Characterization of Contact Pressure in Total Knee Arthroplasty as a Function of Component Position and Ligament Balance

L. Aram\(^1\), F. Amirouche\(^1\), M. Gonzalez\(^2\), R. Giachetti\(^1\)

\(^1\)University of Illinois at Chicago, Department of Mechanical Engineering, Chicago/IL
\(^2\)University of Illinois at Chicago, Department of Orthopaedic Surgery, Chicago/IL

Introduction

In this study, contact pressures inside cadaver knee joints are recorded using thin (0.005") pressure sensors that are built into a special tibial insert. The knee is placed through a range of motion and the contact pressure is recorded in real time. Pressure readings are correlated with component position and ligamentous balance allowing optimization of these parameters.

Component alignment and ligamentous balancing is essential to the proper function of a total knee arthroplasty. Improper alignment or balancing of the knee arthroplasty can lead to component maltracking and varus valgus instability resulting in increased shear force as well as isolated peak pressure across both the bone prosthesis interface and the articulation itself. Current knee jigging systems emphasize bony alignment to reconstitute the mechanical axis of the knee. More subtle aspects of alignment such as tibial component rotation and ligamentous balancing are also important to the proper function of the prosthetic knee. Current statistics show that 5-10% of TKAs fail in the first ten to fifteen years. It is our hypothesis that component malposition and poor ligamentous balancing contribute to premature failure of a total knee arthroplasty. A system is designed to better quantitate dynamic pressures at the tibiofemoral interface to optimize balancing and alignment of a total knee arthroplasty.

Methods

In this study, an array of six pressure sensors was built into a special tibial insert. TKAs were performed on three fresh cadaver knees using an intramedullary jigging system for the femoral component and an extramedullary system for the tibial component. The Johnson & Johnson P.F.C.® Σ Cruciate Substituting Knee System was used. The tibial insert was inserted into the joint with the sensor wiring running through the original surgical wound (see figure 1). A jig was designed that rigidly immobilized the femur while allowing free motion of the tibia and quadriceps mechanism. The quadriceps were loaded using three pulleys to approximate the vector pull of the three main portions of the quadriceps muscle. The rectus femoris and vastus intermedius were tied together and loaded with a 30-N weight, the rectus medialis was loaded with 25-N weight, and the vastus lateralis was loaded with 20-N. Finally, a high precision potentiometer was used to measure the joint angle. The knee was then flexed and extended from 0 to 90 degrees. A distribution of contact pressure was recorded as a function of angle.
Results & Discussion

The contact pressures recorded at each sensor is displayed in figure 2. The joint angle ranges from roughly $0^\circ$ to $90^\circ$, where $0^\circ$ is a straight leg. Sensor 1 is located on the midline of the posterior of the medial condyle, sensor 2 is in the middle of the medial condyle, and sensor 3 is on the midline of the anterior of the medial condyle. Sensor 4, 5, and 6 are located on the lateral condyle. During knee extension, very small contact forces were recorded while the knee was between $0^\circ$ and $50^\circ$. Sensor 1 and 4 have maximums at $95^\circ$ with pressures of 15- and 65-psi. This is due to point loading that occurs when the stabilizing post of the tibial component pushes the femoral component to the distal end of the insert. During flexion, contact pressures were recorded with slightly smaller magnitudes. Forces on the medial and lateral condyle are not balanced in phase and magnitude. This would suggest a varus-valgus unstable knee. The high pressures recorded at the extended end of the graph suggests a joint that is too tight.
Further investigation is scheduled to determine the magnitude of malrotation and tightness.

The desired result of a TKA is joint stability, durability, adequate range of motion, and freedom from pain. This is generally achievable through a joint that evenly and smoothly spreads the dynamic loading of weight bearing from the femur to the tibia. The optimal TKA is not one that is anatomically perfect, but one that evenly addresses the weight distribution at the joint.

**Figure 2:** The recorded contact pressure during extension and flexion

**Acknowledgements:**
The authors greatly appreciate the support of the J&J Depuy Corporation.