Original Article

# An Evaluation Of Stress And Strain Distribution In Cortical And Cancellous Bone Around Microimplant Under Various Loading Conditions-A Finite Element Structural Analysis

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## Abstract

**Aim:** The purpose of the present research was to assess the amount of stress and strain in cortical and cancellous bone around micro or mini-implant under variety of loading conditions using Finite Element Analysis (FEA).
**Methodology:** Three implant designs with the same length and diameter were used. The three-dimensional geometry of the bone was simulated with a cortical bone of three different thicknesses and two medullar bone densities. A 30◦ oblique load of 150 N was applied to the implant restoration. Displacement and stress (von Mises) results were obtained for bone and dental implants.
**Results:** The strain and stress distributions to the bone were higher for the tissue-level implant for all types of bone. The maximum principal strain and stress decreased with an increase in cortical bone thickness for both cancellous bone densities. The distribution of the load was concentrated at the coronal portion of the bone and implants.
**Conclusion:** All implants showed a good distribution of forces for non-axial loads, with higher forces concentrated at the crestal region of the bone–implant interface. Decrease in medullar bone density negatively affects the strain and stress produced by the implants.

**Keywords:** dental implants; design; finite element analysis; strain distribution; stress distribution; bone quality.

## INTRODUCTION

The selection of implant that will provide adequate stability in bone of poor quality is important. Tapered implants imitate the natural form of root. They are known to enhance primary stability by providing pressure on the cortical bone of regions with poor bone qualities.[1] Tapered implant body has a good survival rate because it directs stresses away from the crestal cortical bone while transferring it to the cancellous bone.[2] In addition, bone perforation is less likely to occur due to the anatomical shape.[3] The natural maxillary teeth are loaded at an angle because of their natural angulation compared with the mandibular anterior teeth.[4] Anatomic constraints sometimes make it necessary to surgically position implants at angles that are not optimal for prosthetic restorations or by positioning the implant in the area with the greatest available bone with the intention of correcting the implant alignment at the time of prosthetic restoration. This is made possible, in carefully planned cases, with the use of angulated abutments.[5] Angulated abutments may be considered as a suitable restorative option when implants are not placed in ideal positions.[5,6] Angulated abutments are often used to restore dental implants placed in the maxillary anterior region due to the esthetic and spatial needs.[7,8] The angulation of these abutments varies from 0° to 35° and the most commonly used angulation is 15° and 25°.[8-11] Angled abutment was subjected to higher stress values around the cervical region than those observed for straight abutment.[12] The successful osseointegration of implant depends not only on the bone quantity but also on the bone quality.[13] With the tapered implant body design and triangular, buttress, and square threads, it is not known how various threads contribute to stress distribution in anterior maxillary region. The finite element method (FEM), which has been successfully applied to the mechanical study of stresses and strains in the field of engineering, makes it practicable to elucidate stresses in the living structures caused by various internal and external forces. Finite element analysis (FEA) has become an increasingly useful tool for the prediction of the effects of stress on the implant and its surrounding bone. The key factor for the success or failure of dental implant is the manner in which the stresses are transferred to the surrounding bone. FEA allows predicting stress distribution in the contact area of the implant with the cortical bone, and around the apex of the implant in the trabecular bone.[14] Numerous investigations have been conducted to assess the stress and strain distribution that occurs around larger/bulkier prosthodontic implants, but limited literature is available regarding the same about mini-implants used for orthodontic anchorage.[15,16] Also, the nature of loading of prosthodontic implants would be different compared to those used for orthodontic purposes. Hence, it was felt that there is a need to explore the changes in the bone adjacent to the implant following orthodontic loading.

## AIM OF THE PRESENT STUDY

The purpose of the present research was to assess the amount of stress and strain in cortical and cancellous bone around micro or mini-implant under variety of loading conditions using Finite Element Analysis (FEA).

## METHODOLOGY

A finite element assessment requires definition of the parameters that characterize the model in which the study is carried out. The three-dimensional (3D) geometry of the bone was simulated with cortical bone of three different thicknesses—0.5 mm, 1 mm, and 2.0 mm—and medullar bone with a density at two levels—low density (150 Hounsfield units—HU) and high density (850 Hounsfield units—HU). The implants evaluated in this study were for daily use in dental practice, the Klockner Implant System® (SOADCO, Escaldes-Engordany, Andorra), with the corresponding CE marking. Essential Cone® (from now on designated as implant A) with a 1.5 mm neck or polished portion was used. It is a one-piece tissue-level concept implant, which incorporates the transepithelial portion attached to the implant body without continuity solution, eliminating the gap or implant-abutment connection. The neck of the implant is concave in the shape of a tulip and has a micro-thread (1.5 mm), with a pitch of 0.05 mm. Vega® (from now on designated as implant B) is a two-piece bone-level implant concept that applies the switching platform treatment philosophy, seeking better maintenance of the crestal bone level after insertion. This implant is made of a new generation of grade IV titanium, known as OPTIMUM® titanium. The implant neck is convex cone-shaped and has three rings (0.3 mm) with a 0.4 mm gap between them. Vega+ ® (from now on designated as implant C) is also a bone-level concept implant in two pieces that applies the switching platform treatment philosophy, like implant B. Its design tries to facilitate insertion at the bone site, as well as to achieve greater primary stability. The implant neck is convex cone-shaped and has three rings (0.3 mm), with a 0.4 mm gap between them. The size of the implants used were 4 mm in diameter and 10 mm in length for all types of implants. The loading protocol simulated an intimately connected bone–implant interface (osseointegration simulation, delayed loading protocol). The force between the alveolar crest and the implant was pushed downside, with a 30◦ oblique load of 150 N, avoiding stress concentration errors, and the sides of the alveolar bone were used as a fixed support constraint. The load was applied at the level of the central fossa of the restoration, and the model was fixed in the support bone. A convergence test with the finite element models was carried out to verify the quality of the mesh.

## RESULTS

The strain distributions in the bone were analyzed in both medullar bone densities (150 HU and 850 HU), for all cortical bone thicknesses (0.5 mm, 1 mm, and 2 mm), and for all implant designs. The strain distribution to the bone was higher for implant A followed by implant B and implant C, respectively, and for all types of bone.

Furthermore, the maximum principal strain decreased with an increase in cortical bone thickness for both cancellous bone densities, and this difference was more prominent in the low-density medullar bone. The distribution of the strain to the bone was concentrated, in all the examples, at the level of the most coronal portion of the implants. Likewise, there was a more homogeneous distribution of the strain throughout the body of implant C. (Table 1)

**Table 1: Material properties used in finite element models.**

| Implant Design | Material Component | Material | E * (GPa) # | Poisson Ratio |
|---|---|---|---|---|
| A | Implant Essential Cone® | Titanium Grade 3 | 103.4 | 0.340 |
| B | Implant Vega® | Titanium Grade 4 | 104.0 | 0.340 |
| C | Implant Vega +® | Titanium Grade 4 | 104.0 | 0.340 |
|  | Medullar bone (150 HU) |  | 0.259 | 0.300 |
|  | Medullar bone (850 HU) |  | 3.507 | 0.300 |
|  | Cortical bone |  | 13.980 | 0.300 |

* Young’s Modulus. # Gigapascals, Hounsfield units—HU

The strain distribution in the dental implant was higher for implant A in all types of bone. Furthermore, the maximum principal strain in the implant decreased with an increase in cortical bone thickness for both medullar bone densities, and this difference was more prominent in the low-density medullar bone. The distribution of the strain to the implant was concentrated, in all the examples, at the level of the most coronal portion of the implants. Likewise, there was a more homogeneous distribution of the strain throughout the body of the implant in the case of implant C. The von Mises stress distribution in bone was higher for implant A in all types of bone. The maximum values in stress distribution in bone decreased with an increase in medullar bone density for all implant designs. The von Mises stress distribution was higher for implant A in all types of bone, with the only exception for the low medullar bone density with a cortical bone of 2 mm thickness. The differences in maximum stress values between implant designs tended to be higher in low medullar bone density. (Table 2)

**Table 2: Von Mises stress distribution (maximum absolute values, MPa) in bone, for both medullar bone densities, for all cortical thicknesses (0.5 mm, 1 mm, and 2 mm) in all implant designs: A, B, and C.**

| Bone Density | Implant Design | Cortical Bone 0.5 | Cortical Bone 1 | Cortical Bone 2 |
|---|---|---|---|---|
| 150 HU | A | 170.31 | 231.97 | 167.5 |
| 150 HU | B | 169.89 | 129.43 | 83.03 |
| 150 HU | C | 140.87 | 122.84 | 91.165 |
| 850 HU | A | 129.4 | 157.04 | 146.78 |
| 850 HU | B | 68.838 | 66.678 | 72.354 |
| 850 HU | C | 62.686 | 61.803 | 79.693 |

## DISCUSSION

The FEA offers several advantages including accurate representation of complex geometries, easy model modification, the internal state of stress, and other mechanical quantities.[20] The FEA study offers valuable preliminary information for implant planning for the clinicians. However, one limitation to this study is that the model cannot fully reflect the properties of living tissues. Although it is impossible to reflect oral conditions in the models, this study is valuable in terms of providing preliminary information to clinicians to guide clinicians before planning.[17] The finite element stress analysis method in implant biomechanics is better than other methods in terms of its ability to mimic complex clinical situations. It can be used to predict the distribution of stresses in jaw bones and dental implants.[18] To achieve stable osseointegration for implant restoration, the generation of high stress concentration or distribution in bone should be avoided, since high stress concentration or distribution can induce severe resorption in the surrounding bone, leading to gradual loosening and finally complete loss of the implant.[19] The bone density and the cortical/cancellous bone ratio may be important due to their influence upon the primary stability of an implant.[20] In the literature, there are several studies on the effects of cortical bone thickness in implant stability and they state that there is strong correlation between implant stability and cortical bone thickness. Increased bone density improves the mechanical properties of implants. Holmes and Loftus reported that an increase in bone density provides a decrease in implant micromotion, which decreases the stress levels at the bone implant interface.[21] These studies indicate that cortical bone thickness affects the jaw bones' stress. Melsen and Verna evaluated the load transfer from the Aarhus miniscrew on the bone, and the influence of different cortical bone thicknesses and the underlying trabecular bone density, on applying a mesially directed force of 50 gm. The results obtained from our study matched with their study. The primary component of the load transfer was seen at the first revolution of the miniscrew thread within the cortex. Authors found that on decreasing the thickness of the cortical bone, the peak strain values reached the pathological overload window (Frost's mechanostat theory).[22] But in our study, the thickness of the cortical bone was kept constant with the larger part of the implant being surrounded by the cortical bone. Hence, the cortical bone experienced greater strain values than the underlying trabecular bone. In the implant, the most critical area is its neck, where there is maximum stress concentration, and the marginal bone (cervical margin) which surrounds it. Thus, this area should be preserved clinically in order to maintain the bone-implant interface structurally and functionally. It was seen in our study that the implant tipped to a very negligible amount in the direction of the load applied, like a tooth tipping on application of load. But the displacement seen was very negligible and clinically insignificant.

## CONCLUSION

Both the types of FE models showed the area with the highest stress and strain to be around the neck of the implant and the surrounding bone at the cervical margin. To obtain an optimal biomechanical response, the implant should preferably be placed entirely in the cortical bone.

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