



The Biomechanical Effect of Increased Valgus on Total Knee Arthroplasty: A Cadaveric Study

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ABSTRACT

The effects of valgus load on cadaveric knees following total knee arthroplasty (TKA) were investigated using a custom testing system. TKAs were performed on 8 cadaveric knees and tested at 0°, 30°, and 60° knee flexion in both neutral and 5° valgus. Fuji pressure sensitive film was used to quantify contact areas and pressures and MCL strain was determined using a Microscribe digitizing system. Lateral tibiofemoral pressures increased ($P < 0.05$) at all knee flexion angles with valgus loading. Patellofemoral contact characteristics did not change significantly ($P > 0.05$). Significant increases in strain were observed along the anterior and posterior border of the MCL at all knee flexion angles. These findings suggest that valgus loading increases TKA joint contact pressures and MCL strain with increasing knee flexion which may increase implant instability.

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Restoration of the mechanical axis in total knee arthroplasty (TKA) ensures both proper weight bearing and good long-term functional outcome. This mechanical axis traditionally runs from the center of the femoral head through the center of the ankle. However, sagittal balancing intra-operatively and hindfoot malalignment have been shown to produce a valgus stress and therefore are important when determining the overall loading axis of the lower limb [1–4].

The kinetic chain of the leg can be disrupted by pes planus, hindfoot valgus and hyperpronation of the forefoot [5]. Teitge et al noted that increased pronation of the foot resulted in a decreased lateral thrust of the knee however, it also caused increased loading on the lateral tibiofemoral joint with genu valgum [6]. They concluded that this mechanism accounted for a more frequent association of pronated feet, posterior tibial tendon rupture, and genu valgus [6]. Previous kinematic and motion studies have shown that a lateral wedge prosthesis and excessive rearfoot pronation both can create increased valgus moments at the knee [7,8]. Also, in those patients with Rheumatoid Arthritis, studies have observed the association of hindfoot malalignment, which may not be considered in a primary TKA [2,4,8–10]. In a prospective study of TKA in the osteoarthritic knee, the authors demonstrated that hindfoot malalignment can persist postoperatively which causes a lateral shift of the weight-bearing axis [4]. Further, in an analysis of TKA revisions, Meding et al found that a high incidence of the total revisions was associated with

posterior tibial tendon insufficiency, which can cause a hindfoot valgus deformity [11]. Valgus forces also affect the medial collateral ligament, which serves as the primary restraint to valgus angulation and which can be attenuated over time as a result of repetitive valgus forces. The patellofemoral joint should also be considered when examining valgus forces. The Q angle, defined as the angle between a line drawn from the ASIS through the center of the patella and a line drawn from the center of the patella through the tibial tuberosity, is a guide to help maintain proper patella tracking, which is one of the most common complications of TKA. Changes in the Q angle caused by repetitive valgus forces can create maltracking, pain and prosthetic wear. While restoration of mechanical alignment is paramount in TKA, how valgus forces affect a prosthetic knee in varying degrees of flexion has yet to be described. We hypothesized that valgus loading would alter joint contact characteristics as well as increase strain in the MCL. To that end, we performed TKAs in cadaveric knees in order to assess MCL strain and the contact characteristics of the tibiofemoral and patellofemoral joints in both neutral and in five degrees of valgus.

Materials and Methods

Specimen Preparation

Eight fresh frozen cadaver knees (5 right, 3 left) ranging in age from 73 to 85 years were obtained and stored at -20°C . All specimens were macroscopically intact without gross pathology or evidence of prior surgery. A posterior cruciate ligament (PCL) sacrificing TKA was performed using the Foundation Knee System (DJO Surgical, Austin, TX). All eight total knee arthroplasties were

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performed according to the manufacturer's protocol by a resident orthopaedic surgeon (BJB) supervised by a senior orthopaedic surgeon (WCK) who has extensive experience with the Foundation Knee System. The knee joint was exposed using a medial parapatellar arthrotomy. Intramedullary alignment devices were used to align the femoral surface in 5° of valgus and 3° external rotation using the posterior femoral condyles and the epicondylar axis as reference points. The proximal tibia was resected perpendicular to the anatomic axis using the intramedullary alignment guide. Following the initial femoral and tibial bone cuts, measurement of flexion and extension gaps was performed using tongue depressors interposed between the resected surfaces to balance the flexion/extension gaps.

The tibial tray was sized to obtain maximal coverage of the cortical bone rim, and positioned with the center of the tray aligned with the medial one third of the tibial tubercle. Patellar thickness was measured at the medial patellar ridge using a caliper. A patellar cutting guide was placed on the patella at the level of the subchondral bone of the lateral facet. The amount of bone removed was measured with the stylus, and was equal to the amount to be replaced. Symmetric cuts of the patella were taken with the final thickness within 1 mm of the pre-resection depth. The patellar component was then centered on the resected surface and positioned an additional 2 mm medially to improve patellar tracking and reduce the need for lateral retinacular release. Prior to cementing the final patellar implant, a K-wire was used to drill a hole through the center hole in the patellar trial and out through the anterior patellar cortex. A small screw was placed for use as a kinematic marker.

Following implantation of the components, the knees were taken through a full range of motion to assess soft tissue balance as performed in the clinical setting and the knees were balanced in all directions. The arthrotomy was closed and the intramedullary rods were then reinserted, and digital photography was used with Adobe Photoshop in order to calculate the post-operative coronal tibio-femoral angle and passive knee range of motion.

Specimen Mounting

The skin, subcutaneous tissues, muscles of the posterior thigh, and muscles of the lower leg were removed. The individual quadriceps muscles (vastus lateralis, vastus intermedius/rectus femoris, vastus medialis) and the iliotibial band were identified and isolated along fascial planes to each tendinous insertion into the extensor mechanism. The extensor mechanism, retinaculum, knee capsule, and periarticular soft tissues were preserved. The fibula was fixed with a single wood screw then resected distal to the proximal tibiofibular joint. The tibia and femur were potted in polyvinyl chloride (PVC) pipe using plaster of Paris. After curing, the femur/PVC was cut 25 cm from the joint line, and the tibia/PVC 20 cm from the joint line using a band saw.

Specimens were rigidly mounted on a custom knee testing system that permits six degrees-of-freedom positioning at both the femur and the tibia (Fig. 1). This jig which has been validated in previous studies was fitted with a model 1122 Instron Machine (Instron Corporation, Canton, MA) [12,13]. The testing system allows for variable knee flexion, varus and valgus angles, as well as translation in the x, y, and z axis and independent rotational freedom of the femur and tibia. The specimens were positioned within a mounting cylinder using 8 fixation pins and rigidly fixed using 2 bicortical, diaphyseal, trans-PVC crossbolts in each cylinder. The coronal plane tibio-femoral angle orientation of the femur was determined by the TKA, with the rotation determined by aligning the epicondylar axis parallel to the coronal plane of the femoral cylinder [12,13].

Following mounting of the specimens, small machine screws were placed at pre-determined positions to provide kinematic data measurements. These positions were the medial and lateral femoral epicondyles, the patella center, superior patella, lateral patella, medial



Fig. 1. Custom knee testing system with six degrees-of-freedom at both the femur and the tibia.

patella, inferior patella and tibial tubercle. The soft tissues superficial to the MCL were dissected to isolate the ligament. Suture markers were then placed at eight points along the MCL; 4 anterior and 4 posterior (Fig. 2).

The individual muscles were trimmed to accommodate the width of the loading clamps, and wrapped with saline soaked gauze to prevent slippage. The muscles were clamped perpendicular to their fibers and loaded simultaneously with the vectors of pull in line with their fibers [12,13]. The muscles were loaded in a multi-planar fashion as previously described in an anatomic study [14]. Weights suspended from a cable-pulley system were used for muscle force simulation. These loading parameters were based on the ratios of the physiological cross-sectional area of the muscles as described previously [15]. The total force applied was 450 N (Vastus Lateralis 147 N, Vastus Medialis 97 N, Vastus Intermedius/Rectus Femoris 166 N and the Iliotibial Band 40 N).

Specimen Testing

Knees were tested at flexion angles of 0°, 30° and 60° and at each flexion angle were tested at neutral and with 5° of valgus in the coronal plane. For each flexion angle the femur was locked in position and the neutral tibial position, or the position of the tibia with muscle loading was determined. The valgus angle was then induced by translating the distal tibia directly in the lateral direction until the change in tibial angle was five degrees. The tibia was also able to translate proximally or distally which was determined by the muscle loading. Two trials were performed at each testing condition. Specimens were kept moist throughout the testing phase using normal saline. At each testing condition data were collected on

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