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Does the Size of the Femoral Condyle Contribute to the Development of Osteoarthritis of the Knee? A Retrospective Randomised MRI Study

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Abstract

Aim: Cam impingement in the hip is well recognised with the relative incongruity between the femoral head and acetabulum implicated in the development of osteoarthritis (OA). We propose that a similar situation may occur in the knee joint and explain the commonly observed anteromedial OA in medial compartment disease. This study asked whether a relatively larger femoral condyle could cause impingement on the smaller tibial articular surface and result in early osteoarthritis (OA).

Methods: A retrospective randomised study of 400 age and sex matched knee x-ray and MRI scans of patients aged between 40 and 60 years was performed. Patients with any conditions that could affect their knee joint congruence or predispose them to degenerative changes were excluded. Measurements of the femoral and tibial articular surfaces were performed in the coronal and sagittal planes. The degree of OA was assessed with the modified ICRS grading system. Inter- and intra-observer bias was measured.

Results: There were 234 knees with OA,171 (42.7%) with medial compartment OA, 35 (8.8%) lateral compartment OA and 28 (7%) with bicompartment OA. A significant difference was found between the ratio of the coronal width of the medial femoral condyle and the medial tibial plateau in the presence of early OA (0.85, 95% CI 0.842-0.858) compared those without OA (0.91, 95% CI 0.902-0.919) (p=0.001), and for the same comparison on the lateral side (0.866, (95% CI 0.853-0.879) for knees with OA and 0.917 (95% CI 0.911-0.924) without OA) (p=0.001). Additionally, knees with medial compartment OA had a relative ratio (comparison between medial and lateral ratios) of 0.905 (95% CI 0.896-0.913) compared to 0.993 in knees without OA (95% CI 0.984-1.002) (p=0.001).

Conclusion: Knees with OA had a significantly smaller femur to tibia coronal articular surface ratio. These findings did not support impingement of the femur on the tibial articular surface as a cause for OA. Given this previously unrecognised association, further research is needed to confirm and determine its clinical effect.

Keywords: Knee osteoarthritis; Biomechanics; MRI scan; ICRS

Introduction

Knee osteoarthritis (OA) is one of the most common degenerative joint conditions with approximately 13% of those over the age of 60 experiencing symptomatic disease [1]. Due to the progressive spectrum of disease, its management varies from simple lifestyle modifications to operative intervention [2-4]. Furthermore, with the current reported lifetime risk of developing symptomatic knee OA being 47% and the internationally aging population, knee OA promises to continue to burden all healthcare systems [3,5] In addition, while the disease financially burdens the healthcare system, the effect on the patient cannot be underestimated. Patients often experience debilitating pain and functional impediments which affect their ability to work, live independently and perform their daily activities [3].

The knee joint is a complex diarthrodial hinge joint formed by the articulation of the distal femur, proximal tibia and patella [6,7]. It has multiple associated soft tissue restraints, which ensure its strength and durability while maintaining its range of motion. During normal gait the tibio-femoral joint experiences three times the bodyweight in joint reaction forces, which increase with stair climbing or running. The femoral condyles have a cam-like shape in the sagittal plane, thus during knee flexion the femoral condyles roll posteriorly and slide anteriorly over the tibial plateau. This is particularly important within the medial compartment which acts similar to a ball and socket joint and as such, may result in impingement with knee extension if there is a significant mismatch between the size of the femoral condyle and the tibial plateau [8-10].

OA commonly affects the anteromedial aspect of the medial tibial plateau resulting in a well-documented wear pattern [11]. However, the reason for this characteristic location remains unknown. Our hypothesis was that a larger femoral condyle articulating with a relatively smaller tibial plateau would cause impingement of the anteromedial tibial plateau ultimately resulting in anteromedial OA. Thus, we aimed to assess the relative sizes of the femoral to tibial articular surfaces in the coronal and sagittal planes to investigate if such a relationship was related to radiographic knee OA.

Methods

A retrospective observational study was performed on the Christchurch Radiology Group database of 400 randomly chosen patients aged between 40 and 60 years. All patients had x-ray and MRI scans of their knee joints performed between January 2013 and January

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2015. Patients were divided into four five-year age groups (40-45, 45-50, 50-55, 55-60 years) with each group containing 50 males and 50 females. The MRI scans were performed for a myriad of reasons, thus, the inclusion and exclusion criteria, shown in Table 1, were used to exclude potential causes of degeneration other than a variation in the native anatomy [4,6-12]. The patients' clinical notes and radiographs were reviewed to ensure accuracy of the inclusion criteria. Gross mechanical alignment was reviewed on plain films, while MRI scans were reviewed to exclude patients with ligamentous injury.

Radiographs were initially reviewed to ensure patients were suitable for inclusion. All patients had weight-bearing standard AP and lateral views with only 30% having long leg views. This made assessment of alignment difficult and as such only gross knee alignment was discernable for the majority of patients.

All MRI scans were analysed by the principal author (GD). MRI scans were studied using the inteleviewer PACS system [13]. Axial scans at the level of the tibial plateau were used to identify the centre of the medial and lateral tibial plateaus (Figure 1A and 1B). The centre was selected for its methodological ease of reproducibility. The localiser function was then used to locate this point on both the coronal and sagittal sequences. Static coronal and sagittal images maintained at this point were then used for definitive measurements. Width of the femoral and tibial articular surfaces were measured on the coronal image (Figure 1A and 1B), whilst depth was determined on the sagittal image (Figure 2A and 2B). Measurements of the native subchondral surface were performed rather than abberant anatomy such as an osteophyte.

Inclusion criteria	Exclusion criteria
Age: 40-60 years	Previous fracture, ligamentous injury or significant trauma affecting the knee
Knee X-ray and MRI scan	Meniscal or cruciate pathology
	Previous operative intervention on the knee (including arthroscopy)
	Advanced OA with evidence of joint deformity
	Inflammatory or crystalline arthropathy
	Malalignment (>10 degrees of anatomic malalignment excluded)

Table 1: Inclusion and exclusion criteria.

On the coronal slice the medial femoral condylar width was measured as a straight line from the medial to lateral aspects of the Medial Femoral Condyles (MFC) subchondral bone as illustrated in Figure 1B (line 1).

The medial tibial plateau (MTP) width was measured as a straight line connecting the medial aspect of the subchondral bone to the apex of the medial tibial eminence. The length of this line was defined as the coronal MTP. This is illustrated in Figure 1B (line 2). This method of measurement was repeated for the Lateral Femoral Condyle (LFC) and the Lateral Tibial Plateau (LTP). This is illustrated in Figure 1B (line 3 for LTP and line 4 for LFC).

In order to measure the tibiofemoral articular surface of the lateral femoral condyle and account for the prominence of the lateral femoral condyle anteriorly, to exclude the patella-femoral articular surface on the sagittal image, a line was drawn along the anterior cortex of the femur. Where this line bisected the femoral condyle, measurements were taken to the posterior apex of the femoral condyle (Figure 2A). This was not required for the medial femoral condyle as its tibiofemoral articulation is more clearly defined and does not project anteriorly (Figure 2B).

The extent of degenerative change of each articular surface was determined using the modified International Cartilage Research Society (ICRS) classification on MRI scans [14,15]. The location of the OA was also noted.

Ratios of the relative femoral to tibial sizes for the medial and lateral compartments in both the coronal and sagittal planes were reviewed with respect to the presence of OA.

Inter and intra observer bias

The scans of 41 patients were randomly selected from the sample of 400 patients. These patients' MRI scans were examined using the described method. Inter-observer measurements were taken by author (DK) and compared to those of the same patients recorded by the

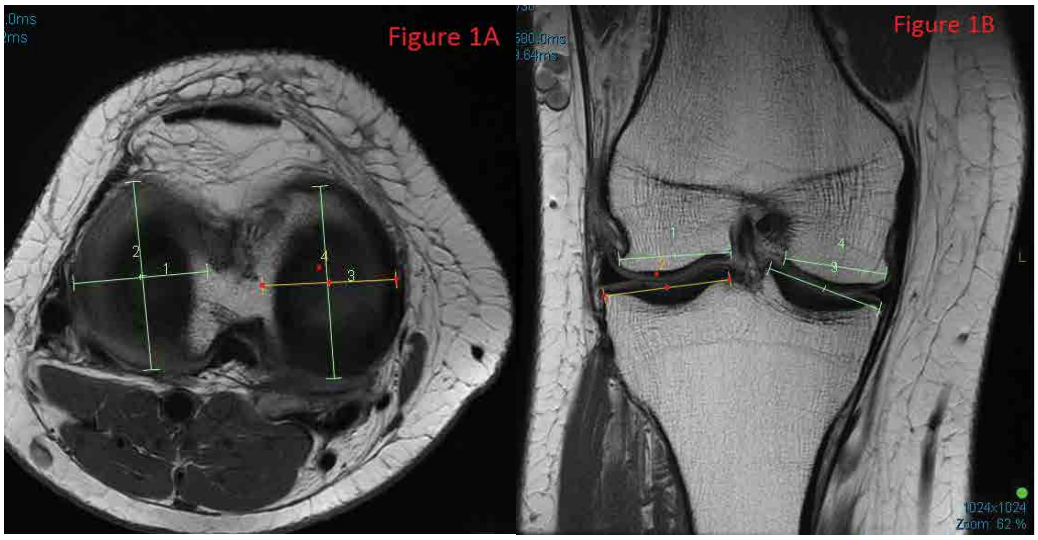


Figure 1: Axial sequences to determine the centre of each tibial plateau. Utilising the localiser function, this position was matched on both the sagittal and coronal sequences to allow measurements to be taken. (**A**) The axial measurements. (**B**) The coronal measurements.

Figure 2: (**A**) Lateral femoral condyle (LFC) and lateral tibial plateau (LTP) antero-posterior (AP) measurements. (**B**) Medial femoral condyle (MFC) and medial tibial plateau (MTP) AP measurements. (Note that the sagittal measurements of the tibial plateau are of the subchondral surfaces.)

principal author (GD). Intra-observer bias was assessed by repeating the measurements at a one week interval after initial measurements were taken.

Inter- and intra-observer bias was assessed statistically using the Intra-class Correlation Coefficient (ICC) and the Correlation Variance (CV%) [16,17]. The CV% is a measure of the standard deviation about the mean. A high CV% implies that the obtained sample distribution is due to chance.

Statistical analysis

The Intra-class Correlation Coefficient (ICC) is a measurement of reliability when looking at a sample that contains multiple groups. It is used predominantly to assess inter- and intra- observer bias. It has an inverse relationship with the level of bias present. Interpretation of the ICC value is shown in Table 2.

The Correlation Variance (CV%) assesses the level of variance and measurement error on repeated measurements by one or multiple observers. A low CV percentage suggests low measurement error [16,17].

Results

Four hundred patient x-ray and MRI scans were reviewed. Overall 171 (42.7%) patients had evidence of medial compartment OA, 35 (8.8%) had lateral OA, 28 (7%) had OA of both the lateral and medial compartments and 166 (41.5%) had no evidence of OA (Table 3).

With respect to patient age and gender there were no significant differences observed between the femoral to tibial ratios and the presence of OA (Table 3).

A medial compartment coronal ratio of 0.85 (95% CI 0.84-0.858) compared to 0.91 (95% CI 0.902-0.919) was identified in patients with and without medial compartment OA respectively (p<0.001) (Figure 3A and Table 3). In patients with medial compartment OA, it was noted that their OA was present in the mid- femoral condyle and tibial plateau in 55% of cases, anteromedially in 35% of cases and 10% being mixed disease. There was no association found between morphology and the location of OA.

ICC value	Level of agreement between observers
0-0.2	Poor agreement
0.3-0.4	Fair agreement
0.5-0.6	Moderate agreement
0.7-0.8	Strong agreement
>0.8	Almost perfect agreement

Table 2: Interpretation of the intra-class correlation coefficient (ICC).

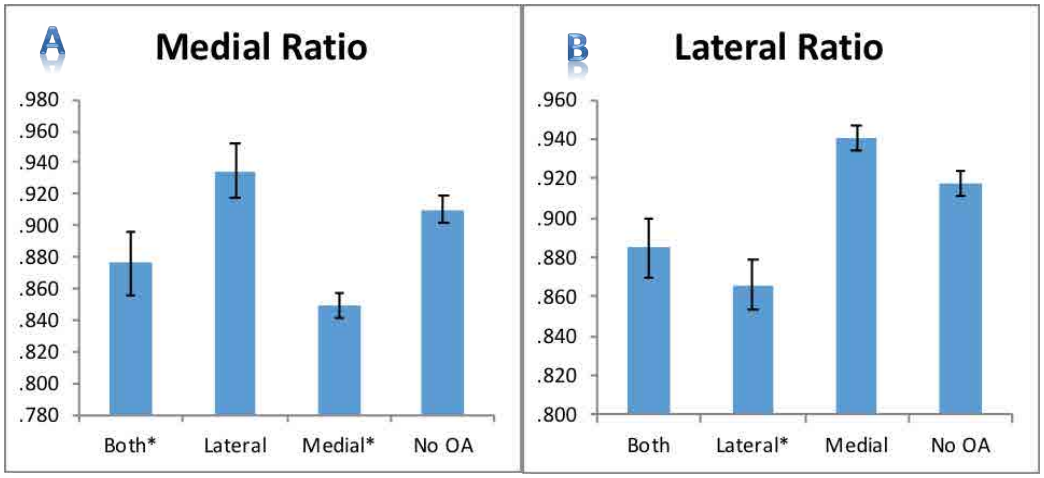
No correlation between the relative AP diameter of the femur and tibia was found for medial or lateral compartment OA (Table 3). Patients with medial compartment OA had a medial compartment sagittal ratio of 1.311 (95% CI 1.292-1.331) compared to patients without OA (1.289 (95%CI 1.269-1.309)) (p=0.404). Patients with lateral compartment OA were noted to have lateral compartment sagittal ratios of 1.805 (95% CI 1.778-1.831) compared to patients without OA (1.799 (95% CI 1.772-1.825)) (p=0.924).

Regarding patients with lateral compartment OA, a lateral compartment coronal ratio of 0.866 (95% CI 0.853-0.879) was noted, compared to 0.917 (95% CI 0.911-0.924) for patients without OA (p<0.001) (Figure 3B and Table 3).

When the medial and lateral coronal ratios were compared, it was found that patients with evidence of medial compartment OA had a significantly lower medial to lateral coronal ratio of 0.905 (95% CI 0.896-0.913) compared to patients without OA (0.993 (95% CI 0.984-1.002) (Figure 4 and Table 3) (p<0.001).

The ratio between the medial and lateral compartments revealed an elevated ratio of 1.081 (95% CI 1.062-1.1) in patients with lateral compartment OA compared to those without OA (0.993 (95% CI 0.984-1.002)) (p<0.001) (Figure 4 and Table 3).

In patients with both compartments affected by OA, the medial compartment ratio was 0.879 (95% CI 0.856-0.896) compared to 0.91 (95% CI 0.902-0.919) in patients without OA (p=0.014). Those patients with bicompartmental disease had a lateral compartment ratio of 0.885 (95% CI 0.87-0.9) compared to those without OA (0.917 (95% CI 0.911-0.924) (p=0.067)) (Figures 3, 4 and Table 3).



Figures 3: (**A**) Graph of compartment ratios (femoral condyle to tibial plateau) to compartments affected by radiographic OA. (**B**) with No OA representing those patients without OA on either compartment. (compartments labelled with * are statistically significant compared with No OA).

	Medial OA	Lateral OA	Both OA	No OA
Patient numbers	171 (42.7%)	35 (8.8%)	28 (7%)	166 (41.5%)
Male	96 (24%)	13 (3.3%)	13 (3.3%	78 (19.5%)
Female	75 (18.7%)	22 (5.5%)	15 (3.7%)	88 (22%)
Average Age	50.9	48.1	52.1	48.8
ICRS Grade 1	4 (2%)	2 (6%)	0 (0%)	Not applicable
Grade 2	66 (40%)	16 (46%)	14 (50%)	
Grade 3	56 (34%)	14 (40%)	11 (39%)	
Grade 4	40 (24%)	3 (8%)	3 (11%)	
MC coronal ratio	0.85 (95%CI 0.842-0.858)	0.935 (95%CI 0.917-0.952)	0.876 (95%CI 0.856-0.896)	0.91 (95%CI 0.902-0.919)
LC coronal ratio	0.94 (95%CI 0.934-0.946)	0.866 (95%CI 0.853-0.879)	0.885 (95%CI 0.870-0.900)	0.917 (95%CI 0.911-0.924)
MC sag ratio	1.311 (95%CI 1.292-1.331)	1.285 (95%CI 1.242-1.329)	1.289 (95%CI 1.240-1.337)	1.289 (95%CI 1.269-1.309)
LC sag ratio	1.805 (95%CI 1.778-1.831)	1.798 (95%CI 1.740-1.856)	1.781 (95%CI 1.716-1.846)	1.799 (95%CI 1.772-1.825)
Medial/lateral ratio	0.905 (95%CI 0.896-0.913)	1.081 (95%CI 1.062-1.100)	0.991 (95%CI 0.969-1.012)	0.993 (95%CI 0.984-1.002)

Table 3: Summary of distribution of patients with respect to the presence of OA.

With respect to the degree of wear, most patients with evidence of knee joint OA had grade 2 or 3 degenerative change (Table 3). There was no statistical correlation between morphology and the ICRS grade.

Coronal measurement inter-observer ICC ranged from 44.0% to 64.5%. This was described to represent fair to moderate agreement and as such the method was found to be reproducible for the coronal ratios [16,17]. The CV% ranged from 4.4% to 5.2% representing minimal variance around the mean and thus a low measurement error [16,17]. Sagittal measurement inter-observer ICC values were low (11.8%) suggesting that there was poor reproducibility between observers [16,17]. The CV%s were 0.8% and 2.2% again suggesting minimal variance around the mean and again low measurement error [16,17].

The intra-observer coronal measurements ranged from 81.5% to 85.9% suggesting excellent agreement and method reproducibility. The CV% values ranged from 2.0% to 4.6% again suggesting minimal variance about the mean [16,17]. The intra-observer sagittal measurements ranged from 81.5% to 95.8% suggesting excellent reproducibility when assessing the primary observer. The sagittal CV% values were 2.4% to 4.6%, suggesting minimal variance around the mean [16,17].

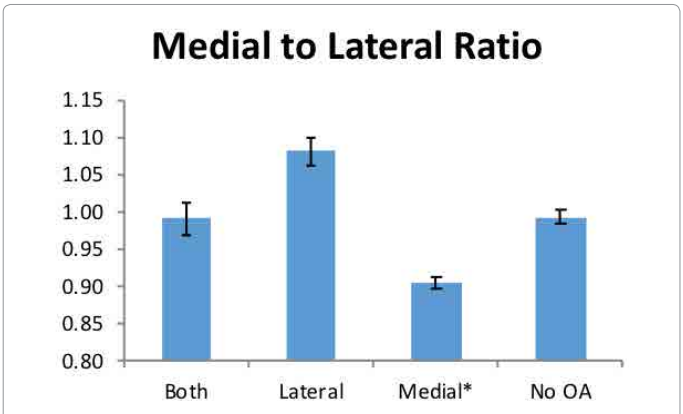


Figure 4: Graph of the medial to lateral compartment ratios with the compartment affected on the x-axis.

Discussion

It is known that morphological differences in joint surfaces can predispose to early degenerative change [18]. This association is well

recognised in patients suffering from developmental dysplasia of the hip causing hip OA and trochlear dysplasia causing patello-femoral OA [18,19].

Similar to cam-type impingement in the hip, we hypothesised that a relatively larger femoral condyle was more likely to cause impingement on the smaller tibial articular surface and therefore predispose those knees to early OA and may offer an explanation for the commonly observed anteromedial OA in unicompartment disease. However, the results of this study demonstrated the reverse result where OA was more prevalent in knees with a smaller femoro-tibial coronial ratio in knees with evidence of medial ($p<0.001$) and lateral compartment OA ($p<0.001$).

On analysis of the relative medial to lateral compartment ratios a statistically significant association was discovered between a smaller relative ratio and the presence of osteoarthritis in that compartment. This was particularly noted when on analysis of the medial to lateral compartment ratios in patients with medial compartment OA and when comparing this relative ratio to patients with no evidence of OA. Patients with medial compartment OA had a significantly lower medial to lateral coronal ratio of 0.905 (95% CI 0.896-0.913) compared to patients without OA (0.993 (95% CI 0.984-1.002) (Figure 4 and Table 3) ($p<0.001$). This association was also observed in patients with isolated lateral compartment OA with these patients having an elevated ratio between the medial and lateral compartments of 1.081 (95% CI 1.062-1.1) compared to those without OA (0.993 (95% CI 0.984-1.002)) ($p<0.001$). The most likely reason for these findings is the development of focally high forces experienced by the tibial articular surface with a relatively narrower femoral condyle as these higher forces have a detrimental effect on articular cartilage, which predispose to degenerative change [6,7].

Patients with bicompartmental OA were found to have similar coronal compartment ratios. In these patients the medial compartment coronal ratio was significantly smaller than those patients without OA ($p=0.014$). However, the lateral compartment coronal ratios were not significantly different ($p=0.067$). This again reinforces the idea that a relatively smaller medial femoral condyle to tibial plateau predisposes to OA and the progression of this medial OA may result in abnormal lateral compartment biomechanics resulting in lateral compartment OA.

Inter- and intra-observer bias assessment revealed inter-observer ICC values ranging from 44.0% to 64.5%, suggesting that the study method had moderate reproducibility [16,17]. The method had good reproducibly when measuring for the coronal ratios. In addition to being easier to measure and reproduce between observers, the coronal measurements also revealed a statistically significant association with OA compared with the sagittal ratios. Regarding our measurement of the sagittal ratios, our method was found to have poor correlation between observers and as such poor reproducibility. Additionally there was no statistically significant association observed on analysis of the sagittal ratios and knee joint OA. Further research with a greater number of examiners is needed to accurately discern this method's reproducibility and clinical utility [16,17].

This study is limited by its retrospective design with images attained for a myriad of reasons limiting the determination of causation [20,21]. The patients' position during the scans were not standardised and as such resulted in measurement difficulty. Furthermore, patient weight, activity level, smoking history and family history of OA, as well as arthroscopic evaluation for soft tissue impingement such as plical bands were not defined. X-rays were short films, rather than long leg weight bearing alignment views, thus only gross knee alignment was discernible [22-24].

Furthermore, accurate measurements of the femoral condyles in the sagittal plane were difficult, given the multi-radial shape of the femoral condyles in this plane [8,10]. We therefore initially assessed two methods of measurement for the femoral condyles in the sagittal plane. The first was a Fibonacci curve as described by Wahl and colleagues [25,26]. However, while this method attempts to approximate the shape of the femoral condyles, we found its accuracy to be limited. The second method utilised a 3D programme (Amira 3D software) to calculate the shape of the femoral condyles [27]. We found this to accurately measure the surface of the femoral condyles, but found its useability to be limited by its time consumption and technical complexity. As such our described method of measuring anterior to posterior length of the femoral condyles was deemed most clinically useful but was found to be prone to inter-observer variability. Lastly, while the findings are statistically significant, the differences in ratios observed are small, limiting its clinical significance.

Despite these limitations, this is to our knowledge, the first paper assessing femoral to tibial morphology and its association with tibio-femoral OA. It appears that a femur which is relatively smaller than the tibia in the coronal plane is significantly more common in patients with OA. This significant association warrants further research to determine its use in clinical orthopaedics.

Conclusion

This study has found a previously unrecognised statistically significant association between tibio-femoral morphology and the presence of early OA. In the coronal plane a smaller femoral condyle to tibial ratio was associated with early OA. Given this previously unrecognised association further research is needed to confirm this association and determine its clinical effect.

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