Preoperative Measurement of Tibial Resection in Total Knee Arthroplasty Improves Accuracy of Postoperative Limb Alignment Restoration

Pei-Hui Wu, Zhi-Qi Zhang, Shu-Ying Fang, Zi-Bo Yang, Yan Kang, Ming Fu, Wei-Ming Liao

Department of Joint Surgery, The First Affiliated Hospital of Sun Yat-sen University, Guangzhou, Guangdong 510080, China

Abstract

Background: Accuracy of implant placement in total knee arthroplasty (TKA) is crucial. Traditional extramedullary alignment instruments are fairly effective for achieving the desired mean tibial component coronal alignment. We modified the traditional tibial plateau resection technique and evaluated its effect on alignment restoration.

Methods: Two hundred and eighty-two primary TKAs in our hospital between January 2013 and December 2014 were enrolled in this retrospective study. Group A consisted of 128 primary TKAs performed by one senior surgeon. Preoperative measurement of the tibial resection was conducted on radiographs, and the measured thicknesses of the lateral and medial plateau resection were used to place the tibial alignment guide. Group B consisted of 154 primary TKAs performed by the other senior surgeon, using a traditional tibial plateau resection technique. In all patients, an extramedullary guide was used for tibial resection, and preoperative and postoperative full-leg standing radiographs were used to assess the hip-knee-ankle angle (HKA), femoral component alignment angle (FA), and tibial component alignment angle (TA). A deviation ≥3° was considered unsatisfactory. Data were analyzed by unpaired Student's t-test.

Results: The mean postoperative HKA and TA angles were significantly different between Groups A and B ($178.2 \pm 3.2°$ vs. $177.0 \pm 3.0°$, $t = 2.54$, $P = 0.01$; $89.3 \pm 1.8°$ vs. $88.3 \pm 2.0°$, $t = 3.75$, $P = 0.00$, respectively). The mean postoperative FA was $88.9 \pm 2.5°$ in Group A and $88.9 \pm 2.6°$ in Group B, and no significant difference was detected ($t = 0.10$, $P = 0.92$). There were 90 (70.3%) limbs with restoration of the mechanical axis to within 3° of neutral alignment and 38 (29.7%) outliers (>3° deviation) in Group A, whereas there were 89 (57.8%) limbs with restoration of the mechanical axis to within 3° of neutral alignment and 65 (42.2%) outliers (>3° deviation) in Group B. The severity of the preoperative alignment deformity was a strong predictor for postoperative alignment.

Conclusions: Using conventional surgical instruments, preoperative measurement of resection thickness of the tibial plateau on radiographs could improve the accuracy of conventional surgical techniques.

Key words: Alignment; Tibial Resection; Total Knee Arthroplasty

Introduction

The goal in total knee arthroplasty (TKA) is to achieve ideal alignment of both the femoral and tibial components of the knee. This can restore a neutral mechanical axis alignment to the lower extremity, balance the mechanical load transmitted through the knee joint, and reduce stress accumulation on the bearing surface and shear stress on the prosthesis/cement/bone interfaces.[1] Many studies have reported that misalignment in the coronal plane exceeding 3° may result in an increased risk of component aseptic loosening.[2]

Distal femoral resection and proximal tibial resection should be made perpendicular to their respective mechanical axes.

In recent years, many studies have been reported using computer-assisted navigation systems and patient-specific cutting guides to decrease the number of alignment outliers.[3-5] However, owing to longer procedure times, increased cost, and highly sensitive instruments, most surgeons still choose

Address for correspondence: Prof. Ming Fu,
Department of Joint Surgery, The First Affiliated Hospital of Sun Yat-sen University, Guangzhou, Guangdong 510080, China
E-Mail: ming_fu@126.com

Access this article online	
Quick Response Code:	**Website:** www.cmj.org
	DOI: 10.4103/0366-6999.192789

conventional mechanical alignment guides when performing TKA. These conventional alignment devices can result in unacceptable intraoperative alignment distortions in clinical practice, due to difficulty in accurately identifying the landmarks around the ankle, tibial torsion, abnormal tibial bowing, and ankle joint deformities.[6] Multiple studies have shown that the potential rate of varus/valgus deviation of the tibial component exceeding 3° ranged from 6% to 40% when using conventional instrumentation.[7,8] However, few studies propose improved tibial plateau resection techniques using conventional instruments.

We presented a simple and reproducible technique to improve the likelihood of restoring a neutral alignment of the tibial component. This technique, radiographic preoperative measurement of the difference between the resection thicknesses of the medial and lateral tibial plateaus for the proximal tibial cut could lessen the influence of tibial torsion and ankle deformity on the placement of the tibial extramedullary guide and could improve the accuracy of conventional surgical techniques.

METHODS

A consecutive series of 236 patients who underwent 282 conventional primary TKAs were enrolled in the study between January 2013 and December 2014. All surgeries were performed by two senior surgeons with the same level of experience and equivalent surgical strategies. Exclusion criteria included prior revision arthroplasty, prior femur or tibia fracture, use of a restrictive prosthesis, and poor-quality radiographs.

All patients underwent preoperative full-length standing radiographs. The standard TKA surgical technique for all patients included an anterior midline skin incision with a medial parapatellar approach, extramedullary guides for the tibia with the center of the tibial intercondylar eminence and the true center of the ankle joint as the proximal and distal landmarks, and intramedullary guides for the femur with 5° or 6° valgus correction angles.[9]

Group A consisted of 128 primary TKAs performed by one senior surgeon, using a modified tibial plateau resection technique [Figure 1]. Preoperatively, the difference between the resection thickness of the medial and lateral tibial plateaus was measured on full-length standing radiographs, conducted on Picture-acquiring Communication System (HAITAI, China) terminal software with an accuracy within 0.1 mm. During the operation, extramedullary guide positioning was adjusted according to the consistency between actual and planned resection thicknesses prior to the osteotomy. Group B consisted of 154 primary TKAs performed by the other senior surgeon, using a traditional tibial plateau resection technique. All the patients were implanted with the cemented posterior-stabilized total knee prosthesis (DePuy, Johnson and Johnson, USA; Biomet, USA; Smith and Nephew, USA). According to the severity of preoperative deformity of lower limb alignment, we defined

five subgroups in each group: varus <10°, varus between 10° and 20°, varus >20°, valgus <10°, and valgus >10°.[10,11]

Postoperative full-length standing radiographs were taken for all patients using a standardized radiographic technique. Patients were required to stand with maximum knee extension, distribute their body weight evenly on both lower extremities and with the patellae facing forward to prevent limb rotation.[12] The initial step of radiographic measurements was definition of reference points and lines [Figure 2]. Line f represented the femoral mechanical axis. Its proximal endpoint was the center of the femoral head and was located using the Mose circle, and the distal endpoint is defined as the center of the medial and lateral condyles of the femoral component after surgery and the femoral intercondylar notch before surgery. Line t represented the tibial mechanical axis. Its proximal endpoint was the midpoint of the tibial component base after surgery and the center of the tibial intercondylar eminence before surgery. The distal endpoint was determined as the center of the talar dome. Line 1 and line 2 were drawn tangential to the distal curve of the prosthetic femoral condyles and parallel to the tibial tray base, respectively. Postoperative radiographic measurements included the following angles: (1) HKA: The medial angle between the femoral and tibial mechanical axis, representing the mechanical alignment of the limb in the coronal plane, with an ideal value of 180°. (2) FA: The medial angle between the femoral mechanical axis and line 1, representing the femoral component alignment in the coronal plane, with an ideal value of 90°. (3) TA: The medial angle between the tibial mechanical axes and line 2, representing the tibial component alignment in the coronal plane, with an ideal value of 90°. Varus alignment was anything <90°, and valgus alignment was anything >90°. All measurements were performed by a single joint surgeon. To identify measurement reliability, all measured radiographs marked with reference lines were checked by another experienced joint surgeon. If there was a disagreement, the measurement was repeated with all definitions of reference points agreed upon.

Statistical analysis

All standard normal distributed data were expressed as mean ± standard deviation (SD) and analyzed with the Statistical Package for the Social Sciences (SPSS, IBM, NY, USA) version 17.0. After normality and variance homogeneity tests had been performed, all continuous variables were evaluated with the use of the unpaired Student's t-test or Mann–Whitney U-test, depending on the distribution characteristics of the data. Pearson's Chi-squared test or Chi-square Yates's correction was applied to sets of categorical data. In all comparisons, the test level was $\alpha = 0.05$ ($P < 0.05$ was considered as statistically significance).

RESULTS

Basic information

There were 112 females and 16 males in Group A, with a mean age of 68.7 years. Group B consisted of 132 females
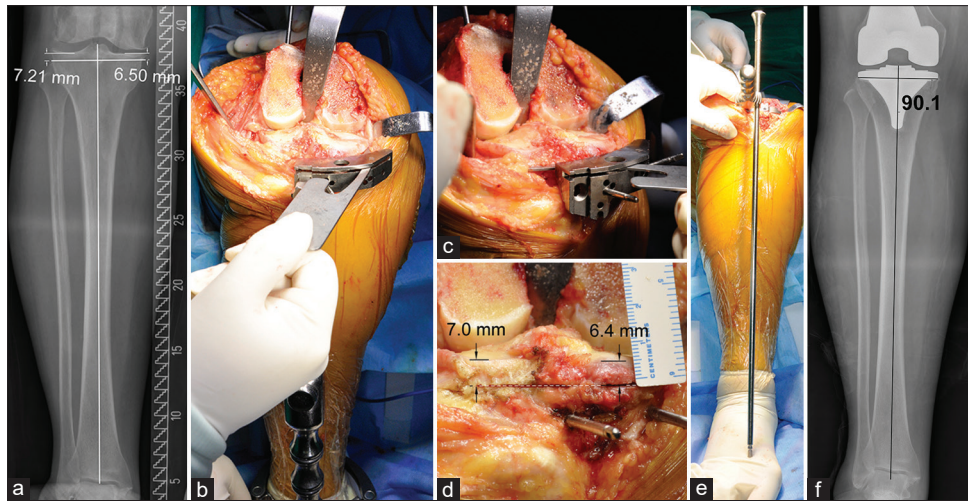
Figure 1: Illustraion of a modified tibial plateau resection technique. (a) The preoperative plan of the proximal tibial cut showed that the thickness of lateral and medial tibial plateau resection was 7.2 mm and 6.5 mm, respectively. (b and c) The tibial cutting block was aligned using conventional extramedullary guide. (d) The thickness of lateral and medial tibial plateau resection was 7.0 mm and 6.4 mm, respectively, which is close to its preoperative measurement. (e) After tibial resection, check the tibial cutting direction by putting a rod to indicate the perpendicular direction of the tibial resection plane. (f) Tibial component angle was 90.1°.
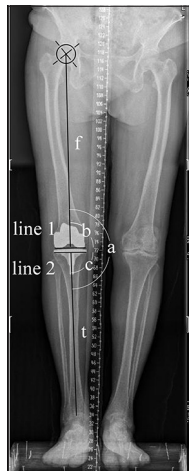

Figure 2: Full-length standing hip-to-ankle radiograph. Identification of hip, knee, and ankle centers, construction of axes. Line f: mechanical femoral axis, line t: mechanical tibial axis; line 1, line 2: knee joint line; angle a: The medial angle between the femoral and tibial mechanical axis, hip-knee-ankle angle; angle b: Femoral component varus angle; angle c: Tibial component varus angle.

and 22 males, with a mean age of 66.6 years. The ratio of preoperative varus deformity to valgus deformity in Group A was 108/20 and was 131/23 in Group B.

Lower limb alignment

The mean angles were 178.2 ± 3.2° and 177.0 ± 3.0° in Groups A and B, respectively, which represented a statistically significant difference ($t = 2.54$, $P = 0.01$). Distribution of postoperative lower limb alignment for both groups is shown in Figure 3. In Group A, 90 (70.3%) limbs had alignment deviations within 3° and 38 (29.7%) were outliers, with more than 3° from neutral alignment. In Group B, 89 (57.8%) knees had alignment deviation within 3° and 65 (42.2%) knees were outliers.

The mean HKA angles were compared between the subgroups and categorized according to the severity of preoperative deformity. There were 56 (43.8%) knees in Group A and 66 (42.9%) knees in Group B, with preoperative varus deformity between 10° and 20°. The mean HKA angles were 177.1 ± 0.5° and 176.2 ± 0.4° in this subgroup, and the difference was statistically significant ($t = 2.28$, $P = 0.01$) [Table 1]. There was no significant difference in the mean HKA between other subgroups.

The preoperative deformity of lower limbs is a strong predictor for the outliers. In Group A, 7 of the ten knees with varus coronal deformity >20° and 3 of the four knees with valgus >10° were outliers. Only 8 of the 43 knees with coronal varus deformity <10° and 3 of the 15 knees with valgus deformity <10° were outliers [Table 1].

Femoral component alignment

The mean FA angles were 88.9 ± 2.5° and 88.9 ± 2.6° in Groups A and B, respectively, representing no significant difference ($t = 0.10$, $P = 0.92$). In Group A, 103 (80.5%) femoral component alignment deviations were within 3° and 25 (19.5%) were outliers with more than 3° deviation from neutral alignment. In Group B, 120 (78.0%) knees had alignment deviation within 3° and 34 (22.0%) knees were outliers.

Tibial component alignment

The mean TA angles were 89.3 ± 1.8° and 88.3 ± 2.0° in Groups A and B, respectively, which represented a statistically significant difference ($t = 3.75$, $P = 0.00$). Distribution of the tibial component alignment for both groups is shown in Figure 4. In Group A, 114 (89.1%) tibial component alignment deviations were within 3° and 14 (10.9%) were outliers with more than 3° deviation from neutral alignment. In Group B, 123 (79.9%) knees had alignment deviation within 3° and 31 (20.1%) were outliers.

Table 1: Postoperative HKA angle and TA and outliers in the two groups stratified by preoperative varus/valgus deformity

Preoperative varus/valgus deformity	Group A (n = 128)	Group B (n = 154)	t or χ²	P
Varus deformity <10°			–	–
Number of knees, n (%)	43 (33.6)	45 (29.2)	–	–
Mean HKA (°), mean ± SD	178.1 ± 0.6	177.8 ± 0.4	0.52*	0.302
Mean TA (°), mean ± SD	89.6 ± 0.4	88.3 ± 0.4	2.11*	0.015
Number of HKA outliers, n	8	13	1.28	0.258
Number of TA outliers, n	7	11	0.90	0.343
Varus deformity, 10°–20°				
Number of knees, n (%)	56 (43.8)	66 (42.9)	–	–
Mean HKA (°), mean ± SD	177.7 ± 0.5	176.2 ± 0.4	2.28*	0.011
Mean TA (°), mean ± SD	89.4 ± 0.3	88.2 ± 0.3	2.93*	0.003
Number of HKA outliers, n	17	33	4.83	0.028
Number of TA outliers, n	4	10	1.91	0.167
Varus deformity >20°				
Number of knees, n (%)	10 (7.8)	20 (13.0)	–	–
Mean HKA (°), mean ± SD	175.4 ± 1.3	174.5 ± 0.9	0.56*	0.292
Mean TA (°), mean ± SD	88.8 ± 0.6	87.8 ± 0.5	1.14*	0.133
Number of HKA outliers, n	7	15	0.09	0.770
Number of TA outliers, n	0	6	2.11	0.146
Valgus deformity <10°				
Number of knees, n (%)	15 (11.7)	20 (13.0)	–	–
Mean HKA (°), mean ± SD	180.4 ± 1.0	179.2 ± 0.7	0.95*	0.175
Mean TA (°), mean ± SD	90.1 ± 0.5	88.8 ± 0.6	1.49*	0.075
Number of HKA outliers, n	3	4	0.18	0.669
Number of TA outliers, n	0	4	1.70	0.192
Valgus deformity >10°				
Number of knees, n (%)	4 (3.1)	3 (2.0)	–	–
Mean HKA (°), mean ± SD	182.3 ± 3.2	179.5 ± 0.2	0.67*	0.276
Mean TA (°), mean ± SD	88.7 ± 0.9	88.5 ± 0.5	0.18*	0.435
Number of HKA outliers, n	3	0	1.47	0.225
Number of TA outliers, n	0	0	–	–

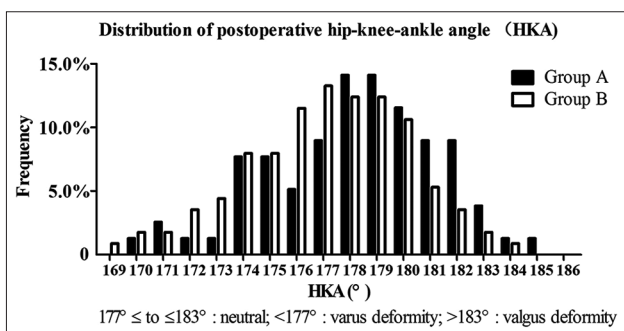HKA: Hip-knee-ankle angle; TA: Tibial component angle; SD: Standard deviation; *: value of t.

Figure 3: Histogram comparing the distribution of postoperative lower limb alignment between Group A (n = 128) and Group B (n = 154). We defined hip-knee-ankle (HKA) angle between 177° and 183° as neutral alignment, <177° as varus deformity, and >183° as valgus deformity.
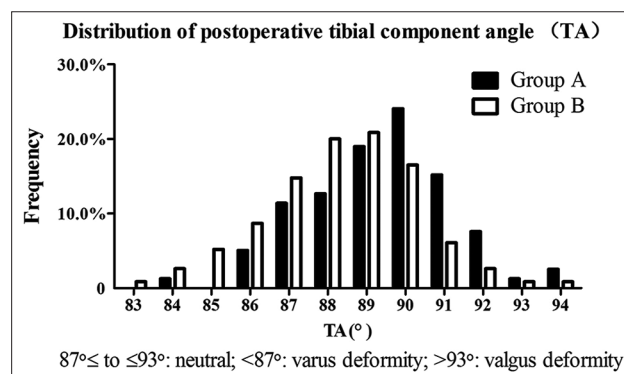

Figure 4: Histogram comparing the distribution of postoperative tibial component alignment between the two groups. We defined TA between 87° and 93° as neutral alignment, <87° as varus deformity, and >93° as valgus deformity. TA: Tibial component angle.

The mean TA angles were compared between the subgroups of Groups A and B [Table 1]. For the knees with preoperative varus deformity between 10° and 20°, the mean TA angles were 89.4 ± 0.3° and 88.2 ± 0.3°, and this difference was statistically significant ($t = 2.93$, $P = 0.00$,). For the knees in the subgroup with preoperative varus deformity <10°, the mean TA angles were 89.6 ± 0.4° and 88.3 ± 0.4°, and the

difference was statistically significant ($t = 2.11$, $P = 0.015$,). There was no significant difference in the mean TA between other subgroups.

In Group A, seven of 43 knees having a preoperative varus deformity <10° were outliers, while four of the 56

knees having varus deformity between 10° and 20° were outliers. There were no outliers in other subgroups of Group A [Table 1].

DISCUSSION

The most important finding of the present study was that preoperative measurement of the difference between the resection thicknesses of the medial and lateral tibial plateaus for the proximal tibial cut could improve the accuracy of tibial component alignment and postoperative limb alignment restoration compared with conventional techniques. Total 89.1% of the tibial components in Group A that were treated with the modified tibial plateau resection technique were within 3° of target alignment, compared with 79.9% of the components in Group B that were treated with the traditional technique alone.

Proximal tibial resection is a vital step in the restoration of limb alignment and should be performed perpendicular to the tibial mechanical axis. Previous studies have investigated and compared the accuracy of tibial cuts achieved with various alignment techniques, including extramedullary guides, computer-assisted navigation, patient-specific jigs, and hand-held surgical navigation.[3-6] Chiu et al.[7] reported 59 tibial components (78.7%) that had a tibial cut within 3° of perpendicular to the mechanical axis when using an extramedullary guide. Cinotti et al.[6] modified the extramedullary alignment technique by setting the extramedullary rod in line with anatomical references in the proximal tibia only, and 96% of the tibial components in that group were neutral (within 3°), compared with 66% of those in the group that was treated with traditional alignment technique alone. Huang et al.[13] reported that when using a hand-held accelerometer-based navigation system for TKA, the misalignment rate for the tibial component was 3.8%. In a large meta-analysis of 29 randomized clinical trials, Mason et al.[14] found a neutral lower limb alignment in 91% using computer-assisted navigation while with the outlier rate without computer navigation was 31.8%. Abane et al.[15] found that the use of patient-specific cutting guides did not reduce the proportion of outliers as measured by postoperative coronal alignment.

Possibly owing to familiarity, most surgeons use conventional mechanical alignment guides when performing TKA. The accuracy of conventional extramedullary systems relies on the identification of anatomical landmarks that should guide the direction of the extramedullary rod in line with the tibial mechanical axis. Many studies have investigated several reference points both in the proximal tibial and distal limb, including the tibial tuberosity, intercondylar eminence, intermalleolar distance, second metatarsal, dorsalis pedis artery, and extensor hallucis longus.[16-19] Errors in the placement of the extramedullary tibial rod may be introduced by multiple factors and mainly occur at the distal tibia and ankle joint. For example, foot supination and tibial torsion are common anatomical features that can affect the identification of distal landmarks of the tibial mechanical axis.[6,19,20]

Severe preoperative varus/valgus deformity of the lower limb is another strong factor affecting postoperative alignment. Bae et al.[21] reported that the severity of preoperative varus deformity influenced postoperative alignment despite using computer-assisted navigation in conventional TKAs. One possible reason is that important anatomical landmarks might be distorted in severely deformed knees, making both femoral and tibial resection difficult. Lateral bowing of the femur is common in the varus knee, making it difficult to insert an intramedullary rod accurately and place the distal femoral cutting block properly. In this study, we found that preoperative deformity had little effect on tibial component alignment in Group A. This finding means that planning the proximal tibial resection is useful for patients with deformed knees.

Owing to the inherent difficulty in identifying the distal projection of the tibial mechanical axis of the operated leg at surgery, we altered the technique in which the proximal tibial cutting plane was determined by measurement of the thicknesses of the medial and lateral tibial plateaus. We found that the tibial plateau resection plane was determined using information from both preoperative radiographic measurements and intraoperative alignment, and as long as the surgeon was aware of the deviation and compensated for it, it mitigated the misalignment risk. In this study, we did not directly compare procedure time between the two techniques. Nevertheless, clearly exposing the tibial plateau and taking intraoperative measurements does not cost much time. This technique improves the surgical accuracy without compromising the efficiency, increasing costs, or requiring special instruments.

The accuracy of preoperative measurements of the thicknesses of the medial and lateral tibial plateaus for proximal tibial resection in relation to the intraoperative measurements was under question at the beginning of the study. Using a standardized radiographic technique and calibration of digital radiographs using a corrected scale are helpful in increasing the accuracy of preoperative radiographic measurements. For patients with severe flexion deformities or tibial torsion, the correct profile of the tibial plateau is difficult to judge. Computed tomography scan data may provide more accurate preoperative plans for these patients, but translation of the plan to the actual surgical procedure is another crucial step. Adequate exposure of the anterior edge of the tibial plateau is required, as is removing the medial and lateral meniscus and intermeniscal ligament and identifying the anterior articular cartilage border of the medial and lateral tibial plateau.

There are several limitations to the current study that warrant consideration. First, only prostheses component alignment and limb alignment restoration between conventional and modified tibial plateau resection techniques were studied. These are the techniques mainly studied in terms of the alignment in coronal plane, but have no effect on sagittal alignment or rotation of the tibial component, which are also important for the knee function after TKA.[22] Second,

this study lacks intraoperative data and follow-up results regarding resection time, tourniquet time, functional scores, revision rates, or other complication rates. Third, any radiological measurement is prone to errors stemming from variations in limb deformity and position.[23,24] Despite our efforts to reduce the variation in limb positioning using a special device to control foot position, for the patients with severe compound flexion-varus deformity (generally >20°) which can cause external rotation of the limb and lead to radiographic measurement errors, changes in limb rotation may have affected some of our findings.

In conclusion, this study found that the conventional tibial plateau resection technique by extramedullary instrumentation has a high potential risk for misalignment of the tibial component. Our results show that the rate of misalignment of the tibial component could be reduced by setting the tibial cutting block using information from both preoperative radiographic measurements and intraoperative alignment. This technique could routinely be used in the clinical practice.

Financial support and sponsorship

Conflicts of interest

There are no conflicts of interest.

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