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

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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 13.1 years; SD 62.1) 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 digitised 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 normalise the JSW of the medial compartment, potentially preventing progression of degenerative change.

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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 UKAs.[8,9] 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 transmitted are reduced in other regions.[16,17] This has a well-recognised 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

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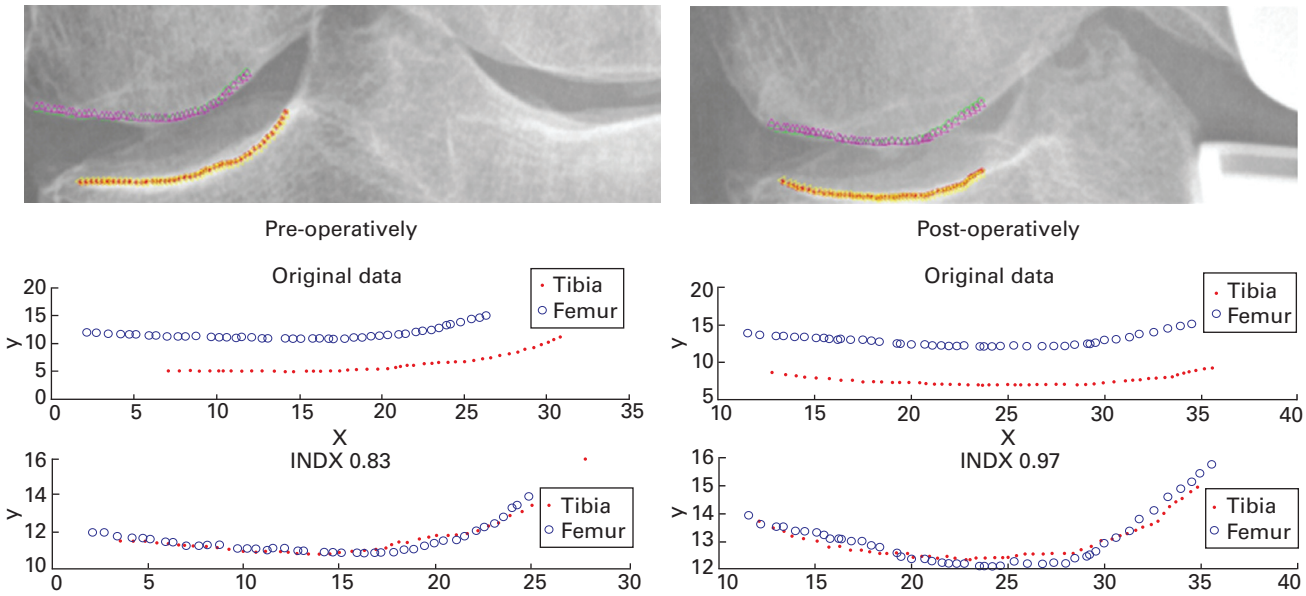

Fig. 1

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 digitisation of the femoral and tibial surfaces.

following lateral UKA. We hypothesised 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 standardised protocol. Care was taken to ensure that each patient stood with their patella facing forward in order to minimise 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 digitisation 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

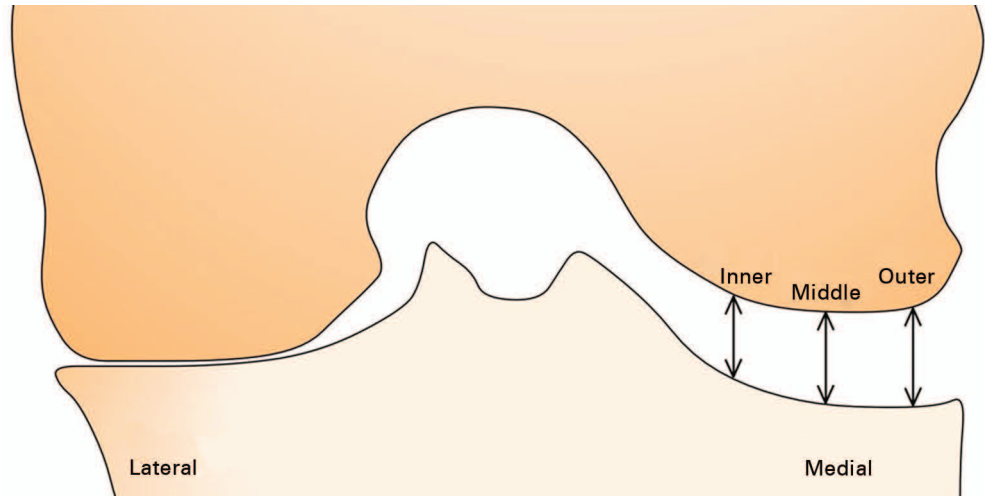

Fig. 2

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

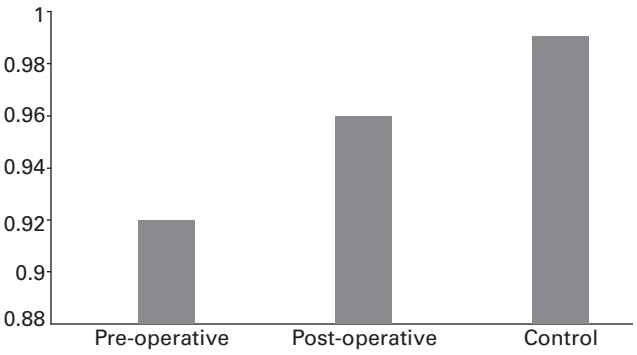

Fig. 3

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

1 indicates a completely congruent joint with an equal distribution of forces over the articular 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 millimetres on weight-bearing tunnel radiographs 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).

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

Table I. 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)*

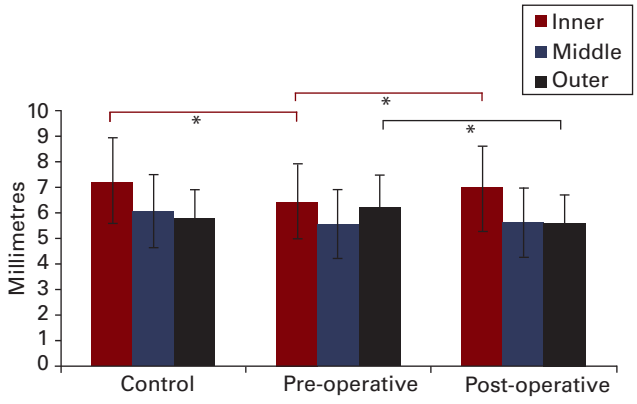

Fig. 4

Alterations of 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).

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).

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

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.

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 external 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 compart-

ment 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 under-reported 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 UKA. We conclude that a well-conducted lateral UKA not only resurfaces the lateral compartment but also has the potential to normalise 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.

H. A. Zuiderbaan: Contributed to study design, Study implementation, Refinement of the study protocol, Data collection and analysis, Writing the paper.

S. Khamaisy: Contributed to study design, Refinement of the study protocol, Revision of manuscript, Approved the final manuscript

R. Thein: Contributed to study design, Refinement of the study protocol, Data collection and analysis, Revision of manuscript, Approved the final manuscript.

D. H. Nawabi: Refinement of the study protocol, Revision of manuscript, Approved the final manuscript.

A. D. Pearle: Refinement of the study protocol, Performed all surgeries, Revision of manuscript, Approved the final manuscript.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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