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The influence of polyethylene bearing thickness on the tibiofemoral kinematics of a bicruciate retaining total knee arthroplasty

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ABSTRACT

Background: The recently reintroduced bicruciate retaining Total Knee Arthroplasty (BCR TKA) is an effort to reproduce kinematics closer to the native knee. However, there is no data on appropriate balancing with this implant. Balancing is crucial and challenging as medial and lateral polyethylene (PE) inlays are modular, which allows for placement of different thicknesses in the medial and lateral compartments. This study aimed at providing a detailed kinematic view on balancing BCR TKA.
Methods: Seven fresh frozen cadaver legs were mounted in a kinematic rig that applied squatting under application of physiologic quadriceps and hamstring forces. Additionally, specimen laxity was assessed using Lachman tests and varus/valgus stress tests. Following testing on the native knee, a BCR TKA was implanted in each specimen and all trials were repeated. Using one millimeter increments, five inlay thicknesses were tested to simulate optimal balancing, symmetric under-, and overstuffing, valgus constellation, and varus constellation.
Results: Overall, knee kinematics following BCR TKA seem to be very close to the native knee. The changes as introduced to tibiofemoral kinematics through over- or understuffing the polyethylene inserts are affecting the system only to a minor degree and generally lack statistical significance. Reproduction of the tibial varus via PE-Inlays did not lead to kinematics much closer to the native knee.
Conclusions: The changes introduced to tibiofemoral kinematics by removal of the conforming meniscus and cartilage and replacement with a flat PE insert and femoral component are of more impact than different inlay sizes and their combinations for a BCR TKA.

1. Introduction

Many patients report persistent problems following total knee arthroplasty (TKA), often stating their reconstructed knee does not feel 'normal' [1]. A potential explanation is that the knee's proprioception mechanism is disrupted following TKA since the anterior cruciate ligament (ACL) is sacrificed [2]. This is done despite that upwards of 30% of patients undergoing TKA have an intact-normal ACL [3]. Preservation of the ACL during TKA, theoretically resulting in improved knee kinematics, can be accomplished using bicruciate retaining (BCR) implants, where the anterior and posterior cruciate ligaments are spared, or bilateral unicompartmental knee arthroplasty. Initial designs for BCR TKAs were introduced in the 1960s and have seen limited usage in Europe, however, they generally fell out of widespread use in the United States [4], perhaps attributable to perceived technical difficulty and early post-operative complications [5].

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BCR has recently undergone a re-emergence with several new designs being introduced to the orthopedic market, largely due to improved polyethylene wear properties and improved locking mechanism designs. Several recent studies have documented the potential advantages of BCR TKA. For example, Pritchett reported that patients preferred a BCR implant relative to a posterior-stabilized (PS) prosthesis two years post-implantation [3]. An additional study from Pritchett demonstrated a Kaplan–Meier survivorship of 89% at 23 years in a series of 489 BCR implants in 390 patients [6]. Baumann et al. reported that proprioception following BCR is similar to unicompartmental knee arthroplasty and is significantly better than a PS TKA [7].

There have been relatively few studies documenting the influence of BCR TKA on tibiofemoral kinematics. Komistek et al. [8] used fluoroscopy to examine the in vivo kinematics during gait for patients who received either a BCR or PS TKA and noted the BCR replicated kinematics more similar to the native knee. Similar findings were reported by Stiehl et al. who also used fluoroscopy to measure in vivo gait kinematics for patients who received a BCR [9]. Moro-oka et al. noted that preserving the cruciates during TKA resulted in more natural knee kinematics relative to a PS implant [10]. Despite these previous works, there have been no studies (to the authors' knowledge) that have characterized tibiofemoral kinematics of a BCR TKA within the same subject, thus allowing for direct comparison with the native knee.

One of the most common failure mechanisms associated with TKA is instability [11], which can be caused by improper ligament tensioning following arthroplasty, among other factors [12]. Generally, ligament balance is subjectively assessed by the surgeon [13] and can be modified by altering the thickness of the polyethylene bearing. If chosen improperly by using either an under- or oversized polyethylene insert, the resulting tibiofemoral kinematics, contact pressure, and wear properties can be altered [14,15].While previous studies have documented the effect of bearing thickness on unicompartmental implants [16,17], there have been no studies documenting the influence on BCR TKA.

The purpose of the current study was to provide a detailed characterization of the influence of polyethylene bearing thickness on the tibiofemoral kinematics of a BCR TKA. To this end, a cadaveric knee simulator system was used to subject specimens to different motion tasks both pre- and post-implantation of a BCR TKA. In addition to a subjectively balanced polyethylene bearing configuration, four alternative insert configurations were assessed. It was hypothesized that a varus constellation as introduced by the insert would result in more normal kinematics. Finally, the influence on anterior–posterior and varus/valgus laxity was determined for the different configurations.

2. Methods

Seven fresh-frozen cadaver legs (six males, all right legs, 76 ± 10 years) with no history of lower-limb trauma, no deformities and fully functional ligaments were acquired under approval from the local Ethics Committee. The sample size was chosen based on cadaver availability and that previous work using the same experimental setup achieved statistical power of 0.8 with six specimens [18]. Specimens were disarticulated at the hip and five millimeters bicortical bone pins were inserted into the femur and tibia. Rigid frames with four spherical reflective markers were attached to the pins and computed tomography (CT) scans (Siemens Definition Flash, Siemens Healthcare GmbH, Erlangen, Germany) were obtained with a slice thickness of 0.75 mm.

One day prior to testing specimens were thawed in a cooler and resected 32 cm proximally and 28 cm distally from the knee joint line. The skin and subcutaneous tissue were removed and suture loops were passed through the medial and lateral hamstring tendons. The quadriceps tendon was exposed and a custom clamping system was attached six centimeters proximal to the distal pole of the patella. Acrylic cement (VersoCit2, Struers, Ballerup, Denmark) was used to secure the tibia and femur in a physiologic orientation within metal containers.

Specimens were mounted in a dynamic knee rig simulator based on a modified Oxford Rig design (Figure 1), which has been previously well described [19]. Specimens were subjected to two motion patterns: fully loaded squats (40°–105°) and passive flexion (five degrees–120°). During squats, constant force springs (50 N) were attached to the medial/lateral hamstrings while the quadriceps clamp was connected to a linear actuator. The force of the quadriceps actuator was modulated throughout the squat motion to apply physiologic quadriceps load [20] while maintaining a vertical ankle load of 90 N. For passive flexion, the tibia was disconnected from the knee rig while the femur remained fixed and was guided through its flexion range by an orthopedic surgeon (P.D.). Hamstrings and quadriceps forces were not applied during passive flexion. For each specimen, squats were performed twice and passive flexion was performed in triplicate. Previous work demonstrated the setup's trial-to-trial variability in terms of tibial rotation, femoral translation and tibiofemoral coronal plane alignment, to measure 0.5°, 0.8 mm, and 0.6°, respectively (all 95% confidence intervals around the mean) [19].

Knee laxity was assessed using a combination of Lachman and varus/valgus stress tests. During laxity trials the femur container was kept rigidly fixed to the knee rig while the tibia was free (similar to passive flexion). Knee flexion was maintained at 20° for all tests and a hand-held force balance was used to apply 100 N during Lachman tests and 30 N for varus/valgus tests. Trials were performed in triplicate and repeatability assessed using intraclass correlation coefficients, which were found to be 0.967, 0.947, and 0.876 for the Lachman, valgus laxity, and varus laxity testing, respectively.

Following completion of testing on the native specimens, a bicruciate retaining TKA featuring an asymmetric femoral component shaped according to the individual condylar J-curves (Vanguard XP, Zimmer Biomet, Warsaw, IN, USA) was implanted using standard surgical technique with a medial parapatellar approach. Five polyethylene inlay thicknesses were tested: optimal balancing (as determined by the surgeon, BCR), symmetric understuffing (one millimeter thinner, U-BCR), symmetric overstuffing (one millimeter thicker, O-BCR), valgus constellation (one millimeter thinner lateral and one millimeter thicker medial, VL-BCR), and varus constellation (one millimeter thicker lateral and one millimeter thinner medial, VR-BCR). All tests were repeated using the same methodology and the testing order of the inlay thickness was randomized to avoid bias.

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