Tibial intramedullary canal axis and its influence on the intramedullary alignment system entry point in Koreans

Dai-Soon Kwak¹, Chang Whan Han², Seung-Ho Han¹
¹Catholic Institute for Applied Anatomy · Department of Anatomy, School of Medicine, The Catholic University of Korea, ²Somang Orthopedic Clinic, Seoul, Korea

Abstract: Using computerized tomographic data and three dimensional model, we studied the influence of tibial intramedullary canal axis and other morphologic factors of the tibia on the entry point for tibial intramedullary alignment guides. Various anatomical parameters including tibial anteroposterior dimensions (AP), mediolateral dimensions (ML), aspect ratio (ML/AP), bowing and the intramedullary canal axis were studied. In addition, the entry point for the intramedullary alignment guide for primary and revision total knee arthroplasty were studied. The averaged entry point at the level of the tibial plateau was 5.7±2.2 mm anterior and 4.3±2.0 mm lateral to the classical entry point (P<.001). Furthermore, this entry point was more anterolateral in females when compared to males (P<.001). At a depth 10 mm below the tibial plateau, the entry point was on average 8.8±1.9 mm anterior and 2.9±1.9 mm lateral to the center of the cut surface. With increasing tibial varus the entry point tended to shift laterally at both levels (r=0.49) (P<.001). In Korean, the entry point for tibial intramedullary alignment systems is anterolateral to the classically described entry point. Moreover, the increment of tibial varus necessitates more lateral placement of the entry point. Intraoperatively, the entry point can be localized during primary knee arthroplasty to a point 15.9±2.8 mm anterior to and 1.2±2.8 mm lateral to the lateral tibial spine. For revision knee arthroplasty the point is on average 8.8±1.9 mm anterior and 2.9±1.9 mm lateral to the center of the cut surface of the tibia at a depth of 10 mm from the articular surface.

Key words: Total knee arthroplasty, Intramedullary alignment systems, Tibial intramedullary axis, Tibial anthropology, Korean

Introduction

An important determinant of long-term survival of a total knee arthroplasty (TKA) is proper implant positioning (Moreland 1988). With regard to tibial component positioning, the tibial cut should be perpendicular to the anatomical axis of the tibia; an acceptable range for varus/valgus is 2° for good long-term survival (Scuderi & Insall, 1989). To achieve this, either an intramedullary or an extramedullary alignment system is used for the tibial cut; both provide equal accuracy (Ishii et al., 1995). A recently introduced alternative is the use of computer navigation systems. Appropriate entry point selection is important for the tibial intramedullary alignment systems (TIAS) to function effectively. The classically described entry point, introduced by Whiteside and Summers (Whiteside & Summers, 1983), for tibial intramedullary alignment systems lies 5 mm anterior to the midpoint of the anteroposterior (AP) dimension of the tibial plateau in the
sagittal plane and at the midpoint of the mediolateral (ML) dimension of the tibial plateau in the coronal plane. However, in our experience, use of the classical entry point in Koreans results in varus implant positioning in many cases. This may be because the implants, instrumentation and techniques used were designed based on Caucasian parameters such as their morphometry, which is likely different from that of Korean where varus deformity is more frequent. Use of total knee implants, techniques and instrumentation designed based on the morphometry of Korean may solve this problem. Korean generally has smaller builds and higher functional requirements, such as the need to frequently kneel or sit cross-legged. Therefore, we assessed the tibial intramedullary canal axis in Koreans using three-dimensional reconstruction and modeling of the data obtained by CT scans of the tibiae of 100 cadavers. In addition, since the tibial intramedullary canal axis influences the entry point for tibial intramedullary alignment systems, we evaluated whether there was a significant alteration in this entry point for Korean compared to the classical entry point described by Whiteside and Summers (Whiteside & Summers, 1983).

Materials and Methods

We studied 100 cadavers (200 tibiae), after confirming that none of them had any prior congenital/pathological deformity, more than a moderate degree of arthritis or a history of prior surgery or fracture. The average age at the time of death was 50.3 years (21 ~ 60 years) and the average height was 166 cm for males and 156 cm for females. There were 50 males and 50 females included for analysis. For the computed tomography (CT) scans, the cadavers were positioned supine with their knees in extension and the lower limbs in a neutral position with respect to rotation. CT scanning was progressively done from the level of the hip joint to the ankle joint, in 1 mm slices using the Pronto scanner (Hitachi medical systems, Tokyo, Japan). Three-dimensional reconstruction and measurements of the tibiae from the acquired data were performed by Mimics software (Ver. 13.0, Materialise, Belgium). The analysis was at two levels: at the level of the tibial plateau to obtain data pertinent to a primary knee arthroplasty setting, and at a level 10 mm below of the tibial plateau, which is the recommended level of tibial resection for revision knee arthroplasty (Benjamin 2006).

Computation of aspect ratio

First, the trans-epicondylar axis of the femur was plotted. Four lines A1, P1, M1 and L1 were defined in relation to the proximal tibia. A1 and P1 were defined as lines collinear to the femoral trans-epicondylar axis, at the level of the tibial plateau, passing tangentially through the anterior and posterior tibial cortices respectively. M1 and L1 were defined as horizontal lines perpendicular to the femoral trans-epicondylar axis passing tangentially through the medial and lateral tibial cortices respectively. A1P1 and M1L1 were estimated as the distances between A1 and P1 and between M1 and L1 respectively (Fig. 1A). The aspect ratio at the level of the tibial plateau (AR1) was calculated as M1L1/A1P1 and expressed as a percentage. Then at a level 10 mm below the tibial plateau A2, P2, M2, and L2 were defined identical to A1, P1, M1, and L1. At this level, the anteroposterior depth...
of the tibia (A2P2) and the mediolateral width (M2L2) were calculated in a fashion similar to that used for A1P1 and M1L1. The aspect ratio at this level (AR2) was calculated as M2L2/A2P2 and expressed as a percentage (Fig. 1B).

**Estimation of the β angle**

The β angle was calculated for all tibiae as the angle between the bottom of plateau line (connecting the bottom of lateral plateau and medial plateau) and the transverse axis (perpendicular line to the tibial anatomical axis) in the AP tibial view (Fig. 1C). The values were recorded as positive for varus and negative for valgus.

**Establishment of a coordinate system**

To define points on the tibial surfaces a coordinate system was established. The X-axis was defined as lying along A1 starting from its point of intersection with M1, and ending at its intersection with L1. The X-axis was then divided into 100 equal parts. The Y-axis was defined as lying along M1, starting at its point of intersection with A1, and ending at its point of intersection with P1. The Y-axis was then divided into 100 equal parts. With this system any point at the level of the tibial plateau could be defined by X and Y coordinates ranging from zero to 100 (Fig. 1A). An identical coordinate system was set up at a level 10 mm below the tibial plateau (Fig. 1B).

**Plotting of the tibial intramedullary canal axis**

After three-dimensional reconstruction of the tibia, 16 equidistant virtual cross sections of the tibia were made through the entire length and a model reconstructed using the third to the eighth section from the proximal end for finding the centerline of medullary canal. The central point of each cross section was plotted a linear line by the least square method. Extrapolation of these central points yielded the intramedullary canal axis of the tibia (Fig. 2). The OriginPro software (Ver. 7.5, Original lab, MA) was used for the above procedures.

![Diagram showing the reconstruction of the tibial intramedullary canal axis.](image)

**Fig. 2.** Diagram showing the reconstruction of the tibial intramedullary canal axis. The six virtual cross sections used for calculations are shown. The centers of the cross sections are calculated as described in the text, and they are joined together resulting in the intramedullary canal axis represented by line AB.

![Diagram showing the coordinate system at the level of the tibial plateau with the LTS, SC1, CP, and combined CAC1 for males and females.](image)

**Fig. 3.** (A) The diagram shows the coordinate system at the level of the tibial plateau with the LTS, SC1, CP, and combined CAC1 for males and females. Note the relationship between the proposed entry point CAC1, the classical entry point (CP) and the proposed landmark (LTS) to allow identification of the proper entry point. (B) The diagram shows the cross section of the tibia with the coordinate system at a level 10 mm below the tibial plateau with the surface center (the suggested intraoperative reference point) and the combined canal axis center for males and females demonstrating their relative positions. The canal axis center is the proposed entry point.
Identification of canal axis center points, geometric surface centers, lateral tibial spine (LTS), and classical entry point (CP)

In order to locate the entry point for the tibial intramedullary alignment system we used the following method. The points of intersection of the tibial intramedullary canal axis with the tibial plateau and the cross section of the tibia at a level 10 mm below the tibial plateau were plotted as canal axis centers 1 and 2 respectively (CAC1, CAC2), and marked based on the aforementioned coordinate system. The position of the lateral tibial spine (LTS) on the tibial plateau was also plotted for all of the tibiae; this was for use as a reference point intraoperatively (Fig. 3A). The centers of the tibial plateau and the tibial cross section, at a level 10 mm below the tibial plateau, were designated as surface center 1 and 2 respectively (SC1, SC2). The classically described entry point was also marked at the level of the tibial plateau (Fig. 3A). The absolute distances from CAC1 to the lateral tibial spine and the CAC2 to surface center 2 were estimated to help with the intraoperative localization of the entry point (Table 1). The difference in position of the CAC compared to the classical entry point was assessed for statistical significance using the student’s t-test (Table 1).

Statistical analysis

Statistical analysis was performed using the Student t-test, the Paired t-test and Pearson’s correlation coefficient using SPSS for Windows version 12.0 (SPSS, Chicago, IL). Values for \(P<0.05\) were regarded as significant. Pearson correlation coefficient was represented as \(r\).

Table 1. Summary of tibial morphometric data in males and females

| Parameters | Male          | Female        | Combine       | \(P\) value |
|------------|---------------|---------------|---------------|-------------|
| Tibial length [mm] | 333.74±18.92  | 309.48±16.00  | 321.48±21.28  | <0.01       |
| A1P1 [mm]  | 51.56±3.24    | 45.57±2.72    | 48.53±4.23    | <0.01       |
| M1L1 [mm]  | 75.36±4.23    | 67.07±3.24    | 71.17±5.60    | <0.01       |
| AR1 (M1L1/A1P1) [%] | 146.32±5.52  | 147.40±6.29   | 146.87±5.93   | 0.11        |
| AR2 (M2L2/A2P2) [%] | 143.98±6.04  | 143.22±5.88   | 143.59±5.95   | 0.20        |
| \(\beta\) angle [deg] | 2.59±2.36    | 3.80±1.74     | 3.20±2.98     | <0.01       |
| CAC1-X [%] | 54.91±2.44    | 57.34±2.98    | 56.16±2.98    | <0.01       |
| CAC1-Y [%] | 27.55±6.12    | 27.71±4.55    | 27.63±5.36    | <0.01       |
| CAC2-X [%] | 53.16±2.30    | 54.78±2.67    | 54.00±2.62    | <0.01       |
| CAC2-Y [%] | 32.51±3.49    | 33.05±3.61    | 32.79±3.55    | 0.15        |
| LTS-X [%]  | 57.10±2.36    | 58.64±3.05    | 58.03±2.89    | <0.01       |
| LTS-Y [%]  | 61.02±3.16    | 61.16±3.90    | 61.10±3.61    | 0.41        |
| CAC1 to LTS [mm] (anteroposterior) | 17.22±2.68    | 15.17±2.53    | 15.99±2.77    | <0.01       |
| CAC1 to LTS [mm] (mediolateral) | 1.70±2.13     | 0.89±3.09     | 1.21±2.77     | 0.04        |
| CAC2 to SC2 [mm] (anteroposterior) | 9.44±1.94     | 8.18±1.72     | 8.79±1.93     | <0.01       |
| CAC2 to SC2 [mm] (mediolateral) | 2.46±1.79     | 3.32±1.86     | 2.90±1.87     | <0.01       |
| CP-X [%]   | 50.00±0.00    | 50.00±0.00    | 50.00±0.00    | -           |
| CP-Y [%]   | 27.55±6.12    | 38.99±0.66    | 39.62±0.90    | <0.01       |
| CAC1 to CP [mm] (anteroposterior) | 6.23±2.45     | 5.11±1.92     | 5.65±2.22     | <0.01       |
| CAC1 to CP [mm] (mediolateral) | 3.70±1.83     | 4.91±2.00     | 4.33±2.01     | <0.01       |

A1P1: Anteroposterior dimensions at the level of the tibial plateau, M1L1: Mediolateral dimensions at the level of the tibial plateau, AR1 and AR2: Aspectratio at the level of the tibial plateau and at a depth of 10 mm below the tibial plateau, CAC1-X and Y: X and Y coordinates of the Canal axis centre at the level of the tibial plateau, CAC2-X and Y: X and Y coordinates of the Canal axis centre at a level 10 mm below the tibial plateau, LTS-X and Y: X and Y coordinates of the lateral tibial spine, CP-X and Y: X and Y coordinates of the classically described entry point, SC2: Surface center at a level 10 mm below the tibial plateau.
Results

To identify the correct entry point for a tibial intramedullary alignment system during total knee arthroplasty, we studied the morphometry of the proximal tibia; the results are summarized in Table 1.

Differences in tibial morphometry between genders

Tibial length and tibial dimensions at the tibial plateau were larger for males and this difference was statistically significant ($P<.001$). The aspect ratios did not differ significantly between males and females. Female tibial varus bowing ($3.8\pm1.7^\circ$) was significantly ($P<.001$) greater than that of males ($2.6\pm2.4^\circ$). Whether this greater varus bowing influenced the entry point for tibial intramedullary alignment system was determined later.

Entry points for the tibial intramedullary alignment system

For the tibial intramedullary alignment system to be in line with the tibial intramedullary canal its entry point should correspond to CAC1 at the level of the tibial plateau and to CAC2 at a level 10 mm below the tibial plateau during total knee revision. Fig. 3A and B demonstrate the relationship of the proposed entry point for a tibial intramedullary alignment system in relation to the lateral tibial spine, surface center, and the classical entry point at the two levels studied. At the level of the tibial plateau (Fig. 3A), the entry point was anterolateral to the lateral tibial spine (15.9±2.8 mm anterior to and 1.2±2.8 mm lateral to it). At 10 mm below the tibial plateau (Fig. 3B), where the lateral tibial spine is not available for intraoperative reference, we used the surface center as the reference point. Here, the entry point was anterolateral to geometric surface center (8.8±1.9 mm anterior and 2.9±1.9 mm lateral). As shown in Fig. 3A, our proposed entry point (CAC1) and the classical entry point (CP) (5 mm anterior to the midpoint of the anteroposterior (AP) dimension of the tibial plateau in the sagittal plane and at the midpoint of the mediolateral (ML) dimension of the tibial plateau in the coronal plane) are at different locations. To determine if this difference was statistically significant, the differences in the X and Y coordinates of CAC1 and CP were evaluated for statistical significance. The averaged CAC1 was $5.7\pm2.2$ mm anterior and $4.3\pm2.0$ mm lateral to CP (Table 1); this difference was statistically significant ($P<.001$). This finding suggests that during TKA for Korean, when using a tibial intramedullary alignment system the starting point should be anterolateral to the classically described entry point. Moreover, the entry point was significantly more anterolateral in females when compared to males at the level of the tibial plateau ($P<.001$) (Table 1). Therefore, especially when operating on females, one has to consider these differences. However, at the level 10 mm below the tibial plateau, the anteroposterior placement of CAC2 did not differ significantly between males and females, even though the difference in the mediolateral placement retained its statistical significance ($P<.001$) (Table 1); this
finding suggests that mediolateral positioning of the entry point varies more than the anteroposterior positioning.

**Relationship between the β angle and the X coordinates of CAC1 and CAC2**

To determine whether the increasing degree of varus of the tibia causes more lateral positioning of the CAC, we evaluated the correlation between the β angle and the X coordinates. As shown in Fig. 4A and B, the CAC was more laterally placed (increase in CAC X coordinate) with an increasing β angle (increasing varus) both at the level of the tibial plateau and at a level 10 mm below the tibial plateau (r=0.49). This indicates that with increasing varus bowing of the tibia, the entry point for the tibial intramedullary alignment system has a tendency to shift laterally (P<.001).

**Relationship between AR and Y coordinates of CAC1 and CAC2**

To determine if the aspect ratio had any bearing on the anteroposterior positioning of the CAC, we evaluated whether there was a correlation between AR1 and the Y coordinate of CAC1, and between AR2 and the Y coordinate of CAC2 using the student t-test correlational analysis. Fig. 5 shows the results; increase in the aspect ratio for the entry point of the tibial intramedullary alignment system had a slight tendency to move anteriorly (r=0.11 and r=0.03 for CAC1 and CAC2 respectively). However, these differences were not statistically significant.

Discussion

Most studies available on tibial morphometry focus on proximal tibial morphometry implant coverage of the proximal tibia and other morphometric factors that have a bearing on knee kinematics (Bloebaum et al., 1994; Westrich et al., 1995; Matsui et al., 2005). In the current study, the analysis of tibial morphometry in Koreans showed that the general dimensions of the tibia were significantly (P<.001) greater in males when compared to females (Table 1), as would be expected. However, a major difference was noted between males and females (Table 1); in females the tibia had significantly (P<.001) more varus bowing (3.8±1.7°) than in males (2.6±2.4°). We could find no references in the English medical literature previously describing such a difference in tibial bowing between males and females in Caucasians. When considered along with the findings of the tibial intramedullary canal axis, this finding becomes very important. Knowledge about the anatomy of the tibial intramedullary canal axis is important, as it influences our operative technique and the outcome of total knee arthroplasty. The relationship of the tibial intramedullary canal axis to the tibial plateau, or the cut surface of the tibia, is what influences decisions on the entry point of the tibial intramedullary alignment system. The position of this entry point is particularly important in two situations: when an intramedullary alignment system is used for making the tibial cut and when long stemmed tibial components are used. In bowed tibias, if an extramedullary alignment system is used, since its reference is the center of the tibial plateau and the ankle, the anatomic axis may not fall centrally within the tibial intramedullary canal, thus producing errors in positioning the tibial tray on the tibial plateau when a long stemmed tibial implant is used. This is because the tibial stem can only be positioned in line with the intramedullary canal, especially if it is long stemmed. Therefore, in such situations it is better to use an intramedullary alignment system (Hicks et al., 1995). When using an intramedullary alignment system to make a tibial cut perpendicular to the anatomical axis of the tibia, it is essential that the intramedullary rod be in line with the anatomical axis for accuracy. For this, the entry point of the intramedullary alignment system must be at the point of intersection of the intramedullary canal axis with the tibial plateau (in cases of primary total knee arthroplasty), or with the cut surface of the tibia at its level of resection (In the case of revision knee arthroplasty). Therefore, in our study we plotted this inter-
section point at two levels: at the level of the tibial plateau and at the level of resection recommended for revision TKA, which is 10 mm from the tibial plateau (Benjamin 2006). If the entry point for the tibial intramedullary alignment system is more medially placed with respect to this intersection point, then the intramedullary rod will tilt into a varus position as it advances in the intramedullary canal, causing the cut to go into varus. Conversely, if the entry point is placed more laterally with respect to the intersection point, the cut will go into valgus. If the entry point is placed anteriorly with respect to the intersection point, the cut will have a tendency to reverse the posterior slope of the tibia. If the entry point is placed posteriorly with respect to the intersection point, the cut will increase the posterior slope of the tibia. In the study by Hicks et al., the intersection point varied from 28 to 53% of the total depth of the tibia from the anterior cortex and from 37% to 56% of the total width of the tibia from the medial cortex (Hicks et al., 1995). However, in our study it varied from 18 to 43% of the total tibial depth from the anterior cortex and from 49 to 65% of the total width of the tibia from the medial cortex. Therefore, in our study it was more anterolaterally placed than in the study by Hicks et al. Moreover, when compared to the classical entry point described by Whiteside also, our entry point was significantly \( P < .001 \) anterolateral (Table 1). Therefore, when using a tibial intramedullary alignment system for TKA in a Korean patient, the entry point is anterolateral to that described by Hicks et al., as well as Whiteside & Summers for Caucasian patients. Our results show that intraoperatively, during primary TKA, the entry point can be localized by choosing a point 16.0±2.8 mm anterior and 1.2±2.8 mm lateral to the lateral tibial spine; this is an easily identifiable landmark (Table 1). During revision TKA at a depth of 10 mm from the tibial plateau, as we have no lateral tibial spine, the surface center is used as the reference point, and the entry point is located 8.8±1.9 mm anterior and 2.9±1.9 mm lateral to it (Table 1). As mentioned previously, females had significantly more tibial varus than did males. In addition, our results showed that the entry point had a tendency to shift laterally with increasing varus of the tibia. Furthermore, the entry point of female was significantly \( P < .001 \) more anterolateral than males (Table 1). Therefore, in the case of females, inappropriate selection of the entry point is more likely to produce inaccuracies while using a tibial intramedullary alignment system, compared to males. This is of particular importance in that females make up the majority of patients undergoing TKA. The greater varus bowing of the tibia in females may be due to the specific functional requirements imposed on them such as frequent sitting in the cross-legged position and kneeling. Long stemmed tibial implants are used in several situations such as poor bone stock, bone loss requiring the use of wedges/graft and in revision total knee arthroplasty (Hicks et al., 1995). When using long stemmed tibial implants, the anatomy of the tibial intramedullary canal axis is important for the use of the tibial intramedullary alignment system, as well as during implantation of the tibial tray. Our study demonstrated that even at a depth of 10 mm below the tibial plateau, CAC2 is anterolateral to surface center 2; therefore, for the tibial stem to be in line with the tibial intramedullary canal axis, the entry point should be anterolateral to the anatomical centre of the cut surface of the tibia even at this level. Furthermore, stem position relative to the tibial tray influences positioning of the tibial tray on the tibial cut surface, especially when a long stem is used. When we implant a tibial tray with a centrally placed stem at the proposed entry point rather than the classical entry point, it will be more anterolaterally placed than with standard procedures. This will affect the size of the tibial tray chosen. Normally the medial tibial condyle is larger than the lateral tibial condyle (Westrich et al., 1995). Therefore, with the use of a symmetrical tibial tray, when sizing is done based on lateral tibial condyle size to prevent lateral overhang, and implantation is done at the classical entry point, there will be undersizing of the medial part of the tibial tray leading to uncovering of the medial tibial condyle, especially the posteromedial part. This undersizing and uncovering of the medial tibial condyle, is likely to be aggravated by a more anterolateral placement of the tibial tray that will result if the proposed entry point is used. Most cortical and cancellous bone that supports the tibial implant is located at the posterior and medial side of the tibial plateau, therefore uncovering the posteromedial tibial condylar area increases the risk of implant subsidence, varus positioning, and eventual loosening of the tibial implant (Bloebaum et al., 1994). To increase coverage of the tibial cut surface by the prosthesis in this situation, two possible solutions are as follows; use of an asymmetrical tibial tray or use of a tibial component with a laterally offset stem. If an asymmetrical tibial tray is used, even when sizing is done based on the lateral femoral condyle, the medial tibial condyle undersizing will be minimized. If a laterally offset stem is utilized, then even if the proposed entry point is used, posteromedial uncovering will be limited due to improved positioning of the tibial tray on the cut surface of the tibia.
In conclusion, our study shows that both at the level of the tibial plateau and at a depth of 10 mm from the tibial plateau, the tibial intramedullary canal axis of Korean passes significantly anterolateral to the classically described entry point for tibial intramedullary alignment systems, and this is aggravated by increasing varus of the tibia. Therefore, we suggest that positioning the entry point at the proposed site may improve final tibial implant alignment. In addition, use of asymmetrical tibial trays or tibial trays with laterally offset stems, may minimize medial tibial uncovering by implants, especially when the implant is long stemmed.

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