Finite Element Analysis of Dental implants to Study the Stress distribution by varying the Thread design and Material properties

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Abstract:

Dental implants have become a vital treatment option in modern dentistry for replacing missing teeth, offering patients improved oral function, aesthetics, and overall quality of life. The effectiveness of an implant depends largely on its ability to reduce peak stress values at the bone–implant interface while maximizing anchorage strength under standard physiological loads. Implant design plays a critical role in controlling stress concentration at this interface, which in turn influences the biological response of the surrounding bone. This paper focuses on optimizing thread design to minimize stress distribution in the jaw bone. Cylindrical implants with micro-threading and square-threading have been shown to enhance anchorage, improve load transfer, and reduce the risk of screw loosening, thereby improving long-term stability. In addition to geometry, the choice of biomaterial is crucial. Among the materials investigated, Ni–Ti shape memory alloys stand out due to their exceptional biocompatibility, wear and corrosion resistance, superelasticity, and shape memory effect, which have enabled their wide application in biomedical devices.

Recent trends in dental implant design focus on modifications in shape, size, material composition, and surface topography to meet clinical and market demands. Accordingly, in this study, a dental implant with improved threading geometry is modeled with precise dimensions using SolidWorks 3D CAD software. Its biomechanical performance is then evaluated using COMSOL Multiphysics, based on finite element analysis (FEA). The effectiveness of dental implants is influenced by several biomechanical factors, including the nature of loading, implant material properties, implant shape and geometry, bone density and volume, surgical technique, and the rate of osseointegration (rapid integration of the implant surface with the jaw bone). By addressing these factors through optimized thread design and advanced biomaterials, the reliability and success rate of dental implants can be significantly enhanced.

Keywords:Dental implant, Nitinol(Ni-Ti)material, Superelasticity, Biocompatibility

1. INRODUCTION

Dental implants have a long and complex history of supporting the replacement of missing teeth since tooth loss is a common occurrence that may occur due to trauma and illnesss [1].

Dental implants are one of the numerous methods of treatment available for replacing lost teeth, and they are commonly utilized. Dental implants come in four primary forms that are developed and utilized in clinical dentistry which includes endosseous, ramus frame, blade form, and subperiosteal form. Endosseous implants are the most frequently used in modern dentistry. In order to replace the tooth root, endosseous dental implants are usually screw-shaped and placed into the mandible or maxilla [3].

Dental implants are made from a variety of biomaterials, including metals, ceramics, carbons, polymers, and combinations of these. Titanium (Ti) is still one of the most common materials used in dental implants today. Ti includes alloy Ti-6Al-4V (Ti-6 Aluminium-4Vanadium), which was the first modern material used for dental implants. Commercially pure titanium is a light metal which has a high corrosion resistance, a relatively high stiffness, and good biocompatibility [4].

In the field of dental implants, several trends have evolved in recent years. Cylindrical dental implants are a popular choice in modern dentistry for supporting prosthetic teeth. The increasing use of minimally invasive procedures, which seek to reduce the patient suffering and speed up recovery times, is one prominent trend. This includes methods like guided implant placement and flapless surgery, which use digital tools like CAD/CAM technology to precisely position implants. Due to their biocompatibility, aesthetic appeal, and lack of metal components, ceramic dental implants are becoming more and more popular. This increase in popularity also makes it possible to place temporary crowns or bridges the same day as implant surgery providing patients immediate functional and aesthetic benefits.

Abutment screw loosening and fractures of the abutment, superstructure, and implant body are among the mechanical issues that limit the success rate of dental implants.

The nature of connection between the implant and abutment, as well as the size of the micro gap between them, are structure-related factors that contribute to bone loss. Biological factors that influence bone loss include peri-implantitis, low bone quality, implant placement surgery, early implant loading, and inadequate osseointegration[5].

The main objective of thread design is to prevent dental implant screw loosening. The long-term stability of a dental implant can be significantly improved by the implant thread design. The most important part of dental implants are the threads, which transfer the occlusal loads to the nearby bone. When the distribution of mechanical stimulation within the bone and at the implant-bone interface is within a suitable range, an optimal thread design can be achieved. The settling effect is important for screw stability, and as a result,the torque required to remove a screw is less than the torque needed to insert it. The first tightening and loosening of the screw causes more thread friction. It then reduces after multiple tightening and loosening cycles. Although the load conditions for the fixture and the screw are the identical in both cases, changing the abutment angle and the stress amount resulted in a difference in the site of maximum stress[6].

The selection of material is crucial to overcome the corrosion resistance and biocompatibility. Shape memoryalloys(SMAs) composed of nickel-titanium (NiTi)are a type of metallic alloy referred to as smart functional materials. Super elasticity, the shape memory effect, and shape memory actuation are the primary areas of their functional behaviors. Shape memory activation states the cyclic recovery of large thermo-elastic transformation strain upon heating underan external bias load, superelasticity is related to the cyclic recovery of large thermo-elastic transformation strains upon unloading, and the shape memory effect is correlated with the recovery of large thermo-elastic transformation strains upon heating. The highly elastic property of NiTi shape memory alloys is due to the induction of phase change during mechanical loading, which has recently been demonstrated to be caused by their microstructure.

Their promising biocompatibility provides new possibilities for use in the creation of numerous cutting-edge implants and biomedical devices. When selecting the optimal implant geometry, a number of parameters needs to be considered. These include systemic and patient- specific characteristics as well as local factors like the condition of the soft tissues and bone at the implantsite. These elements may have an impact on both the implant's long-term durability and the procedure success. By considering such factors the surgeon can decrease the chance of implant failure and guarantee the best possible therapeutic outcome.

Dental implants are designed using the following considerations:
a. Screw Loosening in Dental Implants: Addressing the issue of loose screws in dental implants.
b. Dental Implant Mechanical Behavior: Improving the mechanical properties of dental implants to increase longevity and performance.

The purpose of this study is to develop and design dental implants that are cylindrical in shape and utilize various threading designs. This design improves the biomechanical characteristics of the dental implant and prevents screw loosening by utilizing the current techniques. Using SOLID WORKS software, the implant body is modelled with a square shape on the bottom and a spiralshape on top, with the correct proportions for the implant. The implant's biomechanical characteristics can then be optimized by importing the implant body into the COMSOL MULTIPHYSICS environment.

2. LITERATURESURVEY

According to a study by Jakub Kowalski et al. (2021), dental implants are frequently utilized for oral prosthesis rehabilitation in individuals who are either completely or partially edentulous. Osseo integrated implants have been shown to have a good survival rate over a 20-year follow-up period[1]. Based on a study by Laura Gaviria et al. (2014), dental implants are made to achieve primary mechanical stability and to encourage a robust bone- implant relationship over time through osseointegration. Three main macro-aspects of endosseous implants include solid body press-fit designs, porous-coated designs, and screw threads. The implant's success or failure is mostly determined by the long-term biomechanical characteristics at the bone-implant interface, which are impacted by each configuration [2].

However, other difficulties have also been documented. According to Goodacre et al. (2019), fractures of the abutment, superstructure, implant body, and abutment screw are examples of mechanical problems. According to Avivi-Arber and Zarb (2019), the most common mechanical issue is abutment screw loosening. It apparently causes component failure, peri-implantitis, and other problems,whichcanleadtosignificantcomplications [3].

As reported by Schwarz MS (2000), two-stage implant systems have a high rate of screw loosening and dental implant breakage. Reports of screw difficulties have been made for single-tooth implant replacements as well as fully and partial yedentulous applications. However, the coupling of ITI components has been made somewhat fail-safe through the application of the right materials and fundamental engineering design principles [4].

Mikel Armentia et al. stated on another significant component that contributes to dental implant failure (2020). According to him, the most typical mechanical failure type in dental implants is fatigue. Because of mastication,
dental implants are subjected to varying loads throughout every stage of their lifetime, which increases the risk of fatigue- related structural failure. Depending on the implant's diameter, load circumstances, location, etc., these failures may occur in the prosthetic screw, the abutment, or the implant body [5].

According to a study by Bijan Mohammadi et al. (2021), the screw in dental implants is thought to be more sensitive than other sections. This part also served to investigate the effect of abutment angle tolerance on the stress created in the screw. The results showed that when the abutment angle was increased to a maximum of 24 degrees, the screw's stress decreased; however, when the abutment angle was reduced to 21 degrees, the abutment screw's stress increased and approached the fracture range. As a result, adjusting the abutment angle tolerance causes variations in the stress distribution and implant efficiency, the implant remains within a safe range, and the screw does not fail [6].

According to the author Mohammad Reza Niro omand et al. (2023), the distribution of mechanical stimuli within the bone and at the implant-bone interface can result in an optimal thread design when they fall within a recommended confined range that can offer the highest level of stability. The effects of thread parameters, such as thread pitch, depth, and width, along with upper and lower thread angles, on maximum principal strain within the cortical and cancellous bone and shear strain at the implant-bone interface were examined[7].

In the Pooyan Rahmani vahid's study, the integrity of the bone-implant interface is mostly dependent on the area where implant threads and surrounding bones come into touch. Additionally, the distribution of stress and marginal bone resorption are significantly impacted by thread design.

Particularly, the power of implant's capacity to push in and pull out is determined by thread pitch and flank angles. Osteointegration serves as the biological fixation and is in charge of the implant's long-term stabilization, while implant thread acts as the mechanical fixation and offers the interface its first stability. In order to give masticatory activity a mechanical foundation, the interface needs to undergo constant osseointegration. Osseointegration in the thread contact region provides stability during mastication. Shape and tapering were used to categorize thread patterns. Conical and cylindrical profiles, as well as symmetrical, buttressed, and square thread arrangements, were examined. A higher contact area for the square thread pattern is demonstrated by the measured contact area for the same thread pitch. Instead of implementing scientific research, the design evolution of dental implants has concentrated on altering the core design shape, size, material, and surface topography in response to market demands. A simple expression for the relationship between design geometry and stress distribution is not possible due to the complicated structure of geometry, despite the fact that the relationship between load and stress magnitude could be stated as a mathematical model [8].

Dental implants are largely dependent on the material properties, as Shi Jin et al. (2013) described. Surface topography, surface roughness, chemical and physico chemical properties, such as surface wettability and surface modification, all have a significant impact on cell–material interactions.

Biocompatibility and cell adhesion behavior are interconnected concepts. For guiding cell adhesion and cell colonization onto artificial tissue scaffoldings, surface energy may be a more important indicator of cell adherence and proliferation than surface roughness. Van der Waals, electrostatic forces between materials, and physicochemical connections between cells all had an impact on cell adhesion [9].

The discovery of Nickel-Titanium alloy in dental applications results in a significant improvement, as explained by Swadhin Kumar Patel et al. (2020).Because of its superior fatigue strength and biocompatibility, NiTi alloy is a commercially essential shape memory alloy(SMA).This alloy has low anisotropy, ductility, and a comparatively tiny grainsize[6].

The key characteristic of NiTi SMAs is the transformation from martensite to austenite, which allows strain recovery. When producing NiTi shape memory alloy using the standard method, it is important to ensure homogeneity because a changein the ratio of Ni to Ti will result in an important increase in the transformation temperature. NiTi SMAs have multiple applications such as superelastic, limited, and free recovery materials. In structural engineering, it is also applied to biocompatible and biomedical damping systems, both electrical and thermal actuators[10].

The author Pejman Shayanfard et al. (2023) explains the many qualities that the NiTi alloy exhibits. Shape memory alloys (SMAs) composed of nickel and titanium are a particular kind of metallic alloy referred to as smart functional materials. Superelasticity, the form memory effect, and shape memory actuation are the primary functional phenomena that they cover. Shape memory actuation states the cyclic recovery of large thermo-elastic transformation strain upon heating under an external bias load, superelasticity is related to the cyclic recovery of large thermo-elastic transformation strains upon unloading, and the shape memory effect is related to the recovery of large thermo-elasticransformation strains upon heating. It has recently been demonstrated that the super elastic characteristic of NiTi shape memory alloys originates from its microstructure and is predicated on the induction of phase change under mechanical loading[11].

In 2013, Mahdi Hashemi et al discussed about the use of additive manufacturing in dental implants. In general, Additive Manufacturing (AM), frequently referred to as Rapid Prototyping (RP) or Rapid Manufacturing (RM), is the technique of creating a product by layering on consecutive layers of material instead of removing it, producing little to no waste. A 3D computer-aided design (3D CAD) model defines the precise geometry that each layer is melted to. One benefit of additive manufacturing that it may create parts with extremely intricate geometries without the need for fixtures or cutting tools of any kind. It also uses relatively little material and can be produced rapidly from CAD to a physical item without the need for expensive castings or forged products. As a result, the production process is extremely cost-effective, energy-efficient, and environmentally friendly. Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Laser Engineered Net Shaping

(LENS),and Electron Products are the most widely used and well-known methods for shaping metal powders. These processes result in products with large porosities and sizes, samples that frequently do not fully react or contain precipitates as a result of the rapid formation times and high heating rates, incomplete reactions between elemental powder particles, and the possible formation of secondary phases. Different materials (metals, ceramics, and composites) might be treated; excellent energy efficiency; precise control over heat, cooling, and pressure; homogeneous sintering; ease of operation; low sintering temperature and short processing time preventing any unwanted reaction products. Modern free form fabrication machines are made possible by additive manufacturing technologies, which employ a range of metal powder particles to generate products [12]. Keyvan Safaei et al.'s review paper provided information on various additive manufacturing techniques (2021). Different AM techniques have been developed to produce different structures with the appropriate fine quality. Laser powder bed fusion (LPBF), electron beam powder bed fusion (EPBF), wire-arc additive manufacturing (WAAM), ultrasonic additive manufacturing (UAM), and directed energy deposition (DED) are the primary AM techniques that can be taken into consideration for processing NiTi SMAs. For metallic components with intricate structures which require a greater feature resolution as well as improved surface smoothness, the LPBF method offers an appealing additive manufacturing approach [13].

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3. MATERIALS AND METHODOLOGY

MATERIAL CONSIDERATION

Osseointegration—the process by which titanium(Ti) fuses with surrounding bone tissue—makes Ti a highly desirable material for dental implants. Its other qualities include strength, corrosion resistance, and great biocompatibility. Because of these characteristics, titanium implants last longer and are more dependable. They also minimize the possibility of tissue rejection or unfavorable reactions by giving prosthetic teeth strong support. However, there are drawbacks to titanium implants as well.

- These include high cost,
- Difficulty in modifying after implantation,
- Potential need for adequate bone volumefor successful insertion.

Despite these disadvantages, titanium is still a flexible and useful material for dental implants, providing patients with a long-lasting and useful way to improve their smiles and oral health.

In dental implants, nitinol(NiTi), an alloy of nickel and titanium, has certain benefits over pure titanium.

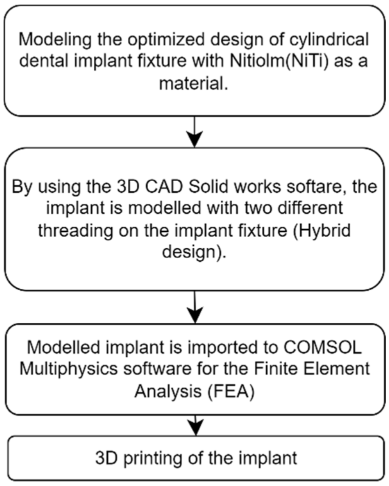
Nitinol has remarkable features:

- Shape memory alloys.
- Lowers the danger of fracture
- Increases implant flexibility with exceptional elasticity.
- Resistance to corrosion
- Diminished elasticity modulus
- Diminished stress shielding
- Durability throughout time

According to numerical study, employing a NiTi alloy rather than a Titanium alloy could enable it to survive significant deformations, stresses, and forces during overloading.

3.1 METHODOLOGY

<u>Flowchart:Design optimizationof Dental Implant</u>



BASIC DESIGN AND SPECIFICATIONS OF DENTAL IMPLANTS

Dental implants serve as crucial replacements for missing teeth, providing both functional and aesthetic benefits to individuals with dental deficiencies. The parts of the dental implants include:

Implant Body serves as the foundational of the dental implant. The implant body is surgically placed into the jawbone and functions as an artificial tooth root, providing stability and support for the prosthetic restoration. The selected dimensions of implant body are 13mmlength, 5mm breadth, 0.9mm diameter and 1mm pitch.

Abutment is a connector piece that attaches to the implant body and protrudes above the gum line. It serves as the interface between the implant and the prosthetic restoration, such as a crown, bridge, or denture. Abutments come in various design, including screw- retained or cemented and can be made from metal alloys, zirconium, or other materials. The selected dimensions of the abutment are 5.5mm length and diameter ranges from 6mm to 7.5mm.

Crownis the visible part of the dental implant that resembles a natural tooth. It is custom-made to match the color, shape, size of the surrounding natural teeth, providing aesthetic results. The selected dimensions of height range from8mm to 12mm and means (SD) crown- implant ratio was ranged from 0.9 to 3.2 **Implant screw** is a small, durable component used to secure the abutment to the implant body. It is designed to with stand the forces exerted during chewing and speaking. Implant screws come in various sizes and designs to accommodate different implant systems and surgical techniques. The selected dimensions of diameter ranges from1.3mm to1.5mm, length ranges from 9mm to 11mm and drilled part ranges from 0.9 mm to 1.1 mm.

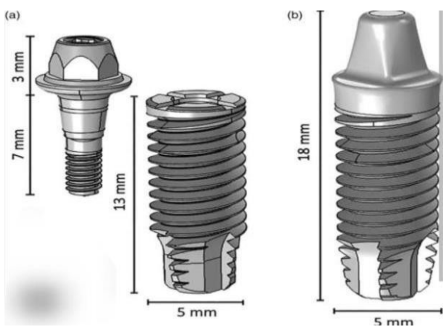


Fig 1: (a) Screw and implant body (b)Implant body with abutment dimensions

DRAWBACK OF BASIC SPECIFICATIONS

The most common problems of the dental implants are loss of osseointegration, abutment screw loosening, abutment screw fracture, implant body loosening and stability of an implant is a crucial factor in osseointegration. A screw loosening can lead to crestal bone resorption. To overcome the disadvantages of these specifications we modified the design parameters of dental implants.

OVERVIEW OF CYLINDRICAL IMPLANTS

The nature of the biological reaction of the bone and the concentration of stress at the implant- bone interface is determined by implant design. The diameter, shape, and direction of force on an implant impact the stress distribution. Minimal stress and primary stability are provided by the cylindrical implant. Cylindrical dental implants are a popular type of dental implant. Unlike other implant shapes, such as conical or blade implants, cylindrical implants have a uniform diameter along them along length. In the entire threading of the cylindrical implants, two different types of threading is introduced. The top of the cylindrical dental implants comprises micro threading, while the bottom has square threading for its optimized design. On the top of implant body, helical or spiral type threading with the dimensions of the height 95mm,pitch 10mm and diameter46.94mm. On the bottom of the implant body square type threading with the dimensions of 120 mm height, pitch 5mm and diameter 63.145mm. With the least amount of stress concentration, the measured contact area for the same thread pitch shows a higher contact area for the square thread design. While screw- shape the tead configurations maximize interface area, enhance initial contact, improve early stability, and effectively distribute interfacial stress, they are frequently used in the dental implant. As a result, this micro threading prevents the screws from loosening around the implant body.

This design provides stability and evenly distributes forces during chewing and biting, promoting long-term implant success.

3.2 WORKFLOW:

Modification of the cylindrical dental implant with two types of threading were designed with the help of SOLIDWORKS software, it creates a 3D model of dental implants with precise parameters such as length, width, diameter, and pitch.

Procedure for making a cylindrical dental implant with two types of threading using Solid works:

- Create a new part: Open Solid works and create a new part document to start designing the dental implant.
- Sketch the base geometry: Sketch the profile of the implant on the top plane. This typically involves drawing a circle with the diameter of 5mm of the implant. And the dimension has the height of 15mm of the implant.
- Extrude the Base Shape: Use the 'extrude base" feature to extrude the sketched profile to the desired length, creating the basic cylindrical shape of the implant.
- Create Threading Profile: Sketch the profiles for the two types of threading on the cylindrical surface of the implant by using the 'Helix' and 'Spiral' tools to create the paths for the threads.
- Extrude cut for Thread Type1(spiral):Use the

Squaretypethreading-Topofimplantfixture	Microtypethreading-Bottom of implant fixture
Pitch-5mm	Pitch- 10mm
Revolution-24	Revolution-9.5
Height-120mm	Height-95mm
Diameter-63.145mm	Diameter-46.94mm

Table1. Designing a Dental Implant Fixture in Solidworks- Dimensional considerations

geometry of implant body and then create a threading profile with same dimension like that of basic cylindrical implant with only helical type of threading for the entire implant body, and save the file in STL document.

Figure 2: Modelled implant fixture in Solid works software

- 'Extrude cut' feature to cut the threading profile for the first types of thread into the implant with the dimensions of height 95mm, pitch 10mm and diameter 46.94mm. Ensure that the cut extends along the desired length of the implant and is appropriately sized and positioned.
- Extrude Cut for Thread Type 2 (Square): Repeat the previous step to create the threading profile for these condyle type of thread. Adjust the parameters to make it as square type of threading with the dimensions of 120mm height, pitch 5mm and diameter 63.145mm.
- Fillet edges: Apply fillets to the edges of the implant to smooth out any sharp corners and improve the aesthetics and functionality of the implant.
- Save the document: Save the Solid Works dental part document in the form of STL file.

Procedure for making a basic design of cylindrical dental implant using Solid Works:

- Repeat the above steps for sketching the basic

The stress analysis was performed after modelling the implant body of the dental implant in the solidworks software for the testing of biomechanical considerations.

Create a new file: Open the COMSOL Multiphysics software and click the model wizard option to open the 3D design in the software window.

- Import first file: Choose the option length to change the dimensions from meter to millimeter and then choose the geometry and import the first basic cylindrical implant STL file into the COMSOL Multiphysics software.
- Adding material properties: To the modelled dental implant, add the Titanium (Ti) material and then analyze the mechanical properties such as Strength, Corrosion resistance, Stress strain analysis, Structural mechanics and Thermal

  behavior and then add the Nitinol (Ni-Ti) material and then analyze the same properties as that of Titanium material.
- Import these condfile:Choose the geometry and import the cylindrical implant with the two types of threading STL file into the COMSOL Multiphysics software.
- Adding material properties: Repeat the same procedures that of basic cylindrical implant and then analyze the properties with material Titanium and Nitinol (Ni-Ti)

PROTOTYPE MODEL

- Prototype of implant: After analyzing all the properties, the implant can be prototype using 3D printer with the help of Poly Lactic Acid (PLA) material.

3.3 MECHANICAL BEHAVIOR OF STRESS AND STRAIN ANALYSIS

The stress- strain analysis of the conventional and optimized threading design was simulated. The analysis shows the stress experienced when the load is applied to the abutment, which compares with the two threading designs and when both Titanium and Nitinol material were applied to each design. The following four cases describe how the conventional and optimized dental implant was modelled with specific considerations.

Case1:

- Implant fixturetype-Cylindricaltype
- Threadingconfiguration-Helicalthreading
- Material-Titanium(Ti)
- Implantfixturelength-13mm
- Implant fixturewidth-5mm
- Abutmentlength-3mm
- Abutmentdiameter- 6mm
- Implant screwlength-7mm
- Implantscrewdiameter-1.3mm
- Diameterofimplantfixture- 0.9mm
- Pitchofimplantfixture- 1mm

Case2:

- Implant fixturetype-Cylindricaltype
- Threadingconfiguration-Helicalthreading
- Material-Nitinol(NiTi)
- Implantfixturelength-13mm
- Implant fixturewidth-5mm
- Abutmentlength-3mm
- Abutmentdiameter- 6mm
- Implant screwlength-7mm
- Implant screwdiameter-1.3mm
- Diameterofimplantfixture- 0.9mm
- Pitchofimplantfixture-1mm

Case3:

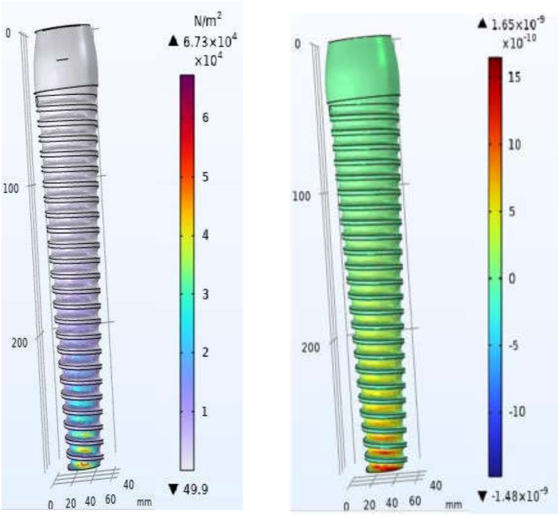
- Implant fixturetype-OptimizedHybriddesign
- Threadingconfiguration-Microthreading(top) & Square threading (bottom)
- Material-Titanium(Ti)
- Implantfixturelength-15mm(Microthreading- 95mm; Square threading- 120mm)
- Implant fixturewidth-5mm
- Abutmentlength-3mm
- Abutmentdiameter- 6mm
- Implant screwlength-7mm
- Implantscrewdiameter-1.3mm
- Diameter of implantfixture- (Micro threading- 63mm; Square threading- 120mm)
- Pitchofimplantfixture-(Microthreading-10mm; Square threading- 5mm)

***Case4*:**

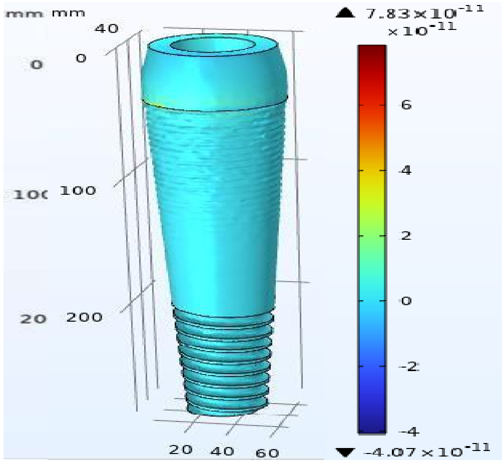
- Implant fixturetype-OptimizedHybriddesign
- Threadingconfiguration-Microthreading(top) & Square threading (bottom)
- Material-Nitinol(NiTi)
- Implantfixturelength-15mm(Microthreading- 95mm; Square threading- 120mm)
- Implant fixturewidth-5mm
- Abutmentlength-3mm
- Abutmentdiameter- 6mm
- Implant screwlength-7mm
- Implantscrewdiameter-1.3mm
- Diameter of implantfixture- (Micro threading- 63mm; Square threading- 120mm)
- Pitchofimplantfixture-(Microthreading-10mm; Square threading- 5mm)

3.4 MECHANICAL STRESS ANALYSIS RESULTS:

Case1: Conventional design of Titanium Cylindrical Dental Implant Fixture

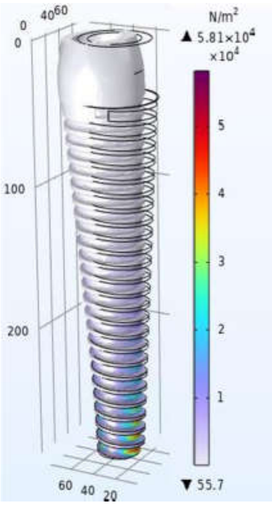


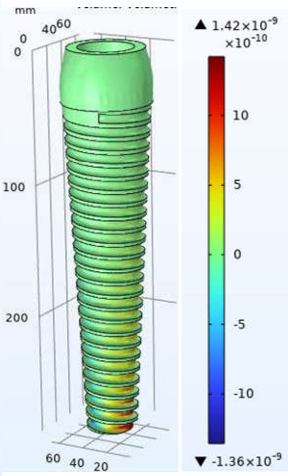
a)Stress analysis



b)Strainanalysis

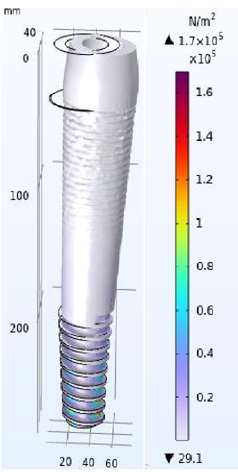
Case2: Conventional design of Nitinol Cylindrical Dental Implant Fixture

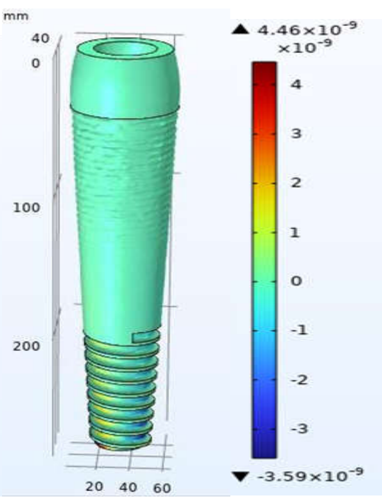




a) Stress analysis b)Strain analysis

Case3:Optimized hybrid designofTitanium Cylindrical Dental Implant fixture



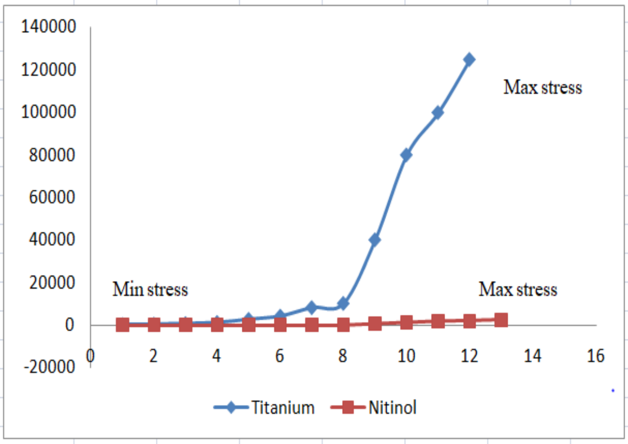


Stress –strain Analysis results:

ANALYSIS	MATERIAL	STRESS	STRAIN
Case1:Conventional design	Titanium(Ti)	Maxvalue=$6.73x10^4N/m^2$ Min value=49.9 N/m^2	Maxvalue=1.65x10$^-$ ^{9}mMinvalue=-1.48x10^{-9}m
Case2:Conventional design	Nitinol(NiTi)	Maxvalue=$5.81x10^4N/m^2$ Min value= 55.5 N/m^2	Maxvalue=1.42x10^{-9}m Minvalue=-1.36x10^{-9}m
Case3:Optimized hybrid design	Titanium(Ti)	Maxvalue=$1.7x10^5N/m^2$ Minvalue=29.1N/m^2	Maxvalue=4.46x10^{--9}m Minvalue= -3.59x10^{-9}m
Case4:Optimized hybrid design	Nitinol(NiTi)	Maxvalue=$2.34x10^3N/m^2$ Minvalue=$3.27x10^{-7}N/m^2$	Maxvalue=7.83x10^{-11}m Minvalue=-4.07x10$^-$11m

The optimized hybrid design with micro threading on the top and the square threading on the bottom, was analysed. Nitinol (NiTi) is applied as the material which experiences a minimal stress around the implant body. The stress and strain comparison of optimized hybrid design with Titanium (Ti) material and Nitinol (NiTi) material is analyzed in the form of graphical representation.

GRAPHICAL REPRESENTATION OF STRESS ANALYSIS:



Hybrid thread design of Titanium implant fixture
Minvalue=29.1N/m2
Max value=1.7×10^5 N/m2

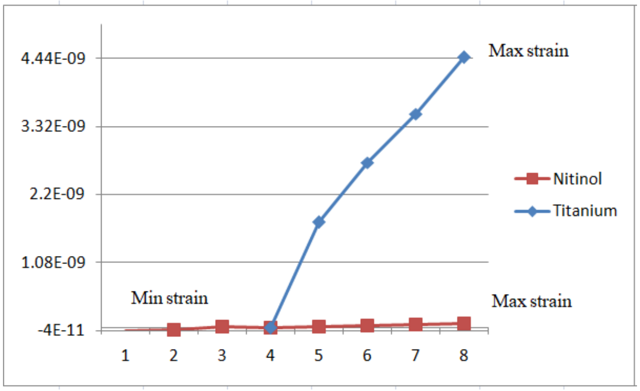
Hybrid thread design of Nitinol implant fixture
Minvalue= 3.27×10^{-7}N/m2
Max value=2.34×10^3 N/m2

the implant structure. To facilitate a thorough understanding, graphical representations were employed to visually depict the variations in stress and strain across the implant fixture for each case. In this section, we present a detailed overview of the results obtained from the stress and strain analysis, highlighting key observations and insights from the graphical representations.

Our fourth stress and strain study scenario (case 4) in COMSOL Multiphysics reveals a significant improvement in implant fixture performance, which we credit to the combined influence of two important factors: the incorporation of Nitinol alloy and the use of a hybrid thread design.

*Integration of Nitinol Alloy:*Employing Nitinol,a shape memory alloy that is well-known for its remarkable flexibility and biocompatibility,greatly reduces stress in the implant fixture. Nitinol's structural integration gives the implant increased resistance to mechanical loads, which lowers the risk of stress concentration and possible failure spots.

GRAPHICAL REPRESENTATION OF STRAINANALYSIS:



Hybridthread design of Titaniumimplantfixture
Minvalue=-3.59× 10-9m
Max value= 4.46 × 10-9m
HybridthreaddesignofNitinolimplantfixture
Minvalue=-4.07× 10-11m
Maxvalue= 7.83 × 10-11m

4.1 RESULTS AND DISCUSSION

The **hybrid thread design** further enhances the biomechanical integrity of the implant fixture. By combining the advantages of multiple thread geometries, this innovative design optimizes load distribution and promotes effective osseointegration. As a result, stress and strain concentrations are minimized, ensuring the implant's long-term stability and durability. When integrated with **Nitinol alloy**, the hybrid thread design represents a significant advancement in dental implant technology, offering superior reliability and performance compared to conventional designs.

4.2 CONCLUSION

The comprehensive finite element analysis (FEA) of dental implant fixtures designed with Nitinol alloy and hybrid threading provides invaluable insights into their mechanical performance under varying conditions. The design incorporates square threading at the apical region and micro-threading at the coronal region, enabling optimal stress distribution across the implant–bone interface. Our comparative analysis of distinct cases, each defined by specific design parameters, demonstrated a notable reduction in stress concentrations and an improvement in biomechanical durability when compared to conventional implant configurations. The unique material properties of Nitinol, combined with the hybrid threading strategy, effectively address the complex biomechanical demands of the oral cavity.

These findings highlight a significant advancement in dental implant technology, offering enhanced longevity, stability, and clinical performance**.** The proposed design demonstrates the ability to overcome longstanding challenges in implantology, ultimately contributing to better patient outcomes and increased satisfaction**.**

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