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Lateral Coronal Bowing of Femur and/or Tibia amplifies the varus malalignment of lower limb as well as increases functional disability in Patients with Knee Osteoarthritis.

ABSTRACT

Purpose:

In the present study we aimed at assessing the effect of femoral and tibial coronal bowing on varus malalignment and Oxford Knee Score (OKS) at different grades of knee osteoarthritis (OA).

Material and method

This prospective observational study was conducted at a tertiary referral centre in New Delhi, India. Consecutive patients presenting to the "knee OA" outpatient clinics were invited to take part in the study conducted over a 12-month period. All consented patients underwent long-leg standing alignment radiographs using standardised technique and patient reported knee pain and function were recorded using Oxford Knee Score.

The following radiological parameters were measured from weight bearing long leg radiographs of 824 varus aligned limbs via a morphometric software (Matlab R2009a) (1)Hip-Knee-Ankle angle (HKAA), (2) Femoral bowing, (3) Tibial Bowing. The knees were graded according to Kellegren and Lawrence grade (K&L) and OKS was recorded. 3 groups of HKAA were made based on the angle, A (0° to -3^{0}), B (-3^{0} to -10^{0}) and C ($<-10^{0}$). Both the femoral and tibial bow were also categorized into 3 groups depending upon the angle; In-range (-2^{0} to $+2^{0}$), Varus ($<-2^{0}$), Valgus ($>+2^{0}$).

Results:

The mean (±SD) HKAA, femoral bow and tibial bow of the whole cohort was -6.97^{0}±5.64°, -1.54^{0}±4.31° and -1.96^{0}±3.5° respectively. An increase in the lateral bow of both femur and tibia was seen with an increase in the severity of OA. A consequent increase in the varus malalignment was observed with an increase in the lateral bow of both femur as well as the tibia at all grades of OA, with significant correlation observed between HKAA with Femoral bowing and HKAA with tibial bowing. The mean OKS for femoral bow, in-range, varus and valgus were 30.6±11.5, 21.3±11.5 and

35.3±11.4 respectively and for tibial bow, in-range, varus and valgus were 27.6±11.5, 26.±11.5 and 28±11.4 respectively. The difference in the mean OKS was observed to be significant when the varus bow group was compared to in range as well as valgus group (p<0.01) for both femur and tibia for all the grades of OA

Conclusion:

The present study shows a significant correlation between varus malalignment and the bowing of extremities. Varus coronal bowing of both femur and tibia were seen to have significantly lower mean OKS as compared to valgus bowing or in –range bowing at all grades of knee OA.

KEYWORDS: Varus malalignment; Hip-Knee-Ankle angle; Coronal bowing; Oxford knee score

INTRODUCTION:

Knee osteoarthritis (OA) is a structural joint disease associated with functional disability adversely affecting the health-related quality of life and has been shown to be influenced by limb malalignment [1]. Hip-knee-ankle (HKA) angle defines the mechanical alignment of the lower limb on a standing long leg radiograph and is considered neutral at 180^0 +/-3^0(2,3). It signifies the distribution of load through the knee and has shown to predict physical functions in patients suffering from OA(4). In a neutrally aligned limb medial compartment bears 60-70% of the total force during weight bearing and since it is subjected to a greater load, OA tends to affect medial compartment more than the lateral compartment(5). A knee is said to be in varus when the line connecting the femoral head to the mid-point of ankle passes medial to the centre of knee joint which results in a greater adduction moment arm across the knee leading to higher forces and greater degeneration.

While malalignment appears to play a critical role in disease progression, factors contributing towards the same have been variably studied. A varus knee has shown to differ morphologically from normal knees with respect to both intra-articular as wells as extra-articular factors. Cooke et al reported, that the major contribution to the coronal malalignment is caused due to the proximal tibial and distal femoral geometry in an arthritic knee(6). The importance of periarticular knee anatomy was further substantiated by Belleman et al who found it to attribute to 70% of the overall varus deformity(7). Previous studies on the overall mechanical alignment of asymptomatic knees in population of different ethnicities have revealed an overall varus alignment, however the orientation of joint line relative to floor as a major mechanical determinant of OA in such limbs was brought to light by Victor et al(8–11). Thienpont et al performed a bone morphometric analysis of both the valgus and the varus malaligned knees(2). Apart from intra-articular factors they found an existence of extra-articular factors as well in these limbs. They reported a presence of femoral bow in the varus malaligned limbs and an extra-articular deformity in either femur or tibia or both in valgus malaligned limbs.

Coronal bowing of lower limb is prevalent in Asian Knees undergoing a Total Knee Arthroplasty (TKA), with an incidence of femoral bowing and tibial bowing to the tune of 88% and 58.3% respectively.(12–14). Matsumoto et al reported an association of femoral bow with OA, with a greater lateral bow seen in higher grades of OA(15). The role coronal bowing of lower limb is considered a risk factor for post-surgical malalignment and component malposition thus affecting the implant survivorship following TKA(16). Functional limitation following OA has been linked to a number of structural changes in the knee that is thought to contribute to the intra-articular varus deformity such as meniscal pathology, loss of cartilage volume and laxity of ligaments(5,17).

What remains unanswered till date is whether this bowing has any functional significance affecting patient's daily living? Furthermore, the effect of bowing on the mechanical alignment of limb is still controversial. Shetty et al reported that femoral bowing did not affect mechanical alignment in asymptomatic individuals whereas Mullaji et al showed that lateral femoral bowing positively correlated with the HKAA in patients with grade IV OA undergoing TKA(10,14).

The aim of the present study was to explore the effect of coronal bowing of the lower limb on OA, with the following objectives (1) To assess the relationship of coronal bow of femur and tibia with the varus malalignment of the limb affected by knee OA (2) To assess the relationship between coronal bowing of extremities and Oxford knee score (OKS) in participants with knee OA.

MATERIAL AND METHOD:

We conducted a prospective observational cross-sectional study where patients of age more than 30 years presenting with knee pain and radiological varus alignment were included. Clinical diagnosis of OA was established on the basis of following symptoms. 1. Knee pain worse with mechanical use 2. Morning stiffness <30 min 3. Joint line tenderness. Patients with prior history of trauma or any surgery of the knee, flexion deformity of knee greater than 20^0, patients suffering from inflammatory arthritis and HKAA $>0^0$ were excluded from the study. The study was approved by the Institutional ethics review board and adhered to the tenets of Helsinki declaration of 1964 (and its later amendments). Informed written consent was taken from all patients prior to inclusion in this study.

The patients' demographic profile was recorded which included age, gender, height, weight and duration of the complaint. The OKS was calculated for the affected knee and the following radiographs were obtained. (1)Weight bearing Antero-posterior (AP) view (2) Lateral view and (3) the Long leg standing scannograms. All assessments were done by a single trained radiologist who was blinded to the questionnaires. The severity of knee osteoarthritis (OA) was graded by Kellegren and Lawrence (K&L) grading (18).

RADIOGRAPHIC ASSESSMENT OF THE LOWER LIMB:

Full weight bearing long legs scannograms were taken in full extension with both patellae facing forward. This standard position ensured that the tibiae were vertical and there was minimal rotation. The digital copies were retrieved using Picture archive and communication system (PACS) and both limbs were assessed using a custom written Matlab (2009, Mathworks, USA) routine. This software uses the digital equivalent of a ruler, circle and goniometer tools to define landmarks and make measurements. The following landmarks were identified manually through the software for each limb (15). Centre of the femoral head (CFH), medial femoral condyle (MFC), the intercondylar notch (ICN), lateral femoral condyle (LFC), medial tibial plateau (MTP) , lateral tibial plateau (LTP), medial tibial spine (MTS), lateral tibial spine (LTS) and the centre of the tibial plafond(CTPF)(Fig 1A). The centre of intramedullary canal for proximal and distal aspect of both Femur and Tibia were identified by an axis connecting the points at predetermined level.

- Centre of the proximal femur (CPF) was calculated by joining an axis connecting the (a) mid cortical point at superior aspect of lesser trochanter (LT) (b) mid cortical point at inferior aspect of LT (c) mid cortical point 5 cm distal to inferior aspect of LT.
- Centre of distal femur (CDF) was calculated by joining an axis connecting the (a) Intercondylar notch (ICN) (b) mid cortical point 5 cm proximal to medial femoral condyle (MFC) (c) mid cortical point 10 cm proximal to medial femoral condyle (MFC).
- Centre of the proximal tibia (CPT) was calculated by joining an axis connecting the (a) mid-point between medial tibial spine (MTS) and lateral tibial spine (LTS) (b) mid cortical point 5 cm distal to medial tibial plateau (MTP) (c) mid cortical point 10 cm distal to MTP.
- Centre of distal tibia (CDT) was calculated by joining an axis connecting the (a) mid-point of centre of the tibial plafond (CTPF) (b) mid cortical point 3cm proximal to CTPF (c) mid cortical point 5 cm proximal to CTPF.

Using these landmarks, the following parameters were calculated.

Coronal alignment of the lower limb:

Hip Knee Ankle axis angle (HKAA) was used to assess the coronal alignment of the limb. It was formed by two axis; first CFH, ICN and the other connecting ICN and CTPF (Fig 1B). The knee was considered to be in varus malalignment if the angle subtended was below O degrees. The limbs were categorized into three different groups depending upon the angle, A (0^0 to -3^0), B (-3^0 to -10^0) and C ($<-10^0$).

Coronal bowing of femur and tibia:

Mechanical axis of the femur was defined by an axis connecting the centre of the femoral head to the intercondylar notch while the anatomical axis of the femur was defined by an axis that connecting the mid-cortical centres of the proximal and distal thirds of the femur. When the axis did not pass through the centre of the mid diaphysis, centre of rotation of angulation (CORA) was defined and the angle was measured.

The mechanical axis of tibia was defined by an axis connecting the centre of the tibial spine to the centre of the talus and the anatomical axis was defined by the line connecting multiple mid-cortical centres of the proximal and the distal third of the tibia. The CORA of the tibia was defined when both of these when these lines were either not parallel or collinear, and the angle was then calculated. The deformity of the femur and tibia was calculated through the software and was defined as varus if there was a lateral bowing and valgus if there was a medial bowing (Fig 1C-F) with an angle at the CORA greater than 2^0 (12). Positive sign (+) was used to denote the valgus deformity and negative sign (-) was used to denote the varus deformity. Both the femoral and tibial bow were categorized into 3 groups depending upon the angle: In-range (-2^0 to $+2^0$), Varus ($<-2^0$), Valgus ($>+2^0$).

Patient Reported Outcome Measures (PROMs):

We used Oxford Knee score (OKS) as an objective evaluation of the knee function(19). It is a 12-item questionnaire containing 5 categories of response, corresponding to a score of 0 to 4 and ranges overall from 0 (worst) to 48 (best) (11).The total score was calculated for the affected knee and recorded.

STATISTICAL ANALYSIS:

To determine intra and inter-observer reliabilities of the radiographic assessment 2 investigators performed all the radiographic assessment in 30 randomly selected radiographs. The Interclass correlation coefficient (ICC) was used to measure intra and inter-observer reliabilities for the radiographic assessment. The ICC measured to be >0.8 for all measurements. Based on the observed reliability of the results, measurements taken by a single investigator (DNS) were used for the analysis. The statistical analysis was performed using IBM SPSS ver. 22.0 (IBM Corp., Armonk, NY, USA). Quantitative data was represented as mean+/- standard deviation with 95% confidence interval. Pearson correlation analysis was conducted between femoral and tibial bowing angle with HKAA. In order to evaluate the effect of alignment and bowing on OKS, the HKAA and the bowing were categorized as mentioned above and the sample was adjusted for age and BMI. Comparison among the groups was done using one-factor ANOVA following which a Post-hoc test, LSD was applied between the groups to see the statistical significance which was set at $p<0.05$.

RESULTS:

A total of 824 limbs of 414 patients were included in the study. The demographic profile of the study group and percentage of limbs affected by OA with their grades has been shown in Table 1. The overall mean HKAA was $-6.97^0 \pm 5.64^o$ (range -14.85^0 to -0.01^0, 95%CI: -6.58^0 to -7.35^0). 54.5% of the limbs were categorised into Group B followed by 23.1% in Group A and 22.5% in group C (Fig 2). The mean bowing of the femur of the whole cohort was $-1.97^0 \pm 3.49^o$ (range -9.7^0 to 12.42^0, 95% CI [-2.21^0 to -1.73^0]) with 54.1% of the femur having a varus deformity. The mean tibial bowing of the whole cohort was $-1.96^0 \pm 3.5^o$ (range -17.58^0 to 5.9^0, 95%CI [-1.72^0 to -2.20^0]) with 46.6% of tibia having varus deformity. The percentage of limbs with advanced HKAA, femoral varus as well as tibial varus bow were observed to increase with higher grades of OA (Fig.2-4.). We observed an increase in the varus malalignment with an increase in the lateral bowing of femur and a significant positive correlation was observed between the two (r=0.69, p=0.02). Similarly, an increase in the varus malalignment was seen with an increase in the lateral bowing of tibia with a significant positive correlation between the two (r=0.634, p<0.001). On performing a subgroup correlational analysis for each grade of OA, both femoral and tibial bowing showed significant correlation with HKAA at each grade (Table 2). A greater lateral bowing was observed at higher grades of OA both femur and tibia (Table 2). The mean OKS for the whole cohort was 26.3±11.5 (range, 4 to 48, 95% CI [25.5 to 27.1]).The patients with a higher grade of OA had a worse OKS and this difference in OKS in between the various grades of OA was found to be statistically significant (p<0.01) (Fig 5). The mean OKS observed for group A, B and C of HKAA were 31.4±11.4 (Group A), 27.5±11.5 (Group B) and 23.1±9.2 (Group C) respectively and the difference was statistically significant (p<0.01). The mean OKS for femoral bow, in-range, varus and valgus were 30.6±11.5, 21.3±11.5 and 35.3±11.4 respectively and for tibial bow, in-range, varus and valgus were 27.6±11.5, 26.±11.5 and 28±11.4 respectively. The difference in the mean OKS was observed to be significant when the varus bow group was compared to in range as well as valgus group (p<0.01) for both femur and tibia for all the grades of OA (Table 3).

DISCUSSION

The most important findings of our study were that both femoral and coronal bowing positively correlated with the overall varus malalignment and a significant lower score of OKS was seen with a varus bowing of the extremities. OKS is a short patient reported outcome that shows a good correlation with other knee-specific and general health questionnaires (20). Although it was originally devised for TKA patients, psychometric testing suggests its reliability and usefulness for OA(19). Due to its relative simplicity and availability in other languages it was used in our study.
In the present study we observed that patients with grade 0 Osteoarthritis had a medial bow of the femur whereas a lateral bow was observed at grade 1 OA which increased subsequently with increase in severity of OA (Table 2). Matsumoto et al observed a similar characteristic in Japanese population and postulated that a change in the femoral bow may contribute to a shift of mechanical axis medially resulting in a varus deformity of Osteoarthritic Knee. (15).

The relationship of coronal femoral bowing with HKAA has been studied inconsistently in the past. Factors affecting the varus malalignment of the limb includes femoral bowing, decreased neck shaft angle and an increased femoral mechanical and anatomical angle difference(21). However Shetty et al reported MPTA to be a predictor of HKAA in Indian and Korean population rather than femoral bow, BMI or femoral neck shaft angle(10). Most of the studies have reported a higher degree of femoral bowing to be associated with postoperative mal-correction of mechanical alignment following TKA. Niki et al.(22) found postoperative HKA malalignment to have a significant association in patients with femoral bow > 4º in patients undergoing revision TKA. Mullaji et al showed that the postoperative mechanical axis outliers were greater in knees with a varus deformity greater than 20 º or femoral bowing > 5 º (23) We tried to establish the relationship between femoral bowing and HKAA and observed that there was significant positive correlation between the two at every grade of OA (Table 3). Our finding may suggest that an increase in the varus deformity cause buckling of the femoral shaft resulting in medial translation of weight bearing axis, further degrading the knee joint. We observed a lateral bow in the tibia even in subjects with no radiographic evidence of OA which might suggest a socio-cultural association (activities like sitting cross legged and squatting are quite prevalent in our population) or could be due to the presence of congenital tibia vara(10). Some studies have also suggested that Vitamin D deficiency can result in coronal bowing of the extremities resulting in overall varus deformity(24).

An increase in lateral tibial bow was seen to be associated with an increase in the severity of OA. Saiba et al observed an extra-articular tibial bowing in 58.3% of the limbs undergoing TKA and reported an under-correction of HKAA with a bow greater than 4 degrees suggesting a positive correlation with HKAA(25). Kim et al on the contrary, reported that tibial bowing did not have any effect on the post-operative coronal alignment and component malposition following conventional TKA(26). Although the proportion of limbs with tibial varus bow was smaller compared to the femoral bow (Fig 3 and 4), a significant correlation was seen with the HKAA. Nagamine et al have reported greater tibial torsion in Asian individuals contributing to overall varus deformity.(27) Other studies have demonstrated a positive correlation between both lateral femoral and tibial shaft bowing with age, BMI and lumbar spine BMD, thus opening frontiers for further research on conservative management of these deformities(28,29). Our findings suggest that surgeons should be careful of a higher femoral and tibial lateral bow in patients with severe varus osteoarthritic knee and therefore use operative techniques like computer assisted surgeries (CAS), patient specific instrumentation (PSI) or extra-articular osteotomy to address the same.

Coronal alignment has been shown to be an important predictor of knee function as it acts as a local factor that affects the ability of the joint to withstand imposed forces. We observed a significant deterioration in the mean OKS with a varus HKAA. Sharma et al. studied both function and pain malaligned osteoarthritic knees. He found a greater decline in function when the overall varus alignment was greater than 5 º and a greater pain score as malalignment increased greater than 4 º (4). Moyer et al examined the effect of malalignment on dynamic joint loading in 487 patient and observed an increase in the load of 3.2Nm for 1^0 increase in varus alignment(30). From a biomechanical point of view, effect of varus malalignment can be attributed disproportionate increase in medial compartment load which further increases during walking(8).

Studies have shown that about a fifth of patients remain dissatisfied following TKA(31–33). The causes that are commonly cited are unequal flexion or extension gap, soft tissue imbalance, and patella maltracking which have been linked to the mismatch between femoral and tibial coronal alignment(34). Thus we sought the effect of bowing of extremities on OKS and observed that both femoral and tibial varus bowing significantly had lower OKS at every grade of OA when adjusted with age and BMI. Slevin et al (35)showed that neutral alignment leads to higher knee society scores in patients with pre-operative non varus alignment suggesting that there might be other factors that might have bearing on clinical outcome in varus limbs. We feel that coronal varus bowing might play a role in affecting the ADLs in people affected by OA and also in patients who have undergone surgeries such as HTO, UKA and TKA, however this needs to be substantiated with further research.

This study had several limitations. The design of the present study was cross sectional in nature than longitudinal and it lacked ethnic diversity, thus limiting its application in other population. We did not perform dynamic assessment using a computer tomography (CT) scan which could have been used to evaluate torsional profiles. Although we tried to exclude the non OA causes of knee pain we relied on patients' history which could have been a cause of recall bias. We did not study other static radiological parameters such as neck shaft angle, lateral distal femoral angle or medial proximal tibial angle. There could have been slight error in the calculation of angles since fixed landmarks were used for all the patients irrespective of the height. And lastly patella-femoral joint was not assessed which might have a bearing on our results.

CONCLUSION:

In the present study we observed both tibial and femoral bowing to significantly correlate with the HKAA at all grades of OA, suggesting its contribution to overall varus malalignment. A significantly lower OKS was observed with varus bowed femur or tibia as compared to non-bowed or valgus bowed at all grades of OA

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Contributions.

Nayak M; Drafting of the article, Critical revision of the article for important intellectual content, Collection and assembly of data, Final approval of the article

Kumar V; Conception and design, Provision of study materials or patients, Final approval of the article.

Srivastava D N; Analysis and interpretation of the data, Critical revision of the article for important intellectual content, final approval of the article.

Pandit H; Conception and design, Final approval of the article

Malhotra R; Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, final approval of the article

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Competing interest

All authors have no potential conflicts of interest, including financial interests, activities, relationships, and affiliations, to disclose.

FIGURE AND TABLE LEGENDS

Figure 1: [A] Following landmarks were identified manually through the software for each limb. Centre of the femoral head (CFH), centre of the proximal (CPF) and the distal third of the intramedullary canal of the femur (CDF), medial femoral condyle (MFC), the intercondylar notch (ICN), lateral femoral condyle (LFC), medial (MTP) and lateral tibial plateau (LTP), medial (MTS) and lateral tibial spine (LTS), centre of the proximal (CPT) and distal third of the intramedullary canal of the tibia (CDT) and the centre of the tibial plafond(CTPF). With the help of these landmarks following angles were calculated. Hip-Knee-Ankle Angle [B]; the angle subtended between the line connecting CFH, ICN and point between MTS and LTS and CTPF. Bowing was calculated from the angle formed between the line connecting proximal and distal mid-cortical centres for both femur (FB) and tibia (TB).It was defined as vara if there was a lateral bowing greater 2 degrees [C,D] and valga if there was medial bowing greater than 2 degrees [E,F]

Figure 2: Bar graph showing distribution (%) of different categories of HKAA at different grade of OA

Figure 3: Bar graph showing distribution (%) of different categories of femoral bow at different grade of OA

Figure 4: Bar graph showing distribution (%) of different categories of tibial bow at different grade of OA

Figure 5: Mean OKS at different grade of OA

Table 1: Showing demographic profile of the study group and limbs affected by different grades of OA

Table 2: Various parameters calculated at various grades of OA (Values represented as mean+/-SD, p value [a]= significance correlation between HKAA and femoral bow and P value¥=significance of correlation between HKAA and tibial bow)

Table 3: Mean OKS for different categories for HKAA, Femoral and Tibial bow. Values represented as mean+/-SD. (P values of femoral and tibial bow represented as varus vs In-range, varus vs valgus)