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# Design Parameters for Hip Prosthesis

Total Hip Arthroplasty (THA) is a surgical procedure to replace damaged cartilage and bone in the hip with prosthetic implants. The ball and socket joint of the hip allows for flexible range of motion and provides stability to support the torso. The femur head connects the leg to the pelvis through the acetabulum socket. This interface is connected by cartilage – a protective tissue that reduces friction as the hip bone moves in its socket. Despite its durability, the hip joint isn't indestructible. With age and use, the cartilage can wear down or become damaged, causing joint pain and stiffness. If the symptoms of this condition – also known as osteoarthritis, impair daily activities, a hip replacement surgery may be the appropriate medical intervention.

During a THA, the damaged femur bone is cut and replaced by a metal or a ceramic ball that is connected to a metal stem which can be cemented on the remaining femur. The acetabulum socket is replaced by a metal shell which is screwed onto the pelvis. To mimic the function of the cartilage, an acetabulum liner is placed between the metal shell and the femur head to reduce the friction during movement. Polymers like Ultra High Molecular Weight Polyethylene (UHMWPE) are commonly used for the liner while the femur head is typically composed of a metal (titanium, cobalt-chromium) or ceramic material. UHMWPE has a low coefficient of friction (< 0.14) which is a good replacement for a fully functional cartilage. While considerations for the material should include biocompatibility to avoid metallosis or triggering inflammatory response, the goal of this project is to study the prosthetic materials from a mechanical standpoint. Since UHMWPE is the most common material for the procedure, this material will be the focus of the project.

The stability and wear of the UHMWPE liner are related to the diameter and material the femoral head. Larger diameter femur heads are associated with increased joint stability through increases in arc range of motion and excursion distance before dislocation. While the prosthetic's metal shell size is dependent on the patient anatomy, different femur head sizes and liner thickness can be compatible within a given shell. The goal of this project is to explore different femur head – liner combinations and how they impact the contact stresses on the liner surface. The analysis was conducted for different metal shell sizes (52mm, 54mm, 56mm, 58mm). Given the common commercially-available femur sizes (28mm, 32mm, 36mm), various UHMPWE liner sizes will be paired with each femur head size to fit the 4 metal shell sizes of interest. Furthermore, as UHMWPE is an elastic-plastic material, this project explored the forces that are required to indent and induce plastic deformation given a certain liner size. The objective was to optimize these two parameters to minimize peak contact stresses and plastic deformation.

Using Abaqus, this problem was modeled as a rigid indenter problem. The femur head, which was originally being modeled with Titanium material properties (E=210 GPa, v=0.361), was idealized as a rigid body. It is a semi-circular 2D axisymmetric, discrete rigid wire that is constrained in the x- and z- direction. It is in direct contact with the liner which is modeled as a 2D axisymmetric, deformable material with an elastic modulus of 1.2 GPa, Poisson's ratio of 0.3, and yield stress of 24 MPa. The static analysis was conducted given an increment size of 0.01 for 1 second. The interaction prescribed was a frictionless, hard contact, with the femur head as the "master surface" while the liner was designated as the "slave surface". The boundary condition of the outer liner surface was constrained to 0 for the x, y, and z direction. This is an appropriate assumption since the liner is attached to a metal shell that is screwed onto a femur. For the femur head, a reference point was assigned atop the wire. For the indentation data analysis, the boundary condition of the reference point did not allow for movement along the x and y direction. However, the y direction is unconstrained with displacement values specifying to indent a certain percentage of the liner thickness being studied. This indentation was applied for 1 cycle and was completely removed at the end of the cycle. With regards to meshing, the deformable part was meshed with triangular elements of size 0.0005 with biased seeding (smaller mesh size of 0.0004) along the inner radius and towards the y-axis. The discrete rigid part required the wire to be meshed (unlike an analytical rigid part) and was assigned a size of 0.0005. This process was repeated for at least 12 models with its own unique femur head and liner size combination.

In the first analysis, an indentation test was conducted to indent a liner by 1% of its thickness. By probing the reaction force at the liner's central point, the force required to indent liners of sizes 16mm to 28mm were largely dependent on the femur head size. The data showed that the force needed to impose a 1% indentation on a liner is greater for a 36mm femur head than for 32mm and 28mm femur heads. Additionally, given a certain femur head size, more force is required to indent thicker liners. At the end of the cycle, the fractional displacement of the liner returned to zero, indicating that a 1% indentation does not require enough force to plastically deform the liner.

While the force required for a 5% liner indentation was also greater from larger femur head sizes, the force was large enough to plastically deform the liner. For instance, after looking at the 5% indentation of 20mm UHMWPE by a 3 mm and a 36mm femur head, the force required was smaller for smaller femur head sizes – 35 kN for a 32mm head and 45 kN for a 36mm head. At the end of the cycle, the liner did not return to its original position and had a fractional displacement of ~0.02. The next objective of this study is to assess how much force is necessary to induce plasmatic deformation on the liner. By varying the concentrated force on a 28mm femur head, it was determined that plastic deformation will occur if the force exceeds 11 kN. By applying the same magnitude of force on the 28mm head, a thicker liner also showed less fractional displacement. For a 36mm head, plastic deformation will occur if the force exceeds 18 kN.

The last objective of this study is to study the contact stress on the liner. Based on literature values, an impact velocity of 3.0 m/s and femoral force of 5200 N are the average values in an unexpected sideways fall for an average individual. By applying this load as a concentrated force to simulate a sideways fall, the data shows that peak contact stress in the liner depend on femur head size. Smaller femur heads impose greater peak contact stress for various liner sizes. Additionally, by looking at the peak contact stress of 20mm and 24 mm liners from 32mm and 26 mm femur heads, a thinner acetabular liner have smaller peak contact stress. Data for a fixed shell size of 52mm, 56, and 58mm were also explored with different liner sizes. The trends for the shells are the same – opting for a smaller liner and a larger femur head can minimize peak contact stress.

Based on the information collected, larger femur heads with thicker linings are recommended to minimize plastic deformation upon large impact. Although the force of a sideways fall (5200 N) is not enough to plastically deform the liner, this recommendation is advisable to the older demographic who are prone to falling, especially from height. Since a thinner liner experiences smaller peak contact stress, opting for a larger femur head with medium to thin

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liner may be recommended for more active people who exert more stresses on their hip. This option may minimize peak contact stress and improve the longevity of the hip implant.