radiographs. The femoral mechanical axis was formed by drawing a line from the center of the femoral head to the center of the center of the femoral notch. Subsequently, a line was drawn from the tibial spine toward to center of the tibial plafond, which formed the tibial mechanical axis. The angle formed between the two lines forms the mechanical alignment.

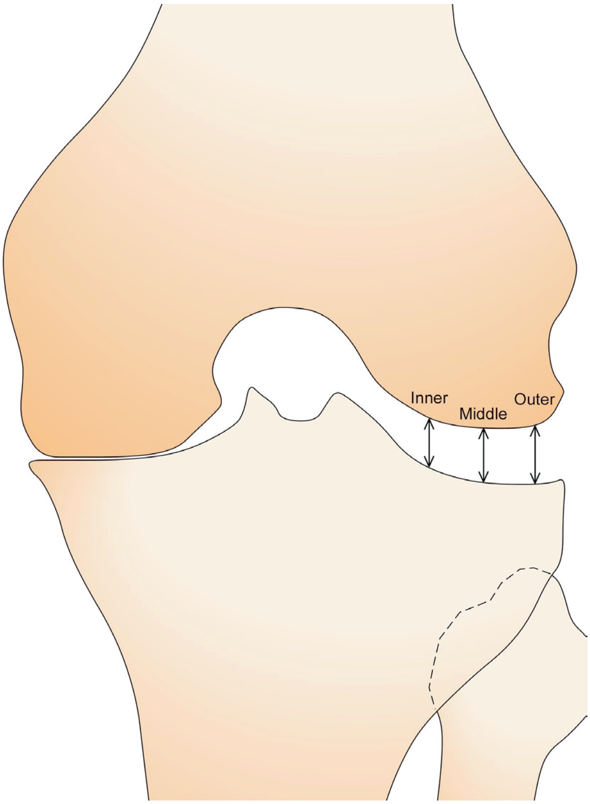

Figure 2. The three measured JSW sides of the lateral compartment in millimeters.

Preoperative degenerative state of the lateral compartment

The preoperative degenerative changes of the lateral compartment were recorded with use of the KL scores.

Statistical analysis

Interclass correlation coefficients (ICC) were calculated to evaluate interobserver reliability for CI and JSW measurements. The ICC's were graded using previously described semi-quantitative criteria: excellent for $0.9 \leq p \leq 1.0$, good for $0.7 \leq p \leq 0.89$, fair/moderate for $0.5 \leq p \leq 0.69$, low for $0.25 \leq p \leq 0.49$, and poor for $0.0 \leq p \leq 0.24$[23]. Student's paired t-tests were used to detect a difference between the preoperative and postoperative congruence index and between the groups with increased and decreased CI's. Chi square test was used to evaluate relationship between gender and changes in CI after surgery. A p-value <0.05 was considered statistically significant.

Results

In the healthy control group, there were 41 knees (15 females, 26 males) with mean age of 33.7 (Standard deviation (SD) ±3.7) years. The mean CI of the lateral compartment was 0.98 (SD±0.01). The study group included 159 patients (74 females, 85 males) with 174 medial UKAs who met the inclusion criteria for final analysis. The mean age at the time of surgery was 65.5 (SD±10.1) years. The average preoperative mechanical axis alignment of patients who underwent medial UKA was 7.9° (±3.7°) of varus, which decreased to 2.8° (± 2.9°) of varus postoperatively ($p<0.0001$). Preoperatively, 103 knees had a KL grade I of their lateral compartment and 71 knees a grade II.

The mean preoperative lateral compartment CI was 0.88 (SD±0.1), which improved significantly to 0.93 (SD±0.03) following implantation of a medial UKA (paired t-test, $p<0.001$) (figure 3). The postoperative lateral compartment CI difference with the control group remained significant ($p=0.01$). Group A (knees with increased CI after surgery) included 143 (82%) knees, with mean preoperative and postoperative CI of 0.87(SD±0.1) and 0.95(SD±0.05), respectively. Group B (knees with decreased CI after surgery) included 31 (18%) knees, with mean preoperative and postoperative CI of 0.92(SD±0.08) and 0.88(SD±0.09), respectively. The mean preoperative CI in the group B was significantly higher than mean preoperative CI in group A (paired t-test, $p=0.03$). There was no significant difference regarding age, gender and the preoperative KL grade distribution of the lateral compartment between group A and group B (table 1).

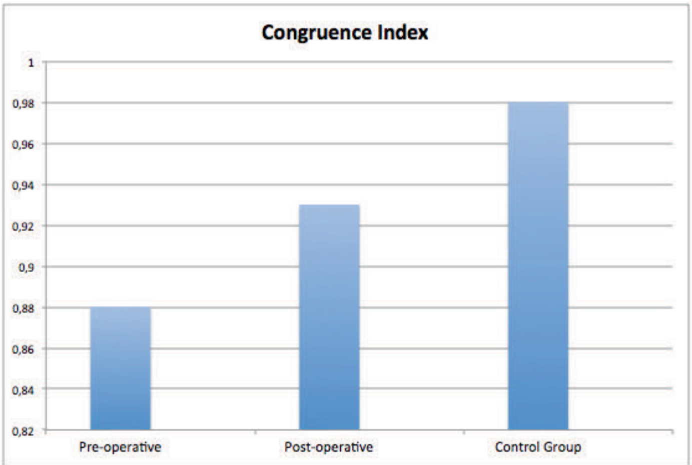

Figure 3. Congruence Index of the lateral compartment preoperatively (0.88 ± 0.01), postoperatively (0.93 ± 0.03) and in control group (0.98 ± 0.01). The preoperative lateral compartment CI improved significantly following medial UKA ($p < 0.001$). However, the postoperative CI difference with the lateral compartment CI of the control group remained significantly ($p = 0.01$).

Table 1. Distribution of Kellgren and Lawrence (KL) grade of the lateral compartment pre-operatively according to an increase or decrease in the congruence index (CI) following medial UKA. No significant differences were observed in the distribution of the KL grade of the two groups (p=0.85, Pearson product moment correlation test).

		N (%)
Decrease Group	KL I	15 (48%)
N=31	KL II	16 (52%)
Increase Group	KL I	65 (45%)
N=143	KL II	78 (55%)

Joint Space Width

Analyzing the inner preoperative JSW, we noted that it was significantly narrower in comparison with the control group (paired t-test, p<0.001) (table 2 & figure 4). Following medial UKA, the inner JSW significantly increased (paired t-test, p<0.001). Postoperatively no significant differences were noted in the inner JSW, comparing it to the control group (paired t-test, p=0.11). The middle JSW of the lateral compartment did not change significantly following medial UKA implantation. No significant differences were noted in the middle JSW, when comparing the preoperative width with the control (paired t-test, p=0.46), the change following UKA implantation (paired t-test, p=0.16) and the postoperative width with the control (paired t-test, p=0.85). The outer JSW of the lateral compartment differed significantly preoperatively in comparison to the control group (paired t-test, p<0.001). We observed that the pre-existing outer JSW became significantly narrower following medial UKA implantation (paired t-test, p=0.03), and did not show significant differences postoperatively compared to the control group (paired t-test, p=0.76).

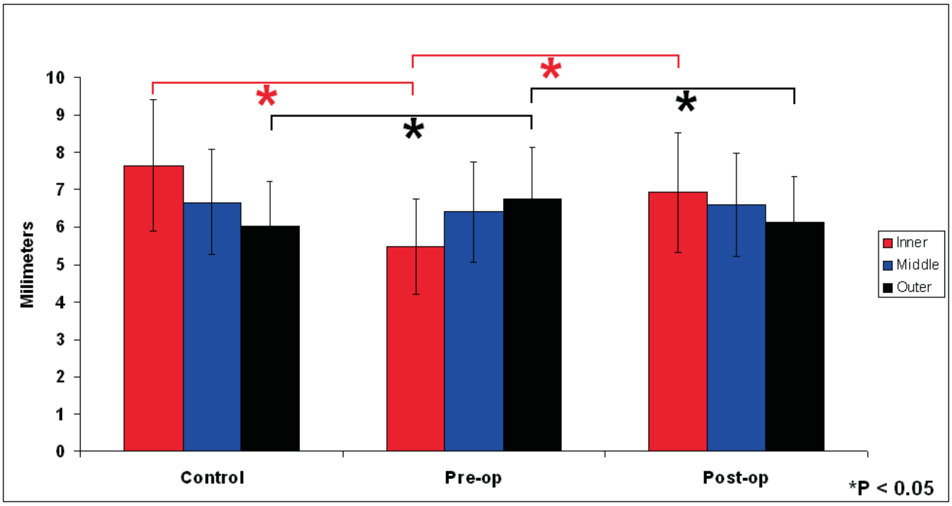

Figure 4. JSW of the lateral compartment preoperatively, postoperatively and in the control group. No significant postoperative differences were noted of the lateral compartment following medial UKA implantation in comparison to the control group (error bars presenting the SD).

Table 2. JSW (± standard deviation) in millimeters pre-operative, post-operative and in the control group.

	JSW Lateral Compartment (mm)		
	Inner	**Middle**	**Outer**
Pre-operative	5.5 (±2.1)	6.4 (±1.7)	6.8 (±1.7)
Post-operative	6.9 (±2.1)	6.6 (±1.8)	6.1 (±1.4)
Control	7.6 (±1.6)	6.7 (±1.5)	6.0 (±1.1)

No correlation was found between CI alterations, JSW (r = 0.12), alignment (r = -0.07) and the preoperative KL grade of the lateral compartment (r = 0.20). The ICC between the two observers was 0.94 for the CI and 0.99 (95% confidence interval 0.89 to 0.99) for the JSW, showing an excellent inter-observer reliability of both methods.

Discussion

The primary surgical options available for the treatment of isolated, medial compartment osteoarthritis of the knee are high tibial osteotomy (HTO), UKA and TKA[24]. Recent improvements in UKA implant designs and surgical techniques have led to higher functional scores[1, 25, 26], improved range of motion[26], lower complications rate[27, 28] and a faster return to sports and work[29] following UKA when compared to TKA. Concerns remain, however, regarding progression of OA in the lateral compartment after medial UKA and the time until revision surgery is needed[2]. This study is the first to demonstrate a significant improvement in the congruity of the lateral compartment of the knee following implantation of a medial UKA. Although the postoperative lateral compartment CI difference with the control group remained significant (p=0.01), the CI in the lateral compartment improved significantly (paired t-test, p<0.001) from 0.88 (SD±0.1) preoperatively to 0.93 (SD±0.03) following medial UKA implantation. Furthermore our data suggests that medial UKA implantation also restores JSW of the lateral compartment, since the existing significant JSW differences preoperatively with the control group, were absent postoperatively. Therefore, we can conclude that medial UKA is not only a resurfacing procedure that affects the medial compartment of the knee, as it also affects the biomechanics of lateral compartment of the knee, and may improve the congruence and restores JSW of the lateral compartment. Potentially, this could prevent or delay the progression of degeneration of the lateral compartment following medial UKA, which is a well-known factor of medial UKA failure.

However, this study also demonstrated that in 18% of the medial UKAs, there was a decrease in the lateral compartment CI. It was observed mainly in knees with a relatively high preoperative CI. This suggests that we should have tight intraoperative control for alignment and tibiofemoral subluxation in order to minimize the risk for lateral compartment CI alterations following medial UKA and be aware of this possible complication, especially in patients with high preoperative CI.

There are a few limitations to our study. First, the study was a retrospective radiographic review and did not evaluate clinical outcomes. Second, the study was a single surgeon case series with extensive experience in performing UKAs using a robotic-assisted surgical technique, and thus these results may not be reproducible at other centers. The majority of UKAs are performed with conventional instrumentation, and use of a robotic-assisted surgical technique may limit the generalizability of our results. A third limitation is that our measurements were performed using AP, standing, tunnel view radiographs, so our congruence evaluation was based on the 2D coronal plane measurements only. Congruence changes in the sagittal plane were not taken into account. Fourth, JSW and CI were measured on radiographs that were obtained six weeks following surgery. Therefore long-term conclusions cannot be drawn from these results and need to be investigated in the future. Finally, we are not able to determine the clinical impact of changes in the lateral compartment CI in this study. We present data on the normal lateral compartment CI from control patients and on the CI in a large group of patient with medial compartment OA. We demonstrate that lateral compartment CI improves after medial UKA in most cases. However, we do not know what CI represents a "pathologic" value and when the CI achieves a level of congruence that allows for effective load distribution and compartment preservation.

Despite these limitations, this study remains important as it presents a novel method for measuring joint congruence and it is the first study, which accurately evaluates the indirect alteration of the lateral compartment following medial UKA. Future studies should be focused on the long-term clinical implications following changes in knee compartment congruence and JSW, along with surgical indications and techniques that may improve the congruence of the lateral compartment following a medial UKA. Our findings suggest that in the majority of patients receiving a well-conducted medial UKA, congruence and of the lateral compartment are improved and JSW is restored, therefore potentially delaying the progression of OA of the lateral compartment. Future studies are needed to evaluate the congruence index and JSW alterations over time and their influence on clinical outcomes scores and implant survivorship results.

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Congruence and joint space width alterations of the medial compartment following lateral unicompartmental knee arthroplasty

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Abstract

Progressive degenerative changes in the medial compartment of the knee following lateral unicompartmental arthroplasty (UKA) remains a leading indication for revision surgery. The purpose of this study is to evaluate changes in the congruence and joint space width (JSW) of the medial compartment following lateral UKA.

The congruence of the medial compartment of 53 knees (24 men, 23 women, mean age 62.1 years; SD 13.1) following lateral UKA was evaluated pre-operatively and six weeks post-operatively, and compared with 41 normal knees (26 men, 15 women, mean age 33.7 years; SD 6.4), using an Interactive closest point algorithm which calculated the congruence index (CI) by performing a rigid transformation that best aligns the digitized tibial and femoral surfaces. Inner, middle and outer JSWs were measured by sub-dividing the medial compartment into four quarters on pre- and post-operative, weight bearing tunnel view radiographs.

The mean CI of knees following lateral UKA significantly improved from 0.92 (SD 0.06) pre-operatively to 0.96 (SD 0.02) ($p < 0.001$) six weeks post-operatively. The mean CI of the healthy control group was 0.99 SD 0.01. Post-operatively, the mean inner JSW increased ($p = 0.006$) and the outer decreased ($p = 0.002$). The JSW was restored post-operatively as no significant differences were noted in all three locations compared with the control group (inner JSW $p = 0.43$; middle JSW $p = 0.019$, outer JSW $p = 0.51$).

Our data suggest that a well-conducted lateral UKA may improve the congruence and normalize the JSW of the medial compartment, potentially preventing progression of degenerative change.

Introduction

Unicondylar knee arthroplasty (UKA) has gained popularity over the last decade in the treatment of unicompartmental osteoarthritis (OA) with a reported survivorship in excess of 95% at ten years.[1,2] Although the early results were inferior in comparison to those of total knee arthroplasty (TKA)[3] recent reports have shown better survivorship, decreased complications, and excellent patient-reported outcome scores.[4] The literature on lateral UKAs is limited,[5-7] and the study populations are often heterogeneous, combining medial and lateral[8,9] UKAs. However, the anatomical and kinematic properties of the medial and lateral knee compartments differ considerably.[10-12] Therefore it can be both inaccurate and misleading to draw conclusions about lateral UKAs based on medial UKA studies.

Most revisions of UKAs are for technical problems caused by malpositioning and loosening. However, another major indication for revision is progressive degenerative change in the adjacent compartment, accounting for 35% of lateral UKA revisions.[13] The chronic uneven distribution of forces over the articular cartilage, which are present in OA[14,15] has been shown to be a risk factor for the progression of OA. Certain regions of the articular cartilage will be exposed to increased chronic loads, whereas the forces which are transmit ted are reduced in other regions.[16,17] This has a well-recognized influence on the viability of articular cartilage and is a precursor of further degenerative change.[16] Congruence of joint has an important effect on the distribution of forces across articular surfaces[18] and tibiofemoral incongruence could cause progressive degenerative change.

In clinical practice, a common method for evaluating the progression of OA is the analysis of joint space width (JSW) on weight-bearing radiographs. Recent studies have suggested that JSW has a strong positive correlation with cartilage compression and volume[19] and meniscal extrusion.[20] The purpose of the current study was to evaluate whether tibiofemoral congruence and JSW of the medial compartment are improved following lateral UKA. We hypothesized that lateral UKA not only resurfaces the lateral compartment, but also improves medial compartment congruence and JSW and therefore may delay or prevent progressive degenerative change in the uninvolved medial compartment.

Patients and Methods

This retrospective cohort study was performed following institutional review board approval. Between June 2007 and July 2012, 47 patients (24 men and 23 women; 53 knees) with a mean age of 62.1 years (43 to 85; standard deviation (SD) 13.1), underwent lateral UKA for isolated lateral compartment arthritis (MCK Lateral Onlay Unicompartmental, MAKO Surgical Corp., Fort Lauderdale, Florida). Inclusion criteria for the study were patients with isolated lateral compartment OA, for whom both pre- and post-operative standing, anteroposterior (AP) hip to ankle and knee tunnel radiographs were available. Those without radiographs of adequate quality were excluded. The indications for UKA included lateral compartment OA, an intact anterior cruciate ligament, a medial compartment without signs of OA, a correctable valgus deformity and a fixed-flexion-deformity of < 10°. Contraindications included the presence of Kellgren–Lawrence (KL)[21] grade 3 or greater patellofemoral or medial compartment changes on pre- operative radiographs, or inflammatory arthritis. All operations were performed by a single surgeon (ADP) using a robot-arm assisted technique[22,23] for the preparation of the femoral and tibial surfaces (MAKO Surgical Corp.). The goal was an undercorrection of the valgus deformity, in order to avoid the progression of OA in the medial compartment.[24]

Routine pre-operative and six-week post-operative, weight-bearing coronal radiographs of the knee and hip to ankle were obtained using a standardized protocol. Care was taken to ensure that each patient stood with their patella facing forward in order to minimize rotational variation. Using the hip to ankle standing radiographs, the mechanical alignment of the lower extremity was measured pre- and post-operatively by drawing a line from the centre of the femoral head to the centre of the femoral notch which formed the femoral mechanical axis and a line connecting the centre of the talus to the centre of the tibial plateau which formed the tibial mechanical axis. The angle formed between them was recorded as the mechanical alignment. The pre-operative degenerative changes of the medial compartment were recorded with use of the KL scores.

The pre- and post-operative congruence of the medial compartment was calculated using a software code (Matlab, MathWorks Inc., Natick, Massachusetts) based on the iterative closest point (ICP) algorithm. The code was specifically developed to measure coronal tibiofemoral subluxation and the angle between the articular surfaces. Subsequently it evaluates the geometrical relationship between the femoral and tibial weight-bearing areas and translates this into a congruence index (CI). We have previously validated the code for measurements of the knee and have shown it to be highly accurate and reliable.[25]

The code enables digitization of the articular surfaces of the femur and tibia, performs a rigid transformation that best aligns the articular surfaces and evaluates the CI, (Fig. 1) which ranges between 0 and 1. A value of 0 represents a completely incongruent joint, as in a dislocated joint where no forces are transferred across the knee. A value of 1 indicates a completely congruent joint with an equal distribution of forces over the articular surfaces.

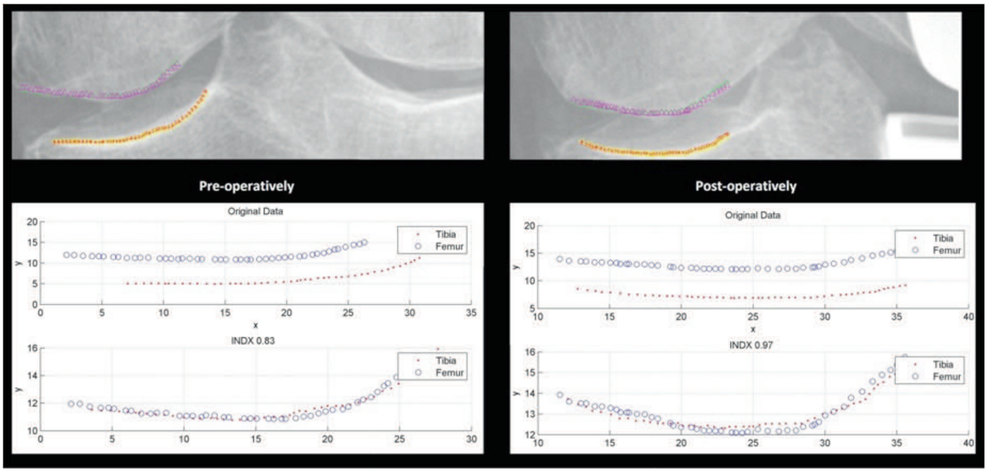

Figure 1. The performed iterative closest point algorithm calculates the congruence index (noted as INDX in the figure) of the medial compartment pre- and post-operatively following manual digitization of the femoral and tibial surfaces.

After evaluating the pre- and post-operative medial compartment CIs, patients were divided into the following three categories; increased CI, unchanged CI and decreased CI. A reportable change between the pre- and post-operative CI was a difference of more than one SD from the control group.

JSW was defined as the tibiofemoral interbone distance, measured in millimeters on weight-bearing tunnel radio- graphs of the tibiofemoral joint as previously reported.[26] Pre- and post-operatively, the three same sites (inner, middle and outer), based on subdividing the medial compartment into four quarters, were chosen to measure JSW (Fig. 2). Any alteration in JSW following lateral UKA was recorded.

We also evaluated the CI and JSW in routine bilateral standing radiographs of patients aged < 40 years who had undergone anterior cruciate ligament reconstruction and who had no symptoms or signs of OA in the contralateral knee as a control group. This group comprised 41 patients (26 men and 15 women) with a mean age of 33.7 years (24 to 38; SD 6.4). All CI and JSW measurements were performed independently by two observers (HAZ, SK).

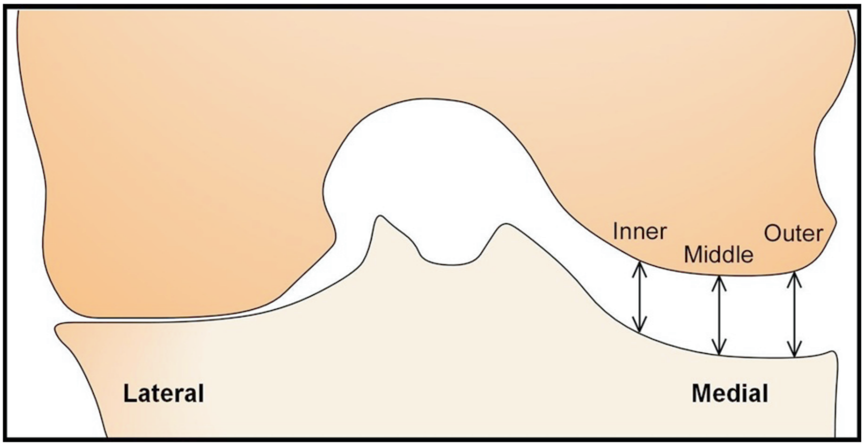

Figure 2. Diagrammatic representation of the measured joint space width sites (inner, middle and outer) of the medial compartment.

Statistical analysis.

A paired t-test was used for comparison of pre- and post-operative values of medial compartment CI and JSW. A p-value < 0.05 was considered statistically significant. The Pearson product moment correlation test was used to estimate the correlation between pre- and post-operative limb alignment, degenerative changes and CI. Interclass correlation coefficients (ICC) for the CI and JSW measurements were calculated using previously described semi-quantitative criteria. The ICCs were graded using previous published semi- quantitative criteria: excellent for $0.9 < p < 1.0$, good for $0.7 < p < 0.89$, fair/moderate for $0.5 < p < 0.69$, low for $0.25 < p < 0.49$ and poor for $0.0 < p < 0.24$.[27]

Results

The mean alignment of the limb improved significantly from 5.9° (1 to 13.6) of valgus pre-operatively to 3.3° (0.2 to 6.3) of valgus six weeks post-operatively ($p < 0.001$, paired t-test). According to the KL score, 40 knees had grade 1 and 13 knees had grade 2 degenerative changes of the medial compartment, pre-operatively.

The mean CI of the medial compartment improved significantly from 0.92 (0.70 to 0.99; SD 0.06) pre-operatively to 0.96 (0.84 to 0.99; SD 0.02), six weeks after lateral UKA ($p < 0.001$, paired t-test) (Fig. 3). In all, 31 knees (58.5%) demonstrated an improvement of the CI in the non-treated medial compartment (pre-operative CI 0.89 (SD 0.06), post- operative CI 0.97 (SD 0.03), $p < 0.001$, paired t-test). However, 11 knees (20.7%) demonstrated an unchanged CI in the medial compartment post-operatively (pre-operative CI 0.97 (SD 0.02), post-operative CI 0.97 (SD 0.02), p = 0.73, paired t-test). In contrast, 11 knees (20.7%) showed a decreased CI in the medial compartment post-operatively (pre-operative CI 0.97 (SD 0.02), post-operative CI 0.94 (SD 0.02), p = 0.74, paired t-test). In the group that showed an increased CI post-operatively, 26 knees (83.8%) had KL grade I and 5 knees (16.2%) had KL grade II degenerative changes of the medial compartment pre-operatively. In the group that showed decreased CIs post-operatively, 6 knees (55%) had KL grade I and 5 knees (45%) had KL grade II degenerative changes of the medial compartment pre-operatively. This difference was statistically significant (p = 0.04; Table I). No correlation was found between CI changes, JSW (r = 0.17), pre-operative KL grade (r = 0.12) or alignment (r =-0.06).

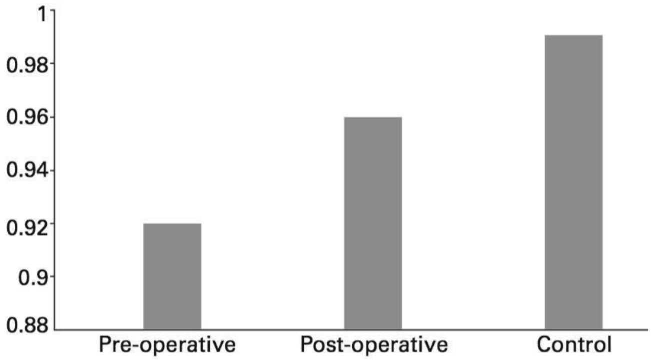

Figure 3. Graph showing overall congruence index changes pre-operatively (CI = 0.92), post-operatively (CI = 0.97) and in the control group (CI = 0.99).

In the control group, the mean CI of the medial compartment was 0.99 (0.98 to 1.00; SD 0.01).

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Table 1. Distribution of Kellgren and Lawrence 21 (KL) grade of the medial compartment pre-operatively according to an increase or decrease in the congruence index (CI) following lateral unicondylar knee arthroplasty. A higher incidence of KL grade II changes in the medial compartment was observed in the decrease group pre-operatively (p = 0.04, Pearson product moment correlation test).

		N (%)
Decrease CI group		
N = 11	KL I	6 *(55)*
	KL II	5 *(45)*
Increase CI group		
N = 31	KL I	26 *(83.8)*
	KL II	5 *(16.2)*

When comparing the pre-operative JSW of the patients that underwent lateral UKA with the control group, the mean inner JSW was significantly lower pre-operatively (p= 0.02). No significant differences were observed between the middle (p = 0.11) and outer (p = 0.14)

JSW compared with the controls. Post-operatively, the mean inner JSW significantly increased ($p = 0.006$), whereas the mean outer JSW decreased ($p = 0.002$). The mean middle JSW did not change significantly ($p = 0.68$). No significant differences were noted between the post-operative JSW of all three measured sites and the JSW of the control group (Inner JSW $p = 0.43$, Middle JSW $p = 0.19$, Outer JSW $p = 0.51$) (Fig. 4).

The ICC between the two observers was 0.94 for the CI and 0.99 (95% confidence interval 0.89 to 0.99) for the JSW, showing an excellent inter-observer reliability of both methods.

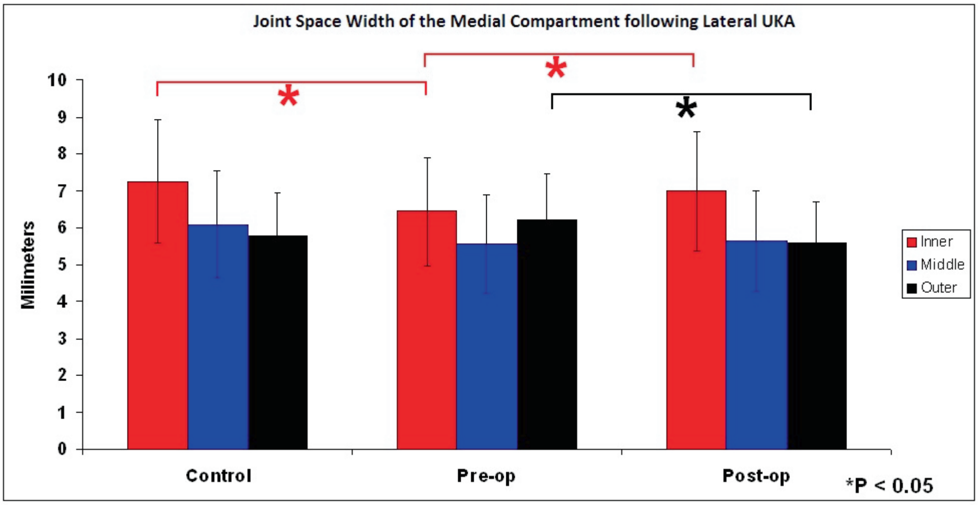

Figure 4. Alterations of the medial joint space width (JSW) following lateral unicondylar knee arthroplasty and in the control group. Note that there were no significant JSW differences post-operatively compared with the control group (paired t-test).

Discussion

Unicompartmental resurfacing procedures of the knee have been a subject of debate since their introduction in the 1970s.[3] Improved surgical techniques, implant designs, less peri-operative blood loss, shortened hospital stay and proven cost-effectiveness[28] have led to an increase in the use of UKA in the treatment of unicompartmental OA. Although numerous reports show comparable survival of TKA and UKA,[4,29,30] national joint registries have shown higher revision rates for UKA compared with TKA.[31,32] Despite the increasing numbers of UKAs being implanted worldwide, the existing literature remains limited about the lateral UKA.

Several reports have described the different characteristics of the medial and lateral compartments. Anatomically, the shapes differ. The medial tibial condyle is concave, the lateral condyle is convex. This results in a more distinctive internal tibial rotation of the lateral tibial compartment compared with the femoral condyle during flexion.[33] Tokuhara et al[34] studied the flexion gap of the two compartments in 20 healthy volunteers using MRI and found that the gap of the lateral compartment is significantly more lax than that of the medial compartment. These different kinematic properties result in wear of the articular cartilage which is located more posteriorly than in the medial compartment.[12] Therefore, the treatment of lateral unicompartmental OA requires a different approach.

The restoration of congruence of the medial compartment is essential to prevent progressive degenerative changes in the medial compartment following lateral UKA.[35] To our knowledge, this is the first study evaluating the congruence of the medial compartment after lateral UKA. Our data show that the overall CI of the medial compartment significantly improved six weeks after lateral UKA from a mean of 0.92 (SD 0.06) pre-operatively to a mean of 0.96 (SD 0.02) post-operatively. These data support our hypothesis that a lateral UKA not only restores the height of the lateral compartment, but also improves congruence in the medial compartment. This is of considerable importance for the restoration of the distribution of load caused by the incongruence of the tibiofemoral joint that has been associated with progressive degenerative changes.[18] However, we observed a decrease in the CI of the medial compartment in 11 knees (20.7%) of patients post-operatively. We noted a significantly higher distribution of degenerative changes (KL grade II) pre-operatively in the group that showed a decrease in CI in the medial compartment post-operatively. This suggests that caution should be exercised when performing a lateral UKA in patients with pre-operative degenerative changes in the medial compartment, due to the deterioration in congruence of the medial compartment that may ensue.

Factors that can affect the congruence of the knee are tibiofemoral subluxation and mechanical axis alignment. Subluxation is a relatively underreported variable in the literature on OA. We recently reported a novel method of measuring subluxation in radiographs of the lower extremity after UKA.[36] In a lateral cohort of 39 patients, tibiofemoral subluxation was corrected from 4.3 mm (SD 2.7) pre-operatively to 2.8 mm (SD 2.5) post-operatively. Mechanical axis alignment was corrected from 5.5° (SD 3.8°) of valgus to 1.6° (SD 3.4°) of valgus. However, the ICP algorithm used in the current study enabled us to evaluate the congruence of the joint accurately rather than in an indirect manner using subluxation and alignment as we have previously described.[36] The ICP method reduces the influence of altered load distribution in the osteoarthritic joint and obviates the need for full length hip to ankle radiographs with their resultant increased radiation and expense.

The use of post-operative mechanical axis alignment as an outcome measure is frequently reported in the UKA literature.[29,37] However, there is no consensus as to the desired degree of correction. It is generally accepted, though, that overcorrection of > 180° in the medial OA varus and lateral OA valgus aligned knee should be avoided in order to prevent progressive degenerative changes in the uninvolved compartment. Hernigou and Deschamps[24] studied the radiographic progression of OA in the lateral compartment and polyethylene wear of the tibial component after medial UKA. Correlations were made with the most recent hip–knee–ankle (HKA) radiographs during follow-up. In ten cases, the pre-operative deformity was overcorrected to valgus (mean HKA overcorrection: 3°). They found that post-operative degenerative changes in the uninvolved lateral compartment were less in the undercorrected cohort (HKA angle < 180°). Price et al[30] retrospectively studied 432 medial Oxford UKAs and found that the most common cause of revision was progression of OA in the lateral compartment. This finding is supported by other authors.[37-40] The importance of restoration of joint congruence, with its resultant equal distribution of forces over the articulating surfaces, was not mentioned in these studies.

The evaluation of JSW is frequently used to assess the progression of degenerative change. Our data suggest that lateral UKA not only resurfaces the treated compartment but also indirectly restores the JSW of the opposite compartment since we did note any significances changes with the control group post-operatively. This finding suggests that the co-existing pre-operative compression of the articular cartilage of the unoperated medial compartment may be indirectly decompressed by resurfacing the osteoarthritic compartment. This may potentially delay the onset of degenerative changes in the uninvolved compartment, which are commonly reported to be the leading cause of failure of UKAs.

There are several limitations of this study. Despite the use of a rigorous radiographic imaging protocol for obtaining weight-bearing radiographs of the knee, these studies are still subject to small rotational variations that can potentially influence measurements. Secondly, all operations were performed by a single surgeon with extensive experience in UKA using a robot-arm assisted technique. The results might not be applicable to low-volume centres or the implantation of UKAs undertaken without robotic assistance. Thirdly, the measurements were performed on coronal radiographs of the knee and, therefore, post-operative congruence in the sagittal plane remains unknown. Fourthly, we acknowledge the absence of clinical outcomes in this study but plan to report these data in due course. Finally, all post-operative radiographs were obtained six weeks following surgery, meaning that our results inform us about the direct post-operative period. Longer follow-up is needed to evaluate potential JSW and congruence alterations over time.

Despite these limitations, this study is an important addition to the scarce literature on lateral UKAs. We conclude that a well-conducted lateral UKA not only resurfaces the lateral compartment but also has the potential to normalize the width of the joint space of the medial compartment and improve congruence. The improvement in congruence of the medial compartment after lateral UKA was not observed in knees with pre-operative degenerative changes in the medial compartment and we therefore recommend caution in this group.

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8

Medial Unicondylar Knee Arthroplasty Improves Patellofemoral Congruence: a Possible Mechanistic Explanation for Poor Association Between Patellofemoral Degeneration and Clinical Outcome

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Abstract

The purpose was to determine the effect of medial fixed bearing unicondylar knee arthroplasty (UKA) on post-operative patellofemoral joint (PFJ) congruence and analyze the relationship of preoperative PFJ degeneration on clinical outcome. We retrospectively reviewed 110 patients (113 knees) who underwent medial UKA. Radiographs were evaluated to ascertain PFJ degenerative changes and congruence. Clinical outcomes were assessed preoperatively and postoperatively. The postoperative absolute patellar congruence angle (10.05 ± 10.28) was significantly improved compared with the preoperative value (14.23 ± 11.22) (P = 0.0038). No correlation was found between preoperative PFJ congruence or degeneration severity, and WOMAC scores at two-year follow up. Pre-operative PFJ congruence and degenerative changes do not affect UKA clinical outcomes. This finding may be explained by the post-op PFJ congruence improvement.

Introduction

Increased utilization of medial unicondylar knee arthroplasty (UKA) for treatment of medial compartment osteoarthritis has been reported over the last two decades[1]. Historically, patellofemoral joint (PFJ) degeneration, and more specifically advanced lateral PFJ facet degeneration, along with anterior knee pain were considered exclusion criteria for medial UKA[2,3]. However, recent studies have reported that PFJ degenerative changes do not influence clinical outcomes following UKA[4,5]. Therefore, controversy still exists on whether pre-existing PFJ degeneration is a contraindication for UKA. Although, patellar alignment after total knee arthroplasty (TKA) has been extensively studied[6–9], there is a paucity of reports on the association between functional outcomes and pre-operative and post-operative patellar alignment and PFJ congruency following medial UKA. Relevant studies are limited to a case series of patellar impingement after UKA[10] and reports of an association between lateral patellar displacement and poor outcomes following UKA[11].

Recently, Robotic-Assisted (RA) UKA is gaining in popularity[12]. Various studies have shown that medial RA-UKA improves postoperative implant positioning and limb alignment when compared to conventional manual techniques[13–16]. In addition, it has been reported that lateral RA-UKA improves the congruence of the medial compartment and that pre-existing tibiofemoral subluxation is being restored after medial and lateral UKA[16,17]. Nevertheless, to the best of our knowledge there are no published data on the ability of either conventional or RA medial UKA in affecting preoperative PFJ incongruence.

The purpose of this study was to 1) determine whether PFJ degeneration is associated with lower clinical outcomes and 2) analyze the effect of medial fixed bearing RA-UKA on postoperative PFJ congruence in a series from a single surgeon who specializes in RA-UKA. We hypothesized that preoperative PFJ arthritic changes do not adversely affect clinical outcomes, and that medial RA-UKA improves PFJ congruence.

Methods

Patient Selection

This study was based on a prospective cohort of patients assembled for the senior author's surgical arthritis registry. Patients were eligible for this analysis if they were adult participants in the registry and underwent medial RA-UKA between October 1st, 2008 and May 1st, 2012. This study was approved by the Institutional Review Board at our hospital, and all patients provided informed consent for participation in the registry. Surgical indications for medial RA-

UKA included medial compartment osteoarthritis (OA), no significant joint space narrowing in the lateral compartment, an intact anterior cruciate ligament, a correctable varus deformity and a fixed-flexion-deformity of <10°. Contraindications included the presence of Kellgren-Lawrence (K-L)[18] grade III or greater OA of the lateral compartment, PFJ related pain symptoms (specifically patient-reported anterior knee pain with sitting [i.e. "movie theater sign"] or stair climbing), or inflammatory arthritis. All enrolled patients underwent minimally invasive medial RA-UKA technique[12] by the senior author utilizing a standardized surgical technique and onlay prosthesis (MCK Medial Onlay Unicompartmental, MAKO Tactile Guidance System [TGS], MAKO Surgical Corporation, Fort Lauderdale, Florida, USA).

Overall, 122 patients (133 knees) were identified and were considered eligible for the study. However, in 12 patients (20 knees) radiographic evaluation could not be completed; in six patients the radiographs could not be retrieved, in five technical difficulties prevented accurate radiographic measurements, and one patient underwent early revision due to symptomatic progression of degenerative changes in the lateral compartment.

Therefore, 110 patients (113 knees) with an average follow-up of 2 years (range, 1 to 4.2) were included in the study. The mean age of the patients at the time of surgery was 63.9 ± 10.4 years. There were 52 (47.3%) females and 58 (52.7%) males with a mean BMI of 28.26 ± 4.6. One hundred and seven unilateral and 3 staged bilateral procedures were performed

Radiographic Evaluation

Radiographic evaluation included preoperative and postoperative anterior posterior (AP) weight bearing views, axial views at 45° of flexion (Merchant view)[19] using a Merchant board to control the flexion angle, and lateral views at 30° of flexion[20]. For the radiographic evaluation of the degenerative changes, pre-operative weight bearing knee radiographs and preoperative and postoperative Merchant view radiographs were used. The change in lower limb mechanical axis was calculated based on pre-operative and post-operative weight-bearing AP views, respectively.

Evaluation of Patellofemoral Degeneration

Arthritic changes of the PFJ was graded according to the Modified Altman scale[21,22]. Patients were divided into a "Mild PF OA group" (Modified Altman grade 0 & I) and "Severe PF OA group" group (Modified Altman grade II & III). Pre-operatively, 72.5% (82) the knees were classified as Modified Altman score 0 or I (mild degenerative changes), whereas 27.5% (31) were classified as Modified Altman score II or III (severe degenerative changes). The Insall–Salvati index was calculated based on lateral radiographs[23].

Patellar Congruence

The patellar congruence was measured on the Merchant views based on the technique described by Merchant et al[9] (Fig. 1). Furthermore, preoperative and postoperative lateral patellar displacement was calculated. The lateral patellar displacement (L) is the length between a line from the highest point of the medial condyle which is perpendicular to a line connecting the highest points of the lateral and medial condyles and a parallel line touching the medial border of the patella (Fig. 1).

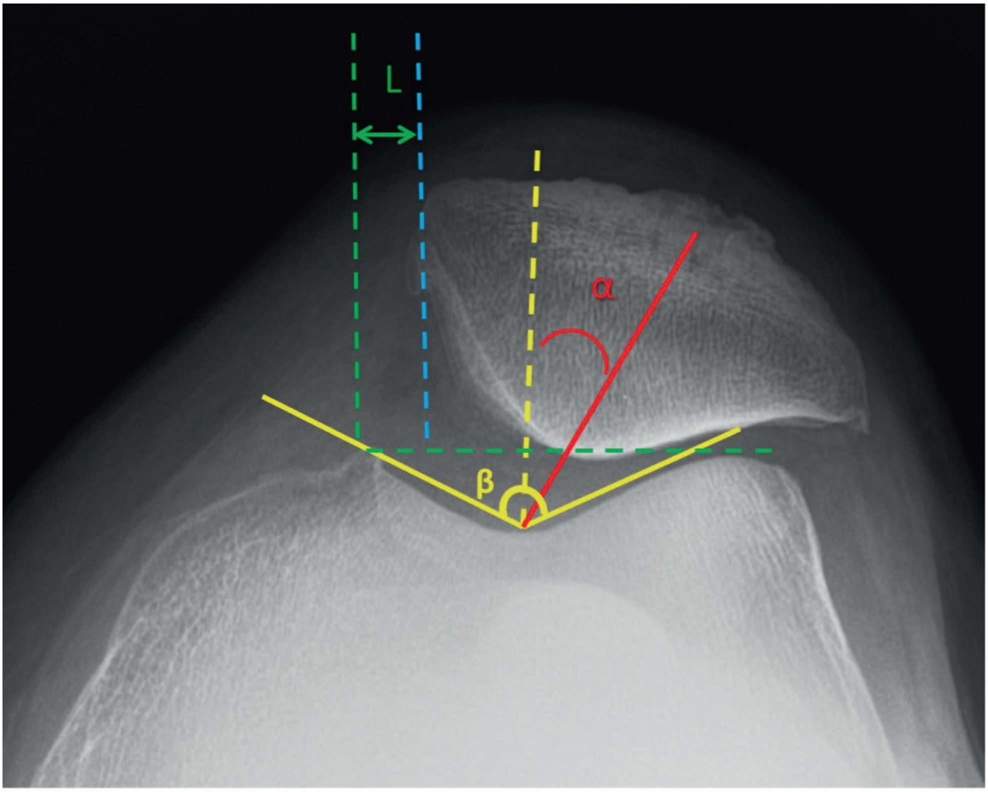

Figure 1. Radiographic measurements of the patellofemoral joint. Bisect line (dashed yellow line) of the sulcus angle (β) represents a zero reference. A second line extending from the vertex of the sulcus angle to the vertex of the patellar facets, forms the patellar congruence angle (α). The lateral patellar displacement (L) is calculated by drawing a line from the highest point of the medial and lateral condyle (dashed green line). Subsequently a second line is drawn from the medial top of the condyle that is perpendicular to this line. Finally the medial border of the patella is identified and a line is drawn that is also perpendicular to the green dashed line. This distance represents the lateral patellar displacement (L).

The radiograph measurements were performed by two investigators. Inter-observer reliability between the two observers was assessed using Interclass correlation coefficients (ICCs). The ICCs were interpreted using previous published semi-quantitative criteria: excellent for $0.9 < p < 1.0$, good for $0.7 < p < 0.89$, fair/moderate for $0.5 < p < 0.69$, low for $0.25 < p < 0.49$ and poor for $0.0 < p < 0.24$[24]. Interclass correlation coefficients for all radiographic measurements were excellent. Specifically, the ICC for patellar congruence angle was 0.981, for Insall–Salvati index 0.995, for lateral patellar displacement 0.993, and for mechanical alignment 0.990, respectively.

Assessment of Symptoms and Function: WOMAC Questionnaire

Clinical measures were collected prospectively both preoperatively and postoperatively using the Western Ontario and McMaster Universities Osteoarthritis Index score (WOMAC). The WOMAC is a widely used validated measure of symptoms and function in patients with osteoarthritis of the knee or hip[25,26], consisting of 3 subscales, pain, stiffness, and physical function. Scores for each subscale can range from 0 to 100, with higher scores indicating better condition. All patients completed postoperative WOMAC questionnaires (N = 110) at latest follow-up. However, 53 (48.2%) patients completed the preoperative questionnaires. To account for this discrepancy, we performed sensitivity analysis tests comparing the baseline clinical characteristics and radiographic measures between participants with missing preoperative WOMAC scores (non-respondents) and those who fully completed the preoperative WOMAC scores questionnaires (respondents). No significant difference was observed between the two groups except for the patellar congruence angle measurements. Non-respondents were associated with lower patellar congruence angle both preoperatively (11.58 ± 8.37 versus 17.24 ± 13.22), and postoperatively (7.88 ± 7.5 versus 12.51 ± 12.33).

Statistical Analysis

Preoperative and postoperative radiographic measurements and WOMAC scores were tabulated using means ± standard deviation and 95% confidence intervals. Paired t-tests were used for the comparison of preoperative and postoperative values of radiographic measurements and WOMAC scores. The association between preoperative radiographic measures and postoperative WOMAC scores was assessed using multiple linear regression, adjusting for age, gender, and BMI. Pearson product moment correlation coefficient was used to estimate the correlation between preoperative limb alignment, severity of degenerative changes, patellar congruence angle, patellar lateral displacement and postoperative WOMAC scores. All analyses were performed using SAS for Windows 9.2 (SAS Institute Inc., Cary, NC, USA). All tests were two-sided, and statistical significance was set at 0.05 for all comparisons.

Results

WOMAC pain, stiffness and function scores improved significantly following medial RA-UKA ($P < 0.0001$) (Fig. 2). Statistically significant difference was not reached in any comparison, however, knees with preoperative modified Altman score of II–III versus 0–I were associated with better improvement in WOMAC pain, stiffness, and function scores, respectively (+ 8.8; + 5.4; + 3.0 points). The results from multiple linear regressions are illustrated in Table 1. No significant association was found between preoperative patellar congruence angle, lateral patellar displacement, limb alignment, age, gender, and BMI and postoperative WOMAC subscale scores.

Table 1. Multiple linear regression model: Association between preoperative radiographic measures and demographics and postoperative WOMAC scores.

WOMAC pain			
	Estimate	**Standard Error**	**Pr > |t|**
Intercept	53,2	24,3	0,034
Limb alignment	0,0	0,7	0,9807
Lateral patellar displacement	0,2	0,3	0,6355
Modified Altman (2-3 vs 0-1)	8,8	5,7	0,1273
K-L grade (3-4 vs 1-2)	-3,1	5,3	0,5598
Age	0,2	0,3	0,3682
Sex (Female vs Male)	-4,5	5,0	0,3739
BMI	0,7	0,5	0,1467
WOMAC stiffness			
	Estimate	**Standard Error**	**Pr > |t|**
Intercept	44,1	27,0	0,11
Limb alignment	0,3	0,8	0,6843
Lateral patellar displacement	0,5	0,4	0,1824
Modified Altman (2-3 vs 0-1)	5,4	6,3	0,393
K-L grade (3-4 vs 1-2)	-2,7	5,8	0,643
Age	0,0	0,3	0,8813
Sex (Female vs Male)	-2,0	5,6	0,7242
BMI	1,0	0,6	0,0905
WOMAC function			
	Estimate	**Standard Error**	**Pr > |t|**
Intercept	76,0	24,1	0,0031
Limb alignment	-0,2	0,7	0,823
Lateral patellar displacement	0,2	0,3	0,4748
Modified Altman (2-3 vs 0-1)	3,0	5,5	0,5864
K-L grade (3-4 vs 1-2)	-4,5	5,0	0,3768
Age	0,1	0,3	0,5772
Sex (Female vs Male)	-3,1	4,8	0,5261
BMI	0,2	0,5	0,6723

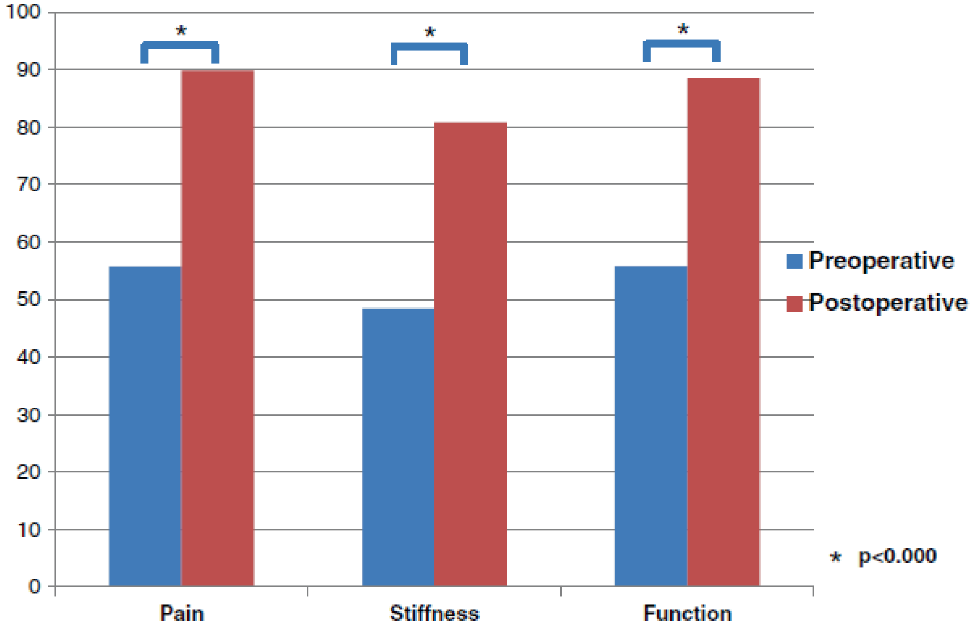

Figure 2. Preoperative and post-operative WOMAC scores. A p-value < 0.05 represents that the measurement demonstrated a significant change.

Pearson product moment correlation test showed no significant correlation between WOMAC subscale scores and pre-operative or post-operative limb alignment, Insall-Salvati index, lateral patellar displacement and patellar congruence angle (Table 2).

Pre-operative and post-operative radiographic measurements for the whole cohort are summarized in Table 3. Mechanical lower limb alignment was corrected from 7.69 (SD ±3.58) of varus angle pre-operatively to 2.95 (SD ±2.65) of varus postoperatively ($P < 0.0001$). The patellar congruence angle was improved from 14.23 (SD ± 11.22) to 10.05 (SD ± 10.28), postoperatively ($P = 0.0038$) (Figs. 3 and 4). No significant change was recorded in the lateral patellar displacement and Insall–Salvati ratio.

Table 2. Pearson product moment correlation coefficients to estimate the correlation between pre- and post-operative radiographic measurements and postoperative WOMAC scores.

			WOMAC pain Post		WOMAC stiffness Post		WOMAC function Post
Variable		N	Corr (95% CI)	N	Corr (95% CI)	N	Corr (95% CI)
Limb alignment	Post	111	0.10 (-0.09, 0.28)	110	0.02 (-0.17, 0.21)	104	0.04 (-0.15, 0.23)
Limb alignment	Pre	98	0.02 (-0.18, 0.22)	97	0.09 (-0.12, 0.28)	91	-0.01 (-0.22, 0.19)
Insall-Salvati index	Post	113	-0.10 (-0.28, 0.08)	112	-0.03 (-0.22, 0.16)	106	-0.12 (-0.30, 0.07)
Insall-Salvati index	Pre	113	-0.06 (-0.24, 0.13)	112	0.03 (-0.16, 0.21)	106	-0.07 (-0.25, 0.13)
Lateral patellar displacement	Post	113	-0.04 (-0.22, 0.15)	112	0.03 (-0.16, 0.21)	106	0.04 (-0.15, 0.23)
Lateral patellar displacement	Pre	113	-0.04 (-0.22, 0.14)	112	0.04 (-0.15, 0.23)	106	0.02 (-0.17, 0.21)
Congruence angle	Post	113	-0.03 (-0.22, 0.15)	112	0.07 (-0.12, 0.25)	106	0.05 (-0.15, 0.23)
Congruence angle	Pre	113	-0.01 (-0.19, 0.17)	112	0.08 (-0.10, 0.26)	106	0.04 (-0.15, 0.23)

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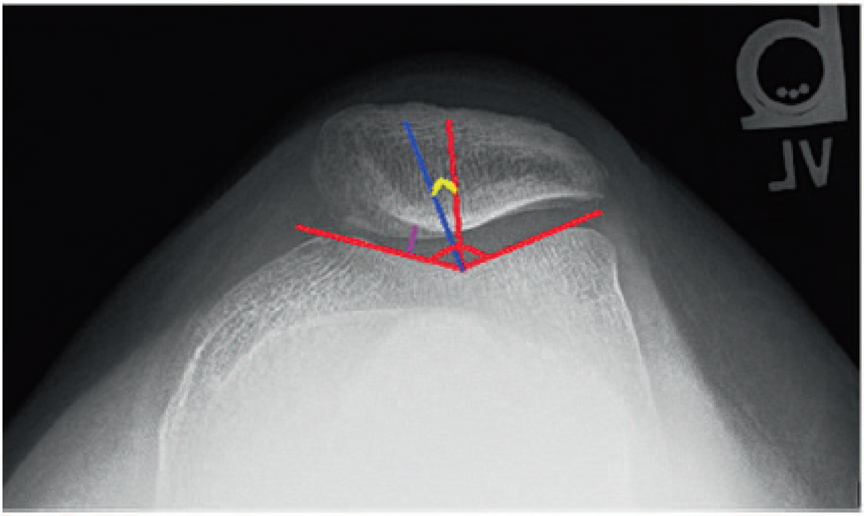

Figure 3. Pre-operative Merchant View of a left knee. The trochlear angle (Red angle) is 140°. The congruence angle (yellow angle) is 14°. The medial patellofemoral joint space is represented by the purple line.

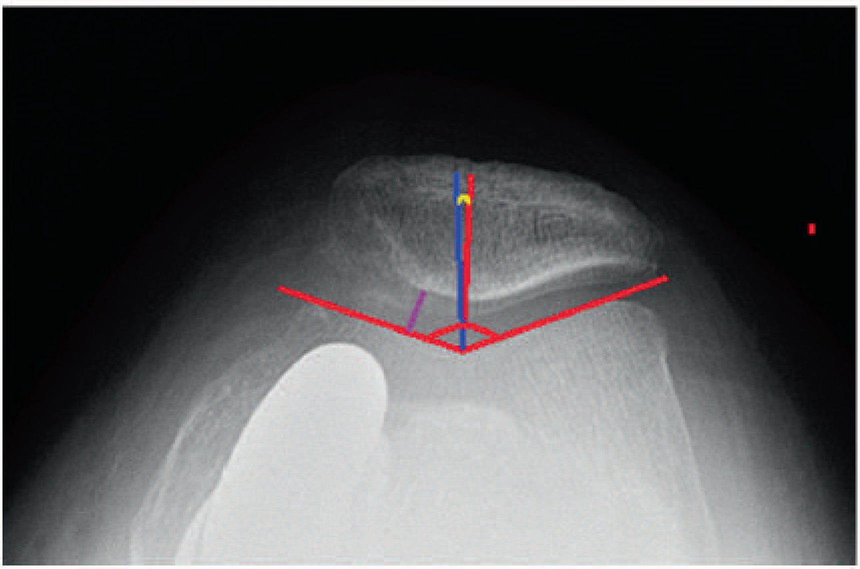

Figure 4. Post-operative Merchant View of a left knee. The trochlear angle (Red angle) is 140°. The post-operative congruence angle (yellow angle: 6°) is decreased compared to the pre-operative one (figure 3). Moreover, the medial patellofemoral joint space (purple line) is increased by 1.5 mm following unicompartmental knee arthroplasty.

Table 3. Radiographic measurements of the patella-femoral joint for the whole cohort pre and post Medial UKA (N=113)

	Preoperative Mean (± Std)	Postoperative Mean (± Std)	P-values
Lower limb alignment	7.69 (± 3.58)	2.95 (± 2.65)	**<.0001**
Insall-Salvati index	1.07 (± 0.16)	1.07 (± 0.16)	0.9678
Lateral patellar displacement (L)	6.67 (± 8.81)	5.77 (± 8.86)	0.4467
Lateral patellar angle	11.21 (± 6.23)	11.33 (± 6.34)	0.8799
Congruence angle (α)	14.23 (± 11.22)	10.05 (± 10.28)	**0.0038**

Discussion

Debate still exists on whether pre-existing PFJ degeneration remains a contraindication for medial UKA. Furthermore, there are no reports on the ability of either conventional or RA medial UKA in correcting preoperative PFJ incongruence. Therefore, we aimed to determine whether severe PFJ degeneration is associated with lower clinical outcomes and to analyze the effect of medial fixed bearing RA-UKA on postoperative PFJ congruence.

Historically, radiographic degenerative changes of the PFJ have been considered a contraindication for UKA. Kozinn and Scott popularized that preexisting PFJ degenerative changes are a contraindication for UKA which has been supported by others as well[27]. Furthermore, preexisting PFJ degeneration has been reported to be a risk factor for PF pain following medial UKA[10]. Berger et al[28] highlighted that strict patient selection criteria (i.e. minor degenerative PFJ alterations) is essential for successful clinical outcomes. The authors reported that 78% of patients who underwent fixed bearing UKA reported excellent outcomes and 20% good outcomes, using the Hospital for Special Surgery Score (6–10 years of follow-up). However, the current study shows no association between the preoperative radiographic PFJ measurements and adverse clinical outcomes following RA medial UKA at an average 2 years of follow-up. Degenerative changes of the PFJ and pre-operative patellar incongruence were not found to affect postoperative WOMAC scores in UKA candidates presenting without severe anterior knee pain. Our results are in agreement with other published studies. The Oxford Group has reported a significant increase in the Oxford Knee Score (OKS) after UKA in patients with preoperative medial patellar degenerative changes as well as those with intact PFJ[29]. Multiple studies, most of them using mobile bearing medial UKA, have reported minimal or no correlation between clinical outcomes and failure rates, and preoperative degenerative changes of the PFJ. Goodfellow et al[30] and Song et al[31] reported no correlation between preoperative degenerative PFJ changes and postoperative PFJ related pain. An MRI study[32] found no significant differences in function or failure rates, after comparing 33 patients with degenerative changes of the adjacent compartment and/or PFJ with 967 medial UKA patients.

In this series, with an average follow-up of 2 years, only one case out of 132 knees (0.75%) was revised due to symptomatic progression of degenerative changes in the lateral compartment. No revision was performed due to PFJ symptoms. Similarly, Hernigou and Deschamps reported that only one of the 22 revisions (cohort 99 fixed bearing medial UKAs) was revised because of PFJ symptoms due to impingement 11 years following index surgery[10].

The Oxford Group showed no correlation between PFJ cartilage damage pre-operatively and poor clinical outcomes. These authors reported that none of the 1701 UKAs were revised because of symptomatic PFJ degenerative changes[29]. The Swedish Knee Arthroplasty Registry[33] has reported, in a series of 699 mobile bearing UKAs, that only 1 out of 50 UKA revisions was performed due to PFJ symptoms. Additionally, long-term (> 10-year) studies including multiple UKA designs, have stated that failure rate related to the patellofemoral and/or adjacent tibiofemoral compartment is relatively low, and ranges from 3% to 9%[10,34–39]. Furthermore, Foran et al[3] showed radiographic evidence of patellofemoral or adjacent tibiofemoral compartment degeneration progression in most of their patients with minimal effect on clinical outcomes. The same group reported that only 2 out of 51 medial fixed bearing UKAs were revised because of progressive PFJ degeneration[3]. Taken together, the historical literature, along with our current data, suggests that radiographic PFJ degeneration does not predict adverse functional outcome after medial UKA in either mobile or fixed bearing implant designs.

We found that the patellar congruence angle was improved following fixed bearing medial UKA. Our finding of patellar congruence angle centralization after RA medial UKA, without interfering with patellar height (Insall-Salvati Index), which might unload the PFJ, may be a mechanistic explanation for the limited impact of PFJ degeneration of clinical outcome after medial UKA. Indeed, medial UKA imparts a multiplanar realignment to the joint. In the coronal plane, our lower limb realignment after medial UKA was improved by an average of 4.74°. While we were not able to measure the axial plane realignment, selectively opening the medial compartment with medial UKA presumably externally rotates the femur as the knee flexes, which could account for the improved PFJ congruence as the patella engages in trochlea. This assumption is supported by the current study. We report that patients with more severe Altman score have higher WOMAC score improvement. This may suggest that improved patellofemoral congruence after medial UKA may lead to redistribution of contact forces across the patellofemoral joint and secondarily treat patellofemoral symptoms.

Our study has specific limitations. First, the retrospective nature of our analysis consists of an important shortcoming. However, this study was based on a prospective cohort of patients assembled for the senior author’s surgical arthritis registry, in which clinical outcomes scores were collected prospectively. Second, we had complete preoperative WOMAC scores for 48.2% of our cohort. Nevertheless, except for the patellar congruence angle, no significant difference was found between respondents and respondents in baseline demographics and radiographic measures. In addition, Pearson product moment correlation test showed no correlation between WOMAC subscale scores and pre-operative or post-operative patellar congruence angle, potentially mitigating the effect of missing pre-operative WOMAC scores on our analysis. Third, radiographs may be subjected to rotational variations and variability in flexion degrees which may influence the measurements. Still, all radiographs were obtained following a standardized protocol (using a Merchant board jig). Fourth, the measurements were performed on two-dimensional radiographs and may have missed 3 dimensional joint realignments after UKA like patellar rotation or translation. Moreover, radiographs are performed in a static position and the dynamic influence of the muscles on the final alignment of the patella cannot be determined. However, this method is widely used since no dynamic modality is available for commercial use. Finally, though studies support the adequacy of the measurement properties of the WOMAC, two potential weaknesses have been debated. Initially, there is little evidence regarding the measurement properties of the stiffness subscale, and its test–retest reliability has been low[40]. Moreover, some studies have found inadequate factorial validity of the WOMAC pain and physical function subscales, potentially leading to weaknesses in the ability of the physical function subscale to detect change when there is a weak association between pain and function[41]. In the context of these limitations, to our knowledge, this is the first study to report patellar congruence alterations following fixed bearing RA medial UKA.

In conclusion, in patients with medial compartment degeneration, radiographic PFJ incongruence and degenerative changes in patients without clinical symptoms of patellofemoral disease do not negatively affect short-term clinical outcomes scores following RA medial UKA. In addition, medial UKA appears to improve PFJ congruence, presumably by increasing the external rotation of the femur as the knee flexes. The improved PFJ congruence after medial UKA suggests that medial UKA may secondarily redistribute contract pressures across the PFJ and may help protect the PFJ against progressive degeneration. This may be a mechanistic explanation for the multiple studies, as well as our data, that demonstrate that PFJ degeneration is not associated with adverse functional outcomes, or increased failure rate, in medial UKA using either a mobile bearing or fixed bearing implant. Further studies, with larger sample sizes and longer follow-up, are warranted to confirm our findings and further investigate the role of multiplanar realignment that occurs during medial UKR on the mechanics of the PFJ.

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Discussion

This thesis addresses various questions that are related to unicompartmental knee arthroplasty (UKA). By examining the frequent modes of UKA failure, an attempt is made to get a better understanding on the indications, subjective outcomes, the indirect alterations to adjacent tibiofemoral compartments and modern imaging modalities that can be used. Thorough knowledge about these factors will help us to optimize the results of the UKA, subsequently lowering the rate of revisions.

Is it still crucial for subjective outcome and survivorship to pursue the traditional UKA inclusion criteria?

Traditionally, the success of an orthopaedic implant is based on survivorship, radiographic results and potential complications. Although these factors are critically important to report, there is a growing interest in patients' perception of functional outcome. The influences of various patient-specific factors on these traditional outcomes have been extensively studied. However, there is currently a paucity of reports about potential factors that may influence subjective outcome of patients undergoing UKA. In the prospective cohort of 104 medial UKA patients that is reported in chapter three, we note that none of the pre-operative factors influenced subjective outcome 2.3 years following surgery. Based on these findings we conclude that BMI, gender and age do not influence subjective outcome of patients undergoing medial UKA. A similar pattern is observed studying the potential influence on survivorship. In chapter two a comprehensive literature search was performed which suggests that both BMI[1-3], gender[4] and age[5-8] at the time of surgery do not negatively influence UKA survivorship. For the future however, it should be noted that longer follow-up is required to get a better understanding on the potential deteriorating trends over time of subjective outcome that may occur.

What about the radiographic parameters? Do they influence results of medial UKA patients?

In contrast to these previous mentioned factors, results from the past and findings based on the results of chapter two and three suggest that attention should be paid to the various radiographic findings in order to optimize implant longevity and subjective outcome. The first is the pre-operative osteoarthritic severity of the medial compartment. Although the pre-operative osteoarthritic severity of the medial compartment does not influence subjective outcome based on our results, the Oxford Group found that mild osteoarthritis of the medial compartment is strongly associated with a higher re-operation rate[9]. Other groups have recently reported identical findings[10]. We can therefore conclude that an ideal UKA candidate should have severe isolated medial compartment degeneration. This is particularly important for optimal survivorship of the implant.

Another radiographic measurement that is frequently debated in literature is the relation between the mechanical axis alignment and UKA. Kozinn and Scott reported in their 1989 paper that the pre-operative varus deformity had to be less than 15 degrees and passively correctable to neutral at the time of surgery[11]. This corresponds to the proposed criteria of the Oxford Group. They advise that a UKA should not be performed with a pre-operative mechanical axis alignment of more than 15 degrees since this is seldom associated with an intra-articular deformity. With regard to the post-operative mechanical axial alignment, literature suggests that an overcorrection of the mechanical axial deformity should be avoided. Various reports prove that an overcorrection is associated with accelerated osteoarthritic progression of the non-operated compartment and thus failure of the implant. However, data about the relationship between functional outcome and the mechanical axis is limited. In chapter three, no relation was proven between the pre-operative mechanical axis and functional outcome 2.3 years following surgery. The post-operative mechanical axis alignment however, is strongly associated with functional outcome. A mechanical axis alignment between 1° and ≤ 4° of varus is associated with significant less pain and a better function. Hernigou and Deschamps reported that this relative undercorrection of the varus deformity is furthermore crucial for implant survival[12]. They noted that a slight post-operative varus deformity seemed to decrease polyethylene wear, which will enhance implant longevity and delay revision surgery. Based on the findings of this thesis and the previous reports, we recommend that a surgeon performing a medial UKA should always aim at a post-operative varus alignment between 1° and ≤ 4° of varus in order to optimize subjective results and implant longevity. Since the post-operative mechanical axis alignment is dependent the level of the tibial resection, ligamentous balance, and thickness of the tibial implant, challenges for the future lie in the development of strategies that focus on this post-operative alignment during medial UKA surgery. Robot-assisted navigated surgery might be the solution for this problem in the near future.

What are the indirect consequences of the non-operated compartment when a UKA is implanted?

Osteoarthritic progression following UKA remains a leading cause of revision surgery[13, 14]. In order to minimize the rate of UKA failure as a result of progressive degenerative changes, it is crucial to investigate the indirect alterations of the non-operated compartment following UKA implantation. Congruence plays a central and critical role in viability of every joint. An optimal geometric relationship between articulating surfaces will ensure equal load distribution. However, incongruence- which is associated with uneven load distribution- has a well-recognized negative influence on cartilage viability and is therefore associated with accelerated osteoarthritis[15, 16]. Since an unicompartmental procedure only treats the affected compartment, optimal congruence of the non-operated compartment is exceedingly essential for cartilage viability of the adjacent compartment and therefore implant longevity. We specially developed and validated an algorithm that enables us to study congruence changes of the tibiofemoral compartment[17]. Data reported in chapter six and seven suggest that a well conducted medial or lateral UKA not only resurfaces the affected compartment but also treats the contralateral compartment by improving congruence and restoring joint space width. In order to minimize the risk of congruence deterioration of the non-operated compartment following surgery, the state of congruity of the lateral compartment before medial UKA implantation should be taken into account. When a lateral UKA is performed, this relationship could not be proven. However, the osteoarthritic state of the medial compartment before surgery, shows to have a significant effect on post-operative congruity of this compartment and should therefore be respected. Since this technique to measure congruence has recently been introduced, data about joint congruence and the indirect consequences to the non-operated compartment following UKA is limited. For the future, the challenges will primarily focus on the clinical value of contralateral compartment congruence. Therefore, longer follow-up studies are needed to evaluate the potential relation between contralateral compartment congruence, implant longevity and subjective outcome results. A better understanding may not only help us to optimize results but will enable us to better inform and set expectations of potential candidates undergoing UKA.

Preexisting patellofemoral degeneration. Should it still be considered as a contra-indication for UKA?

Kozinn and Scott stated that PFJ degeneration was a strict contraindication for UKA, which has been supported by others as well[11, 18]. However, today debate still exists on whether this statement is still legitimate and should be pursued or not. Historic data, including large series of the Oxford Group and data from the Swedish Knee Arthroplasty Registry, show clear evidence that PFJ degeneration does not adversely influence survivorship of various UKA designs[13, 19-22]. As previously mentioned in this discussion, the success of an implant should also be based on subjective outcome. Therefore, we evaluated in chapter three and eight the influence of preexisting PFJ degeneration on subjective outcome following medial UKA. Data from both reports did not show an association between the pre-operative severity of PFJ degeneration and subjective outcome. This is consistent with other reports[23-25]. A possible explanation for the poor association between patellofemoral degeneration and clinical outcome may be caused by patellofemoral congruence improvement following medial UKA implantation. Our data in chapter eight suggests that PFJ congruence significantly improves following medial UKA. This may lead to a redistribution of contact pressures across the PFJ and could potentially protect against osteoarthritic PFJ progression. This finding may be the mechanistic explanation for the poor association between the PFJ and clinical outcomes following medial UKA. Based on these findings and the previous reports, we can conclude that asymptomatic PFJ degeneration should not be considered as an exclusion criterion for potential medial UKA candidates.

Unexplainable pain following unicompartmental knee arthroplasty. Should we revise?
Unexplainable pain following UKA remains one of the dominant reasons for surgeons to revise the implant to a total knee arthroplasty (TKA). Since UKA only treats the affected compartment, the etiology of symptoms can be related to the implant itself or the non-operated compartment. Therefore, it remains challenging to find the underlying diagnosis that may cause the symptoms. As with every symptomatic patient who has undergone joint replacement, a systematic approach is required including a thorough history, physical examination, laboratory testing and radiographic imaging. However, the inability of identifying potential peri-prosthetic soft tissues that may cause symptoms, are an important shortcoming of the current clinical and radiographic examinations. These include traditional radiographs, computed tomography and nuclear imaging. Magnetic resonance imaging (MRI) is the gold standard in evaluating soft tissue pathology. In chapter four we assessed the role of modern MRI in the evaluation of patients with a symptomatic UKA. Based on the MRI findings, 36% of patients underwent surgery whilst 64% was treated conservatively. Sixty-four percent of patients experienced improvement in pain and function after their surgical or conservative treatment that was based on the diagnosis seen on MRI. Although traditional radiographs, laboratory tests and physical examination remain the cornerstone in the workup of a symptomatic UKA patient, data of this chapter suggests that MR imaging should be used as a supplemental imaging modality before an UKA is revised when the etiology remains unclear. Treatment should subsequently be based on the traditional test, together with the MRI findings. Using MR imaging more frequently in the symptomatic UKA patient, will enable physicians to adequately treat the underlying diagnosis instead of revising the UKA without having identified the etiology. This will lead to an optimization of the results of patients undergoing UKA, subsequently lowering the rate of revision.

Total knee arthroplasty versus unicompartmental knee arthroplasty. Is there a difference in artificial joint awareness?
This thesis focuses largely on subjective outcome following UKA. As stated previously, there is an increasing interest in the patients' perception of functional outcome. Recently, a new concept was introduced in this field that measures joint awareness in patients undergoing knee or hip arthroplasty. The group that introduced this new functional outcome score stated that the ultimate goal in arthroplasty is that a patient is unaware of his of her artificial joint in daily life[26]. Moreover, the authors showed that the score is not limited by a ceiling effect; a well-known limitation of the traditional outcome scores. In chapter five we conducted a prospective study of 65 patients undergoing UKA and 65 patients undergoing TKA. At 1.5

and 2.5 years following surgery, we noted that patients who undergo UKA are better able to 'forget' their artificial joint in daily life compared to patients that undergo TKA. This significant finding may be due to the fact that a UKA is a soft-tissue and bone conserving surgical procedure than a TKA. Based on these results, strengthened by the data reported in the other chapters of this thesis, our data suggests that – if possible – joint conserving surgical strategies should be pursued in order to optimize subjective outcome of patients undergoing knee arthroplasty.

Future perspectives

Thorough knowledge about the different modes of UKA failure and the factors that potentially influence them, are essential for every orthopaedic surgeon. By focusing on subjective outcomes and the indirect alterations to the non-operated compartments of the knee, various factors are identified which have to be respected in order to optimize clinical results. The different answers given on the various questions in this thesis will contribute to the ongoing debate concerning the criteria for UKA inclusion. Furthermore, they can provide a possible solution for symptomatic UKA patients where the etiology of symptoms remains unknown. By respecting these criteria and findings given by this thesis, we hope to optimize the results of our patients undergoing UKA and lowering the rate of reported revisions.

However, not a single thesis is completed without evoking new scientific questions that are based on the present findings. For the future, the scientific issues will have to focus on the long-term effects of the examined factors of this thesis. Optimal awareness of these, based on solid scientific research, will lead to the final definition of the "ideal UKA candidate".

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Appendix

Summary

Samenvatting

List of publications

Acknowledgements

Summary

Unexplainable pain following UKA and osteoarthritic progression of the non-operated compartments, are the most frequent reasons that lead to UKA revision. This thesis has the aim to get a better understanding on those two factors. **Chapter I** is a general introduction of this thesis. It consists of a brief description of the anatomy of the knee, osteoarthritis (OA) of the tibiofemoral joint and the various surgical treatment options. Furthermore it contains the following aims of the thesis;

- To report a detailed overview of the modern indications, surgical outcomes and global trends in the use of UKA and high tibial osteotomy for isolated medial unicompartmental knee osteoarthritis.
- To identify the various factors that can potentially influence subjective outcome of patients undergoing medial UKA.
- To assess the role of magnetic resonance imaging in the evaluation of symptomatic patients following UKA, where the traditional tests fail to identify the underlying etiology.
- To analyze artificial joint awareness in patients which have undergone UKA and total knee arthroplasty.
- An extensive radiographic evaluation of the congruence alterations from the contralateral compartments following UKA that can potentially influence the osteoarthritic progression of the non-operated compartments.

In **chapter II** a review of literature was conducted. Modern indications, associated results and global trends in the use of high tibial osteotomy (HTO) and unicompartmental knee arthroplasty (UKA) have been described in patients who present with isolated medial unicompartmental knee OA. Using various articles, the current literature strongly supports the strict adherence of inclusion criteria that should be respected, in order to optimize survivorship and patient satisfaction of patients undergoing HTO. Age, weight and the pre-operative radiographic severity of OA should all be taken into account when selecting a potential HTO candidate. As opposed to the strict adherence to these HTO criteria, modern reports neither prove that nor age nor BMI will influence outcome following UKA. We noted that – if both techniques are performed frequently - 10-year survivorship results can be expected from respectively 90% and 75% of the UKA and HTO, with good to excellent subjective outcome scores. We also studied the trends in the use of both techniques among the western practices. An obvious decreasing trend is reported in the use of HTO, whereas an annual rise is reported in the use of UKA. This might be the result of the less strict inclusion criteria, superior results and improvement of surgical UKA techniques.

Unexplainable pain following medial UKA remains one of the dominant reasons for revision surgery. In order to identify the various factors that can potentially influence subjective outcome, we conducted in **chapter III** a study including 104 patients that had undergone medial UKA (average follow-up 2.3 years). Based on these results, our data suggests that younger patients benefit from a higher degree of pain relief than patients 65 years of age and older who underwent medial UKA. Furthermore, we noted that patients with a post-operative lower limb alignment between 1- 4° of varus had significant better subjective outcome results, compared to patients with a mechanical axis degree of < 1°and > 4° of varus. Gender, BMI and the pre-operative osteoarthritic severity of the medial and patellofemoral compartment did not influence subjective outcome following medial UKA. A better understanding of these factors and taking them into consideration will help us to maximize clinical outcomes, fulfill patient expectations and subsequently minimize revision rates following medial UKA.

Although UKA is a very successful procedure, a subset of patients' presents with continues pain following UKA in the setting of normal radiographic and physical examination. In **chapter IV** the role of magnetic resonance imaging (MRI) was investigated in symptomatic patients that have undergone UKA where the traditional radiographs and physical examination are not aberrant. Retrospectively we identified 28 symptomatic UKA patients who underwent MRI. Based on these findings, 10 patients (36%) underwent surgery, whereas 18 patients (64%) were treated conservatively. Eighteen patients (64%) experienced improvement in pain and function after conservative or operative treatment that was based on the MRI findings. Based on these results, we conclude that MRI investigation can be a valuable diagnostic modality in the case of symptomatic UKA. Although traditional radiographs, laboratory tests and physical examination remain the cornerstone in the workup of a symptomatic UKA patient, data of this chapter suggests that MR imaging should be used as a supplemental imaging modality before an UKA is revised when the etiology remains unclear.

There is an increasing interest in the patients' perception of functional outcome. Recently a new outcome measurement was introduced that measures artificial joint awareness in patients that have undergone knee or hip arthroplasty. This score is named the Forgotten Joint Scores (FJS) and has the advantage that it is less limited by a ceiling effect; a well-known limitation of the traditional outcome scores. In **chapter V** we conducted a prospective study containing 130 patients (65 medial UKA patients, 65 TKA patients). At 1.5 and 2.5 years following surgery, we noted that patients who undergo UKA are better able to 'forget' their artificial joint in daily life compared to patients that undergo TKA. We speculate that this observed difference may be due to the fact that UKA is a more soft-tissue and bone-conserving surgical procedure than TKA. In order to optimize the outcome of patients undergoing knee arthroplasty, this study suggests that—if possible—joint-conserving surgical strategies should be pursued.

As mentioned previously, osteoarthritic progression of the contralateral compartment remains an important reason to revise a UKA. Therefore it is essential to evaluate the changes of the contralateral compartment following UKA implantation. In **chapter VI** and **chapter VII** congruence and joint space width (JSW) alterations of the opposite compartment were evaluated following respectively medial and lateral UKA. Using a novel, validated technique, we noted that a well-conducted medial UKA is able to improve contralateral compartment congruence in 82%, whereas a lateral UKA is able to improve medial compartment congruence in 58.5%. Furthermore we noted that the pre-operative significant JSW differences with the control group, were absent post-operatively. This finding suggests that the contralateral JSW is restored following UKA. Based on these results we conclude that a well-conducted UKA not only resurfaces the affected compartment but also indirectly treats the opposite compartment by improving joint congruence and restoring JSW.

In **chapter VIII** we evaluated the effect of medial UKA on post-operative patellofemoral joint (PFJ) congruence and evaluated the relationship of preoperative PFJ degeneration and clinical outcome. We retrospectively reviewed 110 patients (113 knees) who underwent medial UKA. We noted that the postoperative absolute patellar congruence angle significantly improved following medial UKA implantation. No correlation was found between preoperative PFJ congruence or degenerative PFJ severity and WOMAC scores two years following surgery. Based on these findings we conclude that the pre-operative PFJ congruence and degenerative changes do not affect clinical outcomes of the medial UKA. Our data suggests that PFJ congruence improvement following medial UKA might the mechanistic explanation of the poor association between patellofemoral degeneration and clinical outcome.

Samenvatting, doelstellingen en conclusies

Voor patiënten met osteoarthrose van de knie is prothesiologie geïndiceerd indien conservatieve therapie geen uitkomst biedt. Wereldwijd wordt deze chirurgische behandeling veelvuldig toegepast om de functie van de aangedane knie te verbeteren en patiënten te verhelpen van hun pijn. Ten gevolge van de toegenomen levensverwachting en de huidige epidemie van het overgewicht, zal het aantal geplaatste knieprothesen toenemen. Deze trend is ook in Nederland goed waar te nemen. Volgens de gegevens van de Landelijke Registratie Orthopaedische Implantaten (LROI) werden in 2014 26.754 primaire knieprothesen geplaatst; een toename van 30,1% ten opzichte van 2010. Niet alleen de kwantiteit zal veelvuldig toenemen, maar ook de geassocieerde kosten. Deze stijging is terug te zien in de voorspelde marktwaarde van de knieprothesen. Deze zal naar verwachting 18 miljard dollar bedragen in 2018, terwijl deze in 2011 8,4 miljard dollar bedroeg.

Verscheidene nationale registers laten zien dat de unicompartimentele knie prothese (UKP) 6-9% uitmaakt van het totaal aantal geïmplanteerde knieprothesen. Dit percentage is exponentieel gestegen over het laatste decennium en de verwachting is dat dit de komende jaren zal continueren. Minder peroperatief bloedverlies, minder complicaties, kortere duur van ziekenhuisopname, sneller herstel en hervatting van werk en sport en goede overlevingspercentages van de UKP hebben bijgedragen aan het succes van het implantaat. Echter, de verscheidene nationale registers wereldwijd kunnen deze goede overlevingsresultaten niet reproduceren. In vergelijking met de TKP, ligt het 10-revisiepercentage 10-15% hoger. Osteoarthrotische progressie van het niet-geopereerde compartiment, onbegrepen pijn na een UKP en falen van het implantaat zijn de belangrijkste drie redenen die leiden tot revisie.

Het doel van dit proefschrift is om een beter inzicht te krijgen in de factoren die van invloed zijn op de uitkomst van de UKP. Dit is gedaan middels het analyseren van bovengenoemde redenen tot die leiden tot revisie. Een beter begrip van de verschillende factoren die de subjectieve uitkomst kunnen beïnvloeden en een analyse naar de indirecte veranderingen van de niet geopereerde compartimenten na een UKP, zullen bijdragen aan een verbetering van uitkomsten van patiënten die een UKP ondergaan. In **hoofdstuk I** wordt een algemene introductie beschreven van osteoarthrose van de knie, de mogelijke chirurgische behandelingen en de volgende doelstellingen van dit proefschrift om zo een antwoord te kunnen geven op bovengenoemde vraagstukken:

- Een gedetailleerd overzicht van de huidige literatuur over de moderne indicaties, resultaten en globale trends in het gebruik van de UKP en de valgiserende tibiakop osteotomie (VTO) in de behandeling van geisoleerde mediale gonarthrose (hoofdstuk II)

- Een identificatie van de verscheidene pre- en peroperatieve factoren en hun effect op de subjectieve uitkomst van patiënten die een mediale UKP ondergaan (hoofdstuk III)
- Een evaluatie naar de waarde van de MRI bij patiënten die zich presenteren met onbegrepen pijnklachten nadat zij een UKP zijn ondergaan (hoofdstuk IV)
- Een analyse naar het bewustzijn van het kunstgewricht bij patiënten die UKP en patiënten die TKP zijn ondergaan (hoofdstuk V)
- Een uitgebreide radiografische analyse naar de congruentie veranderingen van de niet-geopereerde compartimenten na een UKP, welke in de toekomst mogelijke progressie van osteoarthrose kunnen beïnvloeden. (hoofdstuk VI t/m VIII)

Hoofdstuk II bestaat uit een uitgebreide beschrijving van de huidige actuele literatuur over de moderne indicaties, geassocieerde resultaten en globale trends in het gebruik van de UKP en VTO in de behandeling van geïsoleerde mediale gonarthrose. De huidige literatuur laat duidelijke verschillen zien in de indicatiestelling, resultaten en de populariteit in het gebruik van beide methoden. In vergelijking met de mediale UKP zijn de indicaties van de VTO veel nauwer en dienen strikt nageleefd te worden om zo de subjectieve uitkomst te optimaliseren en het revisiepercentage te minimaliseren. Leeftijd, gewicht en de mate van mediale gonarthrose dienen gerespecteerd te worden bij de selectie van potentiële VTO patiënten. De indicaties van de mediale UKP zijn in tegenstelling tot de indicaties van de VTO minder strikt. De huidige literatuur laat duidelijk zien dat leeftijd en gewicht ten tijde van indicatiestelling de resultaten niet beïnvloeden.

De overlevingspercentages van beide technieken – mits frequent uitgevoerd - laten een 10-jaarsoverleving zien van respectievelijk 75% en 90% van de VTO en de UKP. In de westerse literatuur is een duidelijke verschuiving waar te nemen ten nadele van het gebruik van de VTO in de behandeling van geïsoleerde mediale gonarthrose. Dit zou mogelijk het gevolg kunnen zijn van de superieure resultaten van de UKP, bredere indicatiestelling en verbetering van chirurgische technieken.

Om de factoren te identificeren die de subjectieve uitkomst beïnvloeden van patiënten die mediale UKP ondergaan, voerden wij in **hoofdstuk III** een studie uit van 104 patiënten (gemiddelde follow-up 2,3 jaar). Aan de hand van een uitgebreide analyse naar de verschillende preoperatieve klinische en radiografische factoren, zien wij dat patiënten jonger dan 65 jaar meer baat hebben van hun mediale UKP dan patiënten ouder dan 65 jaar. Verder toonden wij aan dat postoperatief een relatieve ondercorrectie van 1-4° varus moet worden nagestreefd. Een mechanische varus as tussen de 1° en 4° is geassocieerd met significant betere subjectieve uitkomstresultaten dan een mechanische varus as <1° of >4°.

Body mass index, geslacht, patellofemorale degeneratie en de preoperatieve mechanische as van de aangedane extremiteit zijn niet van invloed op de functionele uitkomst van patiënten die een mediale UKP ondergaan.

Ondanks dat orthopedisch chirurgen hun best doen de uitkomsten van de UKP te optimaliseren, presenteert een deel van de patiënten zich desondanks met onbegrepen pijn nadat zij een UKP zijn ondergaan. In de meerderheid der gevallen laten de aanvullende röntgenfoto's en het lichamelijk onderzoek geen afwijkingen zien en blijft de etiologie onbekend. **Hoofdstuk IV** is een retrospectieve evaluatie van deze symptomatische UKP patiënten waarbij wij de waarde van een aanvullend MRI onderzoek evalueerden. De MRI bleek instrumenteel in het vinden van een diagnose die onopgemerkt bleek op röntgenfoto's. Gebaseerd op deze bevindingen werd 36% van de symptomatische UKP patiënten opnieuw geopereerd en werd 64% conservatief behandeld. Gebaseerd op de bevinding van het MRI onderzoek, bleek 64% van de patiënten na hun conservatieve of chirurgische behandeling uiteindelijk klachtenvrij. Hieruit concluderen wij dat aanvullend MRI onderzoek een goede bijdrage kan leveren aan de diagnostiek van een symptomatische UKP patiënt met onbekende etiologie. Derhalve adviseren wij een aanvullend MRI onderzoek eerst uit te voeren alvorens een symptomatische UKP patiënt te reviseren naar een TKP waarbij de etiologie onbekend is.

Hoofdstuk V richt zich op een recent geïntroduceerd concept om patiënt tevredenheid na knie- of heup prothesiologie te meten. De 'Forgotten Joint Score' (FJS), is een gevalideerd meetinstrument dat aan de hand van 12 vragen meet hoe bewust patiënten zich zijn van hun kunstmatige gewricht in het dagelijks leven. Een groot voordeel van de FJS ten opzichte van andere PROM's is dat de FJS minder wordt beïnvloed door plafond-effecten. Prospectief, includeerden wij 130 patiënten (65 UKP patiënten, 65 TKP patiënten) en evalueerden de FJS 1 en 2 jaar postoperatief. Op beide meetmomenten, liet de UKP significant betere resultaten zien ten opzichte van de TKP groep. Dit verschil kan mogelijk verklaard worden doordat de UKP slechts het aangedane compartiment vervangt en derhalve meer het natieve gewricht behoud in tegenstelling tot de TKP. Deze bevindingen suggereren dat – indien mogelijk – het gewricht zo goed mogelijk dient te worden behouden om zo de subjectieve uitkomst van patiënten te doen verbeteren.

Een substantieel deel van dit proefschrift richt zich op de indirecte veranderingen van de niet-geopereerde compartimenten ten gevolge van UKP. Betere kennis hiervan is essentieel omdat osteoarthrotische progressie van deze compartimenten een belangrijke reden is die leidt tot UKP revisie. In **hoofdstuk VI** en **hoofdstuk VII** evalueren wij de veranderingen van congruentie en de breedte van de gewrichtsspleet van het contralaterale compartiment na UKP implantatie. Met behulp van een recent gevalideerde methode, constateren wij dat een goed uitgevoerde mediale UKP bij 82% van het aantal geopereerde patiënten de congruentie van het laterale compartiment doet verbeteren. Dit in tegenstelling tot de laterale UKP, die dit slechts in 58,5% doet bij het mediale compartiment. Verder lijken zowel de mediale als laterale UKP de breedte van de contralaterale gewrichtsspleet te herstellen. De preoperatief significant gemeten verschillen met de controle groep, bleken postoperatief niet meer aanwezig te zijn. Gebaseerd op deze resultaten concluderen wij dat een goed uitgevoerde UKP niet alleen het aangedane compartiment zal behandelen maar tevens indirect het contralaterale compartiment, door verbetering van de congruentie en het herstel van de breedte van de gewrichtsspleet.

Er blijft controverse bestaan over de invloed van patellofemorale degeneratie op de uitkomst van patiënten die een UKP ondergaan. Om een antwoord en een mogelijke verklaring te kunnen geven op deze controverse, analyseerden wij in **hoofdstuk VIII** de radiografische veranderingen van het patellofemorale compartiment. Tevens onderzochten wij of een mogelijke correlatie bestond met de functionele uitkomst. Bij 110 patiënten die een mediale UKP ondergingen, zagen wij postoperatief een significante verbetering van de patellofemorale congruentie. Geen relatie werd gevonden met de preoperatieve patellofemorale congruentie, de ernst van de degeneratie en WOMAC scores twee jaar na de operatie. Op basis van de gegevens concluderen wij dat preoperatieve patellofemorale congruentie en degeneratie geen invloed hebben op de subjectieve uitkomst van mediale UKP. Verbetering van de patellofemorale congruentie ten gevolge van mediale UKP, zou een mogelijke biomechanische verklaring hiervoor kunnen zijn.

Conclusies

Bewustwording van de meest frequente oorzaken die leiden tot UKP revisie en de verscheidene factoren die mogelijk van invloed kunnen zijn, zijn essentieel voor een optimalisatie van de klinische resultaten. Door het analyseren van de subjectieve uitkomsten en de indirecte veranderingen van de niet geopereerde compartimenten, worden in dit proefschrift de pre- en peroperatieve factoren geïdentificeerd die dienen te worden gerespecteerd om zo de resultaten te verbeteren van onze UKP patiënten. De bevindingen in dit proefschrift dragen bij aan de voortdurende discussie omtrent de inclusiecriteria van mogelijke UKP patiënten. Tevens kunnen ze een handvat bieden voor symptomatische UKP patiënten waarbij het initiële onderzoek geen duidelijk substraat laat zien voor de klachten.

Geen proefschrift is echter voltooid zonder het oproepen van nieuwe vragen op basis van de huidige bevindingen. Voor de toekomst zullen de wetenschappelijke vraagstukken zich moeten richten op de in dit proefschrift onderzochte factoren en hun effect op de lange termijn. Een betere bewustwording hiervan, gebaseerd op gedegen wetenschappelijk onderzoek, zal leiden tot een afname van het revisiepercentage en een uiteindelijk definiëring van de inclusiecriteria waaraan een "ideale" UKP patiënt moet voldoen.

Publications

1. Nawabi DH, Schafer KA, **Zuiderbaan HA**, Nguyen, J, Warren RF, Wickiewicz TL, Pearle AD. ACL Fibers Near The Lateral Intercondylar Ridge Are The Most Load Bearing During Stability Examinations and Isometric Through Passive Flexion. *Accepted: The American Journal of Sports Medicine*

2. van der List JP, Chawla H, **Zuiderbaan HA**, Pearle AD. The role of preoperative patient characteristics on outcomes of unicompartmental knee arthroplasty: a meta-analysis critique. *Accepted: The Journal of Arthroplasty*

3. Khamaisy S, **Zuiderbaan HA**, van der List JP, Nam D, Pearle AD. Medial Unicompartmental Knee Arthroplasty improves Congruence and Restores Joint Space Width of the Lateral Compartment. *Accepted: The Knee Journal*

4. **Zuiderbaan HA**, van der List JP, Chawla H, Khamaisy S, Thein R, Pearle AD. Predictors of subjective outcome after medial unicompartmental knee arthroplasty. *Accepted: The Journal of Arthroplasty*

5. **Zuiderbaan HA**, van der List JP, Khamaisy S, Nawabi DH, Thein R, Ishmael C, Paul S, Pearle AD. Unicompartmental knee arthroplasty versus total knee arthroplasty: Which type of artificial joint do patients forget? *Accepted: Knee Surg Sports Traumatol Arthrosc.*

6. van der List JP, **Zuiderbaan HA**, Nawabi DH, Pearle AD. Impingement following anterior cruciate ligament reconstruction. Comparing the direct versus indirect tunnel position. *Accepted: Knee Surg Sports Traumatol Arthrosc*

7. Kleeblad LJ, van Bemmel AF, Sierevelt IN, **Zuiderbaan** HA, Vergroesen DA. Validity and Reliability of the Achillometer: An Ankle Dorsiflexion Measurement Device. *Accepted: J Foot Ankle Surg.*

8. Van der List JP, **Zuiderbaan HA**, Pearle AD. Why do medial unicompartmental knee arthroplasties fail today? *Accepted: The Journal of Arthroplasty*

9. **Zuiderbaan HA**, van der List JP, Appelboom P, Kort NP, Pearle AD, Rademakers MV. Modern Indications, Results and Global Trends in the use of Unicompartmental Knee Arthroplasty and High Tibial Osteotomy for the Treatment of Isolated Medial Compartment Osteoarthritis. *Accepted: Am J Orthop (Belle Mead NJ)*

10. van der List JP, Chawla H, **Zuiderbaan HA**, Pearle AD. Survivorship and functional outcomes of patellofemoral arthroplasty: a systematic review. *Accepted: Knee Surg Sports Traumatol Arthrosc*

11. Thein R, Boorman-padgett J, Khamaisy S, **Zuiderbaan HA**, Wickiewicz TL, Imhauser CW, Pearle AD. Medial Subluxation of the Tibia following Anterior Cruciate Ligament Rupture as Revealed by Standing Radiographs and Comparison with a Cadaveric Model. *Am J Sports Med. 2015;43(12):3027-33*

12. van der List JP, **Zuiderbaan HA**, Pearle AD. Why do lateral unicompartmental knee arthroplasties fail today? *Accepted: Am J Orthop (Belle Mead NJ)*

13. van der List JP, Chawla H, Villa JC, **Zuiderbaan HA**, Pearle AD. Early functional outcome after lateral UKA is sensitive to postoperative lower limb alignment. *Accepted: Knee Surg Sports Traumatol Arthrosc.*

14. Khamaisy S, **Zuiderbaan HA**, Thein R, Gladnick BP, Pearle AD. Coronal tibiofemoral subluxation in knee osteoarthritis. *Skeletal Radiol. 2016;45(1):57-61*

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Presentations

The Partial Knee Meeting 2016, Knokke, Belguim

Zuiderbaan HA, van der List JP, Pearle AD. Predictors of subjective outcome following medial unicompartmental knee arthroplasty. [Podium presentation]

Zuiderbaan HA, Khamaisy S, Thein R, Nawabi DH, Pearle AD. Unicondylar Knee Arthroplasty Versus Total Knee Arthroplasty. Which Type of Artificial Joint Do Patients Forget? [Podium Presentation]

ICJR World Arthroplasty Congress 2015. Paris, France

Zuiderbaan HA, Khamaisy S, Thein R, Nawabi DH, Pearle AD. Predictors of Outcome Following Robot Assisted Unicompartmental Knee Arthroplasty [e-Poster]

Zuiderbaan HA, Khamaisy S, Thein R, Nawabi DH, Pearle AD. Medial Compartment Congruence and Joint Space Width Alterations Following Lateral Unicondylar Knee Arthroplasty [e-Poster]

International Society for Technology in Arthroplasty (ISTA) 2014. Kyoto, Japan.
Zuiderbaan HA, Khamaisy S, Thein R, Nawabi DH, Pearle AD. Predictors of Outcome Following Robot Assisted Unicompartmental Knee Arthroplasty [Podium presentation]
Zuiderbaan HA, Medial Compartment Congruence and Joint Space Width Alterations Following Lateral Unicompartmental Knee Arthroplasty [e-Poster]
Zuiderbaan HA, Khamaisy S, Thein R, Nawabi DH, Pearle AD. Unicondylar Knee Arthroplasty Versus Total Knee Arthroplasty. Which Type of Artificial Joint Do Patients Forget? [e-Poster]

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Zuiderbaan HA, Ismael C, Khamaisy S, Thein R, Paul S, Pearle AD. Unicondylar Knee Arthroplasty Versus Total Knee Arthroplasty. Which Type of Artificial Joint Do Patients Forget? [Best Poster Award]

American Academy of Orthopaedic Surgeons Annual Meeting 2014, New Orleans, Louisiana, USA.
Khamaisy S, **Zuiderbaan HA**, Pearle AD. Tibiofemoral Subluxation and Angulation throughout the Progressive Stages of Osteoarthritis [Poster presentation]

Arthroscopy Association of North America. Annual Meeting 2014, Hollywood, Florida, USA.
Jones KJ, **Zuiderbaan HA**, Nawabi DH, Potter HG, Wickiewicz TL, Pearle AD. Anterior Subluxation of The Lateral Tibia In The Setting Of ACL Injury: A Comparative Analysis Of Deficient States [Podium presentation]

ACL Study Group, January 2014, Cape Town, South Africa
Nawabi DH, Imhauser C, Tucker S, **Zuiderbaan HA**, Wickiewicz T, Pearle AD. ACL Fibres Inserting on the ‘Lateral Intercondylar Ridge’ Carry the Greatest Loads – Are Modern Anatomic Femoral Tunnel Positions Too Low? [Podium presentation]
Jones KJ, **Zuiderbaan HA**, Nawabi DH, Potter HG, Wickiewicz TL, Pearle AD. Anterior Subluxation of The Lateral Tibia In The Setting Of ACL Injury: A Comparative Analysis Of Deficient States [Podium presentation]

25th Annual Total Knee Course 2013, New York City, NY, USA.
Zuiderbaan HA, Khamaisy S, Thein R, Pearle AD. Joint Space Width and Congruence Alterations of the Controlateral Compartment following Unicondylar Knee Arthroplasty [Poster presentation]

International Society for Technology in Arthroplasty (ISTA) 2013. Palm Beach, Florida, USA.
Zuiderbaan HA, Park C, Ranawat AS, Pearle AD. Role of Magnetic Resonance Imaging in the Diagnosis of the Painful Unicompartmental Knee Arthroplasty. [Podium presentation]
Zuiderbaan HA, Khamaisy S, Pearle AD. Lower Limb Alignment Following Medial and Lateral Unicondylar Knee Arthroplasty [Podium presentation]
Zuiderbaan HA, Khamaisy S, Pearle AD. Lateral Compartment Congruence Alterations Following Medial Unicondylar Knee Arthroplasty [e-Poster]

Orthopaedic Trauma Association. Annual Meeting 2012, Minneapolis, Minnesota, USA.
Berkes M, Lazaro L, Pardee N, **Zuiderbaan HA**, Lorich DL, Helfet DL. Tibial Plateau Fractures Treated with Structural Bone Grafts Experience Minimal Articular Subsidence and Good Clinical Outcomes. [Poster presentation]

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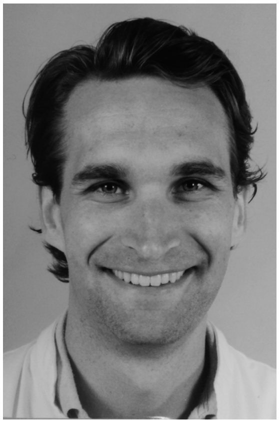
About the author



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After graduation from medical school in the summer of 2012, he worked as a resident in the orthopaedic surgery department of the Spaarne Hospital, Hoofddorp, the Netherlands. In 2013 he returned to the Hospital for Special Surgery in New York, where dr. A.D. Pearle offered him the opportunity to work as a research fellow for the Computer Assisted Surgery Center. In January 2014 he returned to Amsterdam, where he started his orthopaedic residency training. After the first 18 months of his residency training in the Medical Center Alkmaar (dr. W.H. Schreurs) he currently works at the Spaarne Hospital in Hoofddorp, the Netherlands (dr. A. van Noort) as an orthopaedic surgery resident.