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# Computer aided analysis of biomechanical performance of schanz screw with different additive manufacturing materials used in pertrochanteric fixator on an intertrochanteric femoral fracture (corrosion resistance approach)

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**Abstract**

This study examines the use of computer-aided analysis to evaluate the biomechanical performance of Schanz screws made from different additive manufacturing materials (Ti6Al4V, 316 L, Inconel 625, and Inconel 718) in a pertrochanteric fixator for the treatment of intertrochanteric femoral fractures. Intertrochanteric fractures (ITFs) are severe traumas often seen in the elderly population and can lead to serious consequences. The primary objective of ITF surgery is to provide stability and allow for early ambulation and rehabilitation. The Pertrochanteric Fixator is a surgical implant used to treat hip fractures near the greater trochanter, and is attached to the femur with screws. The procedure is performed under general anesthesia and typically takes 1–2 h. Possible complications include infection, nerve injury, and hardware failure. The aim of this study is to evaluate the biomechanical performance of Schanz screw using computer-aided analysis, comparing the effects of various additive manufacturing materials including Ti6Al4V, 316 L, Inconel 625 and Inconel 718 in a pertrochanteric fixator for intertrochanteric femoral fractures. Additionally, this study will also consider the corrosion resistance of these materials to ensure long-term durability and effectiveness in a clinical setting. The stress values mentioned for the implant materials are as follows. Ti6Al4V: 153.33 MPa, 316 L: 180.98 MPa, Inconel 625: 158.94 MPa, Inconel 718: 148.91 MPa. Higher stress values indicate a greater load transfer to the bone, which can potentially lead to stress shielding. Stress shielding occurs when an implant bears a significant portion of the load that should be transferred to the bone. This reduced stress at the fracture site can prevent the healing process, as bones require adequate stress levels for optimal remodeling and regeneration.

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**KEYWORDS**

additive manufacturing materials, biomechanical performance, computer-aided analysis, intertrochanteric fractures (ITFs), Pertrochanteric fixator (PTF), Schanz screw

## 1 | INTRODUCTION

Intertrochanteric fractures (ITFs) are considered serious traumas, often seen in the elderly population and can lead to severe consequences such as pneumonia, pulmonary embolism, morbidity, or even death.[1–4] The importance of achieving anatomical correctness in the treatment of ITFs cannot be overemphasized, as lack of it can result in shortness of extremities, varus and external rotation deformities.[5,6] The primary objective of ITF surgery is to provide stabilization to ensure safe movement and loading on the fracture in the reduction position, thereby allowing early ambulation and rehabilitation for the patient.[5,7] The low magnitude of bearing forces along the fracture line during axial loading indicates the safety of the method used.[8] External fixators have been used in ITF treatment since 1950, but they are not commonly preferred due to the risk of postoperative complications such as infection and mechanical weakness.[9] On the other hand, the dynamic hip screw (DHS) has been widely adopted since the 1960s,[10–12] however, Moroni et al.[5] have stated that these internal fixators are not ideal for ensuring desired fixation and sufficient load transfer at the proximal femur and fracture line. One rare complication is fatigue failure of the sliding hip screw.[13]

A Pertrochanteric Fixator (PTF), also known as a Pertrochanteric Fracture Fixation device, is a surgical implant used to treat hip fractures near the greater trochanter, a prominent bony prominence located on the upper part of the femur (thigh bone). The device is typically used when other methods of fixation, such as internal fixation with a hip screw or plate, are not possible or have failed. The PTF device is attached to the femur with screws and consists of a metal frame that extends around the hip, providing stability and support to the injured bone as it heals. The device is adjustable, allowing for proper alignment and weight-bearing, and it can be removed once the bone has fully healed.

Surgery to insert a PTF is usually performed under general anesthesia and typically takes one to 2 h. After the surgery, patients typically need to use crutches or a walker for support, and physical therapy is usually recommended to help them regain strength and mobility in their hip. The use of a PTF can be an effective method of treating hip fractures, but it is not without risks. Possible complications include infection, nerve injury, and hardware failure. Patients should discuss the benefits and risks of the procedure with their doctor before deciding if a PTF is right for them.

A basicervical fracture[14] refers to a proximal femoral fracture occurring at the junction between the femoral neck and the intertrochanteric region. Various surgical approaches have been suggested for managing basicervical fractures, including proximal femoral nail, monolateral external fixation, and cannulated screws.[14–18]

Additive manufacturing is a method where an object is created by adding material, layer by layer, to form the final product. It is often referred to as 3-D printing and is different from subtractive manufacturing which involves cutting away material from a solid block to create the final product. This method was initially used to produce prototypes in the 1980s, for the purpose of creating scale models quickly and without incurring high costs. As the technology improved, its applications expanded to include the creation of molds for final products through rapid tooling. Today, companies such as Boeing and General Electric use additive manufacturing as a crucial part of their business processes. The process of additive manufacturing starts with the creation of a design, typically using computer-aided design software or by scanning the object to be printed. This design is then transformed into a layer-by-layer framework for the 3-D printer to follow. The 3-D printer creates the object directly from the digital design. A variety of materials can be used in additive manufacturing, including polymers, metals, ceramics, foams, gels, and even biomaterials. As long as the material can be joined locally, it can be 3-D printed.[19]

Materials such as Ti6Al4V, 316 L, Inconel 625, and Inconel 718 can also be used in additive manufacturing methods. In particular, lightweight and high strength materials like Ti6Al4V, Inconel 625, and Inconel 718 can be preferred to increase the strength of products made with layered manufacturing methods. Additionally, materials like 316 L, which are resistant to corrosion, also have the properties to be used in layered manufacturing methods. However, whether each material is suitable for use in layered manufacturing methods can change depending on the production conditions, product requirements, and properties of the material.

The purpose of this study is to evaluate the biomechanical performance of Schanz screw using computer-aided analysis, comparing the effects of various additive manufacturing materials including Ti6Al4V, 316 L, Inconel 625 and Inconel 718 in a pertrochanteric fixator for intertrochanteric femoral fractures. Additionally, this study will also consider the corrosion resistance of these materials to ensure long-term durability and effectiveness in a clinical setting.

# 2 | MATERIALS AND METHODS

## 2.1 | Computer aided finite element analysis

AnsysWorkbench, a commercial finite element analysis program, was utilized to study the biomechanical parameters of the femoral fracture and implants.[20] The use of AnsysWorkbench has been widely adopted in several studies on biomechanical analysis.[21,22] A 3D scan of the human femoral model was obtained using a 3D scanner, and a point cloud was created. The point cloud data was then used to generate a 3D model of the femur using the Geomagic Studio 10 program.[15,16] The material properties of the bone and implants, including Ti6Al4V, 316 L, Inconel 625, and Inconel 718, are summarized in Table 1.[23] The femoral model was not divided into cortical and spongiosa parts and was instead evaluated as having a constant density. The human femoral model was modeled as cortical and the it did not take into account cancellous bone in the FE model. Because, this study evaluated the biomechanical performance of Schanz screws made from different additive manufacturing materials (Ti6Al4V, 316 L, Inconel 625, and Inconel 718) in a pertrochanteric fixator for the treatment of intertrochanteric femoral fractures. The human femoral model used in this study had a mean shaft diameter of 20 mm, a 135-degree femoral neck-shaft varus angle, and a 15° femoral ante version angle. The age of patient is the middle aged and the bone mineral density is 2100 kg/m$^3$. The fracture line, angle, and position were determined based on the classification of Boyd and Griffin for trochanteric fractures.[24]

The intertrochanteric femoral fracture was modeled using the SolidWorks program, as shown in Figure 1. The implant models were also created in 3D using SolidWorks 2019. The models were imported into AnsysWorkbench for finite element analysis (FEA) preparation, and the mesh generation of the FEA was created. The mesh process was performed taking into account the power of the computer's processor. The mesh generation of the models was created using tetrahedrons element type as seen in Figure 2. The generated finite element model consisted of 190,467 nodes and 105,755 elements. The element size of the model was selected to be 2 mm for all components.

## 2.2 | Loading and boundary conditions

The FEA modeling was carried out using tetrahedron elements in AnsysWorkbench. The model consisted of 285,156 nodes and 166,231 elements, with a mesh size of 1 mm. A load of 15 Nm in torque was applied to the femoral head, which was fixed from the distal condylar articular face. To account for the interactions between the bones and screws, friction contact was defined with coefficients of 0.46 and 0.42 for bone-bone and screw-bone interactions respectively.[26] The convergence analysis of the model can be seen in Figure 3.

# 3 | RESULTS

The purpose of this study is to evaluate the biomechanical performance of Schanz screw using computer-aided analysis, comparing the effects of various additive manufacturing materials including Ti6Al4V, 316 L, Inconel 625 and Inconel 718 in a pertrochanteric fixator for intertrochanteric femoral fractures. Additionally, this study will also consider the corrosion resistance of these materials to ensure long-term durability and effectiveness in a clinical setting.

**TABLE 1** Mechanical properties of bone in SEA[25]

| Parameters | Bone |
|---|---|
| Density (kg.m$^{-3}$) | 2100 |
| Elasticity modulus (Gpa) | 17 |
| Tensile yield strength (Mpa) | 135 |
| Tensile ultimate strength (Mpa) | 148 |
| Shear strength (Mpa) | 6290 |
| Poisson ratio | 0.35 |

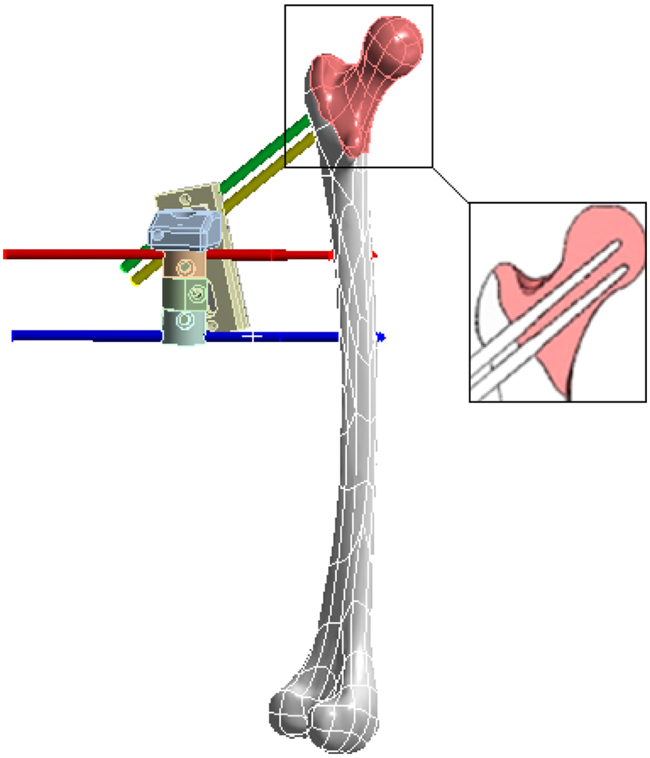

FIGURE 1 Pertrochanteric fixator (PTF).

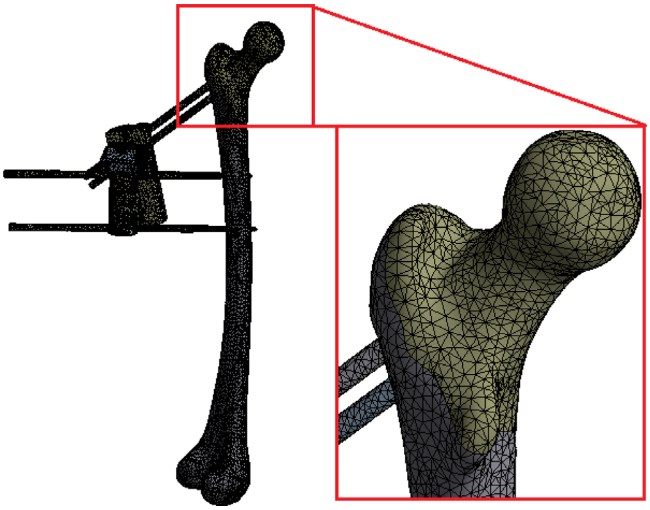

FIGURE 2 Mesh structure of the model.

FE model used in this study was validated with convergence analysis. The convergence analysis was performed, as shown in Figure 3. Force convergence is a commonly used criterion in non-linear analyses, indicating that a solution is considered converged when the purple line on the convergence graph aligns with the cyan line. If the solution does not converge, it indicates that there is a problem. The convergence status is influenced by various factors, including boundary conditions such as friction, contact type, and others. Achieving convergence is crucial for obtaining a reliable and accurate solution in the analysis.

The stress and deformation values in bone fracture line and screws and other results (gap, penetration and sliding distance values occurring in the fracture line) from obtained the computer-aided numerical analyses were given Tables 2 and 3. Figure 4 shows the stresses occurring at fracture line (upper and lower) for additive manufacturing materials.

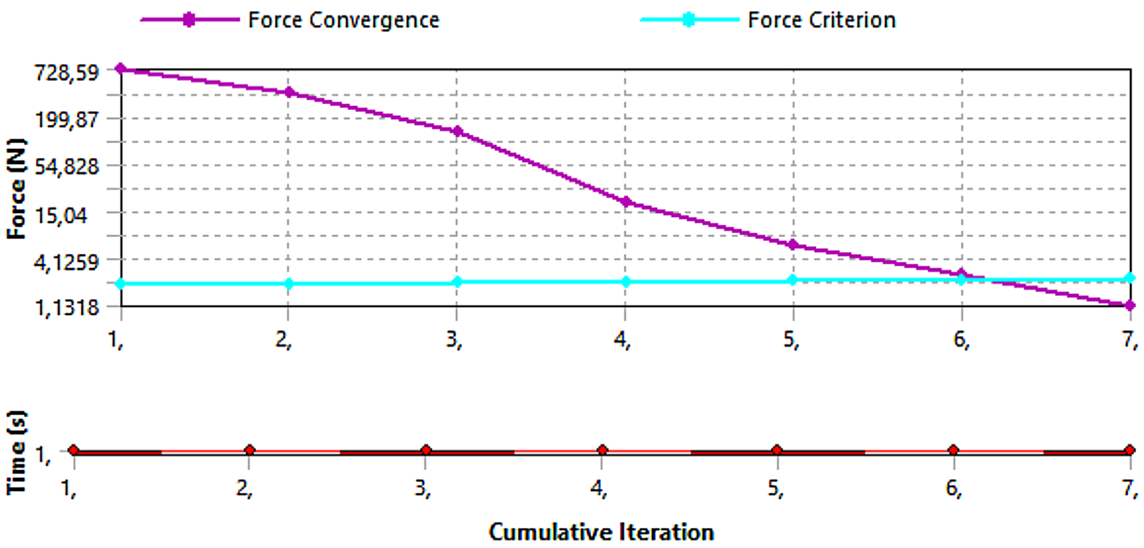

**FIGURE 3** Convergence analysis.

**TABLE 2** The deformation values of screws.

| Screw material | Deformation values (mm) |
|---|---|
| Ti6Al4V | 1722 |
| 316 L | 1132 |
| Inconel 625 | 0,938 |
| Inconel 718 | 1139 |

**TABLE 3** The stress and deformation values in bone fracture line and screws.

| | STRESS DISTRIBUTIONS | | | | | |
|---|---|---|---|---|---|---|
| Screw material | Schanz screw stress von-mises (MPa) | Fracture line (MPa)-upper | Fracture line (MPa)-lower | Gap (mm) | Penetration (mm) | Sliding distance (mm) |
| Ti6Al4V | 153,33 | 11,659 | 12,654 | 0,087 | 0,138 | 0,054 |
| 316 L | 180,98 | 11,019 | 14,228 | 0,069 | 0,160 | 0,073 |
| Inconel 625 | 158,94 | 11,584 | 12,652 | 0,091 | 0,136 | 0,054 |
| Inconel 718 | 148,91 | 11,589 | 12,640 | 0,090 | 0,137 | 0,053 |

## 4 | DISCUSSION

According to Wolff's law, bones grow or reshape in response to the stress they are subjected to. If the stress does not reach the area of the bone that needs healing, no positive effect will be seen. The stress values under load in implant materials such as Ti6Al4V, 316 L, Inconel 625 and Inconel 718 are determined. Ti6Al4V has a value of 153.33 MPa, 316 L has a value of 180.98 MPa, Inconel 625 has a value of 158.94 MPa and Inconel 718 has a value of 148.91 MPa. However, it should not be forgotten that 316 L screws, which have higher values indicated here, may cause a decrease in bone density (stress shield) as they carry more load on the bone. This seems like a negative situation from the perspective of the healing process because it encounters less stress at the fracture line. However, the lower calculated values in gap, penetration, and sliding distance are important parameters for compatibility and stability between the bone and the implant.

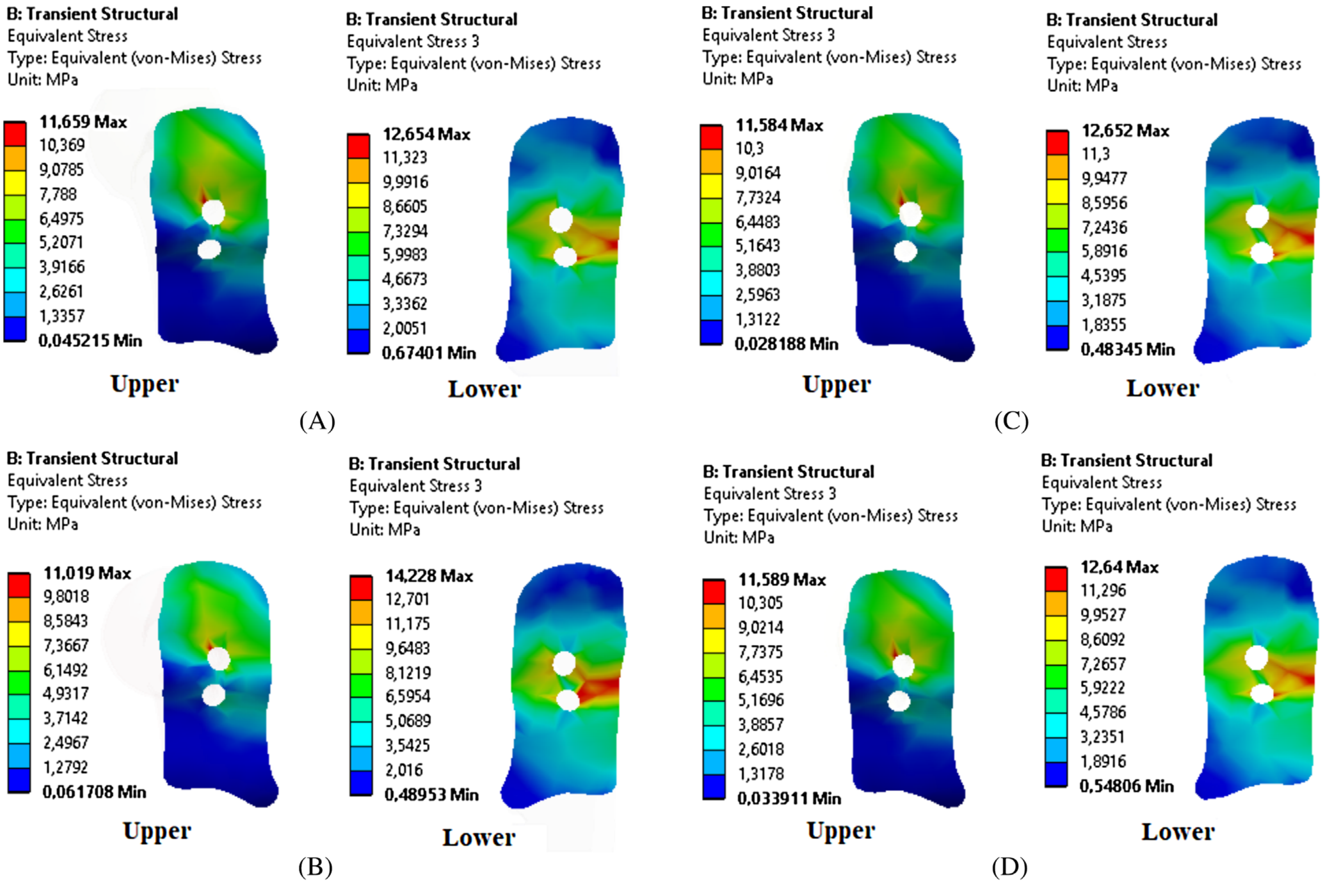

FIGURE 4 The stresses occurring at fracture line (upper and lower) for additive manufacturing materials. (A) Ti6Al4V, (B) 316 L stainless steel, (C) Inconel 625, (D) Inconel 718.

Ti6Al4V, also known as titanium alloy grade 5, is a widely used titanium alloy in the medical industry due to its high strength, low density, and good biocompatibility. In the human body, Ti6Al4V has shown good corrosion resistance and biocompatibility. It is resistant to corrosion in various body fluids, including blood and saline, which makes it a suitable material for use in medical implants and devices. The corrosion resistance of Ti6Al4V in the human body is also due to the formation of a thin, stable, and protective oxide layer on its surface that prevents further corrosion. Ti6Al4V is also resistant to corrosion in salt water, which is an important factor for medical devices that are used in marine environments. It is also resistant to stress-corrosion cracking, which is a type of corrosion that can occur in materials under high stress and in the presence of certain corrosive environments. Titanium alloys are widely used in biomedical applications due to their high strength, low weight, excellent corrosion resistance, and biocompatibility. Ti-6Al-4 V is one of the most commonly used titanium alloys for medical implants. However, titanium's high cost and challenging machinability limit its wider use. A better understanding of the interplay between cost, processing methods, and performance is necessary to effectively use titanium alloys.[27]

Overall, the good biocompatibility, corrosion resistance, and mechanical properties of Ti6Al4V make it a popular choice for use in medical implants and other applications where biocompatibility and durability are important. 316 L stainless steel is a low-carbon variant of 316 stainless steel, a popular type of stainless steel that is widely used in medical and dental implants due to its good biocompatibility and corrosion resistance. In the human body, 316 L stainless steel has shown good corrosion resistance in various body fluids and tissues, including blood and saliva. This is because the low-carbon content of 316 L stainless steel makes it more resistant to corrosion in such environments compared to other types of stainless steel. 316 L stainless steel is also resistant to corrosion in salt water, which is an important factor for medical devices that are used in marine environments. It is also resistant to stress-corrosion cracking, which is a type of corrosion that can occur in materials under high stress and in the presence of certain corrosive environments. Overall, the good biocompatibility and corrosion resistance of 316 L stainless steel make it a suitable material for use in medical implants and other applications where biocompatibility and durability are important. In addition to information, a research takes into account the impact of a complexing agent to accurately replicate the oxidative environment of human body fluids when examining the corrosion properties of 316 L stainless steel (SS) produced through the Selective Laser Melting (SLM) technique. The findings demonstrate a significant influence of the complexing agent, specifically the citrate ion present in Phosphate Buffer Saline (PBS) solution, on the passivation behavior of 316 L SS due to the formation of complex species.[28]

Inconel 718 is a high-strength nickel-chromium-based superalloy that is known for its exceptional corrosion resistance in harsh environments. Inconel 718 superalloy has been extensively studied in various applications, such as gas turbine engineering, submarine construction, nuclear reactors, and oil and gas production parts.[29–31] It is crucial to thoroughly comprehend the corrosion behavior of Inconel 718 in order to implement effective countermeasures and ensure the safety of the alloy system, particularly for ship gas turbines and submarines operating in marine environments. A strong corrosion resistance is advantageous for the service life of parts since surface-initiated cracks are commonly observed. The corrosion performance is influenced by the material's composition[32] as well as surface conditions, including surface roughness and stress.[33] The high nickel content in Inconel 718 imparts relatively robust resistance to chloride stress cracking corrosion, while the presence of chromium further enhances its corrosion resistance, especially in oxidizing environments, surpassing that of pure nickel.[34] When used in the human body, Inconel 718 has shown good biocompatibility and corrosion resistance, making it a suitable material for medical implants and devices. Inconel 718 is resistant to a wide range of corrosive environments, including those encountered in the human body. For example, it is resistant to attack by body fluids such as blood, sweat, and saliva. It is also resistant to corrosion in salt water, which is an important factor for medical devices that are used in marine environments. Inconel 718 also has excellent resistance to stress-corrosion cracking, which is a type of corrosion that can occur in materials under high stress and in the presence of certain corrosive environments. This makes it a good choice for medical implants that are subjected to high stress levels, such as bone screws and spinal implants. Overall, the corrosion resistance and biocompatibility of Inconel 718 make it a suitable material for use in medical implants and other applications where biocompatibility and durability are important.

Inconel 625 is a nickel-chromium-molybdenum alloy that is known for its high resistance to corrosion, particularly in harsh environments. The superalloy, known as Inconel 625, is renowned for its exceptional performance characteristics, including remarkable strength, excellent temperature resistance, and superior corrosion resistance. This alloy primarily comprises nickel (58%–71%), accompanied by chromium (21%–23%), molybdenum (8%–10%), niobium and tantalum (3.2%–3.8%), iron (5%), cobalt (1% maximum), and traces of aluminum (0.4% maximum). As a consequence of the unique composition of Inconel 625, the superalloy has exhibited an exceptional ability to resist corrosion. Consequently, this material becomes the optimal selection for applications in highly saline seawater and even in less severe environments such as freshwater. The inherent protection of Inconel 625 stems from the nickel-chromium matrix that constitutes a vital part of its composition. Furthermore, the presence of molybdenum safeguards this superalloy against pitting corrosion. In scenarios involving 15% sulfuric acid, the corrosion rate of Inconel 625 is a mere 0.188 mm per year.[35] When used in the human body, Inconel 625 has been shown to have good biocompatibility and corrosion resistance. This makes it a suitable material for use in medical implants, such as orthopedic devices and artificial joints. Inconel 625 has good resistance to a variety of corrosive environments, including those encountered in the human body. For example, it is resistant to attack by body fluids such as blood, sweat, and saliva. It is also resistant to corrosion in salt water, which is an important factor for medical devices that are used in marine environments. Overall, Inconel 625's combination of biocompatibility, corrosion resistance, and mechanical properties make it a suitable material for use in medical implants and other applications where biocompatibility and durability are important.

Ali et al.[36] also discusses the biocompatibility and biostability of different metals and alloys used in medical implants, as well as the surface modifications and coatings used to enhance these properties. The discussion includes the impact of different parameters, such as composition, microstructure, surface topography and surface chemistry on the biocompatibility and biostability of the materials.

Ti alloys in the $\alpha + \beta$ phase are commonly used in the human body due to their non-toxic and low allergenic nature, leading to improved biocompatibility. These alloys have become increasingly valuable for their super elasticity and shape memory not only in bio-applications but also in industries such as automotive and aerospace. Despite the advantages, traditional production methods for titanium-based superalloys have limitations in production due to their high cost and poor machinability. Additive manufacturing technologies, such as electron beam melting (EBM), are providing more options for producing specialty materials, including the commonly used Ti6Al4V alloy.[37–39]

The findings of this study can have significant implications for clinical dental treatment. Understanding the properties and characteristics of different implant materials can help dentists and oral surgeons make informed decisions when choosing the appropriate material for dental implants.

The study highlights the properties of various implant materials, including Inconel 625, Inconel 718, 316 L stainless steel, and Ti6Al4V. Dentists can consider these materials based on their biocompatibility, corrosion resistance, strength, and other factors. For example, if a patient requires a dental implant in an environment with high stress levels, such as in the posterior region, Inconel 718 might be a suitable choice due to its high strength and exceptional corrosion resistance. The corrosion resistance of implant materials is crucial in the oral environment, which is exposed to saliva, food particles, and various body fluids. Dentists can prioritize materials with good corrosion resistance, such as 316 L stainless steel or Inconel alloys, to ensure the longevity and integrity of the dental implants.

Overall, the study's findings provide valuable insights into the properties of different implant materials, and dentists can apply this knowledge to make informed decisions during clinical dental treatment. By considering the specific requirements of each patient and weighing the pros and cons of various materials, dental professionals can enhance the success and longevity of dental implants and ensure optimal patient outcomes.

To make a comprehensive evaluation of the results; Ti6Al4V, or titanium alloy grade 5, is widely used in the medical industry due to its high strength, low density, and good biocompatibility. It exhibits excellent corrosion resistance and biocompatibility in the human body, making it suitable for medical implants and devices. The formation of a protective oxide layer on its surface contributes to its corrosion resistance. Ti6Al4V also resists stress-corrosion cracking and is suitable for marine environments. The biocompatibility and stability of different metals and alloys used in medical implants, along with surface modifications and coatings, are discussed in other literature. Ti alloys in the $\alpha + \beta$ phase are commonly used in the human body due to their non-toxic and low allergenic nature, improved biocompatibility, and applications in industries such as automotive and aerospace. However, the high cost and poor machinability of traditional production methods for titanium-based superalloys pose limitations. Additive manufacturing technologies like electron beam melting (EBM) provide alternative options for producing specialty materials, including Ti6Al4V.[27,36–39] In this study, Ti6Al4V has many advantages compared with literature.

Furthermore, the paper highlights the current trends and developments in the field of metal-based implant materials, including the use of new alloys, nanomaterials, and the development of smart implant materials with improved performance and functionality. The recent advancements in the field of 3D printing and the use of metal-based implant materials in this technology are also discussed.

In addition, the paper provides an in-depth analysis of the various failure mechanisms of metal-based implant materials, including corrosion, fatigue, and tribocorrosion. The role of surface modifications and coatings in reducing the occurrence of these failure mechanisms is also discussed.

Overall, this paper aims to provide a comprehensive overview of the current state of the field of metal-based implant materials and their impact on human life. It provides valuable insights into the key principles and challenges involved in the development and use of these materials and the directions for future research and development in this field.[36]

There are several limitations to this study. The information provided about long-term performance, biocompatibility, and corrosion resistance of the materials is limited. Furthermore, the study does not adequately emphasize the performance of implant materials in specific applications and other factors such as wear resistance, fatigue strength, and sterilization requirements. Considering these limitations, it is important to rely on comprehensive clinical studies and expert opinions when making decisions regarding implant material selection. The specific applications and other factors will be performing in the future.

## 5 | CONCLUSION

In conclusion, Wolff's law states that bones grow or reshape in response to stress. The stress values of various implant materials, including Ti6Al4V, 316 L, Inconel 625, and Inconel 718, have been determined. However, it is important to note that while 316 L screws have higher stress values, they may also result in a decrease in bone density, hindering the healing process. The lower values in gap, penetration, and sliding distance of the other materials are important factors for compatibility and stability between the bone and the implant. Ultimately, the choice of implant material should be based on a careful consideration of all factors and their potential effects on the healing process.

All four materials, Inconel 625, Inconel 718, 316 L stainless steel, and Ti6Al4V, have good biocompatibility and corrosion resistance and are widely used in the medical industry for various applications. Here is a comparison of their properties:

1. Inconel 625 is a nickel-chromium-molybdenum alloy that is known for its high resistance to corrosion and its ability to maintain its strength at high temperatures. It is a suitable material for use in medical implants and devices that are subjected to harsh environments.
2. Inconel 718 is a high-strength nickel-chromium-based superalloy that is known for its exceptional corrosion resistance in harsh environments. It is a good choice for medical implants that are subjected to high stress levels, such as bone screws and spinal implants.
3. 316 L stainless steel is a low-carbon variant of 316 stainless steel that is known for its good biocompatibility and corrosion resistance. It is a popular choice for medical and dental implants due to its good resistance to corrosion in various body fluids and tissues.
4. Ti6Al4V, also known as titanium alloy grade 5, is a titanium alloy that is known for its high strength, low density, and good biocompatibility. It is a popular choice for use in medical implants and devices due to its good corrosion resistance and biocompatibility in the human body.

In conclusion, all four materials have good biocompatibility and corrosion resistance and are suitable for use in the medical industry. The choice of material will depend on the specific requirements of the application, such as strength, durability, and resistance to specific corrosive environments.

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## CONFLICT OF INTEREST STATEMENT

We have no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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