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Research article

An investigation into whether changes in the posterior tibial slope affect the outcome of cruciate-retaining total knee arthroplasty by affecting tibiofemoral articular contact kinematics

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ABSTRACT

Aims: The outcomes of total knee arthroplasty (TKA) are affected by many factors. This study aims to evaluate whether changes in the posterior tibial slope (PTS) affect patients' outcomes after cruciate-retaining TKA by affecting tibiofemoral articular contact kinematics. It was hypothesized that changes in PTS affect the outcomes of PCR TKA by affecting tibiofemoral articular contact kinematics.

Methods: A total of 60 knees (30 patients) that underwent posterior cruciate-retaining TKA (with the same size prosthesis) for medial osteoarthritis were assessed preoperatively and one year postoperatively. Before and after TKA, changes in the PTS, as seen on lateral radiographs, were noted. The knees were placed in groups according to these PTS changes (preoperative value − postoperative value): group 1 $>3^\circ$ change and group 2 $\leq 3^\circ$ change. Knee kinematics were observed under mid-flexion weight-bearing conditions and were compared between the two groups using the two-dimensional/three-dimensional registration technique. Pain was measured using the visual analog scale, and knee function was assessed using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and the Knee Society Score (KSS).

Results: Group 2 experienced paradoxical anterior motion of the medial femoral condyle postoperatively, but group 1 did not. A comparison of the results of the TKA between the two groups showed a significant difference in pain using the visual analog scale, and knee function of the KSS and the WOMAC ($P < 0.05$). The postoperative results were better in group 1 than in group 2.

Conclusions: These results suggest that achieving a greater change in the PTS improves outcomes in patients undergoing posterior cruciate-retaining TKA because it reduces the paradoxical motion of the medial femoral condyle.

Article focus

This article aims to evaluate whether changes in the posterior tibial slope (PTS) affect patient outcomes after posterior cruciate-retaining (PCR) total knee arthroplasty (TKA) by affecting tibiofemoral articular contact kinematics.

Knee kinematics were observed under mid-flexion weight-bearing conditions and compared using the two-dimensional (2D)/three-dimensional (3D) registration technique.

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Abbreviations

TKA	total knee arthroplasty
PTS	posterior tibial slope
WOMAC	Western Ontario and McMaster universities
KSS	Knee Society Score
2D/3D	two-dimensional/three-dimensional
PCR	posterior cruciate-retaining
CAD	computer-assisted design

Pain was measured using the visual analog scale, and knee function was assessed using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and the Knee Society Score (KSS).

Key messages

The postoperative comparative analysis of the outcomes of the TKAs between the two groups showed that the mean medial tibiofemoral articular contact point was significantly more anterior in group 1 than in group 2.

The medial femoral condyles of the knees in group 2 developed paradoxical anterior motion during the one-year recovery interval, but the knees in group 1 did not.

There were significant differences between the groups in terms of pain, the pain greater in group 2 than group 1, the functional results were better in group 1 than in group 2 as indicated by the results ($P < 0.05$)

These results suggest that achieving a greater change in the PTS improves outcomes in patients undergoing PCR TKA because it reduces the paradoxical motion of the medial femoral condyle.

Fig. 1. The preoperative posterior tibial slope.

Strengths and limitations

The strength of this study is that all operations were completed by one senior surgeon using the same size prosthetic and a consistent, controllable, and reproducible technique, which reduced the random influences of variations in the surgeon, prosthesis type or size, and surgical technique.

The limitation of this study is that the sample size was small.

1. Introduction

Patient outcomes after TKA are affected by many factors, such as the preoperative state of the patient, type of prosthesis, surgeon's level of experience, surgical technique, and rehabilitation method [1]. Previous studies have focused on the influence of the tibial slope on extension and flexion gaps associated with TKA [2–4]. In recent years, some authors have studied the influence of the tibial slope on knee kinematic patterns [5,6].

For the past two decades, the 2D/3D registration technique has been used to evaluate knee kinematic patterns. Studies have indicated that the outcomes of TKA are affected by knee kinematic patterns [7]. Previous studies have reported that changes in knee kinematic patterns after TKA could affect outcomes, such as polyethylene wear and prosthetic loosening. Pan stated that TKA reduces the PTS and paradoxical motion of the medial femoral condyle [8]. We hypothesize that changes in PTS affect the outcomes of PCR TKA by affecting tibiofemoral articular contact kinematics.

2. Materials and methods

A total of 30 female patients (60 knees) with an average age of 63.5 y (57–68 y) at the time of surgery were enrolled in the study. The average postoperative follow-up duration was 12.4 months (12–13 months). All patients underwent PCR TKA for medial osteoarthritis, and the same size implant was used for each patient. The patients were assessed preoperatively and one year postoperatively. All 60 knees had varus deformity with >90° flexion preoperatively.

All patients provided written informed consent, and the study design was approved by our institutional review board.

In accordance with the procedure described by Utzschneider et al. the PTS was determined by measuring the proximal tibial anatomical axis on the preoperative and postoperative lateral radiographic images [9], and the slope was measured based on the

Fig. 2. The postoperative posterior tibial slope.

configuration of the metal backing (see Figs. 1 and 2). The knees were categorized into two groups based on the change in PTS, which was calculated by subtracting the postoperative value from the preoperative value: group 1 $>3^\circ$ change ($n = 32$) and group 2 $\leq 3^\circ$ change ($n = 28$).

All TKAs were performed by the same senior surgeon using a CR prosthesis (Waldemar Link GmbH & Co. KG, Hamburg, Germany, 3 Medium) using a consistent, controllable, and reproducible technique. All patients have bilateral TKA. Proximal tibial osteotomy was performed with approximately 5° of posterior inclination along the sagittal plane. The coronal alignment is aimed for neutral mechanical alignment. The posterior cruciate ligament was retained, and the anterior cruciate ligament was removed.

Preoperatively, each patient was required to accomplish a weight-bearing leg bend from full extension to 90°, which was monitored using a single fluoroscopic imaging system. During the lunge, the subjects positioned the knee in the field of view of the fluoroscope with their feet and torsos oriented towards the intersection of the image intensifier. As the subjects slowly bent their knees, the fluoroscopes captured knee positions at every 10° increment. At each target flexion angle, the subjects held their knee position for about 2 s while images were captured. The relative 3D position of the femoral and tibial prothesis was reproduced using the 2D/3D registration technique [10,11]. The 3D computer-assisted design (CAD) models of the knee prostheses were imported into the software, where we created a complete match by manipulating the borders of the CAD and the corresponding prothesis on the lateral radiographic image (see Fig. 3). The accuracy of the 2D/3D registration technique has been validated by prior experiments. The accuracy of the technique was within 0.5° for rotations and 0.4 mm for displacement in the sagittal plane [8].

The bending angle was defined as the angle between the femoral and tibial components on the lateral radiographic image, and the contact point of the mediolateral femoral joint was defined as the nearest point between the femoral and tibial components on the CAD model [12]. In the tibial coordinate system, the x-axis was defined as the line connecting the medial point to the lateral point of the tibial surface, and the y-axis was defined as the axis that perpendicularly bisects the x-axis in the transverse plane [13]. The anterior and posterior contact points of the x-axis were designated as positive and negative, respectively.

All kinematic data were normally distributed. A repeated measures analysis of variance and two independent samples t-tests were used to analyze the data. A value of $P < 0.05$ was considered statistically significant. The TKA, KSS, WOMAC three indicators respectively, and the two sample mean comparison sample size estimation formula were used to estimate the sample size. According to 95% reliability and 80% confidence, the estimated sample sizes are 46, 38 and 52 knees respectively.

3. Results

To compare knee kinematics between groups 1 and 2, we first considered the ability to bend the knee. In group 1, while bending the knee, the medial articular contact point continued to move backward ($P < 0.05$). In contrast, in group 2, the medial articular contact point moved backward from 0° to 20° ($P < 0.05$), remained almost motionless from 20° to 50° ($P > 0.05$), and moved forward from 50° to 90° ($P < 0.05$). At 90°, the mean medial articular contact point in group 1 was significantly more anterior than in group 2 ($P = 0.007$; see Fig. 4).

Overall, the lateral articular contact point in both groups moved backward to varying degrees. The average lateral tibiofemoral articular contact point exhibited a more significant posterior movement in group 1 than in group 2 through the entire bending process ($P < 0.001$; see Fig. 5).

According to the results of the functional KSS and the WOMAC, there was a significant difference between the two groups in terms of postoperative pain ($P < 0.05$; see Table 1).

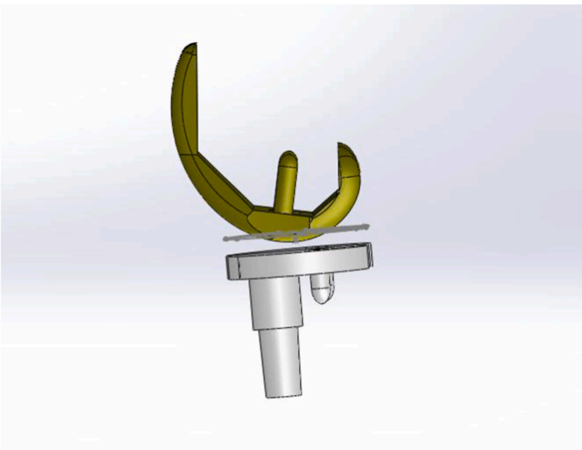

Fig. 3. The 3D computer-assisted design models of the knee prostheses.

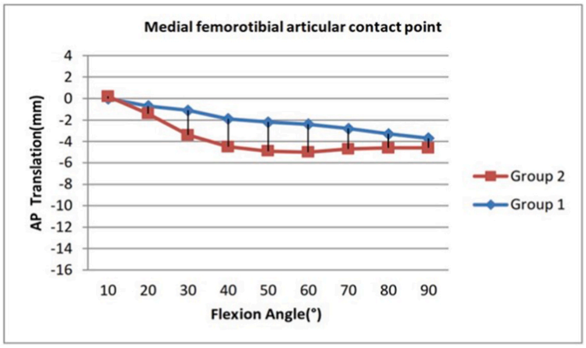

Fig. 4. The medial articular contact point of groups 1 and 2.

4. Discussion

The postoperative comparative analysis of the outcomes of TKA between the two groups showed that the mean medial tibiofemoral articular contact point was significantly more anterior in group 1 than group 2. The medial femoral condyles only developed paradoxical anterior motion during the one-year recovery period in group 2. There were significant differences between the groups in terms of pain, as measured by the functional KSS and the WOMAC ($P < 0.05$). Therefore, group 1 had better postoperative results than group 2. The outcomes of PCR TKA could be improved by gaining a proper understanding of the reduction in PTS in patients undergoing PCR TKA and the postoperative improvement in tibiofemoral articular contact kinematics.

Previous studies have focused on the influence of the tibial slope on extension and flexion gaps associated with TKA [2–4]. In recent years, some authors have studied the influence of the tibial slope on knee kinematic patterns [5,6]. Fujimoto [6] stated that the mean medial tibiofemoral articular contact point was significantly more posterior in the group with a large PTS than in the group with a small PTS, although there was no significant difference at the lateral tibiofemoral articular contact point during weight-bearing and non-weight-bearing activities. Kyoung-Tak Kang stated that tibial posterior translation and external rotation increased as the PTS increased in both CR and PS TKA. PTS is the critical factor that influences kinematics in TKA, especially in the CR TKA [14]. Previous studies have reported that changes in knee kinematic patterns after TKA could affect outcomes, such as polyethylene wear and prosthetic loosening. Paradoxical anterior motion of the medial femoral condyle has also been reported after PCR TKA [15,16]. Another study noted a decrease in PTS after TKA when compared with the preoperative PTS, which resulted in a reduction in the paradoxical motion of the medial femoral condyle. The authors offered a possible explanation for this mechanism [8]. The femur initially moves back and then subsequently moves forward to the equilibrium position as a compensatory mechanism, referred to as paradoxical anterior translation The balance can be restored to normal by decreasing the angle of PTS.

Paradoxical motion after TKA has potential negative consequences, such as pathomechanics and decreased efficiency of the quadriceps, which could affect outcomes [17,18]. The biomechanics of a normal knee are changed by paradoxical motion, which is non-physiological [19], and the dynamic balance of the soft tissue, including the joint capsule, lateral collateral ligament, and patellofemoral joint, is disrupted. This causes discomfort during knee flexion, which has an impact on the postoperative recovery of knee function. Some researchers believe that paradoxical motion reduces the distance between the tibiofemoral articular contact point and the tibial attachment of the patellar tendon during knee flexion, reduces the lever arm of the knee extensor mechanism, and leads to a need for greater quadricep muscle force to extend the knee at high flexion angles [20]. A large PTS could lead to the tibiofemoral articular contact point being posteriorly located, which increases the effort required by the quadriceps and may cause movement inclination from weight borne by the tibia [21,22]. As a result, the patient may experience discomfort during knee extension [23–25]. In addition, if the tibiofemoral articular contact point is more posterior than normal, it could cause joint contact force in unusual

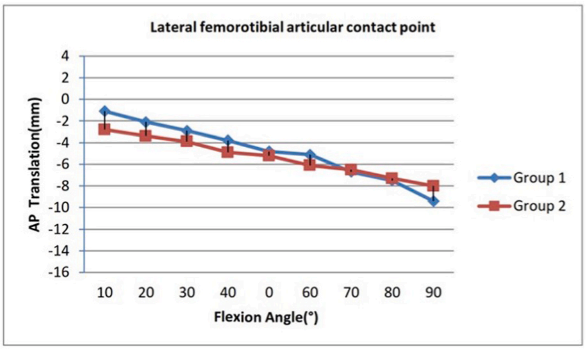

Fig. 5. The lateral articular contact point of groups 1 and 2.

Table 1
Comparison of test parameters between groups before and after operation.

		Group 1	Group 2	*P*-value
Pain	Before	9.20	9.27	0.888
	After	1.05	2.04	0.010
KSS	Before	23.42	23.38	0.675
	After	96.78	91.22	0.000
WOMAC	Before	63.42	62.14	0.712
	After	11.05	11.84	0.001

positions, resulting in abnormal compressive or tensile strain on the weight-bearing point of the tibia [19,26,27], which would cause discomfort during mid-flexion weight-bearing activities.

Consistent with other studies, the present study has several strengths and weaknesses. One limitation was the results are only applicable to female patients with varus deformity. Bilateral TKA is a rather special case, biomechanically, as the gait is compromised by two arthroplasties. Can these conclusions be apply also for patients with unilateral TKA? Hence, a larger sample size is needed in follow-up study.

In conclusion, a proper understanding of the reduction in PTS in subjects undergoing PCR TKA could improve outcomes by affecting tibiofemoral articular contact kinematics. However, a reduction in PTS could also lead to a decrease in the flexion range of motion of the knee and an increase in the probability of postoperative direct impingement of the prosthesis on the posterior femur [28–30]. Hence, the degree of reduction in the PTS and its impact on postoperative outcomes is worthy of further study.

Ethics approval and consent to participate

This study was conducted with approval from the Ethics Committee of our hospital. This study was conducted in accordance with the declaration of Helsinki. Written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Funding

Not applicable.

Author contribution statement

Xi-Qing Pan: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Feng Li: Conceived and designed the experiments; Wrote the paper.
Jin-Hui Liu: Analyzed and interpreted the data; Wrote the paper.
Jiang-Li Zhang: Analyzed and interpreted the data; Wrote the paper.
A Chai: Performed the experiments; Wrote the paper.
Lei Shu: Performed the experiments; Wrote the paper.
Yao Li: Performed the experiments; Wrote the paper.

Data availability statement

No data was used for the research described in the article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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