


CLINICAL ARTICLE

Comparison of Tibial Tubercle Landmark Technique and Range of Motion Technique in Primary Total Knee Arthroplasty: A Retrospective Cohort Study

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Objective: There is not a standard for rotational alignment of the tibial component in total knee arthroplasty (TKA). For now, the most commonly methods are tibial-tubercle landmark technique (TTL) and range-of-motion technique (ROM). The study is aimed to compare clinical outcomes and radiographic data of patients who undergone primary TKA with TTL or ROM technique.

Methods: This single-surgeon retrospective cohort study includes 60 patients with TTL technique and 60 with ROM technique from December 2017 to January 2019. All patients were evaluated clinically using Hospital for Special Surgery Knee Score (HSS), Feller patellar score, visual analogue scale (VAS) and maximum knee flexion and extension angle before and after surgery at both 6 months and 12 months postoperatively. Radiographic data contain hip-knee-ankle angle (HKA), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA), posterior slope angle (PSA) on pre and postoperative X-ray and rotation angle of femoral component (relative to surgical trans-epicondylar axis) and tibial component (relative to surgical trans-epicondylar axis, tibial posterior condylar line and Akagi') on postoperative computed tomography (CT) scan. Clinical outcomes and radiological data were compared between the two groups.

Results: One hundred twenty patients (120 knees) were enrolled in this study, including 38 males and 82 females, aged from 58 to 78, with an average of 65.7 years. There was no significant difference in demographics and preoperative X-ray data between the two groups ($P > 0.05$). Clinical scores of the TTL group were better than those in the ROM group at 6 and 12 months after surgery, when comparing HSS (83.57 ± 5.00 vs 75.90 ± 4.89 , $F = 59.004$, $P < 0.001$; 90.53 ± 4.31 vs 82.83 ± 4.98 , $F = 54.509$, $P < 0.001$), Feller patellar score (21.43 ± 2.54 vs 19.10 ± 2.52 , $F = 14.864$, $P = 0.001$; 26.27 ± 1.98 vs 23.20 ± 2.31 , $F = 42.204$, $P < 0.001$) and VAS (3.70 ± 0.62 vs 4.38 ± 0.92 , $F = 14.508$, $P = 0.001$; 2.10 ± 0.90 vs 2.79 ± 0.80 , $F = 11.554$, $P = 0.002$). But there was no significant difference in the flexion and extension angle between the two groups. In imaging evaluation, no statistical difference was found in pre- and postoperative HKA, mLDFA, mMPTA and PSA. Rotational angles of tibial component only did relative to Akagi' have statistical difference in two groups (2.33 ± 4.3 vs 4.41 ± 3.2 , $t = 2.143$, $P < 0.05$) (Positive value represented external rotation).

Conclusion: The results of our study showed that both methods were reliable, and TTL technique provided better clinical scores and larger external angle of tibial component, compared to ROM technique.

Key words: Alignment; ROM technique; Tibial rotation; Total knee arthroplasty; TTL technique

Introduction

At present, total knee arthroplasty (TKA) has been widely used to treat end-stage knee joint disease, which can relieve knee pain, and improve the knee

function and the quality of life of patients. The success of TKA is closely related to accurate lower limb alignment, proper prosthesis size and position, and sufficient soft tissue balance.

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Rotational alignment of femoral and tibial prosthesis is crucial for achieving optimal knee joint function in TKA. Rotational malalignment is considered the important reason of anterior knee pain,¹ patients' dissatisfaction and surgical failure, and it leads to patellar maltracking, polyethylene liner wearing, knee stiffness, femorotibial flexion instability, gait abnormality, etc.²⁻⁵ Watanabe *et al.*⁶ found that the internal rotation of tibial component or the combined internal rotation between tibial and femoral component is significantly related to anterior knee pain. Panni and Ascione⁷ reported that excessive internal rotation (>10°) of the tibial component is the main cause of knee pain and lower function after TKA.

It is generally assumed that the surgical trans-epicondylar axis (sTEA) is the axis of knee flexion and extension, and it has been recognized as the gold standard axis of the rotational alignment of the femoral prosthesis because less affected by anatomical variation and osteophytes.⁸⁻¹⁰

Up to now, several anatomical references have been used in tibial component rotation alignment, such as the posterior condyle line of tibia, the posterolateral corner of tibial plateau, the maximal tibial coverage, the transmalleolar axis and the second metatarsal bone, etc. Incavo *et al.*¹¹ performed MRI scans on 30 knees and found that referring to the posterior condyle line of tibia to place the tibial component could increase its coverage, but using this method might lead to internal rotation of the tibial component. A cadaver study reported by Rossi *et al.*¹² found that the posterior-lateral corner locked technique was a convenient and reliable technique for rotation alignment of tibial component, but it was less commonly used due to the lack of clinical evidence. Maximal tibial coverage has traditionally been proposed to provide increased fixation by improving load transfer from the implant to the proximal tibia to avoid subsidence and loosening.^{13,14} However, Martin *et al.*¹⁵ found that using maximal tibial coverage technique would result in an average 9° internal rotation of tibial component, which easily led to poor rotation alignment. Akagi *et al.*¹⁶ pointed out that the transmalleolar axis and the second metatarsal bone varied among patients and were unreliable. Meanwhile, computer-assisted surgery and patient-specific instrumentation technique have also been widely used by surgeons in recent years, but many scholars¹⁷⁻¹⁹ found that both of them could obtain more accurate coronal alignment, instead of rotation alignment of tibial component during the TKA. Unlike the femoral component rotational alignment, a gold standard does not exist for the rotational alignment of tibial component.

Two methods of tibial component rotation alignment were commonly used clinically. One takes the medial 1/3 of the tibial tubercle as reference proposed by Insall and Easley,²⁰ which is widely used by Chinese surgeons, and most scholars suppose^{21,22} that the medial 1/3 of the tibial tubercle is an accurate and reliable reference anatomical marker, by which always shows a better clinical effect. Lützner *et al.*²³ reported referencing the medial third of the

tibial tubercle as a landmark resulted in a better consequence, but there was great variety in the rotational mismatch between the femoral and the tibial component using a fixed bone landmark. Bonnin *et al.*²⁴ also pointed out that tibial tubercle is not a reliable landmark for rotation of the tibial component in some patients. Akagi *et al.*¹⁶ reported it could cause excessive external rotation of tibial component in some cases. The other is the ROM technique proposed by Eckhoff *et al.*,²⁸ which aimed to find the most suitable position of the tibial prosthesis relative to the femoral prosthesis according to the placement of femoral prosthesis and soft tissue tension. But some authors concerned this method induces the risk of transferring a femoral malrotation to the tibia.¹ Unfortunately, which method is better between TTL technique and ROM in clinical outcomes and radiological accuracy is still controversial.

The purpose of this study was: (i) to compare the accuracy of rotational and coronal alignment of femoral and tibial components between ROM technique and TTL; (ii) to compare the clinical outcomes and complications in patients using the ROM technique with patients using the TTL technique;

Materials and Methods

Ethics Statement

Ethical approval was granted by The Second Affiliated Hospital of Shanxi Medical University Ethics Committee (2019YX033).

Inclusion and Exclusion Criteria

From December 2017 to January 2019, male and female knee osteoarthritis patients of any age who were undergoing primary unilateral TKA were eligible for this study. The inclusion criteria were: (i) patients diagnosed with osteoarthritis; (ii) patients treated with primary single TKA; (iii) patients who received TKA with ROM technique or TTL; and (iv) preoperative, postoperative, clinical outcomes and radiological data were evaluated. Exclusion criteria for this study were: (i) patients with severe valgus deformity (Ranawat III type) or bone defect (Rand C type); (ii) previous history of knee surgery.

Surgical Technique

Anesthesia and Position

All TKAs were administered by a single senior surgeon. General anesthesia or intraspinal anesthesia was carried out to each patient before surgery. The patients were all placed in a supine position. Tourniquet and traditional instrument were used in all cases.

Approach and Exposure

A standard TKA procedure was performed through a mid-line incision and a medial parapatellar approach. The

quadriceps tendon was split longitudinally, and flipped over the patella to access the femur and tibia.

Femoral and Tibial Resection

The femoral and tibial resection were same between ROM and TTL group according to the manual. The distal femoral resection was performed first. A femoral intramedullary rod was used for guiding the femoral valgus, cut at 4 to 6°, which was determined by the degrees of difference between the femoral mechanical and anatomical axes. Then, tibial resection was performed. When the tibial plateau was fully exposed after cutting the cruciate ligaments and menisci, same extramedullary tibial resection instruments was used in two groups. 8–10 mm bone was cut totally referring to the lateral tibial plateau. The rotation of the femoral component was determined using measured resection method. We tried to obtain an optimal rotation that was coincident with the sTEA.

Tibial Rotational Alignment

In the TTL group, after femoral and tibial resection have been made, select the appropriate tibial base plate.

First, tibial base plate was placed on the tibial resection surface to obtain the maximum contact area as possible. Then the tibial base plate was rotated slightly so that the handle on the tibial base plate was aligned with the medial 1/3 of the tibial tubercle. This method was illustrated by Insall and Easley.²⁰ When correct rotation has been determined, marks the position by extending the anterior mark of the baseplate onto the anterior tibial cortex with electrocautery (Fig. 1).

In the ROM group, with all bony surfaces prepared and soft tissue debrided, select appropriate femoral and tibial trial component and assemble them, then flex and extend the knee five times passively allowing the unsecured tibial trial component to seek its own suitable position. Mark the position in anterior tibial cortex likewise (Fig. 2).

Prosthesis Implantation

A posterior-stabilized prosthesis (Vanguard® Complete Knee System, Zimmer-Biomet, Warsaw, IN, USA) was implanted on the basis of appropriate test mold. No patella resurfacing was required.

Postoperative Management

Postoperative drainage lasted 1 to 2 days until flow volume was less than 50 ml. All patients received the two doses of parecoxib sodium 40 mg. All patients underwent the same postoperative rehabilitation program.

Clinical Outcomes

Clinical outcomes including Hospital for Special Surgery Knee Score (HSS), Feller patellar score, visual analogue scale (VAS) and maximum knee flexion and extension angle, were assessed preoperatively, 6 and 12 months postoperatively.

Hospital for Special Surgery Knee Score (HSS)

The HSS knee score was used to evaluate knee function, and it mainly includes the four aspects of pain, function, range of motion, and stability. The score ranged between 0 (worst outcome) to 100 (best outcome). The outcome categories were based on the following cut points: excellent (≥ 85), good (70–84), fair (55–69), and poor (<55).

Feller Patellar Score

Feller patellar score was used to assess patellofemoral joint function, which also includes the four aspects of anterior knee pain, quadriceps strength, ability to chair rise, and stair climbing. The score ranged between 0 (worst outcome) to 30 (best outcome), but the outcome categories were not defined.²⁵

Visual Analogue Scale

A self-reported score on the 10-point visual analog scale was used for the assessment of patients' knee pain. A minimum of 0 indicates no pain; a score of 1–3 indicates mild pain, with the sleep quality of patients not affected; 4–6 indicates moderate pain, with sleep quality affected; 7–10 indicates severe pain, with patients not able to sleep due to pain; the maximum value is 10. The VAS scores were marked by patients themselves on a paper with a graduated line starting at zero (no pain) and ending at 10 (the most painful).

Maximum Knee Flexion and Extension Angle

The maximum knee flexion and extension angle was measured to evaluate knee activity preoperatively, 6 and 12 months postoperatively. The best maximum knee flexion angle was 120°, and the best maximum knee flexion angle was 0°.

Radiological Measures

X-ray Measures

Lower extremity weight-bearing full-length X-ray photography, anteroposterior and lateral X-ray of the knee were performed before and after surgery (Fig. 3).

Hip-Knee-Ankle Angle (HKA)

HKA was defined as the angle between the femoral mechanical axis (from the center of the femoral head to vertex of femoral intercondylar fossa) and the tibial mechanical axis (from the center of the tibial spine to the center of the superior articular surface of the talus; Fig. 3). Neutral lower-limb alignment was considered if the HKA angle was between 177° and 183°. Varus alignment was defined as HKA less than 177°, and valgus alignment was defined as HKA greater than 183°.

Mechanical Lateral Distal Femoral Angle (mLDFA)

LDFA was defined as the superolateral angle between the tangent line to the articular surface of the distal femur and

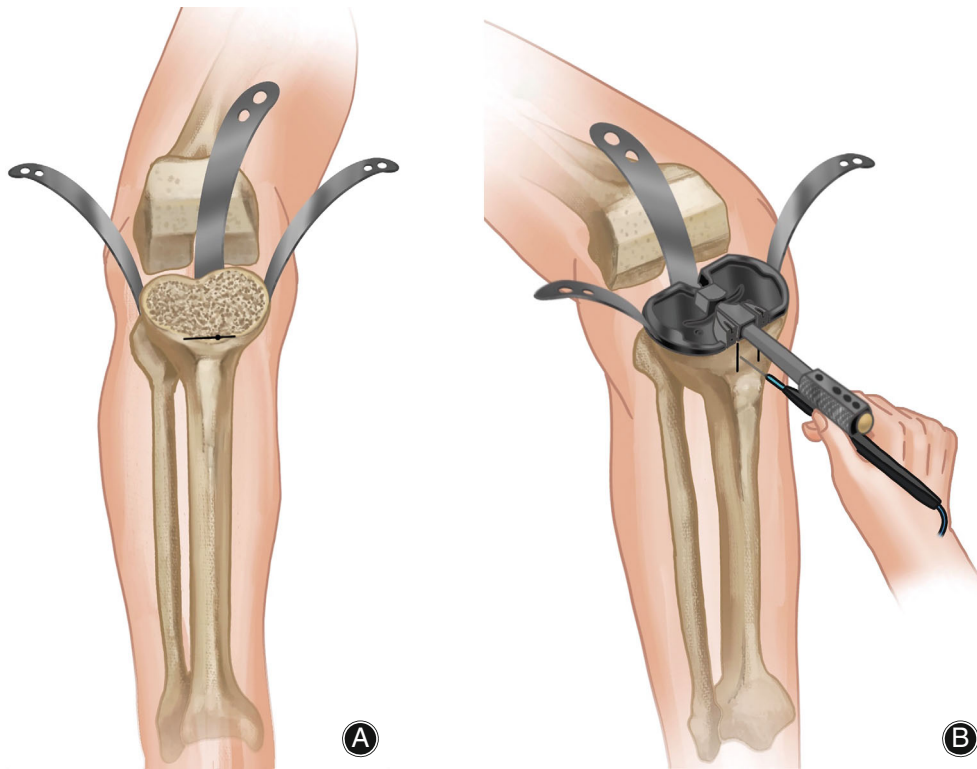


Fig. 1 TTL technique. (A) Tibial resection surface, and the black spot is the medial 1/3 of tibial tubercle. (B) the handle was aligned with the medial 1/3 of tibial tubercle, and mark the position onto the anterior tibial cortex

the line connecting the center of the femoral head to the center of the knee (Fig. 3). Distal femur varus was defined as LDFA greater than 87° , while the distal femur valgus was defined as LDFA less than 87° .

Mechanical Medial Proximal Tibial Angle (mMPTA)

MPTA was defined as the medial angle between the tibial mechanical axis and the tangent line of the medial and lateral edges of the tibial plateau (Fig. 3). The varus alignment

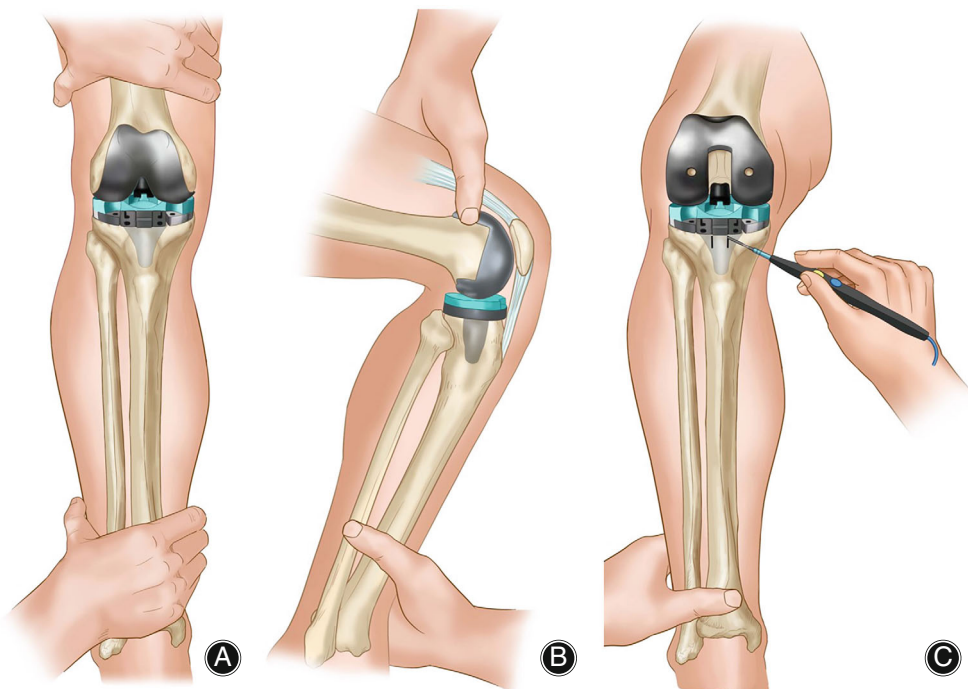


Fig. 2 ROM technique. (A) Assembled the femoral and tibial trial component, and extended the knee first. (B) Then flexed the knee. (C) After five times extension and flexion, marks the position onto the anterior tibial cortex with electrocautery

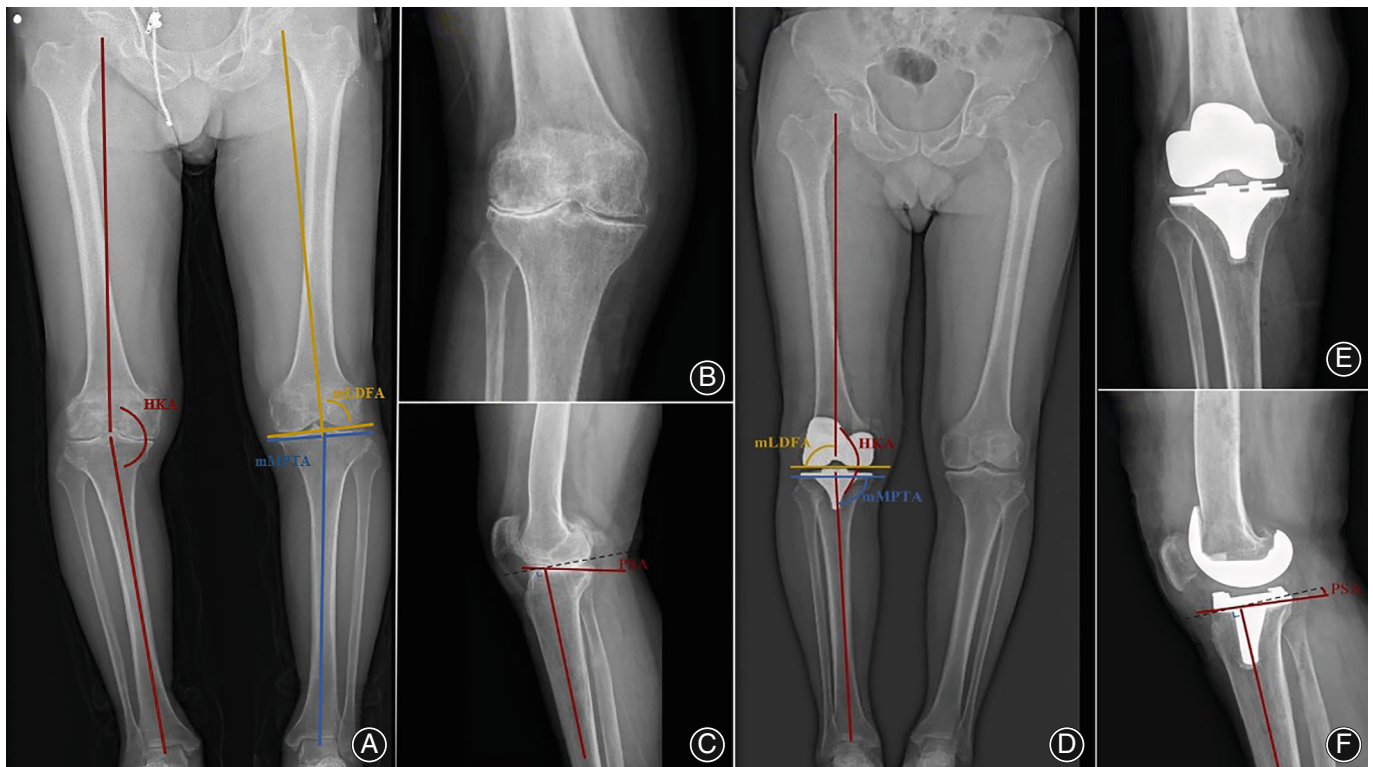


Fig. 3 Lower extremity weight-bearing full-length X-ray photography, anteroposterior and lateral X-ray before and after surgery. (A) the measuring method of HKA, mL DFA and mMP TA in the pre-operative lower extremity weight-bearing full-length X-ray. (B) the pre-operative anteroposterior X-ray. (C) the measuring method of PSA in the pre-operative lateral X-ray. (D) the measuring method of HKA, mL DFA and mMP TA in the post-operative lower extremity weight-bearing full-length X-ray. (E) the post-operative anteroposterior X-ray. (F) the measuring method of PSA in the post-operative lateral X-ray

was considered as MPTA less than 85° , and the valgus alignment was considered as MPTA greater than 90° .

Posterior Slope Angle (PSA)

PSA was defined as the angle between a line perpendicular to an anatomical longitudinal axis of the tibia and a line drawn tangential to the tibial plateau (Fig. 3). The mean PTS angle is $6\text{--}14^\circ$ in a normal knee.

CT Scan Measures

The rotational alignment of the femoral and tibial component was evaluated on the CT scan (Fig. 4). The femoral component axis (FCA) was defined as a tangent line of posterior condyle of femoral component (Fig. 4A). The tibial component axis (TCA) was defined as a line along the posterior border of the tibial component stem (Fig. 4C). Surgical trans-epicondylar axis (sTEA) was defined as a line from the sulcus of the medial femoral epicondyle to the lateral (Fig. 4B).²⁶ Tibial posterior condylar line (PCL) was defined as a tangent line of posterior condyle of tibial plateau (Fig. 4D). Akagi line was defined as a line connecting the mid-point of the posterior cruciate ligament attachment to the point one-third from the medial border of the tibial tuberosity, and Akagi' was the perpendicular of Akagi line

(Fig. 4E).²⁷ External rotation angle of femoral component was the angle between FCA and sTEA. External rotation angle of tibial component was the angle between TCA and sTEA, PCL, Akagi' respectively. Positive value represented external rotation.

Statistical Analysis

Chi square tests were used to compare binary variables (sex ratio) and two-sample *t* tests to compare independent variables (demographic data, pre and postoperative radiological data) in the two groups. Clinical outcomes were assessed using a two-factor multi-level repeated measures analysis of variance. If dissatisfied with the test of spherical symmetry, the degree of freedom is corrected by Greenhouse-Geisser. A *P*-value of <0.05 was defined as statistical significance. All statistical analyses were performed with SPSS version 18.0.0 software (SPSS, Inc. Chicago, IL, USA).

Results

General Results

A total of 120 patients who underwent primary unilateral TKA with ROM or TTL technique and completed follow-up of 6 and 12 months were finally included in this study. In

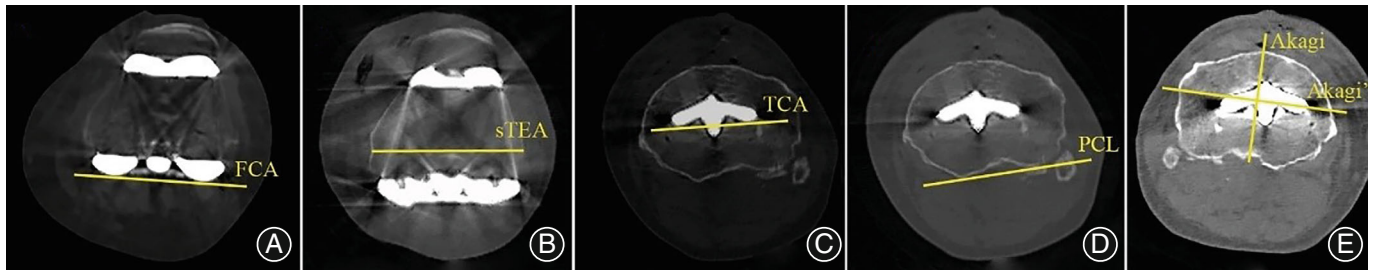


Fig. 4 Postoperative CT scans. (A) femoral component axis (FCA). (B) surgical trans-epicondylar axis (sTEA). (C) tibial component axis (TCA). (D) tibial posterior condylar line (PCL). (E) Akagi line and the perpendicular of Akagi line (Akagi')

the ROM group, there were 60 patients, including 40 women and 20 men, and the mean age at the time of surgery was 66.4 ± 6.1 years. In the TTL group, there were 60 patients, including 42 women and 18 men, and the mean age at time of surgery was 65.0 ± 4.3 years. There was no significant difference in demographics and preoperative X-ray data between the two groups ($P > 0.05$) which proved there was a good homogeneity between two groups (Table 1).

Clinical Outcomes

Clinical outcomes were repeated measurement data, which were analyzed by two-factor and multi-level repeated measurement analysis of variance. First, the spherical symmetry test and repeated measurement analysis of variance were carried out for each index. It was found there were interactive effects in the HSS, Feller patella score and VAS between the two groups (Fig. 5 and Tables 2 and 3). Thus, the separate effect of surgical technique and time should be analyzed. No interaction effect existed in maximum knee flexion and extension angles between two groups, so the main effect of surgical technique and time should be analyzed.

Hospital for Special Surgery Knee Score (HSS)

The separate effects of surgical technique at different time point were tested, without the need for spherical symmetry test. There was no significant difference in preoperative HSS scores between ROM group and TTL group (39.63 ± 8.80 vs 38.90 ± 6.38 , $F = 0.158$, $P = 0.694$). The HSS score at 6 and 12 months postoperatively were lower in the ROM group. At 6 months postoperatively, the HSS score in the ROM group

was 5.3% lower than that in the TTL group (75.90 ± 4.89 vs 83.57 ± 5.00 , $F = 59.004$, $P < 0.001$); at 12 months postoperatively, the HSS score in the ROM group was 9.2% lower than that in the TTL group (82.83 ± 4.98 vs 90.53 ± 4.31 , $F = 54.509$, $P < 0.001$) (Table 4). Meanwhile, the HSS score increased significantly from preoperative to postoperative in TTL and ROM group, and the differences between any two time points were statistically significant (Fig. 5 and Table 4).

Feller Patellar Score

Similarly, there was no significant difference in preoperative Feller patellar scores between the ROM and TTL groups (12.80 ± 3.51 vs 11.90 ± 1.99 , $F = 2.144$, $P = 0.154$). The Feller patellar score at 6 and 12 months postoperatively were lower in the ROM group. At 6 months postoperatively, the Feller patellar score in the ROM group was 12.2% lower than that in the TTL group (19.10 ± 2.52 vs 21.43 ± 2.54 , $F = 14.864$, $P = 0.001$); at 12 months postoperatively, the Feller patellar score in the ROM group was 13.2% lower than that in the TTL group (23.20 ± 2.31 vs 26.27 ± 1.98 , $F = 42.204$, $P < 0.001$) (Table 4). The Feller patellar score also increased from preoperative to postoperative in each group, and the differences between any two time points were statistically significant (Fig. 5 and Table 4).

Visual Analogue Scale

Likewise, there was no significant difference in preoperative VAS between the ROM and TTL groups (7.57 ± 0.76 vs 7.75 ± 0.86 , $F = 1.137$, $P = 0.260$). The VAS at 6 and 12 months postoperatively were higher in the ROM group.

TABLE 1 Demographics and preoperative X-ray data of the patients

| Group | Age (years) | Male sex (%) | BMI (kg/m ²) | HKA (°) | mLDFA (°) | mMPTA (°) | PSA (°) |
|-------------------|----------------|--------------|--------------------------|-----------------|----------------|----------------|---------------|
| ROM (n = 60) | 66.4 ± 6.1 | 33.3 | 25.0 ± 3.4 | 174.4 ± 2.8 | 86.6 ± 2.0 | 86.6 ± 2.0 | 9.1 ± 2.3 |
| TTL (n = 60) | 65.0 ± 4.3 | 30 | 23.7 ± 3.3 | 173.3 ± 2.3 | 86.8 ± 2.0 | 83.4 ± 2.2 | 8.6 ± 1.7 |
| t-value/ χ^2 | 1.012 | 0.077 | 1.434 | 1.648 | 0.504 | 0.858 | 0.985 |
| p-value | 0.316 | 0.781 | 0.157 | 0.105 | 0.616 | 0.390 | 0.390 |

Abbreviations: BMI, body mass index; HKA, hip-knee-ankle angle; mLDFA, mechanical lateral distal femoral angle; mMPTA, mechanical medial proximal tibial angle; PSA, posterior slope angle; ROM, range-of-motion technique; TTL, tibial-tubercle landmark technique.

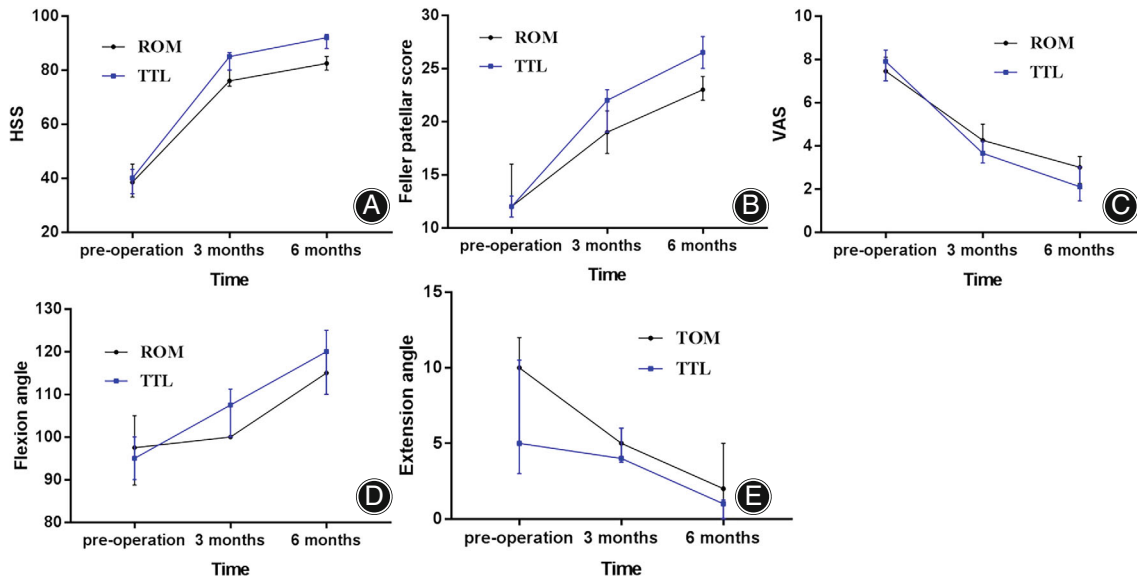


Fig. 5 Interaction diagram of each clinical outcome. (A) there was the interactive effect in HSS ($F = 19.661, P < 0.001$); the HSS scores between two groups in different time. (B) there was the interactive effect in Feller patellar scores ($F = 29.500, P < 0.001$); the Feller patellar scores between two groups in different time. (C) there was the interactive effect in VAS ($F = 9.439, P < 0.001$); the VAS scores between two groups in different time. (D) there was no interactive effect in maximum knee flexion angle ($F = 0.196, P = 0.745$); the flexion angle between two groups in different time. (E) there was no interactive effect in maximum knee extension angle ($F = 0.119, P = 0.803$); the extension angle between two groups in different time

TABLE 2 Spherical symmetry test of repeated measurement materials

| Within subjects | HSS | Feller patellar score | VAS | Flexion angle | Extension angle |
|-----------------|--------|-----------------------|-------|---------------|-----------------|
| time | | | | | |
| Mauchly's W | 0.311 | 0.604 | 0.690 | 0.605 | 0.815 |
| P | <0.001 | 0.001 | 0.006 | 0.001 | 0.057 |
| group*time | | | | | |
| Mauchly's W | 0.360 | 0.863 | 0.726 | 0.583 | 0.498 |
| P | <0.001 | 0.128 | 0.011 | 0.001 | <0.001 |

Note: After the spherical symmetry test, if $P < 0.05$, the degree of freedom was corrected by the Greenhouse–Geisser.; Abbreviations: HSS, Hospital for Special Surgery Knee Score, VAS, visual analogue scale

TABLE 3 Analysis of variance for repeated measurement materials

| Between/Within subjects | HSS | Feller pate-llar score | VAS | Flexion angle | Extension angle |
|-------------------------|---------|------------------------|---------|---------------|-----------------|
| Group | | | | | |
| F | 23.163 | 10.151 | 10.390 | 0.805 | 0.532 |
| P | <0.001 | 0.003 | 0.003 | 0.377 | 0.472 |
| Time | | | | | |
| F | 1080.01 | 512.790 | 610.714 | 100.362 | 122.930 |
| P | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Group * Time | | | | | |
| F | 19.661 | 29.500 | 9.439 | 0.196 | 0.119 |
| P | <0.001 | <0.001 | 0.001 | 0.745 | 0.803 |

Abbreviations: HSS, Hospital for Special Surgery Knee Score; VAS, visual analogue scale.

TABLE 4 Comparison of clinical scores of both groups at different time point

| Clinical Scores | Group | preoperatively | 6 months postoperatively | 12 months postoperatively | F [‡] | P |
|-----------------------|----------------|---------------------------|---------------------------|---------------------------|----------------|--------|
| HSS | ROM group | 39.63 ± 8.80 ^a | 75.90 ± 4.89 ^b | 82.83 ± 4.98 ^c | 516.066 | <0.001 |
| | TTL group | 38.90 ± 6.38 ^a | 83.57 ± 5.00 ^b | 90.53 ± 4.31 ^c | 1017.076 | <0.001 |
| | F [†] | 0.158 | 59.004 | 54.509 | | |
| | P | 0.694 | <0.001 | <0.001 | | |
| Feller patellar score | ROM group | 12.80 ± 3.51 ^a | 19.10 ± 2.52 ^b | 23.20 ± 2.31 ^c | 279.684 | <0.001 |
| | TTL group | 11.90 ± 1.99 ^a | 21.43 ± 2.54 ^b | 26.27 ± 1.98 ^c | 408.677 | <0.001 |
| | F [†] | 2.144 | 14.864 | 42.204 | | |
| | P | 0.154 | 0.001 | <0.001 | | |
| VAS | ROM group | 7.57 ± 0.76 ^a | 4.38 ± 0.92 ^b | 2.79 ± 0.80 ^c | 328.695 | <0.001 |
| | TTL group | 7.75 ± 0.86 ^a | 3.70 ± 0.62 ^b | 2.10 ± 0.90 ^c | 454.495 | <0.001 |
| | F [†] | 1.317 | 14.508 | 11.554 | | |
| | P | 0.260 | 0.001 | 0.002 | | |

Abbreviations: HSS, Hospital for Special Surgery Knee Score; ROM, range-of-motion technique; TTL, tibial-tubercle-landmark technique; VAS, visual analogue scale.; [†] Is the comparison between the two groups at each time point.; [‡] Is the comparison at different time points within each group. Different letters indicate there are statistical differences between different time points

At 6 months postoperatively, the VAS in the ROM group was 18.4% higher than that in the TTL group (4.38 ± 0.92 vs 3.70 ± 0.62 , $F = 14.508$, $P = 0.001$); at 12 months postoperatively, the VAS in the ROM group was 24.7% higher than that in the TTL group (2.79 ± 0.80 vs 2.10 ± 0.90 , $F = 11.554$, $P = 0.002$) (Table 4). The VAS decreased significantly from preoperative to postoperative in two groups, and the differences between any two time points were also statistically significant (Fig. 5 and Table 4).

Maximum Knee Flexion and Extension Angle

Because of no interaction effect at the knee flexion and extension angle (Table 3), the main effect of the operation method and time should be analyzed. In terms of maximum knee flexion angle, the group main effects between the ROM and TTL groups had no statistical difference (104.44 ± 7.56 vs 106.00 ± 7.78 , $F = 0.805$, $P = 0.377$), and the time main effect in each time point (preoperatively, 6 and 12 months postoperatively) had statistical difference through pairwise comparison (95.08 ± 7.36 vs 104.83 ± 8.07 vs 115.75 ± 7.32 , $F = 100.362$, $P < 0.001$). Similar results were showed in maximum knee extension angle, there was no statistical difference in the group main effects (4.93 ± 2.18 vs 4.49 ± 2.36 , $F = 0.532$, $P = 0.472$), the time main effect in each time point had statistical difference (8.42 ± 2.80 vs 4.33 ± 1.85 vs 1.38 ± 1.41 , $F = 122.930$, $P < 0.001$) (Fig. 3).

Radiological Measures

X-ray Measures

The postoperative X-ray showed that the position of the component and the force line of the lower limbs were good, and there was no significant difference in postoperative HKA (178.20 ± 1.9 vs 178.22 ± 1.4 , $t = -0.063$, $P = 0.950$), mL DFA (90.0 ± 1.4 vs 90.4 ± 1.6 , $t = -0.997$, $P = 0.323$), mMPTA (88.5 ± 1.5 vs 87.9 ± 1.4 , $t = 1.378$, $P = 0.173$)

and PSA (4.0 ± 1.6 vs 4.6 ± 1.4 , $t = -1.452$, $P = 0.152$) between the ROM group and the TTL (Figs 6 and 7 and Table 5).

CT Scan Measures

External rotation angle of femoral component had no statistical difference between the ROM and TTL groups (0.58 ± 1.1 vs 0.48 ± 1.5 , $T = 0.313$, $P = 0.755$) (Table 5). External rotation angle of tibial component in the ROM group was $1.86^\circ \pm 4.5^\circ$, $2.33^\circ \pm 4.3^\circ$, $0.72^\circ \pm 4.8^\circ$ relative to sTEA, Akagi' and PCL, and the coefficient of variation was 241.9%, 184.5% and 666.7% respectively. External rotation angle of tibial component in TTL group was $3.51^\circ \pm 3.1^\circ$, $4.41^\circ \pm 3.2^\circ$, $1.6 \pm 3.5^\circ$ relative to sTEA, Akagi' and PCL, and the coefficient of variation was 88.3%, 2.5% and 218.8%. The difference of external rotation angle relative to Akagi' between the two groups was statistically significant (2.33 ± 4.3 vs 4.41 ± 3.2 , $t = -2.143$, $P < 0.05$) (Table 5).

Complications

One case in each group with anterior knee pain was found at 12 months postoperatively. In TTL group, a case involved incision fat liquefaction and resolved after being treated by more frequent dressing changes. No case of periprosthetic fracture, prosthesis loosening, subsidence, periprosthetic infection, and patella dislocation occurred in either group.

Discussion

In our study, almost all patients achieved satisfactory surgical results, and all postoperative clinical scores were significantly improved compared with preoperative scores, which indicated that both methods were relatively safe and reliable. In addition, in postoperative CT, the tibial prosthesis was placed in a mild external rotation in both groups, which was beneficial to improve the patellar tracking.

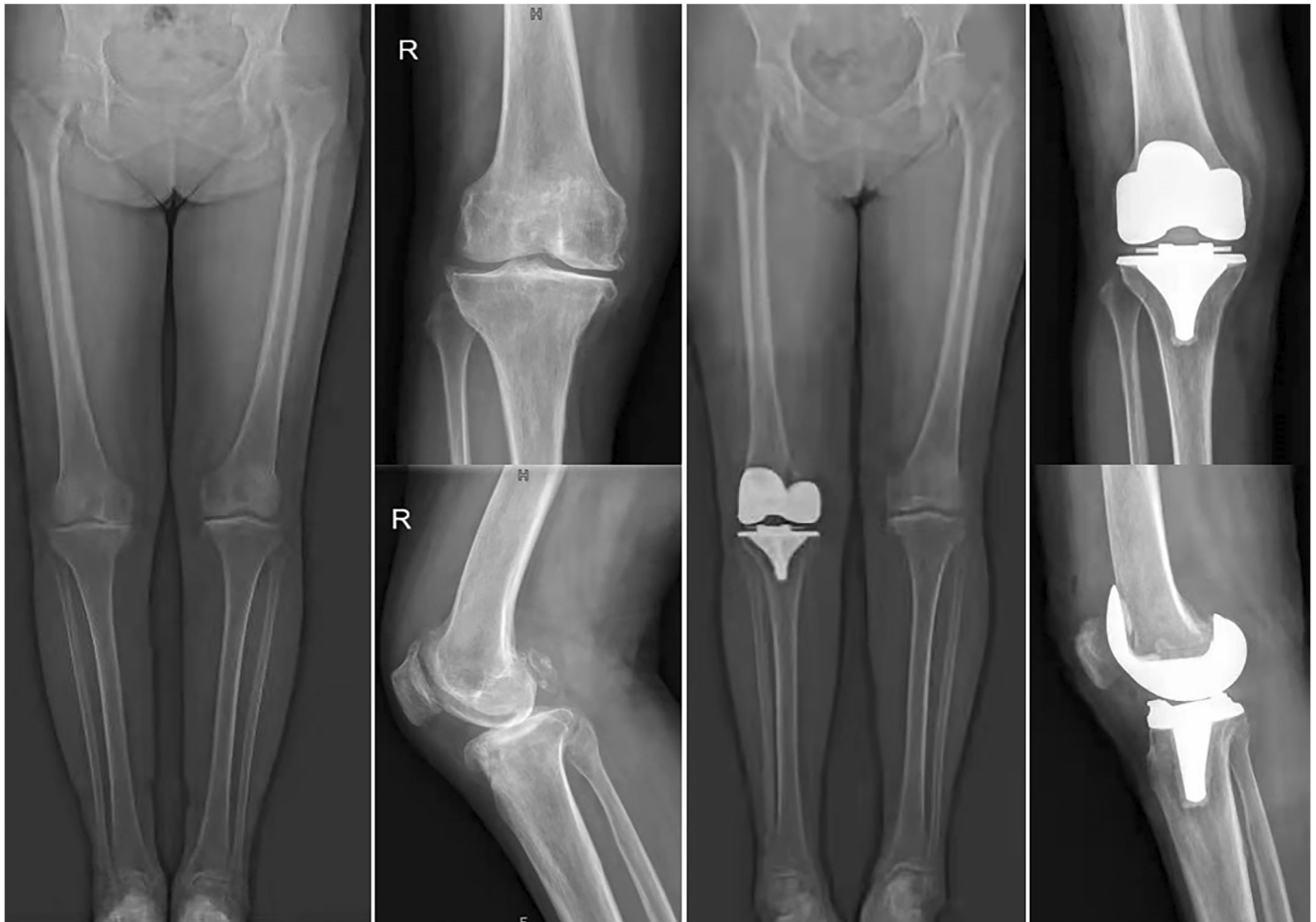


Fig. 6 X-ray images of a patient in the ROM group before and after TKA

A large number of studies have shown that malalignment of component rotation after TKA can lead to knee pain, stiffness and other serious complications. Nicoll *et al.*¹³ found that 4.3° internal rotation of tibial prosthesis is related to postoperative knee pain, and put forward an internal rotation threshold, that is, knee pain occurs when the internal rotation angle is greater than 9° , while the maximum external rotation is 18.2° and there is no obvious knee joint pain. However, Eckhoff *et al.*²⁸ pointed out that mild external rotation of the tibia component can lead to the medial displacement of the tibial tubercle, reduce the Q angle and improve the patellar tracking. Excessive external rotation will cause adverse complications such as protrusion of the posterolateral tibial prosthesis, excessive internal rotation of the tibia, toe-in gait and so on.

Radiological Accuracy

Lee *et al.*²⁹ and Berhouet *et al.*,¹⁴ found that mildly external rotation placement of tibial prosthesis could be achieved by ROM. Rossi *et al.*¹² also proposed to obtain 0.35° external rotation placement of tibial prosthesis relative to the Akagi

axis through ROM technique. Our measurements show that the rotational angle of tibial component is $1.86 \pm 4.5^\circ$, $2.33 \pm 4.3^\circ$ and $0.72 \pm 4.8^\circ$ relative to sTEA, Akagi' and PCL respectively in ROM group after surgery, which showed an external rotation alignment. Most scholars believed that the medial 1/3 of the tibial tuberosity is a reliable anatomical marker of tibial prosthesis rotation alignment.^{13,20,21} Through our CT scans, it was found that the rotational angle of tibial component was $3.51 \pm 3.1^\circ$, $4.41 \pm 3.2^\circ$ and $1.6 \pm 3.5^\circ$ relative to sTEA, Akagi' and PCL respectively in TTL group, which was larger than that in ROM group, and the difference of rotation angle between the two groups relative to Akagi' was statistically significant ($P < 0.05$). Therefore, the tibial component rotational alignment is more external in TTL group than that in ROM group.

Coronal alignment is also an important factor in TKA, which may cause polyethylene liner wear, prosthesis loosening, and femorotibial instability. In our study, no significant difference in HKA (178.20 ± 1.9 vs 178.22 ± 1.4 , $t = -0.063$, $P = 0.950$), mLDEA (90.0 ± 1.4 vs 90.4 ± 1.6 , $t = -0.997$, $P = 0.323$), mMPTA (88.5 ± 1.5 vs 87.9 ± 1.4 ,



Fig. 7 X-ray images of a patient in the TTL group before and after TKA

$t = 1.378$, $P = 0.173$) between ROM and TTL group. Therefore, we suppose the postoperative knee dysfunction caused by poor coronal alignment of lower limbs was excluded. In fact, these two methods do not affect the coronal alignment in TKA.

Clinical Outcomes

Comparing the clinical outcomes between pre and postoperative, it is found that the knee function has been greatly improved after operation, which shows that both two techniques are reliable. TTL technique could lead to a superior

TABLE 5 Postoperative radiographic results

| Groups | External rotation angle of femoral component Relative to sTEA (°) | External rotation angle of tibial component | | | HKA (°) | mLDFA (°) | mMPTA (°) | PSA (°) |
|--------------|--|---|------------------------------------|---------------------|--------------|------------|------------|-----------|
| | | Relative to sTEA (°) | Relative to Akagi ¹ (°) | Relative to PCL (°) | | | | |
| ROM (n = 60) | 0.58 ± 1.1 | 1.86 ± 4.5 | 2.33 ± 4.3 | 0.72 ± 4.8 | 178.20 ± 1.9 | 90.0 ± 1.4 | 88.5 ± 1.5 | 4.0 ± 1.6 |
| TTL (n = 60) | 0.48 ± 1.5 | 3.51 ± 3.1 | 4.41 ± 3.2 | 1.6 ± 3.5 | 178.22 ± 1.4 | 90.4 ± 1.6 | 87.9 ± 1.4 | 4.6 ± 1.4 |
| t-value | 0.313 | -1.649 | -2.143 | -0.814 | -0.063 | -0.997 | 1.378 | -1.452 |
| p-value | 0.755 | 0.105 | <0.05 | 0.419 | 0.950 | 0.323 | 0.173 | 0.152 |

Abbreviations: HKA, hip-knee-ankle angle; mLDFA, mechanical lateral distal femoral angle; mMPTA, mechanical medial proximal tibial angle; PCL, Tibial posterior condylar line; PSA, posterior slope angle; ROM, range-of-motion technique; sTEA, Surgical trans-epicondylar axis; TTL, tibial-tubercle-landmark technique.

postoperative outcome compared with ROM technique during TKA, which was demonstrated in terms of not only knee pain but also functional outcomes during the 6-months and 1-year follow-up periods postoperatively by using our primary outcome measures, including HSS, Feller patellar score, VAS, and maximum knee flexion and extension angle. We hypothesize that the following reasons might lead to poor clinical scores: (i) insufficient balance of soft tissue release or osteotomy cause a bad match between the tibial prosthesis and the femoral because of the larger rotational resistance during flexing and extending the knee; (ii) the type of polyethylene; and (iii) the misplacement of femoral component.

Limitations and Strengths

A few limitations should be noted. First, the 12-months follow-up time of our study may not be sufficient for knee functional scores, which need longer follow-ups to confirm whether the difference in the HSS between the two groups still exists after a longer time period. Second, patients in our study did not have severe varus or valgus deformity and bone defect. Perhaps the ROM technique is more advantageous in these cases because of the anatomic variations. Third, the population of our study is limited to Asian subjects and there might be differences between Asian people and those of other races.

At present, there is no gold standard for the rotational axis of tibial prosthesis, so there may be errors in just using

one reference axis to evaluate the rotation alignment of the tibial prosthesis. However, we used multiple reference axes to measure the accuracy, including sTEA, PCL, Akagi', which can obtain more reliable results. In addition, there is no study that has directly compared the CT data of the two methods of tibial component rotation alignment.

Conclusion

In our study, both rotational alignment methods were reliable by analyzing the clinical outcomes and radiographic data. Using the TTL technique is prone to place a component in an external rotation position compared with the ROM technique, and obtain good clinical efficacy. Due to the existence of deformity and variation of the tibial tubercle, it is necessary that surgeons should master both methods, choose an appropriate one according to specific conditions, or two should be used at the same time so as to effectively reduce the incidence of rotation malalignment of tibial component.

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