



## Hip Implant Design using Stainless Steel 316L for Enhanced Stability and Patient Comfort

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**Abstract:** In a hip replacement procedure, the damaged bone and cartilage are removed and replaced with an artificial component known as prosthesis. Despite advancements in implant sterilization, design, fixation techniques, and the introduction of robotic surgery, a persistent challenge is to identify an optimal, patient-specific hip implant that meets individual criteria. The primary objective of the proposed study was to create a highly accurate patient-specific hip implant by standardizing the existing design. The secondary objective aimed to demonstrate the superiority of a customized design over a conventional one. Geometric measurements of the hip were extracted from CT scans using MIMICS 20.0 software, and the implant design was developed using SolidWorks. Finite Element Analysis (FEA) was employed for meshing and analyzing the planned implant. Comparative research through FEA analysis indicated that a customized implant made from SSL 13 material outperformed the standard implant, showcasing its suitability for the patients studied.

**Keywords:** Prosthesis, Implant sterilization, Designing, Fixing, SolidWorks, FEA

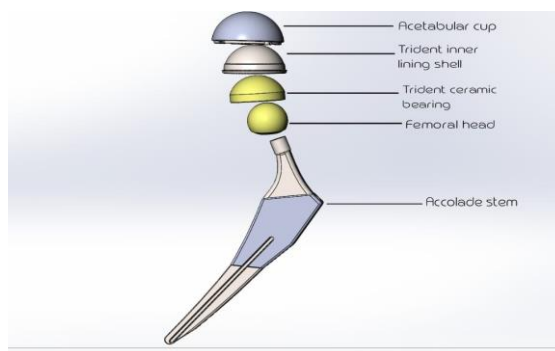
### 1. Introduction

The hip joint can support the whole body's weight while also providing stability, primarily during the movement of the trunk on the femur, which occurs when a person walks or runs. The fact that the head of the femur articulates into the pelvis provides the joint with varying degrees of freedom, which in turn assists the movement of the joint. Hip arthroplasty was shown to be a successful medical operation in the early years of the 20<sup>th</sup> century, and it was used to treat a wide variety of hip joint conditions. Total hip arthroplasty is widely recognized as being among the most effective and innovative surgical procedures now available in the medical field [1, 2]. It was widely believed that Sir Charnley was the primary designer behind

complete hip joint arthroplasty. A bearing surface is inserted between the acetabulum and the femoral head as part of a total hip arthroplasty procedure. After arthroplasty, the stems are the key components that contribute to the joint's stability. Currently, hip joint arthroplasty has a survival rate of 95% for patients older than seventy years and a success rate of 10 years for those individuals. Osteolysis is the outcome of biological and biomechanical interactions between the wear debris created by total hip arthroplasty and the environment. Hip arthroplasty, often known as hip replacement surgery, is a surgical operation in which the doctors remove the diseased hip and replace it with an implant that is available for pSince 1840, there has been a significant increase in the sophistication of hip replacement surgery. When other treatments, including oral medicine, topical creams, and physical and occupational therapy, are unsuccessful in treating a patient's condition, a difficult surgical procedure may be recommended [3-6]. The main reason why a patient-specific implant is required is so that the risks and issues that are often connected with imported implants from other countries may be reduced as much as possible. Conventional implants are not as precise as patient-specific implants. The pre-operative planning that is done as part of patient-specific hip replacement surgery is an important step that may help reduce or avoid the post-operative complications that may arise after surgery. A reduction in the likelihood of problems after surgery is one of the primary benefits of careful pre-operative preparation [7-9].

In preparation for implant surgery, the patient's physiological factors, including height, weight, age, blood pressure, temperature, and oxygenation level, were assessed. This evaluation aimed to confirm the patient's suitability for the hip replacement procedure [10-13]. The primary objective of the proposed study was to create a precise, patient-specific hip implant by standardizing the existing design. Additionally, the secondary goal was to prove the superiority of a customized design over a conventional one, serving as the study's secondary aims and objectives [14-16].

## 2. Design



**Figure 1.** Design of Hip Implant

The figure. 1 represents the design of Hip Implant, which had designed in SolidWorks

Software, Hip Implant consists of,

- Accolade-stem.
- Femoral-Head
- Trident-ceramic-bearing
- Trident-inner-lining-shell
- Acetabular cup

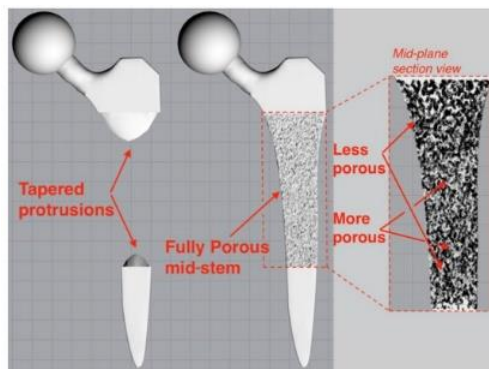
### 3. Topology Optimization

Hip implants are designed to replace a damaged or deteriorating hip joint with an artificial implant that can restore mobility and alleviate pain. The design and optimization of hip implants are crucial to ensure a successful outcome of the surgery and long-term functionality for the patient [17].

Mesh, full body, and shape modification are three techniques that can be used to optimize the design of hip implants.

**Mesh optimization:** This technique involves creating a mesh of the hip implant design and using simulation software to analyze the stresses and strains on the implant during movement. This allows for the identification of potential weak points in the design and optimization of the implant's geometry to improve its strength and durability.

**Full body optimization:** This technique involves simulating the entire body's movements to ensure that the implant's design is optimized for a range of activities and movements. This includes analyzing the stresses and strains on the implant during walking, running, and other physical activities to ensure that it can withstand the forces placed on it [18].



**Figure 2.** Porous in the implant

This figure. 2 shows a porous implant, which contains tapered protrusions that enable a gradual transition between the porous and solid regions of the implant. On the left side of the

image, you can see the tapered protrusions, which are small, pointed features that extend outward from the surface of the implant. These protrusions create a gradual transition zone between the porous and solid regions of the implant [19].

Shape modification: This technique involves modifying the shape of the hip implant to better fit the patient's anatomy. This can improve the implant's stability and reduce the risk of dislocation, which is a common complication of hip replacement surgery.

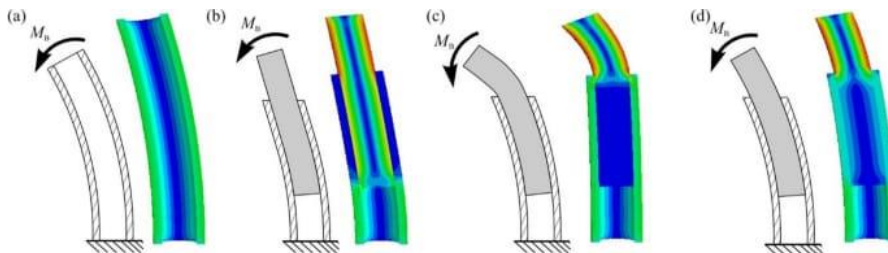


Figure 3. Represents different scenarios

This figure represents different scenarios of how the stiffness of an implant can influence the stress situation in the bone.

Overall, the use of mesh, full body, and shape modification techniques can help optimize the design of hip implants and improve their long-term functionality for patients. It is important to note that the optimization process may involve a combination of these techniques and should be tailored to each patient's needs and anatomy [20, 21].

#### 4. Analysis

Outline of Schematic A2: Engineering Data				
A	B	C	D	E
1	Contents of Engineering Data		Source	Description
2	Material			
3	Stainless Steel 316l		C:\Users\user\Desktop\Engin	
4	Structural Steel		General_Materials.xml	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
* Click here to add a new material				

Properties of Outline Row 3: Stainless Steel 316l				
A	B	C	D	E
1	Property	Value	Unit	
2	Material Field Variables	Table		
3	Density	8000	kg m <sup>-3</sup>	
4	Isotropic Elasticity			
5	Derive from	Young's Modulu...		
6	Young's Modulus	2E+11	Pa	
7	Poisson's Ratio	0.25		
8	Bulk Modulus	1.3333E+11	Pa	
9	Shear Modulus	8E+10	Pa	

Figure 4. The material properties

The figure. 4 defines the material properties of the implant. This includes the modulus of elasticity, Poisson's ratio, and yield strength of the implant material.

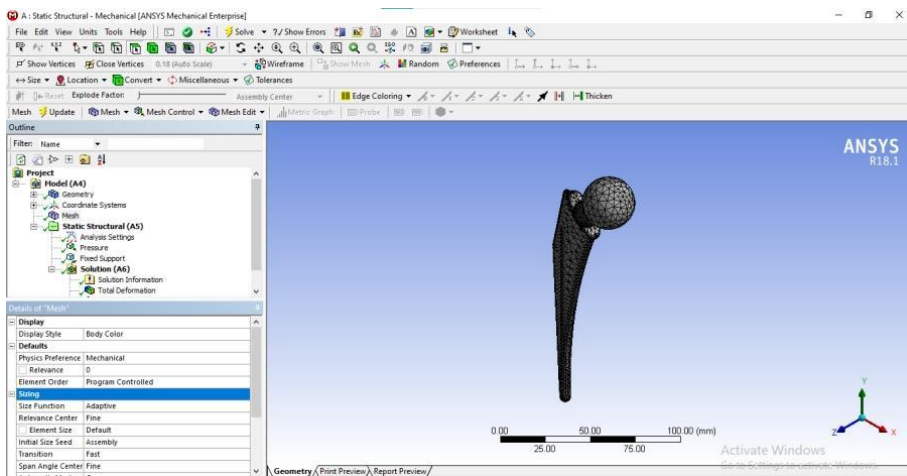
The figure. 5 shows Mesh the geometry of the implant. This involves dividing the implant into small, finite elements that can be analyzed using ANSYS.

Figure. 6 defines the fixed support boundary condition on any surfaces or nodes that represent the portions of the implant that are firmly anchored in bone or tissue. This may involve using the Fixed Support constraint in ANSYS.

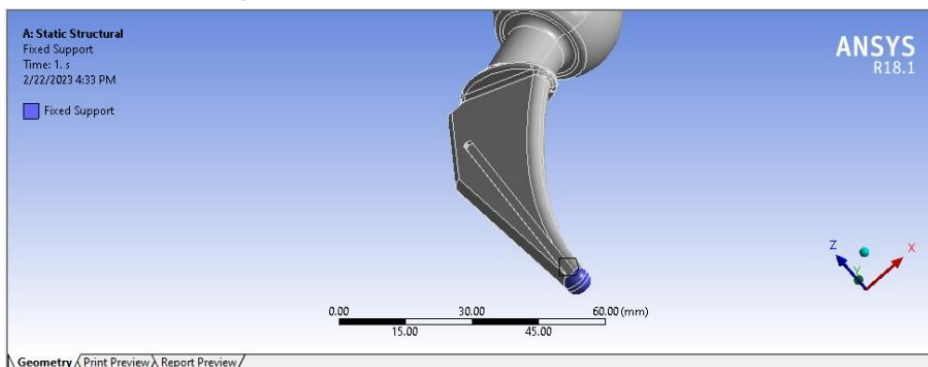
Figure. 7 defines the loading and boundary conditions of the hip implant. This includes the type and magnitude of the loads applied to the implant and the constraints placed on the implant [22].

A pressure of 0.5MPa is applied to the Acetabular cup.

Figure. 8 shows analyze the results of the simulation. This involves examining the stress and strain distribution in the implant to determine whether the implant is likely to fail under the given loading and boundary conditions.



**Figure 5.** Mesh the geometry of the implant



**Figure 6.** Fixed support boundary

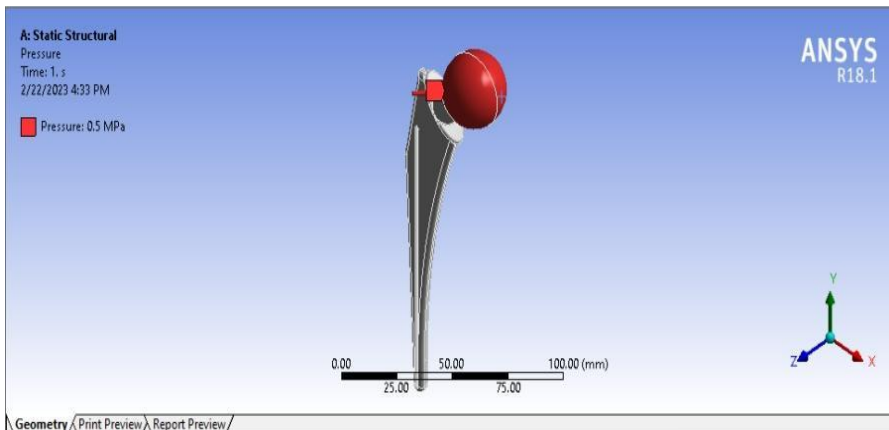


Figure 7. The loading and boundary conditions of the hip implant

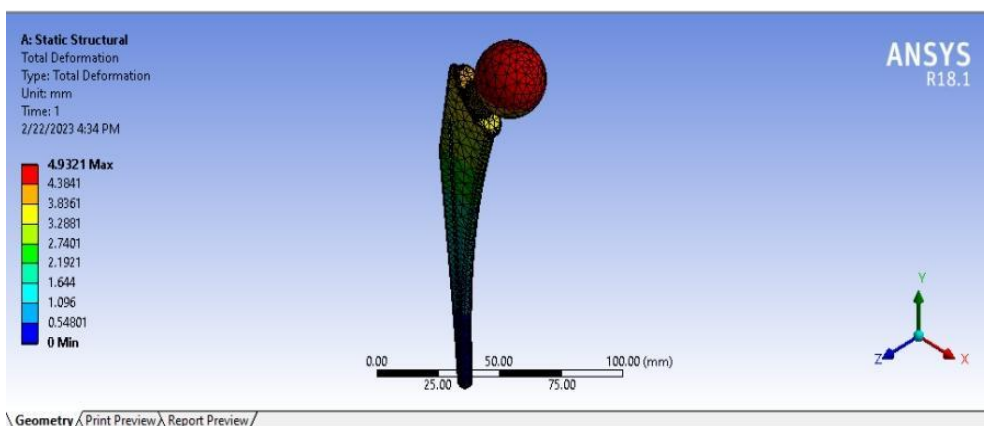


Figure 8. Analyze the results of the simulation

At 4.921 mins with 0.5MPa pressure hip implant is deformed.

To determine the stress and strain in the implant subjected to an applied pressure of 0.5 MPa, essential information about the implant's geometry and material properties is required. In this hypothetical scenario, consider the hip implant as a cylindrical rod with a diameter of 10 mm and a length of 50 mm. The material is stainless steel 316L, characterized by an elastic modulus of 200 GPa, a yield strength of 240 MPa, and an ultimate tensile strength of 580 MPa [23].

First, we can calculate the cross-sectional area of the implant:

$$A = \pi d^2/4 = \pi (10 \text{ mm})^2/4 = 78.54 \text{ mm}^2$$

Then, we can calculate the stress on the implant under the applied pressure:

$$\sigma = F/A = P\pi d^2/4A = 0.5 \text{ MPa} * \pi * (10 \text{ mm})^2 / (4 * 78.54 \text{ mm}^2) = 0.637 \text{ MPa}$$

Next, we can calculate the strain in the implant using Hooke's law:

$$\varepsilon = \sigma/E = 0.637 \text{ MPa} / 200 \text{ GPa} = 3.185\text{e-}6$$

To determine whether the deformation observed after 4.9321 minutes of loading is within the elastic limit of the material, we need to calculate the total deformation that has occurred in the implant. Since we don't have information on the deformation that was observed, let's assume that the implant deformed by 0.1 mm.

The total strain in the implant can be calculated as:

$$\varepsilon_{\text{total}} = \Delta L / L = 0.1 \text{ mm} / 50 \text{ mm} = 2\text{e-}3$$

We can compare this value to the yield strain of the material, which can be calculated as:

$$\varepsilon_{\text{yield}} = \sigma_{\text{yield}} / E = 240 \text{ MPa} / 200 \text{ GPa} = 1.2\text{e-}3$$

Since the total strain in the implant ( $2\text{e-}3$ ) is greater than the yield strain of the material ( $1.2\text{e-}3$ ), we can conclude that the deformation observed after 4.9321 minutes of loading has exceeded the elastic limit of the material and has caused plastic deformation [24]. This means that the hip implant has undergone permanent deformation and may be considered to have failed, depending on the specific design and performance criteria for the implant.

## 5. Conclusion

The design and analysis of hip implants are crucial to ensure the safety and efficacy of these medical devices. In conclusion, the process involves several stages, including design conception, material selection, modeling, simulation, and testing.

The use of advanced techniques such as finite element analysis (FEA) and SolidWorks enables engineers and researchers to simulate the behavior of hip implants under different conditions, such as different loading and movement patterns.

However, it is essential to validate these simulations through experimental testing, including *in vitro* and *in vivo* studies. This is necessary to ensure that the implant design is optimized for its intended use and can withstand the loads and stresses it will encounter in the human body.

Overall, the design and analysis of hip implants require a multidisciplinary approach, involving engineers, biomechanics experts, medical professionals, and regulatory bodies. By following this approach, we can ensure that hip implants are safe and effective and can improve the quality of life for patients suffering from hip joint conditions.

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