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Effect of Posterior Tibial Slope on Flexion and Anterior-Posterior Tibial Translation in Posterior Cruciate-Retaining Total Knee Arthroplasty

Andrew W. Chambers, MD [a,b], Addison R. Wood, MS [b], Victor Kosmopoulos, PhD [b,c], Hugo B. Sanchez, MD, PhD [a,b], Russell A. Wagner, MD [a,b]

[a] *Department of Orthopaedic Surgery, John Peter Smith Health Network, Fort Worth, Texas*
[b] *Department of Orthopaedic Surgery, University of North Texas Health Science Center, Fort Worth, Texas*
[c] *Department of Materials Science and Engineering, University of North Texas, Denton, Texas*

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ABSTRACT

Reduced posterior tibial slope (PTS) and posterior tibiofemoral translation (PTFT) in posterior cruciate-retaining (PCR) total knee arthroplasty (TKA) may result in suboptimal flexion. We evaluated the relationship between PTS, PTFT, and total knee flexion after PCR TKA in a cadaveric model. We performed a balanced PCR TKA using 9 transfemoral cadaver specimens and changed postoperative PTS in 1° increments. We measured maximal flexion and relative PTFT at maximal flexion. We determined significant changes in flexion and PTFT as a function of PTS. Findings showed an average increase in flexion of 2.3° and average PTFT increase of 1 mm per degree of PTS increase when increasing PTS from 1° to 4° ($P < .05$). Small initial increases in PTS appear to significantly increase knee flexion and PTFT.

Total knee arthroplasty (TKA) is one of the most successful and common surgeries performed in the United States [1]. Improvements in health-related quality of life are third to only coronary artery bypass grafting and total hip arthroplasty [2]. Relief of pain and achieving a functional range of motion are paramount in achieving success. Flexion range of motion is important for daily activities such as ascending stairs and sitting. Flexion angles of 135° to 155° may be required for certain cultural and religious activities that involve kneeling [3,4]. In addition, reduced total flexion after TKA has been shown to negatively affect patient reported outcome scores in TKA [5,6].

Knee flexion after TKA can be affected by factors such as implant design, preoperative knee flexion, postoperative physical therapy, and intraoperative balancing [5,7]. Mechanical factors such as impingement of the posterior aspect of the tibial plateau on the posterior femoral cortex can also limit flexion. Impingement during deep flexion can be delayed with increased posterior tibial slope (PTS) and increased posterior tibiofemoral translation (PTFT) of the femur during deep flexion [7-10]. Although PTS can be adjusted via intraoperative bone cuts, PTFT has been shown to be highly variable in posterior cruciate-retaining (PCR) TKA [11].

Bellemans et al [12] showed in a cadaveric model that for every 1° increase in PTS, total flexion is increased 1.7°. In a radiographic model, Massin and Gournay [8] showed that increased tibial slope and a more posterior tibiofemoral contact point at full flexion predict more total flexion after TKA. Although PTS and PTFT have independently been found to improve flexion, we hypothesize that PTS directly affects PTFT, and at the optimal degree of PTS, maximal flexion and PTFT will occur. We also hypothesize that native knee PTS is not reliable in predicting the degree of PTS at which maximal flexion will occur after PCR TKA.

Materials and Methods

Nine transfemoral fresh frozen cadaver specimens (5 male, 4 female; mean age, 76.8 years) were thawed overnight at room temperature before testing. Specimens with evidence of prior knee surgery, abnormal ligament contracture, coronal or sagittal plane deformity, and severe obesity were omitted from the study. Lateral and anteroposterior (AP) radiographs were taken to document native PTS and coronal plane deformity.

A balanced PCR-TKA was performed through a medial parapatellar approach using Biomet Vanguard PCR TKA system (Biomet Complete Knee System, Biomet, Inc, Warsaw, IN) with 3° of posterior slope inherent to the polyethylene. Trial components were then removed, and C-arm fluoroscopy (Flouroscan InSight Mini C-arm, Hologic, Inc, Bedford, MA) was used to cut the tibia in 10° of PTS using the extramedullary jig provided in the TKA set. A “V cut” in the tibial plateau

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Reprint requests: Andrew Chambers, MD, Department of Orthopaedic Surgery, John Peter Smith Health Network, 1500 South Main Street, Fort Worth, TX 76104.

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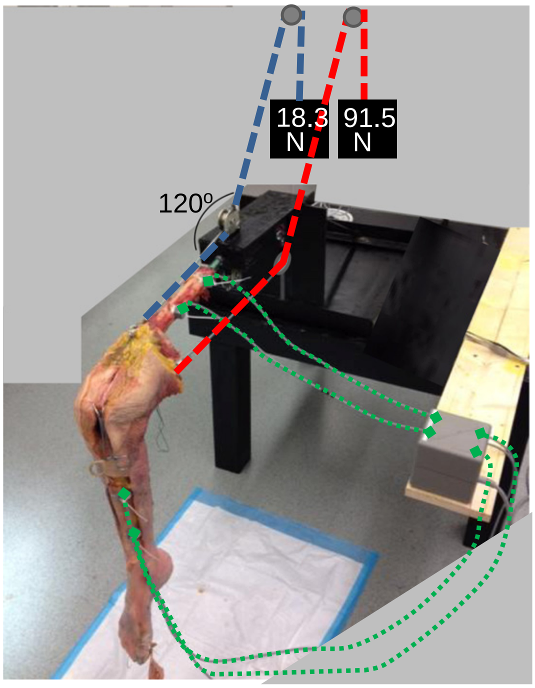

Fig. 1. Photodiagram of experimental apparatus. The hamstring and quadriceps tendons were attached to a 91.5- and 18.3-N weight via a series of pulleys and cables shown above (red and blue dashed lines, respectively). Four motion tacking sensors (dotted green line) were used to measure small changes in total flexion (2 attached to femur shaft and 2 attached to tibia shaft). The femur was fixed to the apparatus via an intramedullary femur nail and was parallel to the floor.

was used to preserve an island of bone attached to the posterior cruciate ligament (PCL). The "V cut" method allowed for a large tibial slope to be cut without compromising the integrity of the PCL insertion in any of the 9 specimens. All specimens were inspected and found to have an intact PCL before and after each stage of the experiment.

Four motion tracking sensors (Liberty; Polhemus, Colchester, VT) were calibrated, fixed to the femoral and tibial shafts (Fig. 1), and programmed to accurately measure changes in flexion angle. Custom shims made for the trial components were used to build back the slope in 1° increments by changing the posterior superior-inferior height of the tibial component (Fig. 2). The specimens were sequentially secured to a mechanical loading system that consisted of a 13-mm diameter interlocked titanium anterograde femoral intramedullary nail (Tri-Gen Intertan; Smith and Nephew, London, UK) secured to a custom-made steel support with wooden base to allow for unimpeded flexion (Fig. 1). The foot was not fixed to any part of the mechanical loading system. The magnitudes of quadriceps and hamstring loads used to achieve maximal flexion of the knee were based on previously published reports of loads used in similar experimental designs [13-16]. We performed a preparatory study in our laboratory to verify that the previously published quadriceps and hamstring loads were sufficient to achieve full flexion without being unnecessarily excessive for our particular experimental setup. We determined that a 91.5-N force applied to the hamstrings tendons and a concurrent 18.3-N force applied to the quadriceps tendon (simulating simultaneous antagonistic eccentric contraction) fulfilled these requirements. These forces were applied to their respective tendons via a running locked #5 suture (Ethibond Excel; Ethicon Endo-Surgery, Blue Ash, OH). After the respective forces were applied to the hamstring and quadriceps tendons, the specimens were preconditioned with 25 cycles of manual flexion/extension. A lateral radiograph of the tibial baseplate was obtained at maximal flexion to measure relative PTFT. A blinded analysis of each x-ray was performed, and the lowest point of the medial and lateral femoral condyle was digitally marked using ImageJ software (ImageJ 1.48; US National Institutes of Health, Bethesda, MD). Because the AP contact point was not always the same for the medial and lateral femoral condyles, the sagittal position of the medial femoral condyle was averaged with the position of the lateral femoral condyle to determine the AP contact point between the femoral and tibial components.

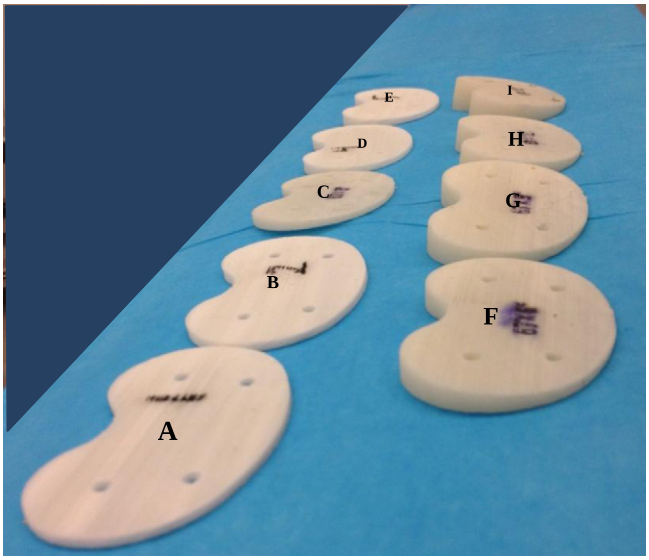

Fig. 2. Custom-made shims. Increasing slope by 1° (1°-9°, A-I, respectively).

Because of the anatomical variations inherent in cadaveric specimens, each cadaver served as its own control. The total flexion at 1° of PTS was represented as 0, and any increase or decrease in total flexion compared to this condition was represented as (+) or (−), respectively. At each degree of PTS, 3 trials were performed to verify that the total flexion angle remained consistent.

Similarly, the AP contact point at 1° of PTS was represented as "0", and any change in the posterior and anterior directions were represented at (+) and (−) tibiofemoral translation, respectively.

We used a repeated-measures analysis of variance with a post hoc Tukey test to determine significant changes ($P < .05$) in flexion and PTFT as a function of PTS. Regression analysis was used to determine if there was a correlation between the PTS at which the best flexion was achieved and the PTS of the native knee.

Results

The total flexion of the knee increased significantly with increased PTS. Increases in PTS from 1° to 4°, 5°, 6°, 7°, 8°, 9°, and 10° resulted in significant increases in flexion of 6.9°, 8.1°, 9.8°, 10.6°, 10.1°, 9.3°, and 8.9°, respectively (Fig. 3). In addition, increasing from 2° of PTS to 6°, 7°, 8°, 9°, and 10° of PTS also resulted in significant increases in total flexion.

Posterior tibiofemoral translation also increased significantly with increased PTS. Increases in PTS from 1° to 4°, 5°, 6°, 7°, 8°, 9°, and 10° resulted in significantly increased PTFT of 3.1, 3.1, 3.0, 3.4, 3.3, 3.7, and 3.2 mm, respectively (Fig. 4).

There were similar significant increases in total flexion and PTFT in response to the same interval changes in PTS from 1° to 4°, 5°, 6°, 7°, 8°, 9°, and 10° (Figs. 3 and 4). There was no correlation ($r^2 < 0.01$) between the native degree of PTS and the degree of PTS that yielded the highest postoperative flexion.

Discussion

Small increases in PTS in the range of 1° to 6° appear to significantly increase knee flexion. For example, 6.9° of additional flexion can be achieved by increasing the PTS from 1° to 4° (2.3° improved flexion