Effect of Surface Roughness on Mechanical Stability of Highly Porous Metal Cementless Tibial Implants

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INTRODUCTION:

The initial mechanical stability of press-fit implants is critical in order to limit micro-motion at the implant-bone interface and facilitate osseointegration. Recent development of highly porous metal technology has provided improved biomechanical and biological properties, which theoretically allow improved stability and ultimate osseointegration. The initial mechanical stability of these devices has been partially attributed to their greater frictional resistance, or roughness, as compared to traditional press-fit implant materials. The objective of this study is to assess the contribution of roughness to the mechanical stability of cementless tibial components made from highly porous metals.

MATERIALS AND METHODS:

The experimental group consists of three groups of modular tibial components with varying degrees of surface roughness. A group of cemented CoCr components served as the control. The test groups each had highly porous (60-65% porosity) metal ingrowth surfaces and were identical in design, with two pegs for initial fixation. The three test groups were manufactured with different levels of roughness on their porous surfaces (smooth, low roughness, and high roughness). A perceptible difference in roughness was confirmed by surgeon co-authors prior to testing and it was felt that the smoothest surface finish was inadequate for clinical success.

Each tibial component was implanted into a rigid polyurethane foam mechanical testing replicate specimen. The replicate bone is a custom design with 12.5 pcf closed cell foam (Sawbones, Pacific Research Laboratories Inc. Vashon, WA.) Specimens were impacted into the tibial specimen under the supervision of an experienced arthroplasty surgeon. Cemented components were inserted with standard cementing technique.

All components were tested utilizing a modular posterior stabilized tibial insert. The tibial components were individually loaded through a mating femoral component, fixed at 60^{o} of flexion and 6^{o} of fixed external rotation. A constant compressive load of 700 N was applied using an air cylinder while anterior and posterior displacement of the tibia was controlled by a servohydraulic load frame (MTS Eden Prairie, MN) (Figure 1). Cyclic AP motion was applied for 30 cycles at a rate of 0.1 Hz. Components were positioned such that cam post engagement resulted in shear forces of up to 350 N.

Figure 1: Experimental Test Setup

Six LVDTs were mounted on a rigid frame attached to the tibial specimen and the LVDT plungers contacted a flat surface of cubes attached to the loaded tibial component. Micromotion was calculated at the specimen-implant interface in five peripheral locations via the LVDT displacement data. Maximum cyclic displacement was calculated as the difference in minimum and maximum for the last 5 cycles of the LVDT data. Student's T-test at 95% confidence was used for statistical comparison between test groups.

RESULTS:

The posterior medial and lateral edges exhibited the greatest liftoff and translation of the tibial component. The average maximum displacement at these two locations for the 3 test groups and control is reported in Figure 2. A significant difference in initial stability was observed between the cemented control and all uncemented test groups at both locations. The cementless two-peg smooth test group performed the most favorably and was significantly more stable then the rougher cementless test groups at the posterior medial location. No other differences were significant at a confidence level of 95%.

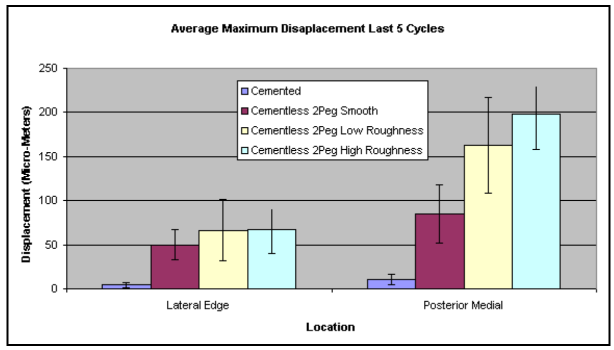

Figure 2: Average Maximum Displacement

CONCLUSION:

The unexpected results from this study reveal that the surgeon-perceived correlation between surface roughness and initial tibial component stability is more complicated than originally thought. In this study the cementless tibial component with the least amount of surface roughness (and surface porosity) demonstrated the greatest stability. This may indicate that the rougher highly porous surfaces may damage the surrounding bone with insertion, relegating the subsequent interference fit less than optimal. This may support the fact that geometrical interference fit is a more dominant factor related to implant stability.

These findings may also be related to the fact that rougher surfaces have a reduced surface area which increases the perception of roughness but minimizes the surface contact, potentially reducing the frictional resistance. However, greater porosity has been shown to facilitate the biologic response and subsequent osseointegration, so this must be weighed carefully when considering the optimal surface roughness and porosity of cementless tibial components. Continued research and testing should be carried out with fresh frozen cadavers to explore these features against more biologically and mechanically representative surfaces.

The results of this study shed new light on how surface roughness, porosity, and geometrical interference fit effect the stability and mechanical behavior of cementless implants made of highly porous metal. These mechanical features must be taken into account, along with the biological properties of the highly porous metal, when developing future designs of modern cementless knee arthroplasty.