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A Finite Element Analysis to Compare Three Dimensional Stress Distribution in Different Bone Densities by Extra Short Implants with Varying Abutment Lengths and Diameters.

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KEYWORDS

Extra-short implant, finite element analysis, varying bone densities, varying abutment lengths and diameters.

ABSTRACT:

Introduction: Dental implants have revolutionized the rehabilitation of partially and completely edentulous patients, offering a functional and aesthetic alternative to traditional prostheses. However, in patients with severe alveolar bone resorption, placing standard-length implants can be challenging due to limited vertical bone height. This often necessitates invasive procedures such as bone grafting or sinus augmentation, which may not be feasible in all clinical scenarios due to increased cost, surgical morbidity, or systemic contraindications.

Objectives: To evaluate and compare three-dimensional stress distribution in different bone densities (D1, D2, D3, D4) using extra-short dental implants with varying abutment lengths and diameters through Finite Element Analysis.

Methods: A total of 24 three-dimensional models were created using CAD software to simulate extra-short implants (6 mm length) with varying abutment diameter and length (5mmx5mm, 5mmx6.5mm, 5mmx10mm, 5mmx12mm, 6.5mmx6.5mm, 7.5mmx8mm). These implant-abutment assemblies were placed in bone models representing D1, D2, D3, and D4 bone densities. Finite Element Analysis was conducted under axial and oblique loading conditions. The von Mises stress values were evaluated at the implant, abutment, and crestal bone regions.

Results: Implants with larger diameters showed reduced stress in all bone types, particularly at the crestal bone level. Higher abutment heights increased stress concentration, especially in oblique loading scenarios. Among the bone types, D2 bone showed the most favorable stress distribution, while D4 bone exhibited the highest stress values, indicating a higher risk of biomechanical failure.

Conclusions: Bone density plays a critical role in stress distribution around extra-short implants. Increased implant diameter can enhance stress dissipation, while taller abutments may compromise stability in low-density bone. Optimal implant-abutment combinations must be selected based on bone quality to improve long-term success in atrophic jaw rehabilitations using extra-short implants.

1. Introduction

Dental implants have revolutionized oral rehabilitation, offering predictable and long-term solutions for tooth loss, providing functional and aesthetic rehabilitation. However, clinical success depends significantly on factors such as bone density, implant dimensions, and biomechanical stress distribution, bone quality, implant design, and load distribution. There are variations in success and survival rates across different implant sites, with the posterior maxilla showing particularly lower rates compared to the mandible. This trend is often linked to unfavourable bone conditions in the posterior region of maxilla, caused by from inadequate bone quality or quantity.[1]

When bone height is diminished, particularly in the posterior region of the maxilla and mandible, placing conventional implants can be difficult due to anatomical limitation.[2]

The purpose of this finite element study is to analyze the distribution of the stresses generated in the different structures (abutment, implant, and bone) of an extra-short implant with internal hex connection (length and width 6mm) with varying abutment diameter and length (5mmx5mm, 5mmx6.5mm, 5mmx10mm, 5mmx12mm, 6.5mmx6.5mm, 7.5mmx8mm) on 4 types of bones densities (D1, D2,D3,D4) with an axial load (150N) and oblique load (100N).

2. Objectives

The primary objective of this study is to evaluate and compare the three-dimensional stress distribution patterns in peri-implant bone across different bone densities—specifically D1 (dense cortical bone), D2 (porous cortical and coarse trabecular bone), D3 (thin cortical and fine trabecular bone), and D4 (very fine trabecular bone)—when rehabilitated using extra-short dental implants. These implants are analyzed with varying abutment lengths and diameters to assess their biomechanical behavior under simulated masticatory forces.

The study employs Finite Element Analysis (FEA) as a computational method to simulate real-life conditions and quantify the stress distribution in the surrounding bone. By doing so, the research aims to determine how implant-abutment configurations influence stress transfer, particularly in compromised bone conditions such as D3 and D4. The findings are expected to contribute to optimizing implant selection and prosthetic design in cases where available bone height is minimal and bone quality varies, thereby enhancing clinical outcomes and long-term implant success.

3. Methods

In the method mentioned above implant, abutment and dental crowns models were fabricated. All the 3 models were aligned and fixed to each other to simulate oral conditions.

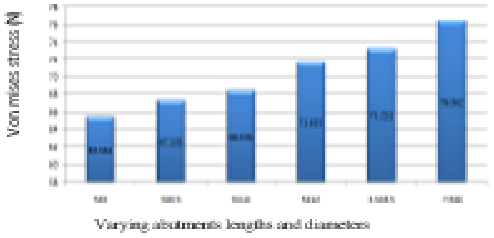
Extra-short Implants of length and diameter 6mm (constant) were loaded with varying abutment length and diameter namely 5×5mm, 5×6.5mm, 5×10mm, 5×12mm, 6.5×6.5mm and 7.5×8mm with varying abutment dimensions under axial (150N) and oblique (100N) loads on four types of bone densities namely D1, D2, D3, D4. Six models were fabricated with all the above-mentioned combination of abutment lengths and diameters while the diameter and the length of the implant remained constant(6mm). Each combination of the abutment length and diameter was then fixed with the four types of bone (D1, D2, D3, D4). Thus, twenty-four models were created. These twenty-four models were analysed with an axial load (150N) and oblique (100N) load.[3] Finite element analysis was used to evaluate the stress distribution inside each type of bone density. Thus, a total of forty-eight models were created. All these data were then exported to ANSYS SOFTWARE and the material properties were assigned.

After all the data was assigned, high quality MESH was generated which ensured the refinement at the critical regions (implant-bone interface and abutment connection)

The base of the bone model was fully constrained. Load of 150N axially was applied at the top of the 24 models to simulate real-world mastication forces. Similarly, a load of 100N was applied 25 degrees obliquely on the remaining 24 models and the stress distribution was analysed.

4. Results

Axial load 150n on D1 bone the highest von-mises stress value is **76.362Mpa** for the **7.5×8mm** dimension, while the lowest von-mises stress value is **65.362Mpa** for the **5×5mm** dimension whereas on D2 bone the highest von-mises stress value is **78.635Mpa** for the **7.5×8mm** dimension, while the lowest von-mises stress value is **68.522Mpa** for the **5×5mm** dimension. On D3 bone the highest von-mises stress value is **81.125Mpa** for the **7.5×8mm** dimension, while the lowest von-mises value is **71.203Mpa** for the **5×5mm** dimension and on D4 bone the highest von-mises stress value is **89.565Mpa** for the **7.5×8mm** dimension, while the lowest von-mises value is **73.263Mpa** for the **5×5mm** dimension as shown below graphs 1,2,3,4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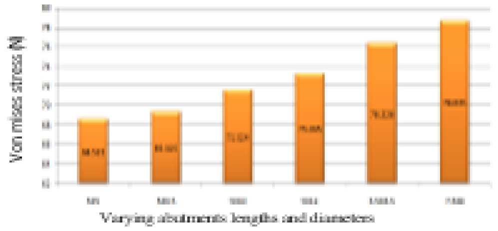
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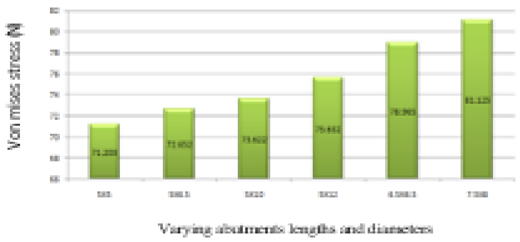
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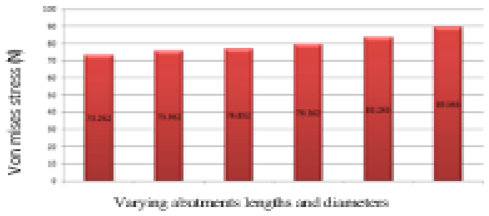
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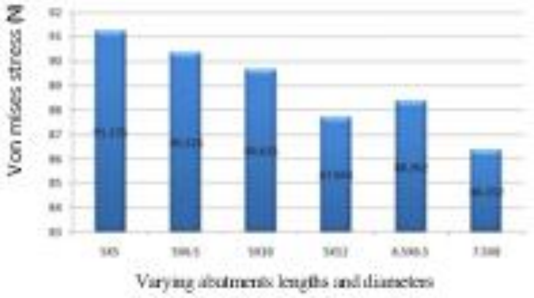
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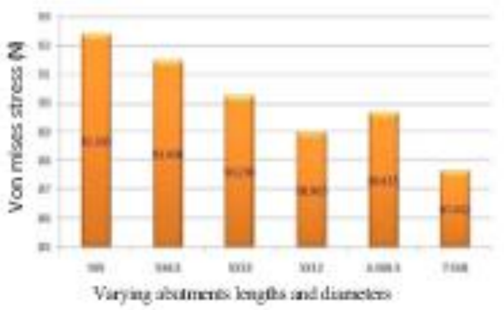
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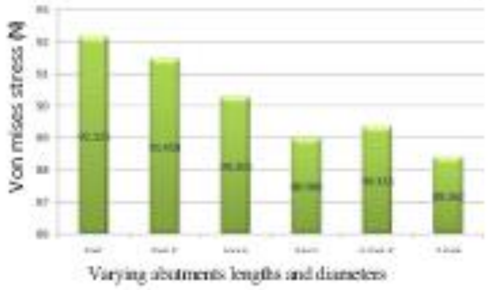
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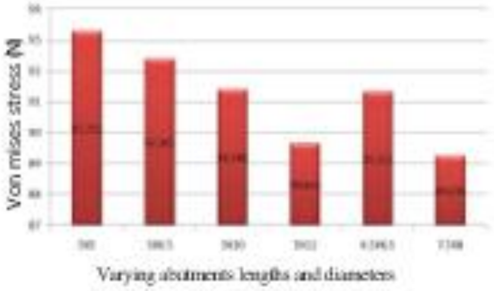
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5. Discussion

Over few decades dental implants have been considered a viable treatment option for the missing natural tooth/teeth which has been lost due to any reason. For the implant to succeed it has to blend with the human body more specifically the alveolar bone.[4]

When we rehabilitate atrophic ridges with the extra short implants by bypassing the surgical intervention, there will be discrepancies that occur in superstructure to fixture ratio of the implant. Implants become shorted and wider whereas crowns become thinner and longer.

Franck Renouard[5] used extra short implants of 6mm as an alternative to augmentation for maxilla and found 94.6% of success rate. Fabio Rossi[6] placed 40 sandblasted and acid etched active implants of 6mm size, resulting in 95% survival rate. Rangert et al[7] emphasized that offset forces play a major role in implant failure due to heavy bending movements. Whereas, Xiao-Meng Zhang et al[8] compared all conventional implants with surgical intervention and extra short implants bypassing surgery and emphasizing that both of the types possess similar patient satisfaction.

In this experimental study, six dimensions of abutment lengths and diameter – 5×5mm, 5×6.5mm, 5×10mm, 5×12mm, 6.5×6.5mm and 7.5×8mm were placed on a 6mm (length and width) extra short implant. These six models were subjected to axial load(150N) and oblique load(100N) which were tested on all four types of bone qualities. The findings were interpreted through Von mises stress analysis, which provided an important information about the stress distribution of the extra short implants on different types of the bone.

COMPARISION OF DIFFERENT TYPES OF BONE DENSITIES:

Our study results clearly show that bone quality makes a markable difference in stress distribution.

D1 bone as it is dense cortical with highest mineral content, constantly shows lowest von mises stress which were generated on the bone as well as implant abutment complex under both axial and oblique loads. M Danza et al[9] in finite element analysis revealed that dental implants placed in D1 bone exhibited lower stress distribution within the surrounding bone. However, the high stiffness of D1 bone also concentrated more stress at the implant–bone interface, potentially increasing the risk of localized bone resorption.

D2 bone known for its dense trabecular bone with thick cortical bone, it provides moderate von mises stresses generation in both axial and oblique load conditions. Compared to D1 bone, D2 bone have shown stresses distribution is along the long axis of the bone in axial load, and in oblique load all the stresses were concentrated at the crestal bone and generated more stresses than in axial loading. Montip Monstaporn et al[10] mentioned that bone density plays a crucial role in stress distribution and elaborated D2 bone good has mineral content as well as adequate blood supply for the bone to remodel when the stresses are exerted on the bone as well as implant.

D3 bone have thinner cortical bone with porous trabecular pattern, in both axial and oblique loads it shows less mechanical support than D1 and D2 bone, but still can be managed. D3 bone exhibits higher stress concentrations around the crestal region and overall implant axis which indicates vulnerable mechanical behaviour particularly in oblique loading where stress exceeds 90MPa indicating higher risk of overload. D4 bone with porous bone and poor cortical plates shows highest von mises stresses, distribution is non uniform, might be in the risk of implant micromovement, faster bone resorption, may result in poor primary stability, high risk of fibrosseogration. Out of all bone qualities it has the poorest mechanical behaviour and higher mechanical overload. Sevimay et al[11] showed softer bones (D3, D4) have higher stress concentrations, especially at the crestal bone region compromising biomechanical stability and may increase the risk of marginal bone loss. Sesha MR et al.[12] suggested that despite the low density of D4 bone, short implants with subcrestal positioning maintained biomechanical stability by promoting better load transfer along the implant body. So, combining platform-switching and subcrestal placement is an effective strategy for enhancing implant performance and preserving bone integrity in low-density bone conditions.

ROLE OF ABUTMENT LENGTH AND DIAMETER:

Our study results indicated that even the abutment length and diameter play an important role in success of the implants.

Amirreza Hendi et al.[13] highlighted shorter abutment heights were more prone to mechanical complications under higher crown height conditions. In this study in varying abutment length, the results were complicated. Longer abutments enhanced stability in D1 and D2 bone, while in D3 and D4 bones the higher the length of the abutment the higher was the generation of von mises stresses. In lower-density bone, excessively long abutments may exacerbate leverage effects under oblique loads, increasing stress at the implant-abutment junction.

Whereas in varying abutment diameter, the stress distribution of the wider implants was less and while narrower implant had an increased stress distribution. Wider abutments may also offer improved platform switching, which has been linked to reduced crestal bone loss. Anupama Aradya et al[14] Implants with wider abutment diameters showed reduced stress concentrations at the crestal bone level, promoting better load distribution and potentially minimizing marginal bone loss. In contrast, narrower abutments concentrated more stress at the implant–bone interface, increasing the risk of bone resorption over time.

INFLUENCE OF LOAD DIRECTION AXIAL VS OBLIQUE:

As we know the direction of the load which is applied in to the tissues is the deciding factor for the long-term success of the implant/ implants system.

Axial load of 150N has been chosen to simulate the functional load in the oral cavity and it resulted in more uniform and lesser stress concentrations in all bone types as the load is aligned to the long axis of the bone and implant. In contrary, oblique load (100N) are the forces in which implant tend to bend and possess shear forces. So, the intensity of the forces is huge in D3 and D4 bones. Hector deLlanos- Lanchares et al[15] studied implants stress distribution in different loading conditions and concluded non-splinted designs showed higher stress concentrations, particularly under oblique loading. Malathi Dayalan et al[3] concluded that von mises stresses are concentrated more at crestal regions of 2:1 crown to implant ratios restorations in oblique loadings of 100N than axial load of 150N.

LIMITATIONS OF THE STUDY:

In Finite Elemental Analysis, the simulations are static and based on fixed models, however in clinical scenarios we have biological remodeling, muscle forces, dynamic loading, micromovements, which are not replicated. These structures also influence the load distribution, so to validate the above data, there is simultaneously need of clinical trials and follow-up.

CONCLUSION

This study provides crucial data about the biomechanical performance of the extra short implants with various combinations of abutment length and diameter under two different loads upon all the available bone qualities.

Results were critically evaluated across all the bone types and the stress distribution reveals the following pattern:

As the abutment length and diameter increased in **axial loading condition**, von mises stress values also increased. **Highest stress** values were seen in the **longest and wider abutment system** (7.5×8mm) while the **lowest stress** was generated on **smallest abutment system** (5×5mm). whereas the trend was inverse in **oblique loading condition**, as the abutment length and diameter increased von mises stress values decreased. **Highest stress** values were seen in the **smallest abutment system** (5×5mm), while the **lowest stress** was generated on **longest and wider abutment system** (7.5×8mm).

However, stress values followed only one pattern; they increased from D1 type of bone to D4 type of bone in both loading conditions. As the **D1 type of bone** is denser due to hyper mineralized bone matrix system all the load is concentrated on the crest of the edentulous ridge and neck of the implant, the **load is not transferred throughout the long axis of the implant**. Whereas, D2 bone is has reasonably dense mineral matrix allowing the **stresses to travel throughout the long axis of implant and bone, allowing better load and stress distribution in the rehabilitated area.** Thus, we can make an inference that **D2 bone is best** suited for the placement of **extra short implants.**

As the oral cavity of the human differ from each other precautions should be taken while choosing the abutment length and diameter. Sticking to smaller abutment sizes may have low stresses in the axial loading condition but same abutment size has the highest stresses exerted during the oblique loading. While the longer and wider abutments have exactly reverse configuration irrespective of any bone quality.

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