Original Article

A clinical study of the rotational alignment of the femoral component in total knee arthroplasty

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Abstract. [Purpose] The reasons for femorotibial rotational malalignment after total knee arthroplasty (TKA) were analyzed to provide evidence for clinical knee joint surgery and to reduce complications. [Subjects and Methods] Ninety knees of 60 patients were selected and randomly divided into two groups (n=30). For one group, rotational alignment of the femoral component was determined by the transepicondylar axis and TKA was performed. For the other group, rotational alignment of the femoral component was conducted through 3° external rotation of the posterior femoral condyles. Knee joint specimens were operated with TKA and various biomechanical indices were measured. [Results] The femoral epicondylar axis was a constant, reliable reference for femoral component rotational alignment. When the femoral component was rotated by 0° versus the epicondylar axis, the peak contact pressure on the patellofemoral joint was optimal. When the femoral component was arranged in parallel with Whiteside's line, the peak contact pressure on the patellofemoral joint varied largely. The patellofemoral contact areas of the two groups were similar. [Conclusion] Axial rotational alignment of the femoral component influenced the contact pressure of patellofemoral joints in TKA more significantly than external rotation of the femoral condyles. It is more reliable to use the femoral epicondylar axis as the reference for the rotational alignment of the femoral component.
Key words: Total knee arthroplasty, Femur, Rotational alignment

INTRODUCTION

The rotational alignment of the component, especially that of the femoral component, is an important part of total knee arthroplasty (TKA). Once the rotational alignment of the femoral component has been determined, the tibiofemoral joint can be aligned by the adaption of the tibial component to this alignment. Femoral component rotational malalignment easily leads to postoperative patellar tracking abnormalities, increases in the shear and torsional stresses of femorotibial components, and knee flexion instability, resulting in patients suffering from anterior knee pain, patellar dislocation, and wear and loosening of prostheses[1]. It is now well-established that finding an anatomical reference axis is crucial for femoral component rotational alignment, by which, osteotomy for the distal femoral epicondyles and posterior condyles can be correctly carried out and component can be correctly placed[2]. At present, at least 4 references are being used to determine the rotational alignment of the femoral component in clinical practice: 3° external rotation of the posterior femoral condyles, Whiteside's line (the perpendicular line of the distal femoral anterior-posterior (AP) axis in the frontal plane), the femoral epicondylar axis, and the femoral component rotational angle when the knee flexion space is rectangularly shaped in ligament balancing[3]. Of the four references, the first one has been most widely used. However, the posterior femoral condyles of many patients with osteoarthritis or other injuries always undergo anatomical changes due to lesion and dysplasia, thus easily misleading surgeries[4]. Therefore, Whiteside's line and the femoral epicondylar axis have been employed in these cases, but their reliabilities remain unclear[5]. In addition, Mongoloid Asians show significant differences in the anatomic morphology of the distal femur from those of Caucasians. The physiological genu varum of Mongoloid Asians is 5° on average, while those of Caucasians are 3° on average. Moreover, the anterior and posterior distal femurs of Mongoloid Asians are smaller than those of Caucasians[6].

To compare the outcomes of each reference axis in determining the rotational alignment of the femoral component, we conducted imaging measurements of a large amount of normal knee joint specimens and anatomical measurements of a small amount of knee joint specimens. The results provide valuable evidence for TKA of Chinese people to reduce the incidence of postoperative patellofemoral complications and the wear of tibial polyethylene inserts.

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Table 1. Three measurement results of angle α and angle β

		Angle α	Angle β
First measurement	5.7°±0.8°	6.3°±1.1°	5.7°±0.8°
	5.4°±0.9°	7.2°±1.3°	5.4°±0.9°
Second measurement	5.5°±0.7°	5.6°±1.0°	5.5°±0.7°
	5.2°±0.8°	6.8°±1.2°	5.2°±0.8°
Third measurement	5.5°±0.7°	5.3°±1.0°*	5.5°±0.7°
	5.1°±0.6°	6.4°±1.1°*	5.1°±0.6°

Compared with the first measurement results, *$p < 0.05$.

SUBJECTS AND METHODS

This study was approved by the ethics committee of our hospital, and written consent was obtained from all patients.

Ninety knees of 60 patients were selected. The patients were aged 20–60 years old, 38.7±16.2 on average. The knees were randomly divided into two groups (n=30). For one group, rotational alignment of the femoral component was determined by the transepicondylar axis and TKA was performed. For the other group, rotational alignment of the femoral component was determined with reference to 3° external rotation of the posterior femoral condylar axis. The selected patients all had genu varum deformities caused by osteoarthritic lesions: those with >40° flexion contracture deformities were excluded. Uncomplicated primary TKA was performed for all cases.

Twelve fresh frozen human knee specimens collected from cadavers were also used, including 6 left and 6 right knees. The cadavers were aged 20–70 years old (average: 42.6 ± 18.2), and included 7 males and 5 females.

The angle between the femoral epicondylar axis and the posterior femoral condylar axis was recorded as angle α, and that between Whiteside's line and the posterior femoral condylar axis was referred to as angle β.[7]

After experimental data and images were input into a computer, angle α and angle β were measured using Auto-CAD software. The patellar tendon was employed to replace the tibial tubercle. LMON was the angle of tibiofemoral rotational malalignment[8].

The tendon part of the quadriceps femoris was retained for clamping traction. Femoral shafts were disconnected 20–30 cm above the joint line, and tibiae were disconnected 15–25 cm below the tibial tubercle. The fibula was cut off adjacent to the superior tibiofibular joint to protect the lateral collateral ligament. The tibiofibula was then fixed using a 3.5 × 24 mm cortical screw.

The test instrument supplied a 30 kg downward vertical load through the part connected with the experimental frame to simulate the weight load normally born by a unilateral lower limb. Knee joints that started to flex from full extension were observed at flexion angles of 30°, 60°, 90° and 120°. Tests were conducted when mechanical equilibrium was reached at the above angles[9].

In this test, we first found the femoral medial epicondyle and femoral lateral epicondyle of a specimen. Then a Kirschner pin was guided by an aiming device to pass through this specimen. Parallel to this Kirschner pin, we placed Nexgen LPS reference guides for the femoral medial and lateral epicondyles. The external and internal rotational angles of the femoral components were controlled by 3°, 5°, and 7° indicator holes on the reference guides. Whiteside's line was determined by the position locator of the distal femoral AP axis. The expected rotational positions of the different femoral components were finally reached.

PFC total knee system (DePuy Company in America) was used as the artificial total knee component. The surgeries were all performed by the same experienced surgeon. In a typical surgical process, the knee joint was first exposed by longitudinally incising the center of the anterior knee and the patella medial approach. Subsequently, the articular cavity was opened by rolling the patella outward. We then removed all medial and lateral menisci as well as the anterior and posterior cruciate ligaments, and sequentially cut off the tibia and the femur. Afterwards, soft tissue balancing and lower-limb force lines were tested. The tension status of internal soft tissue in the knee flexion and extension positions was evaluated, and the internal soft tissue was released and adjusted.

All data are expressed as the mean±SD. SPSS 15.0 software was used to conduct the t test with a significance level of a=0.05.

RESULTS

There was no significant difference in angle with respect to gender ($p > 0.05$), and angle α and angle β did not show significant differences between the first and second measurements ($p > 0.05$). Angle α did not differ significantly between the first and third measurements ($p > 0.05$), but angle β showed significant differences ($p < 0.05$). The measurements were conducted at time intervals of one month, as shown in Table 1.

The clinical epicondylar axis group showed significant differences in the angle of tibiofemoral rotational malalignment from those of the surgical epicondylar axis group and the posterior femoral condylar axis group ($p < 0.05$), but the surgical epicondylar axis group had similar outcomes to those of the posterior femoral condylar axis group ($p > 0.05$) (Table 2).

Concerning the lateral peak contact pressures after TKA measured at the observation angles of 60°, 90° and 120°, the transepicondylar axis rotation of 0° group showed significant difference from those of the transepicondylar axis external rotation of the 2° and 4° groups ($p < 0.05$). At the observa-

Table 2. Mean values and ranges of the angle of tibiofemoral rotational malalignment obtained according to each reference axis for femoral component rotation

	Mean value of angles of tibiofemoral rotational malalignment	Range of angles of tibiofemoral rotational malalignment
Clinical femoral epicondylar axis	3.17°	−3.4° to 9.2°
Surgical femoral epicondylar axis	5.31°*	−1.1° to 11.6°
3° external rotation of posterior femoral condyles	7.82°*	−2.0° to 16.3°

Compared with the clinical femoral epicondylar axis, *p<0.05.

Table 3. Maximum medial and lateral peak contact pressures on patellofemoral joint, and those at the knee flexion angle of 120° (MPa)

Group	Maximum lateral peak contact pressure		Maximum medial peak contact pressure	
		Knee flexion angle of 120°		Knee flexion angle of 120°
Transepicondylar axis internal rotation of 2° group	6.67	7.13±0.92	10.68*	9.46±0.73*
Transepicondylar axis internal rotation of 4° group	7.31	7.28±0.84	8.92*	8.94±0.76*
Transepicondylar axis rotation of 0° group	6.92	7.64±0.91	4.87	8.16±0.68
Transepicondylar axis external rotation of 2° group	12.26*	10.81±0.85*	4.03	7.03±0.62
Transepicondylar axis external rotation of 4° group	16.25*	14.25±0.90*	3.31	5.86±0.67
Whiteside's line group	13.46*	9.83±0.98*	2.62*	4.91±0.59*

Compared with the transepicondylar axis rotation of 0° group, *p<0.05.

Table 4. Proportions of the number of lateral patellar retinacular releases

	Femoral epicondylar axis group (45 cases)	Posterior femoral condylar axis group (45 cases)
Patella replacement group	4/33	6/27
Group without patella replacement	2/12	4/18

tion angles of 90° and 120°, the transepicondylar axis rotation of 0° the group showed a significant difference from that of the Whiteside's line group (p < 0.05). With regard to the medial peak contact pressure of the patellofemoral joint after TKA at the observation angle of 120°, the transepicondylar axis rotation of the 0° group exhibited significant difference from those of the transepicondylar axis rotation of the 2° and 4° groups as well as the Whiteside's line group (p < 0.05) (Table 3).

The patellofemoral contact areas ranged between 1.0–3.0 cm² at each observation angle, but did not differ significantly among the groups (p > 0.05). However, the patellofemoral contact forms in different specimens and at different observation angles were obviously different.

Regarding the proportions of the number of lateral patellar retinacular releases, there were significant differences among the groups which used different reference axes for femoral component rotation (p < 0.05). Whether or not the patella was replaced did not significantly affect the lateral patellar retinacular release (p > 0.05) (Table 4).

DISCUSSION

TKA is a mature surgical technique, and has well-documented clinical effects. However, the constantly high incidence of patellofemoral joint complications in recent years has attracted global attention. Experimental and clinical studies have suggested that the axial rotation of the femoral component is closely associated with the kinematics of the patellofemoral joint[10]. The femoral component in internal rotation evidently increases the lateral contact pressure of patellofemoral joint and thus shifts the patellar inward. Besides, patellar tracking also generates corresponding outward movement after external rotation of the femoral component. Therefore, the Q angle and the lateral vector of the quadriceps tendon are decreased. Nevertheless, excessive external rotation facilitates medial patellar dislocation and increases the contact pressure on the patellofemoral joint[11]. Normally, the patellar trochlea has a raised crista on its anterolateral side. Since most lateral patellar surfaces contact with this crista, patellar dislocation is prevented. When the femoral component is externally rotated, the patellar trochlea is moved outward. The patellar sliding track correspondingly shifts outwardly, which is not obvious in knee flexion, but is significant in extension when the patella moves to the proximal end. Therefore, the Q angle and the lateral vector of the quadriceps femoris are decreased during knee extension. Although external rotation of the femoral component shortens the lateral crista of the patellar trochlea, patellar dislocation cannot be induced due to mutual offset of the factors described above[12]. Currently, femoral component rotational alignment is still determined referring to 3° external rotation of the posterior femoral condylar axis[13].

However, this method has failed in some cases[14], probably because many patients who receive TKA suffer from wear, erosion, and dysplasia of the posterior femoral condyles due to osteoarthritis or other injuries[15].

Whiteside's line and the femoral epicondylar axis have been extensively studied in recent years. Sun et al. suggested using the distal femoral AP axis to determine the rotation position of the femoral component. It was reported that Whiteside's line showed 3.72°± 1.68° external rotation versus the posterior femoral condylar plane, while the femoral epicondylar axis presented 4.33°± 1.92° external rotation[16]. By using the femoral epicondylar axis as the reference, Hwang et al. found that the Whiteside's line showed 3.19°±1.87° external rotation versus the posterior femoral condylar plane[17]. Since genu varum deformity, genu valgum deformity, and soft tissue factors after osteoarthritis had been taken into account, their results were more reliable. In addition, Mongoloid Asians have significant differences in the anatomical morphology of the distal femur from those of Caucasians. The physiological genu varum of Mongoloid Asians is 5° on average, while those of Caucasians are 3° on average. Moreover, the anterior and posterior distal femurs of Mongoloid Asians are smaller than those of Caucasians[18].

Basic experimental and clinical studies have verified that axial rotation of the femoral component is closely related to the kinematics of the patellofemoral joint[19]. The femoral component in external rotation can significantly elevate the contact pressure on the lateral patellofemoral joint. Moderate external rotation of the femoral component can reduce the Q angle and thus decrease the lateral vector of the quadriceps femoris, so more optimal patellar tracking can be obtained[20]. Nonetheless, excessive external rotation promotes medial patellar dislocation and raises the medial contact pressure on the patellofemoral joint[21]. By placing the femoral component in appropriate external rotation, the patellar motion tracking is close to that of the normal knee. Moreover, the patella is not constrained by the high lateral side of the femoral component[22]. However, when the knee flexion angle exceeds 80°, the patella is bound to move inward. Excessive external rotation of the femoral component also affects the tibiofemoral joint[23]. When the femoral component is placed in 10° external rotation, the femur undergoes inward movement at knee flexion angles of over 100°. At external rotation of 15°, the femur moves inward at knee flexion angles of more than 40°. At knee flexion angles of 120°, the patella moves 10 mm versus the tibia. At knee flexion angles of more than 100°, patellofemoral and tibiofemoral joints change and increase the lateral contact pressure on the patellofemoral joint, thereby causing femoral component wear and patella fracture[24]. Also, external rotation of the femoral component induces genu varum by rapidly externally rotating the femur. In this condition, the tensions of soft tissues on both sides are unbalanced, are responsible for tibial component loosening and abrasion that are correctable by soft tissue balancing techniques[25, 26].

TKA has mainly been used to treat osteoarthritis, but it has also caused obvious knee joint deformities among which genu varum is the most common[27]. In follow-ups, a high proportion of the patients bearing genu valgum deformity need LRR correction, possibly because their lateral retinacula are prone to contraction. Therefore, LRR correction is necessary regardless of the suitability of the femoral component axial rotation[28]. In this study, we only included the patients with genu varum deformity to avoid this influence. Akasaki et al. pointed out that LRR should not be decreased or increased based on the position the femoral component[29].

It remains difficult to establish an experimental model to simulate the kinematics of normal knee joints. Applying fixed loads on muscles cannot reflect the condition of knee joints in normal motion[30]. In this study, dynamic load was applied to the quadriceps femoris to simulate the variations of muscle strength in the squatting process of humans. Besides, a fixed load of human body weight was added. Several representative observation angles in the motion of the knee joint, i.e. 30°, 60°, 90° and 120°, were selected. With intergroup and intra-group comparisons, error factors were effectively controlled. In summary, we herein mainly investigated the biomechanics of patellofemoral joints after TKA under currently available experimental conditions. Nonetheless, the patellofemoral kinematics should be further studied when more conditions are available.

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