Evaluating the Knee Implant-Bone Interface from a Mechanics and Materials Science Perspective

key words: knee implant, ossesointegration, implant surface treatment

In the United States, over 500,000 knee replacement procedures are performed each year in patients of all ages, but most patients are age sixty to eighty [1]. With an aging world population, these knee implants must be designed to last longer than ever before. For these implants to succeed in the long term, they must maintain stability; and the strength of the implant-bone interface is an important factor in this stability [2]. The integrity of the implant-bone interface is influenced by several aspects of the implant design, including the materials used in the design as well as the forces distributed onto the surrounding bone by the implant [2, 3, 4]; and the main causes of failure of cementless knee implants are due to stress shielding along this interface and the accumulation of wear debris [3, 4, 5]. The primary objective of my proposed research is to increase the knowledge of how different materials and surface treatments affect the biomechanical properties of the implant-bone interface of knee implants.

Understanding the biomechanics of the implant-bone interface, including why stress shielding occurs, is important in developing implants with longer lifespans because one of the main causes of knee implant failures is the aseptic loosening of the implant-bone interface [3, 5]. It is thought that this loosening occurs because of stress shielding in the bone surrounding the implant [3, 5, 6]. Since the implant is much stiffer than natural bone, abnormal loading patterns lead to stress shielding [3, 6]. Many materials used in implants today do not allow for osseointegration into the implant, which can increase the strength of the implant-bone interface and distribute the load to the surrounding bone from the implant, similar to the nature of natural bone [3]. Currently, research to develop different surface treatments and bioactive coatings is underway, and this research aims to increase the level of osseointegration of bone into the implant, which could reduce the occurrence of aseptic loosening [7].

Understanding the changes within the implant-bone interface of knee implants has great potential to lead to improved implant design. It is thought that the rougher surfaces, especially laser nanogrooved surfaces, will enable a higher degree of integration of the bone with the surface of the implant and increase the interface strength while better distributing loads and decrease stress shielding. Specific objectives include the following:

1. *Ex vivo* pushout tests to determine the mechanical properties and strength of the implant-bone interface
2. Histological analysis to determine the differences in implant-bone interface structure
3. Finite Element Modeling of the Knee-Implant interface

The pushout tests of the implant-bone interface will be conducted using a 100 N load cell on a MTS 858 Mini Bionix II to perform the tests on transversely cut prepared *ex vivo* specimens from cementless knee implants. The pushout is one of the most common methods used to test the *ex vivo* mechanical properties of the implant-bone interface of orthopaedic and dental implants [9]. Pushout tests generally produce a load-displacement curve, and from this data, the ultimate shear strength can be calculated by dividing the maximum pushout force by the interface area

[9].

Specimens from the same *ex vivo* cementless knee implants will then be prepared for histological analysis by using Exakt® cutting and grinding system to produce a ground section. Then the specimens will be stained with methylene blue basic fuchsin before observation under a bright field microscope. The pictures obtained will then be analyzed using Bioquant® software to acquire the measurements needed. Histological analysis will allow for the mechanical testing results to be compared to the structure of the implant-bone interface. Understanding both the mechanical properties and the underlying structure of the interface will enhance the knowledge of how different surface treatments and implant materials affect the integrity of the interface. Abaqus finite element analysis (FEA) software will be used to simulate multiple loading states onto the knee-implant interface. Changes in the amount of stress within the interface area will be quantified based on the specific stress states and loading rates in the knee-implant complex.

My past research focused on the stability of the implant-bone interface of dental implants. I plan to use this knowledge and apply similar principles to the implant-bone interface of both the femoral and tibial components of knee implants. This proposed research will allow me to collaborate with those developing new surface treatments to study whether these surface treatments are effective in improving the stability of the implant-bone interface. It is known that rougher surfaces allow for better implant-bone attachment, but the degree of roughness and whether large-scale or nano-scale roughness affects the interface is under debate. It is anticipated that this proposed research will show that surface treatments on the nano-scale will produce better attachment and increase the long-term stability of the implant

This research will also help us to better understand how different surface treatments affect the biomechanical properties of the interface, while the ultimate goal of the research is to help improve the longevity and success of cementless knee implants. Cementless implants have not been used as frequently in the past in the United States as their cemented counterparts because of the current high failure rate associated with them [5]. If knee implant longevity is improved through the use of well-designed cementless implants, younger patients receiving the implants would have to undergo fewer revision surgeries, reducing costs; and those with severe knee pain would not have to wait or suffer as long in order to receive a total knee arthroplasty.

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