Influence of Implant Dimensions in the Resorbed and Bone Augmented Mandible: A Finite Element Study

Abstract

Aims: The scope of this study was to analyze the influence of clinically feasible implant diameter and length on the stress transmitted to the peri-implant bone in the case of a resorbed and bone augmented mandible through finite element analysis. **Settings and Design:** The study was carried out *in silico*. **Subjects and Methods:** Resorbed and bone-augmented 3D models were derived from *in vivo* cone-beam computed tomography scans of the same patient. Corresponding implant systems were modeled with the diameter ranging from 3.3 to 6 mm and length ranging from 5 to 13 mm, and masticatory loads were applied on the abutment surface. **Statistical Analysis Used:** None. **Results:** In the bone augmented ridge, maximum stress values in the peri-implant region drastically decreased only when using implants of a diameter of 5 mm and 6 mm. Implants up to 4 mm in diameter led to comparable stress values with the ones obtained in the resorbed ridge, when using the larger implants. The increase of length reduced stress in the resorbed mandible, whereas in the bone augmented model, it led to small variations only in implants up to 4 mm in diameter. **Conclusions:** It was concluded that bone augmentation provides the optimal framework for clinicians to use larger implants, which, in turn, reduces stress in the peri-implant region. Diameter and length play an equally important role in decreasing stress. Implant dimensions should be carefully considered with ridge geometry.

Keywords: *Bone augmentation, bone resorption, finite element analysis, implant dimensions, peri-implant stress*

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Introduction

Dental implants have been proven to be a successful solution in the oral rehabilitation of edentulous patients. Advancements in materials, coating technology, and a wide variety of designs have allowed dental implants to be used in almost all clinical cases.[1] Among the most important factors in choosing the optimal implant are bone quality, density, and dimensions.[2,3] Implant dimensions are dependent on available bone volume and also have a great influence on the stress values and distribution in the mandibular bone. Certain dimensions of implants may not even be considered in some cases such as bone resorption due to restrictive dimensions of the mandibular bone. When the loss of bone tissue is substantial, bone augmentation can be done, aiming to restore its dimensions, both in height and width, thus allowing the use of a larger implant. Bone augmentation is a surgical procedure that presents certain risks such as postoperative morbidity of the donor site, increased costs of oral rehabilitation, pain, treatment time.[4]

Many current *in vivo* and *in vitro* studies have tried to assess the impact of implant dimensions on the stress transmitted to the peri-implant tissue but have yet to reach a clear conclusion on this complex matter.[4-8] Some studies have reported that a larger implant may lead to smaller stress values in the peri-implant bone.[5-7] However, other studies show that smaller implants used in resorbed mandibles have a comparable long-term survival rate and stress values to larger implants.[4-6] Furthermore, there is a lack of studies on the importance of bone geometry and its influence on the implant induced stress at the crestal bone level, since implant dimensions, stress, and bone geometry are all inter-related and should not be studied separately.[4]

Stress values and distribution are important factors for long-term implant survival. High-stress concentration at the peri-implant bone due to excessive implant loading may lead to bone resorption.[8-11] Bone loss around the implant

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neck is associated with implant failure. The long-term success of dental implants depends on the ability of the bone tissue to respond positively to implant loading.[11-14] Physiological loads applied to the implant are transferred to the surrounding tissue. These forces can either improve bone remodeling or produce bone resorption. Several factors are reported to have a significant influence on the homeostasis of the bone tissue: the type and magnitude of loading, implant geometry and materials, the volume and density of bone tissue, and the characteristics of the bone-implant interface.[12-19] Approximately 50% of implant losses occur due to the loss of bone support.[20] Implant dimensions can influence bone loss due to their impact on stress values generated in the bone tissue.[20]

Thus, the issue is whether or not bone augmentation is necessary to allow for the use of larger implants when smaller ones could potentially perform comparably and avoid preliminary surgical procedures. Finite element analysis (FEA) is an advantageous technique because it allows the exploration of certain parameters through iterative analysis with no ethical implications that would be otherwise difficult or even impossible to achieve under clinical conditions.[21]

To the best of our knowledge, no previous FEA studies have yet to explore the impact of implant dimensions using a real case of the resorbed mandible and the clinically bone augmented version, by assessing implant dimensions in the pre and post bone augmented mandible model.

The scope of this study was to analyze the influence of clinically feasible implant diameter and length on the stress transmitted to the peri-implant bone in the case of a resorbed and bone augmented mandible through FEA.

Subjects and Methods

Two 3D models representing a segment of the human mandible were derived from two separate *in vivo* cone-beam computed tomography (CBCT) scans belonging to the same patient, performed pre and post bone augmentation. The mandible presented with mandibular atrophy corresponding to a bone field class II (bone height >10 mm, bone crest width 2.5–5 mm) according to the Misch and Judy classification.[22] Vertical and horizontal bone graft augmentation was performed, aiming to restore bone dimensions. Measurements of bone-implant site pre and postaugmentation are presented in Figure 1.

Models were constructed and processed in Autodesk Fusion360 (Autodesk, Inc., San Rafael, CA, USA). Both mandible sections consisted of two macro-structures, a 2 mm thick cortical bone and an internal cancellous bone, as shown in Figure 2. Classic tapered threaded implants were modeled. Implant diameter (D) and length (L) were set as input variables. D ranged from 3.3 mm to 6.0 mm, and L ranged from 5.0 mm to 13.0 mm. A conic 10 mm length abutment was used in all simulated cases to allow
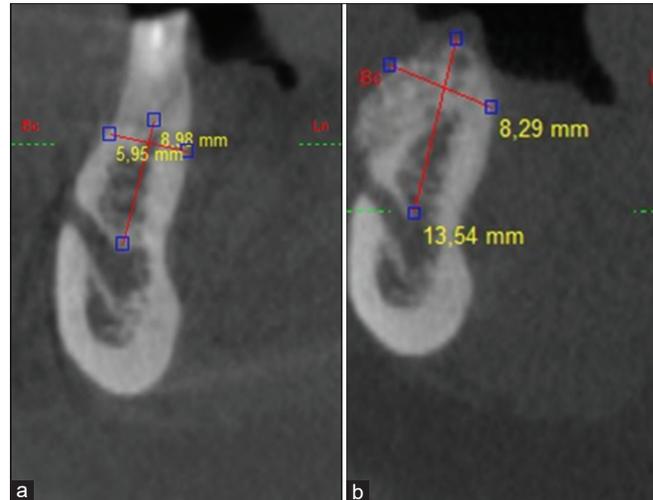

Figure 1: (a) Image depicts a cone-beam computed tomography scan image made before the bone augmentation and revealed the initial measurements of the mandibular bone. (b) The image depicts a second cone-beam computed tomography scan image made after the bone augmentation which revealed the obtained measurements of mandibular bone

for adequate comparison, eliminating a possible effect of the abutment length.[23]

Simulations were carried out in Simulation Mechanical version 2017 (Autodesk, Inc., San Rafael, CA, USA). A static type analysis with linear, elastic, and homogeneous material properties was chosen for all simulation cases.

For the implant and abutment, the isotropic mechanical properties of Ti-6Al-4V were assigned. The cortical and the cancellous bone were assumed to be isotropic. Material properties assigned for each analysis element are listed in Table 1.

Boundary conditions were applied to end surfaces of the mandibular model, fixed in all directions. The contact type between bone and implant was defined to be perfectly bonded. From a clinical perspective, perfectly bonded contact between bone and implant would translate in perfect osseointegration between the two. Studies have shown that introducing a friction coefficient between the implant and surrounding bone as an expression of various degrees of osseointegration may artificially decrease stress in the peri-implant bone.[24] Masticatory type loads were applied on the abutment surface based on the previous work of Himmlová *et al*.: 114.6 N in the axial direction, 17.1 N in the lingual direction, and 23.4 N in the distomesial direction as illustrated in Figure 3.[25]

Results

In the resorbed mandible, values of stress in the cortical and cancellous bone were highest when using the 3.3D/5L implant. The 3.7D/8L implant led to the lowest stress values in the bone tissue, in the resorbed mandible. In the bone augmented ridge, at cortical bone level, the highest value of stress was recorded when using the 3.7D/13L

Table 1: Material properties

Material	Young's modulus (GPa)	Poisson coefficient
Cortical bone[17,26,27]	13.7	0.30
Cancellous bone[17,28]	1	0.30
Implant/abutment - Ti6Al4V[29]	110	0.35

implant and lowest when using the 5D/11.5L. In the cancellous bone, the 5D/11.5L implant led to a decrease in stress as opposed to the 3.7D/11.5L implant which led to an increase in stress. In the bone augmented mandible model, differences in stress values were small between implants of diameter 5 and 6. Stress values obtained in the simulations in both resorbed and bone augmented mandible are shown in Figure 4.

For all simulated cases, stress was concentrated at the crestal bone level, around the neck of the implant. Peak von Mises stress values were situated opposite side of the applied distomesial masticatory loads, as illustrated in Figure 5. A more prominent stress concentration at the crestal bone level in the resorbed mandible was obtained when using the 3.7D/5L implant. In the bone augmented mandible, a similar area was observed when using the 4D/13L implant.

Discussion

In this study, analyzing the resorbed and the bone augmented mandible models using various implant dimensions allowed to evaluate bone dimensions relative to stress values. Unlike many prior studies mentioned in the literature, our research has paid specific attention to using a CBCT derived mandible model of a pre and post bone augmentation clinical case, allowing for an adequate analysis of the influence of various implant dimensions on the stress values and distribution in the mandibular bone. Thus, an assessment was made with smaller implants in the resorbed mandible model and with larger implants in the bone augmented model. The overall results indicate that larger implants, both in diameter and in length, placed in a bone augmented mandible are more favourable in terms of stress values. However, while implants with diameter up to 4 mm led to overall similar stress values in the augmented ridge in comparison to some of the smaller implants in the resorbed ridge, stress only decreased considerably when using larger diameter implants of 5 mm and 6 mm.

In the resorbed mandible model, the increase of the implant diameter showed a consistent decrease of stress in both the cortical and cancellous bone. One notable peak of stress, in both of the bone tissues, was obtained when using the 3.7D/5L implant, where even though there was an increase in implant diameter, the insufficient length led to greater stress values. In the bone augmented mandible, results outlined a similar pattern. Although this in accordance with several studies that suggest that an increase in implant diameter decreases stress in surrounding cortical and
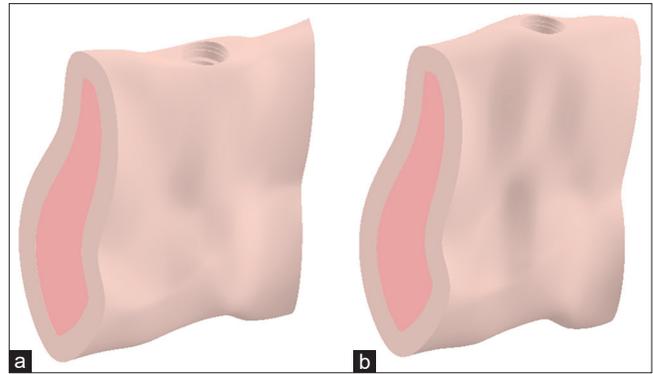

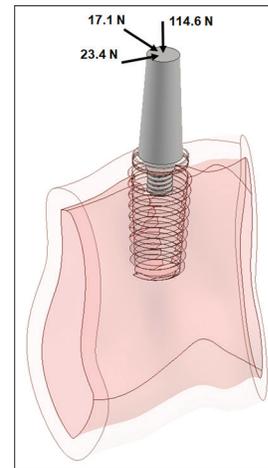**Figure 2:** Modeled 3D FE of the resorbed mandibular section (a) and bone augmented mandibular section (b)

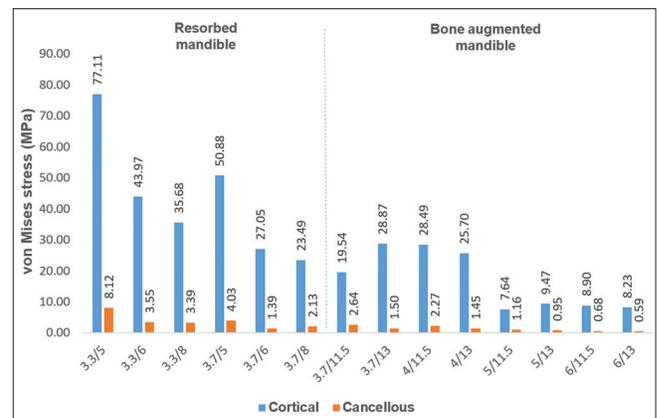**Figure 3:** 3D model of the mandibular bone section with loads applied

Figure 4: von Mises stress in resorbed and bone augmented mandible bone when using various implant dimensions

cancellous bone, our results showed that this is only valid for certain implant dimensions.[6,30,31] This may be due to the dependence of the stress values and the distribution on the model geometry, thus the importance of using real clinical models in such FEA.[32] Lee *et al.* reported in their study that implants of diameter 6 mm showed the most noticeable reduction in stress values.[6]
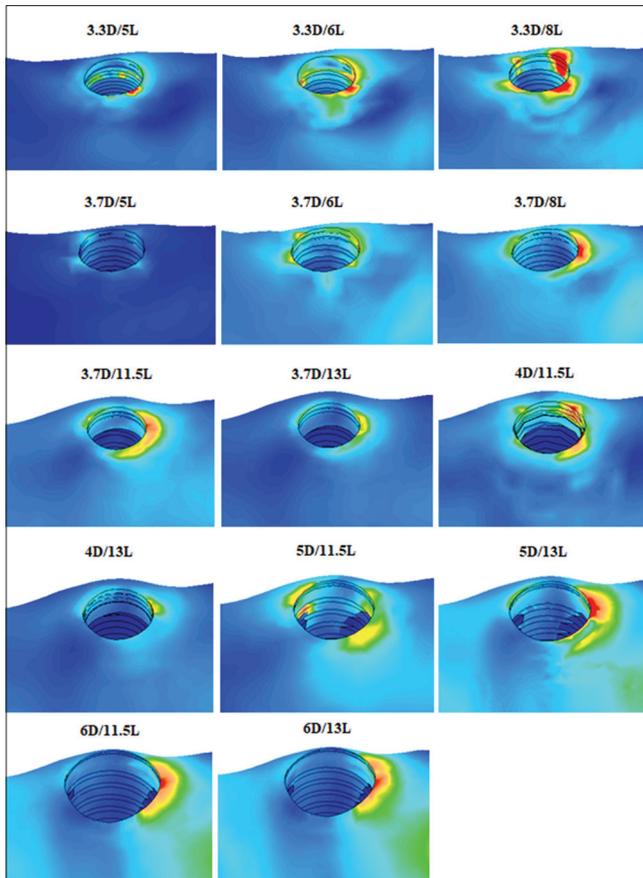
Figure 5: Stress distribution at crestal bone level in the resorbed and bone augmented mandible models when using various implant dimensions

less stress distributed to the surrounding bone tissue.[35] Thus, it is important to note that the diameter and length of the implant correlated with bone dimensions need to be optimized to ensure appropriate stress values. Besides geometry characteristics, bone field quality also needs to be taken into consideration.[36,37] Treatment planning must be thorough and must cater to the specific needs of the patient. For example, without any pro-implant surgical interventions, in implant-supported restorations in fully edentulous patients, the probability of placing sufficient implants is 58.62%.[38] Implants are made of materials that have a higher elastic modulus compared to bone tissue allowing for better load take on. Bone augmentation alone ensures a larger geometry at implant site which allows the bone to be able to better withstand physiological mastication forces but larger implant results in more volume of material with greater mechanical properties to take over the load. The mechanical characteristics of the available bone tissue such as elastic modulus, density, and behaviour under masticatory loads are important, but the size must also be considered.

The distribution of stress was similar in the resorbed and bone augmented ridge. Stress was concentrated at the crestal region, around the neck of the implants. These results are consistent with several studies, showing that this type of stress concentration is not necessarily dependent on the implant dimensions but rather on the mechanical properties of the cortical and cancellous bone and the type of loading applied.[5,7,15,24]

However, in our study, both 5D and 6D implants could be favourable choices since they resulted in similar stress values. The diameter of implants must be analyzed in conjunction with length because, as our results show, length can help decrease stress in the mandibular bone as in the case of the smaller and larger implants but may lead to peak stresses in some of the diameters used. The length variable showed that its increase led to smaller stress values in the resorbed mandible in both bone tissues while keeping the diameter as a constant. However, in the bone augmented mandible, the length of the implants did lead to some variation of stress values for implants of diameter up to 4 mm and very little variation for implants of diameters 5 and 6 mm. In our study, we hypothetically went to limit of the available bone height, thus including implants of length 13 mm. However, for clinical applications, a well-known safety distance of 2 mm from the inferior alveolar canal needs to be taken into account when choosing the implant length. Some studies have reported that length may be a less influencing parameter than the diameter of the implant.[33,34] Conversely, Li *et al*. reported in their study that length was effective in reducing stress in cancellous bone.[8] Also, in regard to length, Guan *et al*. concluded in their study that a larger implant offers a larger surface area for the load to be applied, thus resulting in

In interpreting the results, we must take into account several limitations. We considered the bone to be isotropic, and the bone-implant interface to be completely osseointegrated. In reality, the bone is anisotropic and there are various degrees of osseointegration at the bone-implant interface.[39] The obtained results of stress values in the bone tissue may be underestimated when lower degrees of osseointegration in certain areas of the implant-bone interface and are associated with higher stress values and changes in stress patterns.[39] In bone augmented mandible case, from a clinical perspective, different types of bone augmentation techniques may lead to better results in the obtained bone geometry and improved osseointegration. For example, the piezosurgery splitting technique allows for simultaneous implant insertion without creating dehiscence and fenestrations.[40] In FEA, these parameters are hard to replicate or to convey in mathematical variables. Implants with different types of the design were not compared. This parameter can greatly influence the connection between the implant and peri-implant bone tissue and the homogeneous or nonhomogeneous mode in which the forces developed at this level are dispersed.[12,14,41] Thus, a favorable design can provide the long-term protection of implant-prosthetic restoration. In interpreting the results, we must take into account that while vertical forces are associated with uniform stress distribution along

the implant-bone interface, oblique forces cause shear forces and bending moments on the implant, with the stress concentration on the implant neck and bone contact area.[42] The amplitude of masticatory type loading forces in the current literature is characterized by a large variability and is dependent on the patient, type of food consumed, and position of the implant in the oral cavity, values reported ranging from 100 N to 2400 N.[2,14] Therefore, if the magnitude of the forces that act on the implant is not well defined, optimization of stress values through the selection of the implant dimensions in a resorbed or bone augmented mandible, becomes a major important factor. Furthermore, the mode of application of loads varies, from the axial and horizontal application of loads to loads applied at an angle ranging 15°–30°.[2] Applied loads must describe as best as possible physiological masticatory loads for reliable results. However, in a linear elastic type study with isotropic material properties, increasing the load would only lead to a linear increase of the resulted stress. Hence even though a load value is important to define, in this type of analysis, you would only expect a direct proportionality.[2]

Conclusions

Within the limitations of this study, it was concluded that bone augmentation provides the optimal framework for clinicians to use larger implants, which, in turn, reduces stress in the peri-implant region. Our results showed that in the bone augmented ridge, maximum stress values in the peri-implant region drastically decreased only when using 5D and 6D implants. Implants up to 4D led to stress values, which were similar with some of the ones obtained in the resorbed ridge, when using the larger implants. With the increase in implant diameter, the stress decreased in both cortical and cancellous bone in the resorbed and bone augmented mandible. Length of implants also played an important role in decreasing stress in bone tissue in the case of the resorbed mandible, whereas in the bone augmented model, it led to small variations only in implants up to 4 mm in diameter. Taking into consideration bone geometry, implant length, and diameter, there must be an optimal balance between these parameters, as shown by the results of our study. FEA used in determining the ideal stress formula at the implant-bone interface can be a useful tool when modeling real clinical situations. Further finite element studies using patient-specific data are needed and should be validated with long-term clinical studies.

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Conflicts of interest

There are no conflicts of interest.

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