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A soft-tissue preserving method for evaluating the impact of posterior tibial slope on kinematics during cruciate-retaining total knee arthroplasty: A validation study

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ABSTRACT

Background: The reconstructed posterior tibial slope (PTS) plays a significant role in restoring knee kinematics in cruciate-retaining total knee arthroplasty. However, conventional methods for the investigation of PTS can be limited by sample size or prone to errors due to damages to the bone and/or soft tissues. The purpose of this study was to validate a novel method for the evaluation of the effects of PTS on knee kinematics.
Methods: Seven computer-assisted cruciate-retaining TKAs were performed by two surgeons on healthy cadaveric knees. The implanted tibial baseplates allowed precise and easy modification of the PTS in situ. Knee kinematics were evaluated during passive full range of motion test. The evaluation was performed three times at each of the five PTSs in the order of 10°, seven degrees, four degrees, one degree, and back to ten degrees. The variability of the repeated measurements, inter-surgeon variation of the data, and test reproducibility were investigated.
Results: The test method was shown to be highly repeatable (low root-mean-squared errors) and has low sensitivity to surgeon variability (ANOVA). No statistical difference was found in the knee kinematics between the first and last measurements at 10° PTS (paired *t*-test).
Conclusion: The results suggested that the developed method can be used to investigate the impact of PTS on knee kinematics without disrupting the soft-tissue environment of the knee. The use of the novel tibial baseplate allowed for adjusting the PTS without re-cutting the tibia and removing the components. The method may be applied to improve the future investigation of PTS.

1. Introduction

Accurate bone cuts and appropriate soft-tissue balancing are essential to ensure a successful total knee arthroplasty (TKA). For cruciate-retaining (CR) designs, the success in restoration of normal kinematics and longevity of the implants depend on functional integrity of the soft-tissue environment; more specifically, a well preserved and balanced posterior cruciate ligament (PCL). A poorly implanted CR knee can overly tense the PCL, causing postoperative stiffness, excessive femoral rollback, severe

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polyethylene wear, even rupture of the ligament itself [1–4]. On the other hand, a loose PCL can lead to improper femoral rollback, compromising postoperative kinematics.

Despite clinical success, studies have shown abnormal knee kinematics after CR TKA, including non-physiologic anterior sliding of the femur relative to the tibia or so called “paradoxical motion” [5–7]. This phenomenon is believed to be caused by the flexion gap being larger than the extension gap, which may lead to complications such as difficulty with activities reliant on early to mid knee flexion (stair climbing and inclines) [8], earlier impingement of the posterior aspect of the polyethylene insert that prevents achieving high flexion [9], increased wear of the polyethylene insert [10,11], as well as pain and swelling in the knee. Although abnormal postoperative kinematics can be multi-factorial, the anteroposterior (AP) inclination of the reconstructed proximal tibia, or PTS, has been shown to significantly affect the sagittal kinematics of the postoperative knee [12–15] and therefore led to the improvements in surgical techniques and implant designs to address the needs of proper PCL preservation and balancing [16]. Fujimoto et al. compared postoperative CR TKA kinematics between knees reconstructed with small PTS (~5°) and those with large PTS (~10°), and found that the large PTS group had a significantly more posterior displacement of the medial femoral condyle between the flexion range of 10° to 90° [12]. However, this difference was not found to be significant on the lateral side of the knee. An investigation of postoperative kinematics during three common activities reported that PTS significantly correlated with the AP position of the tibiofemoral lateral contact point and the maximum flexion angle achieved [13]. PTS was also reported to significantly impact the 12-month postoperative range of motion [14]. Okazaki et al. reported that when the PTS increased or decreased by five degrees, the size of the flexion gap for CR TKA increased or decreased accordingly by approximately two millimeters [17]. Maximum flexion and posterior tibiofemoral translation in CR TKA were found to increase significantly with higher PTS [15]. Although similar general conclusions were drawn from these investigations, detailed results varied from study to study. This may be due to differences between the CR TKA designs investigated, and the specific methods used in the investigations.

In general, the methods applied in the previous investigations can be categorized into two types. The first type was based on clinical observations, where comparisons between different subject groups with varying ranges of PTS were made [12–14]. This type of clinical investigation usually demands a large sample size to overcome inter-subject variability in order to identify statistical significance specifically related to the PTS. In contrast, the second type of investigation used each subject as its own control [15,17]. By comparing the kinematics at various PTSs in the same knee, the required sample size can be significantly reduced. However, the methods used to adjust posterior tibial slope may be problematic. Previous studies modified the PTS either through anterior open wedge high tibial osteotomy with plate fixation [17] or inter-changeable tibial articular surface inserts with varying AP inclinations [15]. PTS manipulation with osteotomies is subject to surgical variability, limiting the capability of accurately adjusting the PTS to the planned target; on the other hand, the impact of frequently changing the tibial inserts on the soft tissue integrity remains unknown. Furthermore, most CR TKA studies found to date on PTS related kinematics were based on either fluoroscopic or radiographic assessment, which is prone to human and can be limited by the resolution of the images.

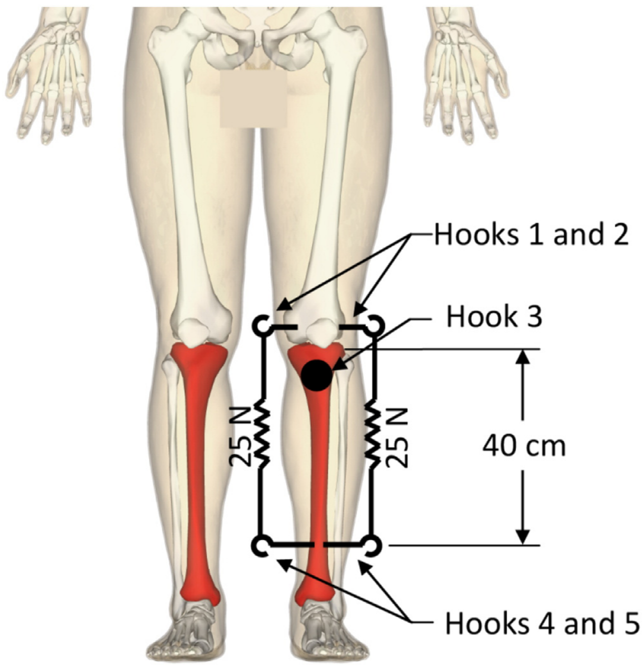

Figure 1. Illustration of the cadaver test setup for this study.

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