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A Comparison in Proximal Tibial Strain Between Metal-Backed and All-Polyethylene Anatomic Graduated Component Total Knee Arthroplasty Tibial Components

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Abstract: Loading in total knee arthroplasty (TKA) is multifactorial and dependent on alignment, ligament balance, patient, and implant factors. Abnormal loading has been linked to clinical failure; however, the respective contribution of each factor to failure is not well known. This study defined the effect of metal backing on loading patterns in the proximal tibia. Composite tibiae were implanted with metal-backed and all-polyethylene Anatomic Graduated Component TKA tibial components (Biomet, Inc, Warsaw, Ind) and coated with photoelastic material allowing full-field dynamic strain quantification. In simulated varus loading distributions, significant increases in measured strain were observed ranging from 40% to 587% for all-polyethylene vs metal-backed tibial components. Higher observed strains in the proximal tibia observed with all-polyethylene tibial components could possibly explain increased clinical failure rates observed with this TKA design.
Keywords: loading, total knee arthroplasty, implants, strain, alignment.

Metal-backed tibial components in total knee arthroplasty (TKA) currently dominate the orthopedic market because of intraoperative flexibility afforded by modularity [1]. Metal-backing was first used in TKA as a method to potentially improve loading distributions over the tibial plateau at the interface between the prosthesis and the supporting cancellous bone [2]. Many studies have compared metal-backed and all-polyethylene tibial components with variable survivorship [1,3-7]. We have found decreased clinical survivorship with all-polyethylene [4] Anatomic Graduated Component (AGC) TKAs (Biomet, Inc, Warsaw, Ind) compared to the nonmodular metal-backed [5] design at 10-year follow-up (68% vs 98%, respectively). Loosening or bony collapse beneath the medial plateau accounted for 74% of failures in our AGC all-polyethylene cohort [4].

However, metal-backed tibial components in this design require greater bone resection to accommodate the added thickness of the metal tray and maintain the same ultra-high-molecular-weight polyethylene (UHMWPE) thickness, which effects early implant migration and may influence long-term survivorship [1,3,8]. The purpose of this study was to compare AGC all-polyethylene tibial components with metal-backed tibial components in neutral and varus loading conditions in vitro to characterize induced patterns of maximum shear strain on the tibial cortex. Study of these loading patterns is needed to understand the increased failure rate of all-polyethylene components as compared with their metal-backed counterparts in this TKA design. We hypothesize that all-polyethylene tibial components may lead to increased strains in the proximal tibia with this TKA design, possibly correlating to osseous overload in the medial compartment and accounting for the increased observed rates of clinical failures in the all-polyethylene group.

Materials and Methods

Metal-backed and all-polyethylene AGC Total Knee Systems were used in this study. Sawbones Third Generation composite tibiae (Pacific Research Laboratories, Inc, Vashon, Wash) designed to replicate the mechanical properties of cadaveric bone were chosen as test specimens to minimize interspecimen sizing and bone density variability [9]. Five left tibiae for each prosthesis type were implanted by a board-certified orthopedic surgeon 5 mm below the joint line with 75-mm-sized AGC tibial components in neutral alignment. Cuts in all

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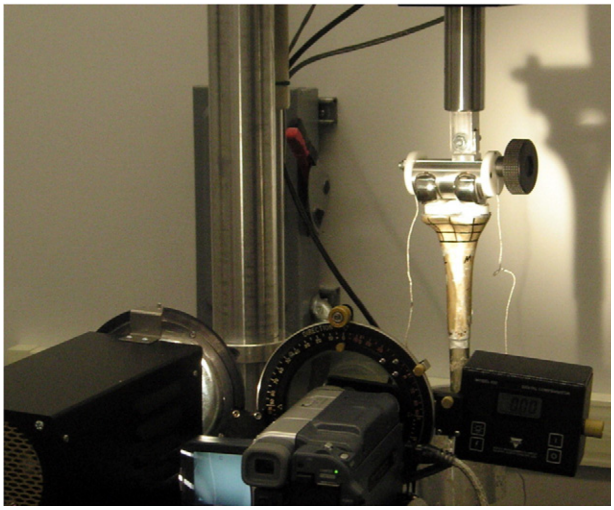

Fig. 1. Reflection polariscope and null compensator for quantitative strain measurement. Test specimens were mounted on a tabletop servohydraulic materials testing machine for compressive loading. Custom loading apparatus for the application of 80:20 medial/lateral condylar loading distribution via AGC femoral component. Device design courtesy of Richard R. Glisson, Orthopaedic Research Laboratories, Duke University Medical Center, Durham, NC.

tibiae were measured and verified to minimize interspecimen deviations in slope and component rotation.

Because the exact location of peak shear strains in the tibia were not known in advance, the photoelastic method of shear strain analysis was used to provide a full-field description of strain on the surface of the proximal tibia [12]. Before mechanical testing, a photoelastic coating was molded and bonded to the proximal third of the tibia following procedures from the manufacturer and prior validation studies [10,12]. Photoelastic resin (Vishay Micro-Measurements, Raleigh, NC) was cast into 2-mm-thick sheets, molded to the proximal tibia, and permanently adhered with a reflective epoxy (Vishay Micro-Measurements, Raleigh, NC). A section of each coating was retained and measured in 10 random locations to determine a mean coating thickness for strain calculation. A standardized measurement grid was created to designate 24 locations on the proximal tibia at which peak strain values were measured. Strain measurements were taken in 1-cm increments distal to the tibial plateau and in each of 8 longitudinally marked columns. An alignment apparatus was constructed to ensure repeatable region delineation between each specimen. Measurement rows were designated as proximal (0-1 cm), middle (1-2 cm), and distal (2-3 cm), whereas columns were designated as anteromedial central, anteromedial peripheral, anterolateral central, anterolateral peripheral, posteromedial central (PMC), posteromedial peripheral, posterolateral central (PLC), and posterolateral peripheral (PLP).

AGC metal-backed tibial components with modular 10-mm UHMWPE tibial tray inserts were compared to 10-mm-thick all-polyethylene AGC tibial components. A 70-mm AGC femoral component was fitted to a custom-loading apparatus allowing axial compressive loads to be applied directly from the femoral component to the tibiofemoral interface at both a 50:50 and an 80:20 medial/lateral condylar distribution. The femoral component was positioned onto the tibial component, replicating full extension of the lower leg at the knee during stance phase. Loads on each condyle of the femoral component were measured with subminiature load cells (Honeywell Sensotec, Columbus, Ohio) installed within the custom-loading apparatus [10]. Each tibia was potted distally in a hard polyester resin and mounted with a universal joint to a materials testing machine (MTS Systems Corporation, Eden Prairie, Minn). A static axial load of 2700 N (4× assumed body weight of 70 kg) was applied to reproduce typical forces seen at the tibiofemoral joint during normal gait [11] (Fig. 1). Four trials for each test specimen were conducted with no evidence of fracture or fatigue.

Shear strain measurements were taken during loading using a reflection polariscope (Vishay Micro-Measurements, Raleigh, NC) following methods outlined in prior studies [10,12]. In summary, a circularly polarized light source was used to illuminate the test specimen and subsequently viewed through a set of analyzer lenses and camera system mounted on the reflection polariscope (Fig. 2). Changes in the index of refraction of the photoelastic coating bonded to each specimen created color bands when viewed through the analyzer lenses of the polariscope [10,12]. These quantifiable color bands, named *isochromatic fringes*, are directly related to strains induced on the surface of the tibia during axial loading

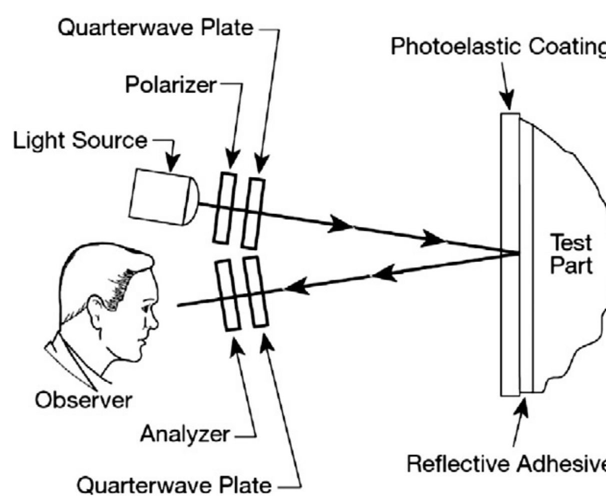

Fig. 2. Schematic of photoelastic shear strain measurement test setup. White light is polarized and then reflected off of the coated tibia. Coloration bands on the tibia corresponding to quantifiable strain are viewed through the analyzer lens. Image used with permission from Vishay Inter-Technology, Inc. "Introduction to Stress Analysis by the PhotoStress Method" TN-702-2.