The Knee 26 (2019) 1088–1095

Contents lists available at ScienceDirect

The Knee

# Improving the accuracy of tibial component placement during total knee replacement in varus knees with tibial bowing: A prospective randomised controlled study

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ARTICLE INFO

*Article history:*
Received 24 April 2018
Received in revised form 2 April 2019
Accepted 16 May 2019

*Keywords:*
Extramedullary tibial jig
Limb alignment
Tibial bowing
Tibial component placement
Total knee arthroplasty
Varus knee

ABSTRACT

*Background:* Lateral tibial bowing leads to varus placement of the tibial component during total knee replacement in varus knees. Lateralised tibial jig placement can improve the accuracy of the tibial cut.

*Methods:* A total of 227 patients (300 knees) undergoing total knee replacements were randomised into two groups. In the study group, the point of intersection of the distal tibial diaphyseal line at the tibial plateau drawn on long films was represented by zones. Knees with femoral bowing >5° (28%) were excluded. Tibial jig placement on the proximal tibia was lateralised according to the zones. In the control group, the mid-point of the tibial plateau was taken as a reference. Femoral and tibial bowing, postoperative limb alignment and component placement were assessed.

*Results:* Of the 216 knees that were studied, 106 were in the study group and 110 in the control group. Bowing ≥3° had a significant positive correlation with lateralisation of the proximal tibial reference ($p < 0.001$). The Incidence of tibial bowing ≥3° was 57.33%. The mean postoperative hip–knee–ankle (HKA) angle was 178.31 ± 2.88° and 176.53 ± 2.88° ($p < 0.001$), whereas the mean medial proximal tibial angle (MPTA) was 89.91 ± 1.42° and 88.79 ± 1.72° ($p < 0.001$) in the study and control groups, respectively. Considering bowed tibiae alone, HKA angle and MPTA in the study group were 178.08 ± 2.81° and 89.72 ± 1.39° compared with 175.88 ± 2.87° and 88.38 ± 1.38° in the control group ($p < 0.001$).

*Conclusion:* There is a high incidence of tibial bowing in varus knees. Lateralised tibial jig placement improved tibial component placement and postoperative limb alignment in total knee arthroplasty in varus knees with tibial bowing.



## 1. Introduction

The importance of correct alignment in total knee arthroplasty (TKA) is a fact [1]. Malalignment especially in varus can cause several complications, poor clinical outcomes, excessive polyethylene wear, patellar complications, implant loosening, medium

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https://doi.org/10.1016/j.knee.2019.05.010
0968-0160/

and long-term failure and early revision of the arthroplasty [1–3]. Poor outcome is usually associated with malalignment of the femoral or the tibial component [4–7]. The tibial component must be in neutral alignment of 90° ± 2° for the longevity of the replacement [8].

Tibial bowing is very common in Asian patients. In a study by Yau W et al., the incidence of tibial bowing (>2°) was 32% with an error of >2° in tibial component placement seen in 40% in the bowed tibia compared to six percent in patients with straight tibiae [9]. This anatomic variation of the knee should be taken into consideration as a part of preoperative surgical planning [10]. Ko et al. reported an unacceptable tibial cut in 22% of Chinese patients with lateral tibial bowing [11]. An extramedullary cutting guide is preferred in such situations.

We hypothesised that a lateralised proximal tibial reference for jig placement by individualised preoperative planning would improve the accuracy of the tibial component in knees with a bowed tibia and also give a better limb alignment postoperatively. The purpose of the study was to assess the incidence and severity of tibial bowing in patients undergoing total knee arthroplasty in knees with varus deformity and to analyse the effect of individualised planning of the tibial cut and intraoperative lateralisation of the extramedullary tibial jig.

## 2. Material and methods

### 2.1. Study design

In a prospective randomised trial, 227 patients (300 knees) with osteoarthritis of the knee with varus deformity of ≤177° hip–knee–ankle (HKA) angle undergoing primary total knee arthroplasty at our institute from March to December 2015 and willing to participate were included in the study. Patients with post-traumatic pathology causing tibial bowing, congenital or dysplastic bowing, proximal and distal tibial metaphyseal varus, previous femoral or tibial osteotomy or previous fracture of the tibia with or without internal fixation, femoral bowing >5° and those with rotational malalignment on radiographs were excluded. In cases with severe bowing, distal tibial metaphyseal varus and malunited fractures, an additional extra-articular corrective osteotomy may be required along with intra-articular correction and hence these were excluded from our study.

Written informed consent was obtained from all the patients. Ethical committee approval was obtained from the institutional review board. Preoperative full-length standardised radiographs were taken and analysed with PACS software (Med Synapse version 5.0). This was a single blinded study, where the patients were allotted by the principal investigator to study and control groups by simple randomisation. Simple randomisation was done by generating a random digit table on which the equally likely digits 0 to 9 were arranged in rows and columns. By randomly selecting a certain row (column) and observing the sequence of digits in that row (column), the study group were assigned to those subjects for whom the next digit was even and the control group to those for whom the next digit was odd.

In the study group, the mechanical axis of the tibia was drawn preoperatively using the distal tibial diaphyseal line passing through the middle of the medullary canal of the distal third of the tibia and the point of exit at the proximal tibial surface was marked (Figure 1a). The reference was taken from two mid-diaphyseal points in the distal third of the tibia above the tibial metaphysis. The distal tibial diaphyseal line was used instead of the mid-diaphyseal line as bowing can be in the proximal third, middle third and distal third of tibia and this distal tibial diaphyseal line can be used to assess the bowing in the entire three regions and also helps to place the tibial component in a plane perpendicular to the dome of talus. Since patients with distal tibial bowing were excluded, the distal tibial axis was used as a reference assuming the fact that the anatomy of the distal tibia would be normal and this was used as a reference for measuring the bowing and deciding the zone of reference for the tibial jig.

According to this the tibial plateau was divided into five zones (Figure 1b).

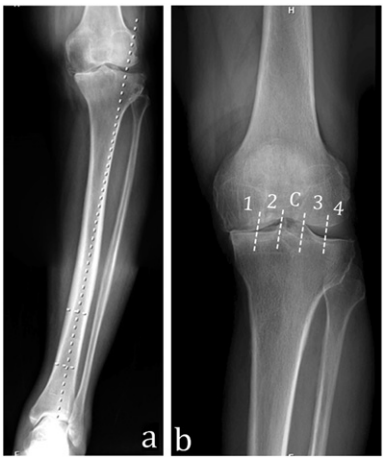


**Figure 1.** Tibial bowing & zones: a) distal tibial diaphyseal line and point of exit at the proximal tibial surface, b) zones of the tibial plateau: zone 1) far medial — medial half of the medial plateau, zone 2) medial — lateral half of the medial plateau, zone C) central — between the two tibial spines, zone 3) lateral — medial half of the lateral plateau and zone 4) far lateral — lateral half of the lateral plateau.

Zone 1: Far medial — medial half of the medial tibial plateau,
Zone 2: Medial — lateral half of the medial tibial plateau,
Zone C: Central — between the two tibial spines,
Zone 3: Lateral — medial half of the lateral tibial plateau and
Zone 4: Far lateral — lateral half of the lateral tibial plateau.

These zones were used as a guide for the reference for the tibial jig placement intraoperatively for the tibial cut. For zone 3 knees, the lateral tibial spine was used as a reference and for zone 4, a point lateral to the lateral tibial spine was chosen as far lateral as possible up to the patellar tendon. Accurate measurement of the target point for jig placement can be done but needs the additional step of standardisation of radiographs. As the target point is calculated from long leg standing radiographs the accuracy and reproducibility could be low and chances of over estimation are present and hence the zonal reference was used. Using the distal tibial axis can lead to over correction in patients with distal tibia vara and hence the exact zone was not used for tibial jig placement. The distal tibial axis was used only to assess the severity of bowing (Figure 1a) and to assess the zone of intersection in the proximal tibial plateau. Intraoperatively either the lateral tibial spine or a point just lateral to the lateral tibial spine was used for reference. The accuracy of the tibial cut was assessed using a trial tibial tray and drop rod. If the tibial cut was still in varus the cut was revised to achieve a component placement perpendicular to the tibial mechanical axis by checking with the drop rod. In the control group, the centre of the tibial plateau corresponding to the medial third of the tibial tubercle was used as a reference. Distally a point three millimetres medial to the centre of the ankle was used as a reference in both the groups. In both groups, tibial and femoral bowing was measured as the angle between the proximal third and distal third mid-shaft axis respectively. In this study, to evaluate the effect of tibial bowing exclusively, knees with a bowed femur were excluded. Hence the final correction in alignment would be contributed only from the tibial component placement. In a study by Shetty et al. femora with coronal bowing >5° were considered to have excessive bowing and considered significant [12].

Preoperatively HKA angle, valgus correction angle (VCA), femoral and tibial bowing, medial proximal tibial angle (MPTA) and medial distal femoral angle (MDFA) with the mechanical axis of the femur were measured. Hip–knee–ankle angle was defined as the angle between lines passing through the centre of the head of the femur and the mid-points of knee and ankle joint respectively on full length alignment radiographs (Figure 2a). We measured femoral and tibial bowing as the angle between the proximal third and distal third of the mid-shaft axis of the respective bones (Figure 2b & c). Valgus correction angle was measured as the angle between the mechanical axis of the femur and the distal femoral axis of the femur passing from the centre of the intercondylar notch to the femoral isthmus (Figure 2d). The distal femoral cut was made at a valgus correction angle individualised for each patient measured from the preoperative long film with the intramedullary jig. The medial proximal tibial angle was measured as the angle between the tibial mechanical axis and the line tangential to the proximal tibial articular surface (Figure 2e). The randomisation is given in the CONSORT flow chart (Figure 3). The patients were followed up at six weeks. Full-length weight bearing radiographs were taken. The postoperative HKA angle and MPTA were measured (Figure 4a & b). The

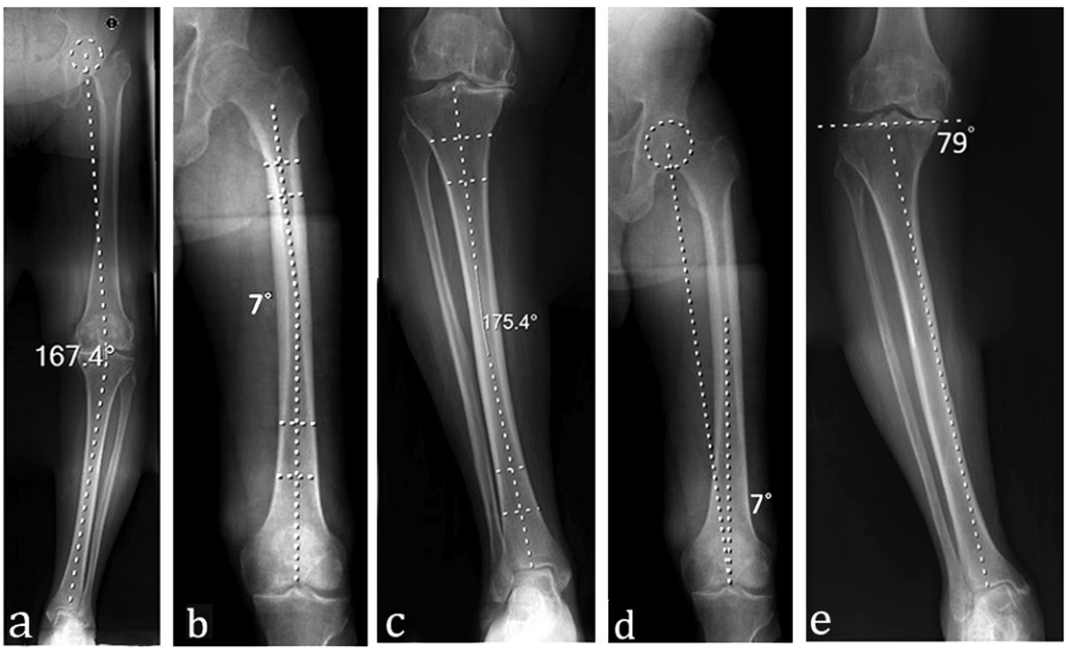


**Figure 2.** Preoperative measurements: a) Pre-operative hip–knee–ankle (HKA) angle 167.4°, b) femoral bowing seven degrees, c) tibial bowing 4.6°, d) valgus correction angle (VCA) seven degrees and e) pre-operative medial proximal tibial angle (MPTA) 79°.

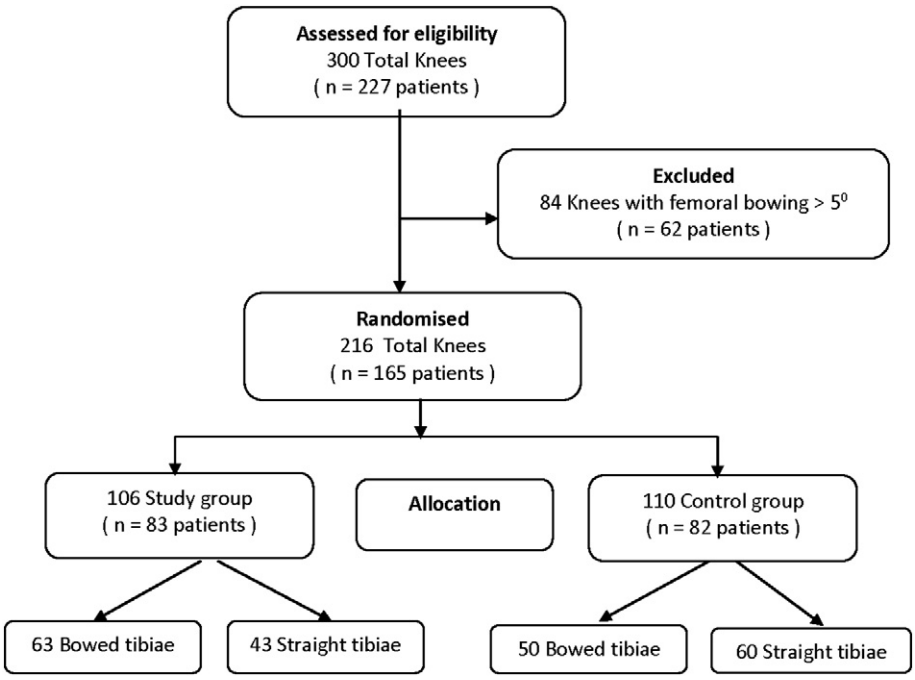


**Figure 3.** CONSORT flow diagram showing randomisation and allocation of study participants.

measurements were performed by two surgeons and the average of the two values was taken. Intra-class correlation ratings were calculated to assess inter-rater reliability.

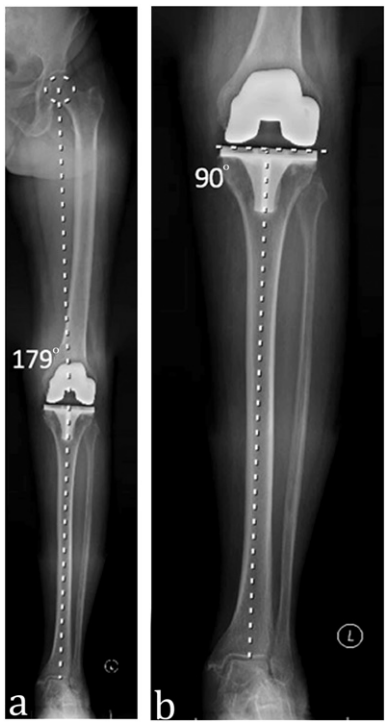


**Figure 4.** Postoperative measurements: a) post-operative hip–knee–ankle (HKA) angle 179°, b) post-operative medial proximal tibial angle (MPTA) 90°.

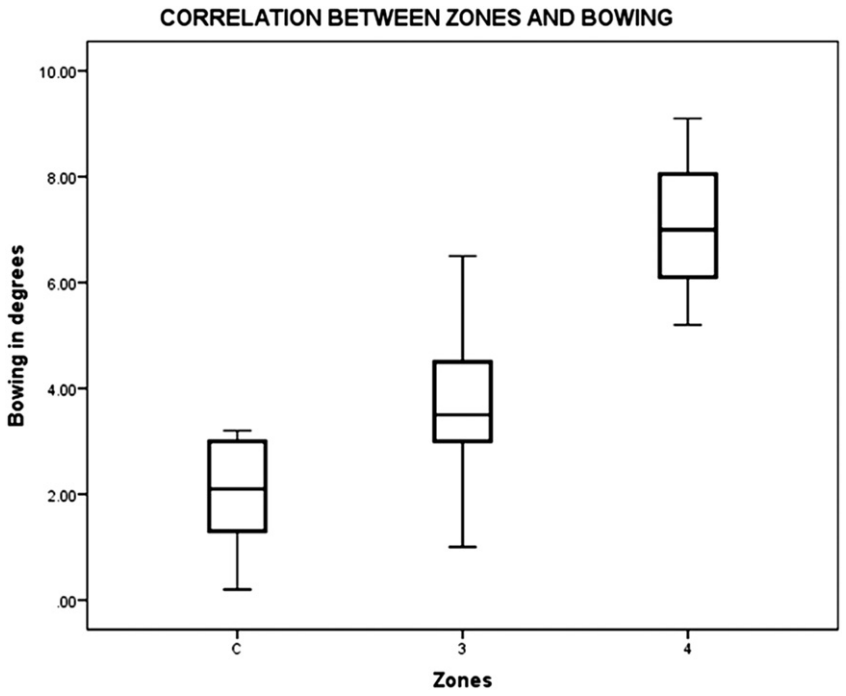


**Figure 5.** Shows the correlation between the degree of tibial bowing and the proximal tibial zones used. Bowing of three degrees correlates with the lateral tibial spine as a reference ($p < 0.001$).

### *2.2. Statistical analysis*

The data were analysed using SPSS for Windows INC Version 20. Chicago, Illinois. Descriptive statistics were presented as mean (SD) for continuous variables. Correlations between tibial bowing with MPTA, HKA angle, femoral bowing angle and, MPTA with HKA angle were assessed using the Pearson correlation coefficient. The independent-samples t-test was used to compare the means between two unrelated groups on the same continuous, dependent variable. A two-sided p-value <0.05 was taken as statistically significant. Intra-class correlation coefficient (ICC) estimates and their 95% confident intervals were calculated based on a mean-rating ($k = 2$), absolute agreement, two-way mixed-effects model.

## 3. Results

### *3.1. General*

The preoperative deformity of the 300 patients included in the study was 165.6° (140.5–177°, SD 6.48). The tibial bowing of the entire study population was an average 3.2° (0.2°–9.1°, SD 1.74) and the femoral bowing was an average 4.02° (0–19.8°, SD 3.03). The correlation between the tibial reference zones with bowing was assessed (Figure 5). The reference changes from zone C to zone 3 with tibial bowing of three degrees and hence bowing of three degrees was considered significant ($p < 0.001$). Out of 300 tibiae, 172 (57.33%) had bowing >3°. The bowing was located in the mid-third of the tibia in 162 (94%) cases. Four had bowing in the proximal third and six had bowing in the distal third of the tibia. Zonal placement of the tibial mechanical axis was found to have significant correlation with tibial bowing (Table 1). Tibial bowing angle had a significant negative correlation with MPTA and HKA angle ($r = -0.2$ and $-0.25$ respectively, $p < 0.001$). There was a significant positive correlation between

**Table 1**
Correlation between tibial bowing with proximal tibial angle, preoperative limb alignment and femoral bowing.

| Correlation | N | Pearson r value | p value |
|---|---|---|---|
| Tibial bowing vs MPTA[a] | 300 | −0.2 | <0.001 |
| Tibial bowing vs HKA[b] angle | 300 | −0.25 | <0.001 |
| MPTA with HKA angle | 300 | 0.69 | <0.001 |
| Tibial bowing vs FB[c] angle | 300 | 0.19 | <0.001 |

[a] MPTA — medial proximal tibial angle.
[b] HKA — hip–knee–ankle.
[c] FB — femoral bowing.

**Table 2**
Comparison of MPTA[a] and HKA[b] angle preoperatively and postoperatively between the study and control groups.

| Parameter | | Study (n = 106) | Control (n = 110) | p value |
|---|---|---|---|---|
| | | Mean, range | Mean, range | |
| HKA[a] angle | Preoperative | 165.39° (140.5°–177°) | 167.68° (148.9°–176.8°) | 0.067 |
| | Postoperative | 178.31° (169.8°–185.5°) | 176.53° (169.5°–185.2°) | <0.001 |
| MPTA[b] | Preoperative | 84.42° (71.7°–91.7°) | 84.73° (77.1°–91°) | 0.51 |
| | Postoperative | 89.91° (86°–92.5°) | 88.79° (84°–94.1°) | <0.001 |

[a] HKA — hip knee ankle.
[b] MPTA — medial proximal tibial angle.

MPTA and HKA angle ($r = 0.69$, $p < 0.001$), and also between the tibial bowing angle and femoral bowing (FB) angle ($r = 0.19$, $p < 0.001$).

Out of 300 knees, 84 knees (28%) with femoral bowing >5° were excluded and the remaining 216 knees (165 patients) were included in the study. Out of 216 knees (165 patients), 106 were in the study group and 110 in the control group respectively. Of the 165 patients, 114 were females and 51 males. The mean age was 64.64 years (45–84; SD 9.75) in the study group and 61.3 years (37–82; SD 11.25) in the control group. The average VCA measured was 5.3° (range 3.1°–6.6°; SD 0.88). Among the study group, 63 knees had bowed tibiae and 43 knees had straight tibiae. Similarly, among the control group, 50 knees had bowed tibiae and 60 knees had straight tibiae. Tibial zones assessed during preoperative planning were distributed as follows: (1) bowed tibiae (113 knees), 62 were in the central zone, 47 in zone 3 and four in zone 4 and (2) straight tibiae (103 knees), 94 were in the central zone and nine were in zone 3.

### *3.2. Study vs. control group*

The mean preoperative MPTA angle in the study and control groups was 84.42° (71.7°–91.7°, SD 3.793°) and 84.73°(77.1°–91°, SD 3.44°) respectively which was comparable ($p = 0.51$). The mean postoperative MPTA angle in the study and control groups was 89.91° (86°–92.5°, SD 1.42°) and 88.79° (84°–94.1°, SD 1.72°) respectively which was statistically significant ($p < 0.001$). The mean preoperative HKA angle in the study and control groups was 165.39° (140.5°–177°, SD 6.57°) and 167.68° (148.9°–176.8°, SD 6.1°) respectively which was comparable ($p = 0.067$). The mean postoperative HKA angle in the study and control groups was 178.31° (169.8°–185.5°, SD 2.88°) and 176.53° (169.5°–185.2°, SD 2.88°) respectively which was statistically significant ($p < 0.001$) (Table 2). The mean postoperative medial femoral component placement angle (MDFA) in the study and control groups was 88.57° (82.4°–93.7°, SD 2.3°) and 87.95° (82.5°–94.1°, SD 1.91°) respectively which was statistically significant. However the difference was only 0.6°. In the two-way mixed-effects model, the ICC = 0.97 with a 95% confident interval = 0.96–0.98. About 97% of the variance in the mean of the inter-rater results was true.

## 4. Discussion

The most significant findings of our study were as follows: there was a high incidence of tibial bowing of three degrees in patients with varus osteoarthritis (57.33%). There was also a high incidence of femoral bowing >5° in these patients (28%). The severity of the bowing correlated with the extent of lateralization of the extramedullary jig on the proximal tibia required, femoral bowing and the severity of varus of the proximal tibial angle (mean 84.42°, 71.7°–91.7°, SD 3.793°). Individualised preoperative planning resulted in good tibial component placement and improved limb alignment in spite of bowing of the tibia causing a combined intra-articular and extra-articular deformity. Implant malalignment was found to be the primary reason for revision in seven percent of primary TKA [13]. Tang et al. studied 6070 knees, there were 0.84% failures: 1.8% in the varus group and 1.5% in the valgus group respectively [14]. Varus knees failed primarily by medial tibial collapse whereas valgus knees from ligament instability [14]. In a cadaveric study by Green et al., there was a statistically increased strain on the posteromedial quadrant of the proximal bone in the varus cut tibia [8].

In the Asian population, the medullary canal of the tibia and femur is often bowed [15]. Along with preoperative varus deformity, bowing leads to an increased incidence of varus outliers for the postoperative tibial and femoral component with limb mechanical axis alignment [9]. In our study, the incidence of tibial bowing ≥3° was found to be 57.33%. The mean tibial bowing found in the total population was 3.22° with the maximum being 9.1°. The incidence of tibial bowing reported in Chinese population was 32% (>2°) with mean bowing of 4.2° in the study by Yau et al. [9]. Whereas, in the Japanese population its mean was 0.6° [16]. In our study population, we found a higher percentage of bowed tibiae compared to Chinese or Japanese populations. However in our study, knees only with moderate to severe varus deformity have been included compared to the other studies which included the valgus knees also. The mean femoral bowing was found to be 4.02°, maximum being 19.8° and incidence ≥5° is 28%. The femoral bowing severity of ≥5° was reported in 16.5% of patients by Shetty et al. [12], and 41.4% by Chow et al. [17].

Tibial bowing has a significant correlation with preoperative deformity (HKA angle) and the proximal tibial angle (MPTA). The more severe the bowing the more the deformity, as bowing causes extra articular deformity in addition to the intra articular deformity. Also the tibial bowing leads to a higher proximal tibial varus angle. Thus tibial bowing adversely affects both limb

alignment and proximal tibial component placement. In a study by Shigeshi Mori et al. significant negative correlation of tibia vara on aspect ratio of the tibial resected surface was found [16].

Zonal placement of the tibial mechanical axis has been found to have a significant correlation with tibial bowing. Preoperative planning and lateralised jig placement reduce outliers and give better component placement (Supplementary Figures 1,2). Postoperative mean MPTA in the study group was 89.91° compared to 88.79° in the control group, and the difference was statistically significant. Postoperative mean HKA angle in the study group was 178.31° compared to 176.53° in the control group, and the difference was statistically significant. Hence limb alignment was improved by a mean of 1.78° using a lateralised reference point. The femoral component placement angle (MDFA) in the study group was a mean of 88.57° compared to a mean of 87.95° in the control group, and the difference was only 0.6°. Therefore 1.18° improvement in HKA angle was contributed by MPTA. The outliers for tibial component placement were four (3.77%) in the study group which was significantly less compared to 16 (14.55%) in the control group. Better component placement was achieved in knees with bowed tibiae using lateral referencing in the study group. This implies that tibial bowing deformity can result in unacceptable tibial component placement, if the centre of the tibial plateau is used as the reference point. However, using the lateralised proximal reference point for the proximal tibial cut (decided preoperatively) is associated with better component placement. As better tibial component placement was also achieved in patients with three degrees of bowing. A more lateral reference point using individualised planning was useful even in patients with mild tibial bowing. Better component placement was achieved in knees with bowed tibiae using lateral referencing in the study group. This implies that tibial bowing deformity can result in an unacceptable tibial component placement, if the centre of the tibial plateau is used as the reference point. However, using the lateralised proximal reference point for the proximal tibial cut (decided preoperatively) is associated with a better component placement. A better tibial component placement was also achieved in patients with three degrees of bowing. A more lateral reference point using individualised planning was useful even in patients with mild tibial bowing. Postoperative MPTA found in the study group was comparable to MPTA of 90.57° ± 0.6° achieved with the lateral eminence of the tibia for the proximal tibial cut in the study by Han and Chae [18], but this study lacks the association of the proximal tibial reference between bowed and straight tibiae with no individualised planning which was established by this study. It is better to do planning as the lateral reference leads to a valgus placement in the straight tibia [19]. Severe resection of the lateral tibial condyle caused by excessive valgus osteotomy can affect implant fixation and lead to subsidence in the long term [20,21] which can be avoided by lateralising the reference point for the proximal tibial cut according to the severity of the preoperative deformity.

In the control group, the difference between postoperative HKA angle in bowed tibiae (175.88°) and straight tibiae (177.07°) was significant, with overall 1.2° varus malalignment in bowed tibiae group. However, the difference in postoperative HKA angle in the study group between bowed tibiae (178.08°) and straight tibiae (178.65°) was not statistically significant, suggesting that there is significant improvement in lower limb alignment if the proximal tibial reference is individualised. There was a statistically significant positive correlation between tibial and femoral bowing angle. So an increase in the tibial bowing was also associated with increase in femoral bowing. This could be effectively addressed by an individualised valgus correction angle for the distal femoral cut measured from the preoperative long films [22]. However meticulous soft tissue release needs to be done to ensure a balanced medial and lateral joint space. This study established the presence of tibial bowing in patients with varus osteoarthritis undergoing TKA. It is one of the first studies to validate a simple technique to improve the accuracy of the extra medullary jig for the tibial cut using a randomised trial resulting in improved component placement and limb alignment. Our study showed that if bowing is three degrees the proximal tibial reference has to be shifted from centre to lateral. However surgeons should be aware of the fact that some external rotation of the limb will lead to over estimation of the tibial and femoral bowing and can lead to over correction and valgus placement of the components. Too much lateralization should be avoided.

## 5. Conclusion

There is a high incidence of tibial bowing in varus knees undergoing total knee arthroplasty. Lateralised tibial jig placement improves tibial component placement and postoperative limb alignment in TKR in varus knees with tibial bowing.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.knee.2019.05.010.

## Source of funding

Nil.

## Declaration of Competing Interest

None of the authors declare any conflict of interest.

## Acknowledgement

Nil.

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