

Fatigue performance analysis of dental implants: Influence of thread design

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Abstract. This study investigates the fatigue performance of dental implants made from titanium alloy (Ti-6Al-4V), with a focus on the influence of thread geometry on fatigue resistance. Two implant models with distinct thread profiles are considered: triangular and trapezoidal. The implants were designed using CAD software and analyzed via finite element analysis (FEA) by ANSYS. A fixed part was considered to simulate the surrounding bone, and a force of 118.2 N was applied according to ISO 14801 dental standard [1]. The results of static analysis reveal that the triangular thread design is subjected to the high peak stress of 290MPa localized at the thread edges, which could be a potential site of fatigue failure. In contrast, the trapezoidal thread design demonstrates lower level of stress distribution, with a reduced of the maximum stress concentrations of 216MPa. Fatigue analysis shows that the trapezoidal threaded implant offers significantly better performance, with a minimum lifespan approximately 4.7 times higher than the triangular threaded implant. The obtained result could be attributed to its larger contact surface and optimized load distribution compared to the triangular thread geometry. These findings highlight the importance of thread geometry in enhancing the mechanical reliability and longevity of dental implants.

Keywords: dental Implant, thread parameters, Titanium Alloy.

1 Introduction

Dental implant is a reliable long-term solution for replacing missing teeth, offering both functional and aesthetic benefits. Their success depends on achieving primary stability immediately after placement and ensuring secondary stability through osseointegration, the process by which bone integrates with the implant surface [1]. This phenomenon, first described by Brånemark in 1983[2], allows for a firm anchoring of the implant

without fibrous tissue formation. However, the ability of an implant to withstand cyclic masticatory forces is crucial in preventing mechanical failure over time. Among the various factors influencing implant performance, thread design plays a key role in determining stress distribution, stability, and overall fatigue resistance [2]. Threaded implants help initiate contact with bone, enhance load transmission, and promote osseointegration by increasing the surface area for bone attachment [3]. The geometrical characteristics of the threads such as thread depth (TD), thread width (TW), pitch, facing angle, and surface roughness, directly impact implant stability and fatigue performance [2]. Advancements in numerical simulation techniques by finite element analysis (FEA), have allowed researchers to optimize thread designs by assessing their impact on stress distribution and bone adaptation. Masoud Arabbeiki et al. [4] identified TD, TW, and upper thread angle as the most critical parameters for reducing stress and improving implant performance. Vineet Khened et al. [5], have used the Taguchi method to confirm, that thread depth is the most influential factor in minimizing stress at the bone implant interface. Additionally, implant diameter has been shown as a key parameter that affect stress dissipation. Finite element studies indicate that increasing implant diameter can significantly reduce stress around the implant neck, with a 4.2 mm of implant diameter, a 31.5% of stress reduction was obtained compared to a standard diameter of 3.6 mm [2]. The study of over 2000 dental implant designs available today underscores the need for continuous improvements in implant geometry to enhance mechanical performance and fatigue resistance [7]. Given the importance of thread geometry in fatigue resistance, this study aims to compare two types of dental implants that differ significantly in thread design. Through a fatigue analysis and finite element analysis (FEA), we will evaluate their impact on implant longevity under cyclic loading conditions, providing insights into how thread geometry influences stress distribution, stability, and fatigue performance.

2 Material and method

2.1 Material Properties

Ti-6Al-4V was modeled as an isotropic elastic material, with its mechanical properties are illustrated in Tab.1 [8]. The fatigue behavior was analyzed using the stress-life approach (S-N curve), considering an applied stress ratio ($R = 0.1$) to account for cyclic loading effects [9]. The corresponding S-N curve is illustrated in Fig.1.

Table 1. Mechanical properties of Titanium alloy

Property	Titanium Alloy (Ti-6Al-4V)	Reference
Young's Modulus (MPa)	96	[11]
Poisson's Ratio (ν)	0.36	[11]
Density (kg/m^3)	4500	[12]
Max of Deformation (%)	17	[13]
Ultimate Tensile Strength	1054	[13]
Endurance limit (MPa)	380	[12]

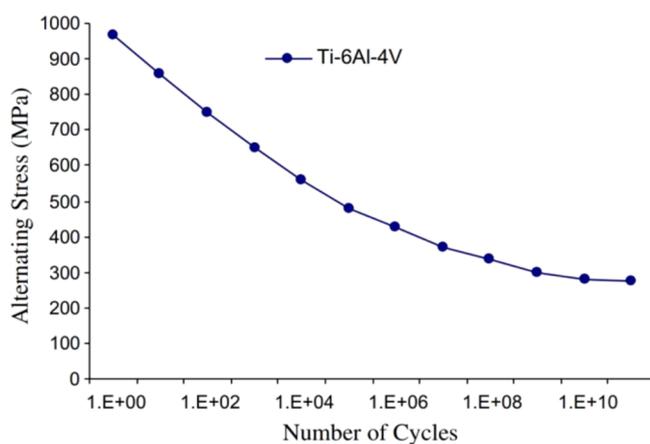


Fig. 1. Fatigue curve for Titanium Alloy [14]

2.2 Implant Design and Modeling

The dental implant models were designed using CAD software, allowing a precise parametric control of all the geometrical features. The initial implant model was replicated to create two variations, differing only in thread geometry:

- Model A: Triangular thread profile detailed in Fig.2
- Model B: Trapezoidal thread profile shown in Fig.3

Both implants were constructed from Ti-6Al-4V titanium alloy, ensuring identical overall dimensions (length, diameter, and pitch) to focus on the effect of thread design on fatigue performance. The shared structural parameters, including bone-implant contact (BIC) length and prosthetic platform angulation, are illustrated in Fig.4. However, variations in thread pitch, width, and thread angles are outlined in Tab.3 and visually represented in Fig.5

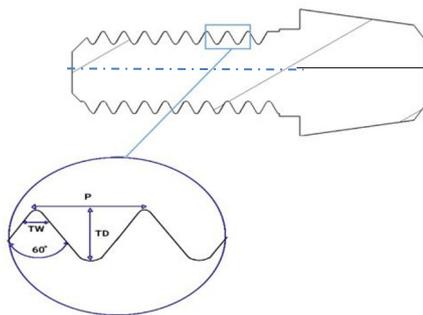


Fig. 2. Triangular thread profile

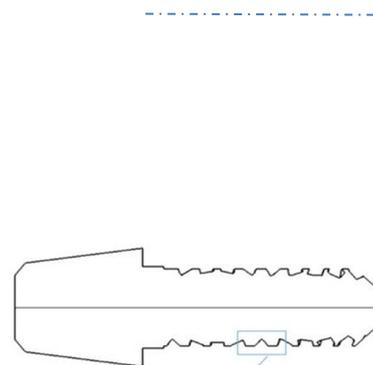
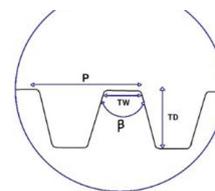


Fig. 3. Trapezoidal thread profile



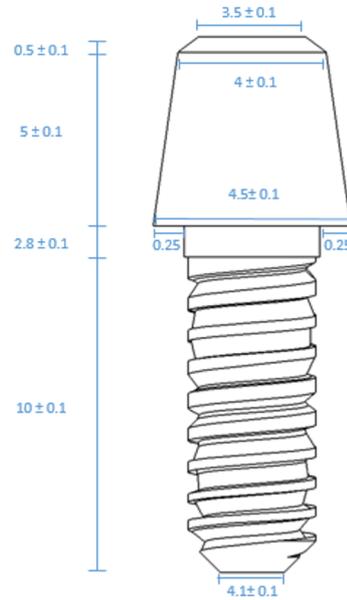


Fig. 4. Structural parameters of a dental implant

Table 2. Dimensions of thread profile

	Model A	Model B
Thread depth (TD) (mm)	0,866	0,366
Thread width (TW) (mm)	0,144	0,5
Thread pitch (TP) (mm)	1	1
Thread angles (β) (deg)	60	30

2.3 Finite Element Analysis (FEA) Setup

Study investigated axial and bucco-lingual oblique loading to simulate different levels of masticatory forces. A force of 118.2 N was applied at a 15° angle to the implant's longitudinal axis (Fig. 5).

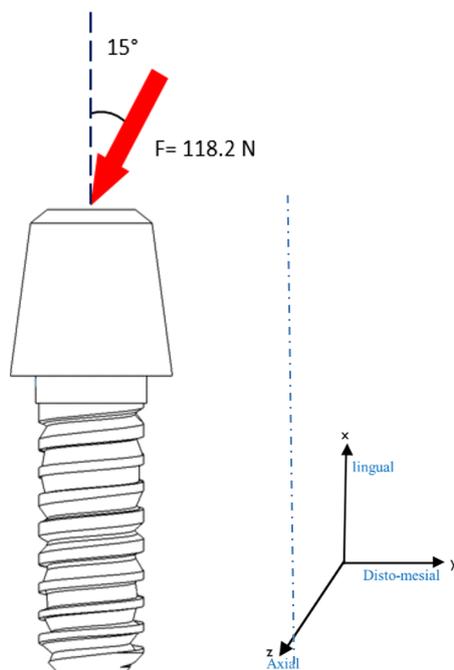


Fig. 5. Components of oblique loading and the net force acting on the implant

3 Results and interpretations

The results of the stress distribution across the components of both implant designs, as well as their corresponding fatigue life are given in Fig 6, 7, 8 and 9.

3.1 Stress Analysis

Figures 6 and 7, illustrates the von Mises stress distribution for both implant designs, highlighting the critical stress concentration areas and differences in mechanical resistance between triangular and trapezoidal thread geometry.

- Peak Von Mises Stress Concentration:
 - Superficial Threads: The highest stress is seen at the first few threads in both designs, which experience the most load transfer.
 - Implant-Abutment Connection: This is another critical area where stress accumulates.
- The maximum von Mises stress values are:
 - Triangular thread: 290MPa

- Trapezoidal thread: 216MPa

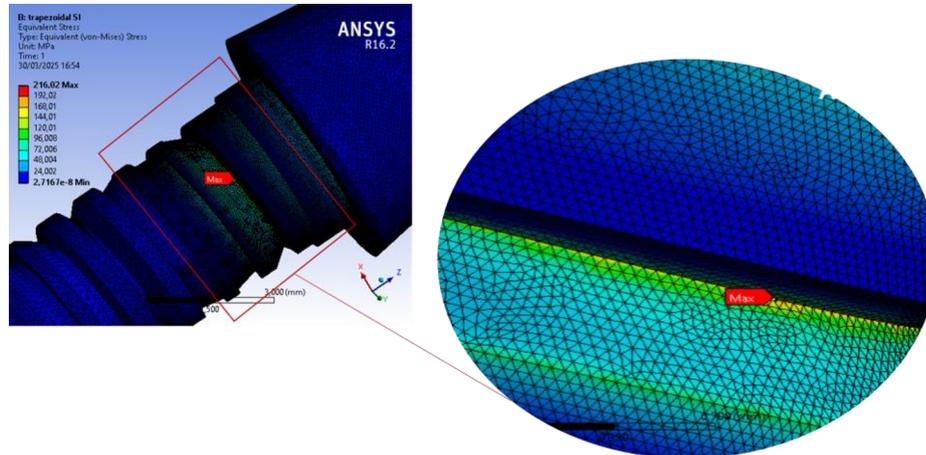


Fig. 6. Stress distribution on the trapezoidal thread model.

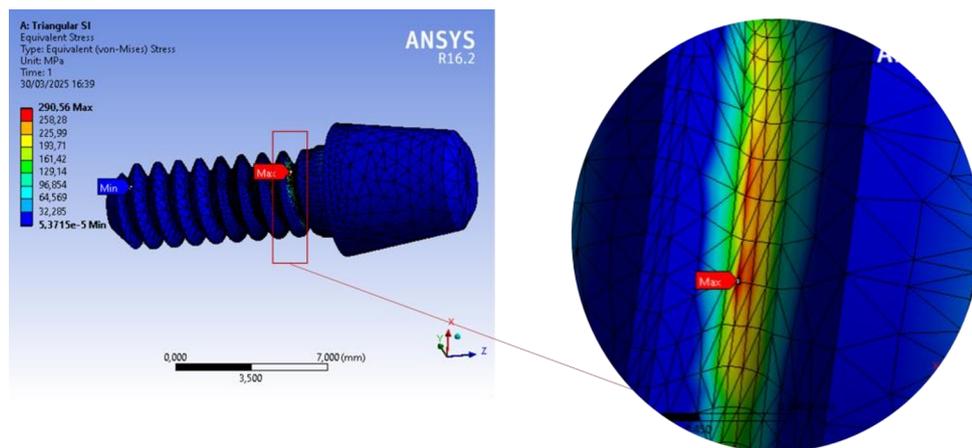


Fig. 7. Stress distribution on the triangular thread model.

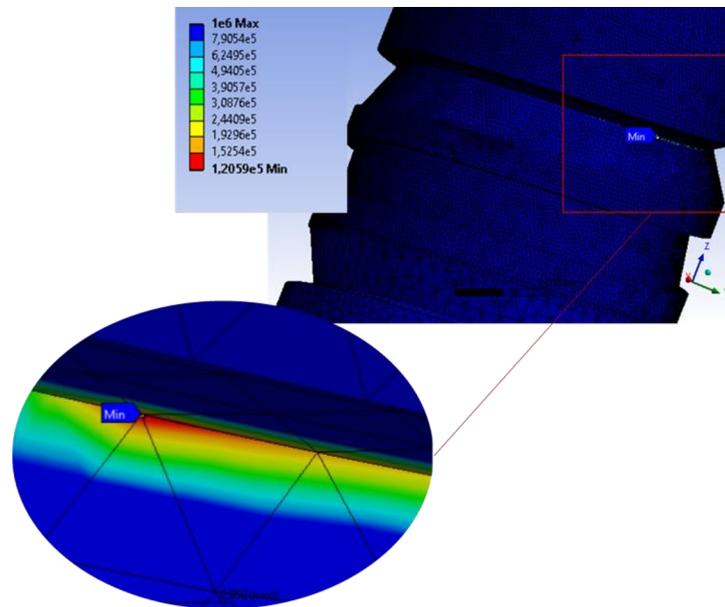


Fig. 8. Fatigue cycle life distribution of the trapezoidal thread model.

The results indicate that the triangular thread design experiences higher peak stress, making it more susceptible to localized failure or deformation. This increased stress concentration could increase the risk of mechanical damage.

In contrast, the trapezoidal thread design distributes stress more evenly, resulting in a lower maximum stress concentration.

3.2 Fatigue Analysis

Figures 8 and 9 show the fatigue life distribution analyses performed on the two types of dental implants:

- Triangular-threaded Implant
 - Maximum cycle life: 6.65×10^5 cycles
 - Minimum cycle life: 25466 cycles

The lowest lifetime is observed at the thread roots, where the highest stress concentrations occur.

- Trapezoidal-threaded Implant.
 - Maximum cycle life: 7.9×10^5 cycles
 - Minimum cycle life: 1.20×10^5 cycles

The minimum lifetime is significantly higher than that of the triangular-threaded implant.

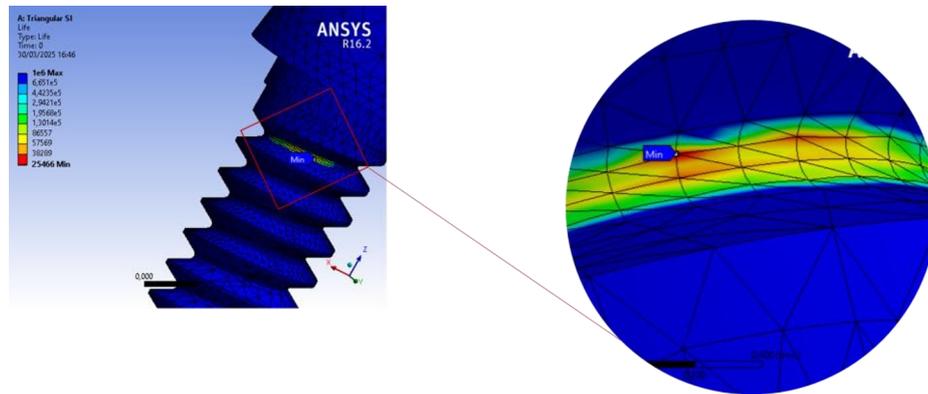


Fig. 9. Fatigue cycle life distribution of the triangular thread model.

The results indicate that the trapezoidal-threaded implant exhibits significantly better fatigue resistance, with a minimum lifespan approximately 4.7 times higher than that of the triangular-threaded implant. This superior performance can be attributed to better stress distribution, likely due to its larger contact surface and improved load distribution. In contrast, the triangular-threaded implant experiences higher stress concentration at the thread edges, leading to faster fatigue failure, while the trapezoidal-threaded design minimizes these stress concentrations, enhancing its fatigue performance.

4 Conclusion

This study highlights the critical influence of thread geometry on the fatigue performance and longevity of implant. Through Finite Element Analysis, it was found that the triangular thread design is prone to higher stress concentrations at the thread edges, leading to a greater risk of fatigue failure and reduced durability. Conversely, the trapezoidal thread design distributes stress more evenly, significantly enhancing fatigue resistance and achieving a lifespan approximately 4.7 times greater than that of the triangular design. The superior performance of the trapezoidal thread implant can be attributed to its larger contact surface and improved load distribution, which mitigate stress concentration and mechanical failure. These findings emphasize the importance of optimizing thread geometry to improve the mechanical reliability and clinical success of dental implants.

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