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Influence of the Implant Prosthetic Restorations Components on the Stress Values and Distribution in Surrounding Bone - Finite Element Analysis Study

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Abstract

Background: This FEA study aims to help the dentists in choosing the most appropriate implant-prosthetic components for predictable results in cases of deficient bone quality and quantity; this type of analysis can be made without biological implications.

Methods: we used 3.75 mm diameter implants, in molar mandibular area, with 8, 10, 11.5 and 13 mm lengths, straight, angled 15° and 25° abutments and a two mesio-distal dimensions metal-ceramic crown (12 and 7.6 mm). The von Mises stress distribution in bone was analyzed using IBM Autodesk Inventor 2014 software.

Results: maximum von Mises stress decreases in cortical bone from 40.3 MPa for the 8 mm implant to 35.03 MPa for the 13 mm implant and in trabecular bone from 5.073 MPa to 4.214 MPa; in cortical bone is rising from 39.07 MPa in the straight abutment to 56.2 MPa in the 25° angled abutment, while in trabecular bone from 4.78 MPa to 5.371 MPa; in cortical bone is rising from 40.3 MPa for the 12 mm crown to 46.76 MPa for 7.6 mm crown, while in trabecular bone from 5.073 MPa to 5.932 MPa.

Conclusions: using longer implants reduces the maximum stress'values in the implant-prosthetic restoration and also in bone. The stress distribution is independent to the implant's length. Using angled abutments and also reduced mesio-distal dimension crowns raises the stress, especially in cortical bone.

Keywords: FEA; Stress distribution; Implant length; Abutment; Mesio-distal crown dimension; Bone

Introduction

Currently the implant-prosthetic therapy is widespread and has a great success regarding the rehabilitation of edentulous patients [1,2]. Although in many studies it has been reported a high rate success for this type of treatment, in daily practice is very difficult to avoid failures that consist in different complications such as mechanical or aesthetic ones, resulting in relatively short term or late loss of the dental implants [2,3]. This is the reason why the researchers' concern has been focused on finding the appropriate ways to increase the success rate of the implant-prosthetic therapy. Randomized clinical trials and *in vitro* studies such as the finite element analysis are necessary to assess the efficiency of the biomaterials and of the biomechanical aspects of all the components, including the surrounding bone [4-8]. The success or failure of the implant-prosthetic treatment is influenced by the stresses developed in the periimplant bone [9] and the stress values and distribution that depend both on the implant and the bone characteristics [7].

Materials and Methods

The aim of this study was to analyze stresses distribution in bone surrounding dental implants with 3.75 mm diameter and 8, 10, 11.5, respectively 13 mm length. It has been considered that the implants were inserted in the molar mandibular area, in a type III bone with a 1 mm cortical component. The metal-ceramic crown was made from a Cr-Ni alloy of 0.5 mm, respectively 1.5 mm ceramic thickness, with two different mesio-distal dimensions (12 and 7.6 mm) and an occluso-cervical one of 8.6 mm; it was done on straight, 15° and 25° angled abutments. The study regarding the influence of the implant length on the stress distribution in bone was done using different lengths of implant (8, 10, 11.5 and 13 mm), straight abutments and metal-ceramic crown with a mesio-distal dimension of 12 mm. The study regarding the influence of the abutment angle was done on a 10 mm implant with mesio-distal dimension of 12 mm using different types of abutments. The study regarding the influence of the available space was realised using an 8 mm straight abutment with different mesio-distal dimension of the dental crown. The mesh of the implant-prosthetic restoration and the mandibular bone was made using IBM Autodesk Inventor 2014 software. For the 3D model we considered the characteristics of the implant components and the mechanical and thermic stress constants of their materials. The mechanical stress characteristics are shown in Table 1 [10].

We applied two fixed constrains to mesial and distal, the implant being considered immobile in the mandibular bone, as recommended by Petrie and Williams [11]. The force applied was simulated using a normal component of 160N applied on the disto-lingual cusp and a tangential (oro-vestibular) component of 23.5N, according to Las Cassas studies (2007) about the size and distribution of masticatory forces in the lateral mandibular region [12]. The stress evaluation was performed using Autodesk Inventor 2014 software. The discrete model and the applied forces for 11.5 mm implant length is shown as an example in Figure 1.

Results

The study regarding the influence of the implant length on the stress distribution in bone

In case of an 8 mm implant, the maximum von Mises stresses

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that appear on the implant-prosthetic restoration are 226.1 MPa. The stresses are unevenly distributed between the two components of the mandibular bone. The highest stress concentration appear at the contact area between the cortical bone and the implant neck, where the maximum von Mises stress is 40.3 MPa and the minimum is 0.28 MPa. The maximum von Mises stress value in the trabecular bone is lower, 5.073 MPa, while the minimum is 0.016 MPa. In the trabecular bone the highest stress appears in the immediate vicinity of the cortical bone, the values decreasing as we move away from this area. Furthermore, the study shows that higher values of stress appear only over 2-3 mm from the part of the cortical which is adjacent to the trabecular bone; otherwise the tensions in this segment are minimal.

In case of an 10 mm implant length inserted in the mandibular molar area, the masticatory forces applied on a metal-ceramic crown with a straight abutment are generating a maximum von Mises stress of 220.1 MPa, lower than in the case when a 8 mm implant is used. All the same with the 8 mm case, the maximum stress in bone occurs in the cortical area at the contact surface of the dental implant with the cortical bone; the maximum von Mises stresses value was 39.07 MPa and the minimum was 0.26 MPa (Figure 2). The maximum von Mises stress value (4.718 MPa) recorded in the trabecular bone was registered in the immediate vicinity of the cortical bone; the minimum value was 0.02 MPa (Figure 3).

Material	Poisson's Ratio (E)	Young's Modulus
Titan	0.3 ul	113.8 GPa
Cr-Ni alloy	0.3 ul	172 GPa
Ceramics	0.28 ul	67.7 GPa
Cortical bone	0.3 ul	13.7 GPa
Trabecular (cancellous) bone	0.3 ul	0.69 GPa

Table 1: The mechanical stress characteristics of the implant-prosthetic materials.

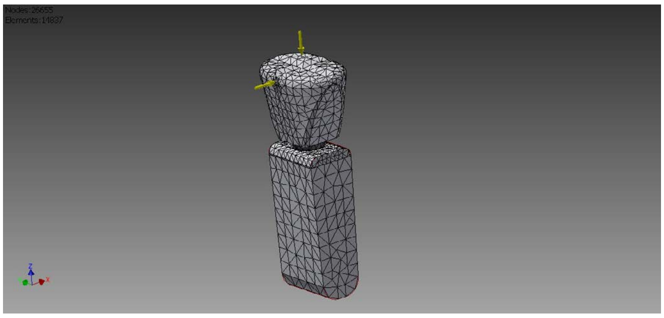

Figure 1: The discrete model of the implant-prosthetic complex with 11.5 mm implant length-straight abutment.

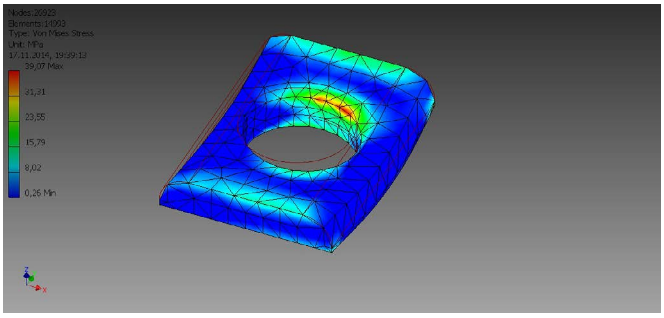

Figure 2: The von Mises stress in the cortical bone area for the implant-prosthetic complex with 3.75 × 10 mm length implant-straight abutment.

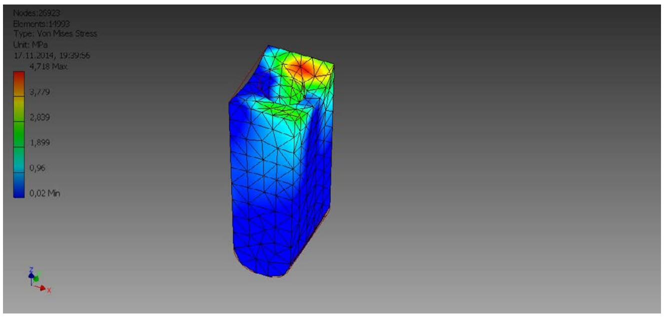

Figure 3: The von Mises stress in the trabecular bone area for the implant-prosthetic complex with 3.75 × 10 mm length implant-straight abutment.

Implant	Maximum von Mises in the implant-prosthetic restoration	Maximum von Mises in the cortical bone	Maximum von Mises in the trabecular bone
3,75 × 8 mm	226 MPa	40,3 MPa	5,073 MPa
3,75 × 10 mm	220 MPa	39,07 MPa	4,718 MPa
3,75 × 11,5 mm	212 MPa	38,05 MPa	4,531 MPa
3,75 × 13 mm	161,9 MPa	35,03 MPa	4,214 MPa

Table 2: Maximum von Mises stresses for different lengths of implant.

In case of using the 11.5 mm implant, the maximum von Mises stress was 212.5 MPa. The cortical bone was subjected to a maximum von Mises stress of 38.05 MPa, respectively a minimum of 0.39 MPa, located in the same area as in the previous cases. The stress distribution in the trabecular bone is the same as the one presented for the 8 mm and 10 mm implants. At this level the maximum value of von Mises stress was 4.531 MPa and the minimum was 0.02 MPa.

In case of using a 13 mm implant, there is a maximum von Misses stress of 161.9 MPa. The cortical bone is subjected to a maximum von Mises stress of 35.03 MPa, the lowest value of all the cases analyzed in our study. In this case, the trabecular component is also less affected than in the 11.5 mm implant's situation, the maximum von Mises tensions value being 4.214 MPa. It can be also observed that the tensions are higher in the mesial and distal bone areas around the implant than in the buccal and lingual ones.

The comparative values of maximum von Mises stresses in the implant-prosthetic restoration and the mandibular bone are shown in Table 2. The study demonstrates that increasing the length of the implant leads to decrease the periimplant bone tensions. The differences of von Mises stress values in the cortical bone for 8, 10 and 11.5 mm implant lengths are around 1 MPa; the variations that appear in the trabecular bone are less than that. Larger differences in the cortical are reported between 11.5 and 13 mm lengths (3 MPa). Higher variations (6-8 MPa) are recorded of the maximum von Mises stresses in the implant-prosthetic restoration.

The study regarding the influence of the abutment angle on the stress values in bone

It was done on a 3.75 × 10 mm implant with of 12 mm mesio-distal dimension crown. In case of using a straight abutment, the maximum von Mises stress was 39,07 MPa in the cortical bone and 4,718 MPa in the trabecular bone; for the 15° angled abutment, the maximum values in the cortical are 48.67 MPa (Figure 4) and in the trabecular bone are 5.644 MPa (Figure 5). Both values are higher than in the straight abutment case.

In case of using a 25° angled abutment, the von Mises stresses have

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higher values than for the straight abutment, the maximum value being 56.2 MPa in the cortical bone (Figure 6), respectively 5.371 MPa in the trabecular one (Figure 7).

Table 3 shows that, when we use a straight abutment, the tensions in the periimplantar bone are generally lower than when we use angled abutments. It can be observed that the abutment's angle is directly proportional with the stress values in cortical bone, comparing with the trabecular bone where the tensions are approximately the same.

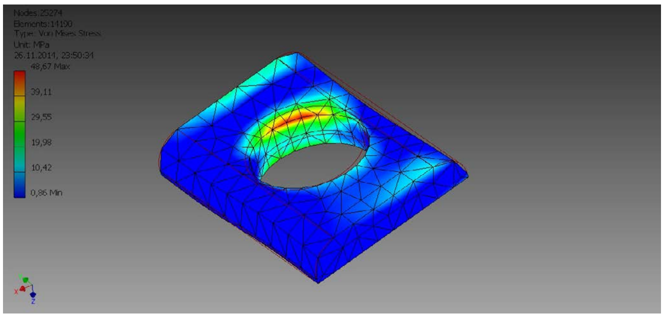

Figure 4: The von Mises stress in the cortical bone area for the implant-prosthetic complex with 3.75 × 10 mm length implant - 15 ° angled abutment.

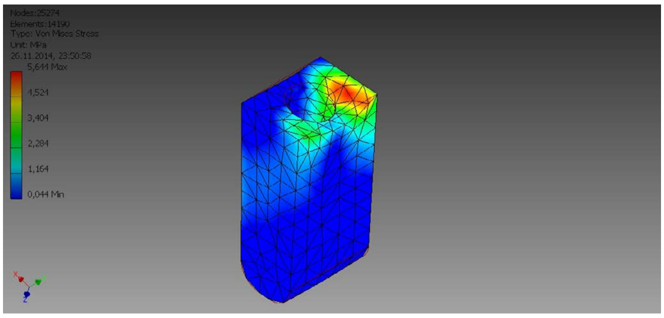

Figure 5: The von Mises stress in the trabecular bone area for the implant-prosthetic complex with 3.75 × 10 mm length implant - 15° angled abutment.

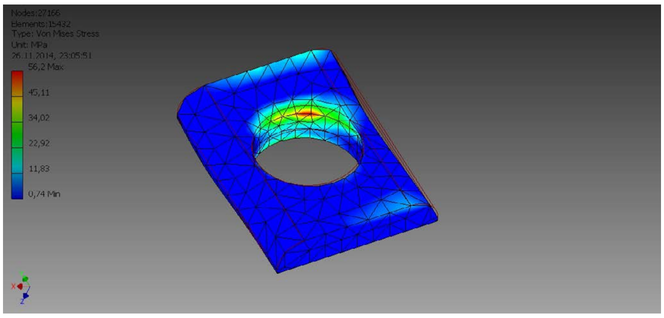

Figure 6: The von Mises stress in the cortical bone area for the implant-prosthetic complex with 3.75 × 10 mm length implant - 25° angled abutment.

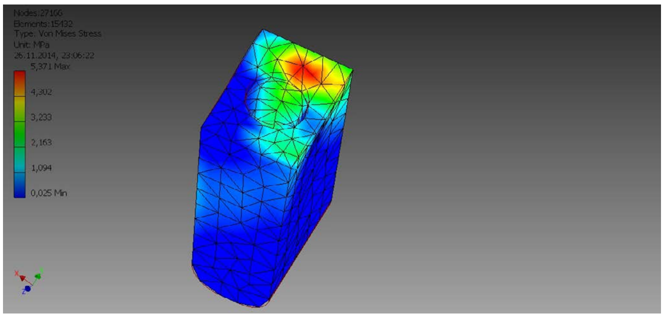

Figure 7: The von Mises stress in the trabecular bone area for the implant-prosthetic complex with 3.75 × 10 mm length implant - 25° angled abutment.

	Straight abutment	Angled 15° abutment	Angled 25° abutment
Von Mises in cortical bone	39,07 MPa	48,67 MPa	56,2 MPa
Von Mises in trabecular bone	4,78 MPa	5,644 MPa	5,371 MPa

Table 3: Von Mises tensions in bone according to the abutment type for the 3.75 × 10 mm implant.

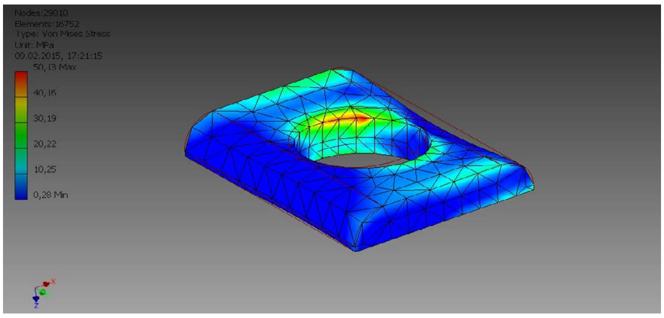

Figure 8: The von Mises stress in cortical bone area for the implant-prosthetic complex with 3.75 × 8 mm implant straight abutment – 7.6 mm mesio-distal diameter crown.

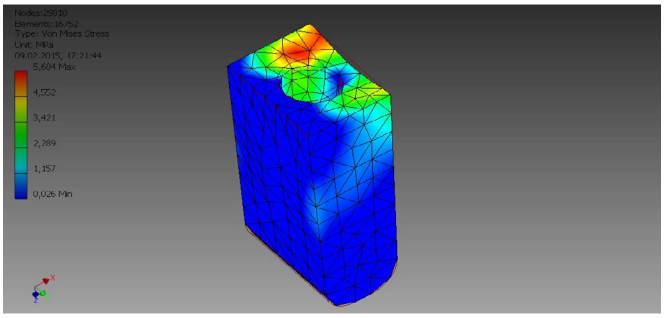

Figure 9: The von Mises stress in trabecular bone area for the implant-prosthetic complex with 3.75 × 8 mm implant straight abutment – 7.6 mm mesio-distal diameter crown.

The study regarding the influence of the mesio-distal dimension of the edentulous space on the stress values in bone

For an 8 mm implant, with straight abutment and 12 mm mesio-distal diameter metal-ceramic crown, the maximum value of von Mises stresses in cortical was 40.3 MPa, respectively 5.073 MPa in trabecular bone. For an 8 mm implant, with straight abutment and 7.6 mm mesio-distal diameter metal-ceramic crown, the maximum value of von Mises stresses in cortical was 50.13 MPa (Figure 8), respectively 5.684 MPa in trabecular bone (Figure 9).

The influence of the mesio-distal space available for this situation is shown in Table 4. It can be observed that reducing the mesio-distal space is increasing tensions in both components of the periimplantar bone, the changes in cortical being more intense than in trabecular area.

Discussion

These studies examine the tensions developed in an unfavourable

Von Mises stress	12 mm mesio-distal crown diameter	7.6 mm mesio-distal crown diameter
Cortical bone	40.3 MPa	50.13 MPa
Trabecular bone	5.073 MPa	5.684 MPa

Table 4: Von Mises stress in bone according to the mesio-distal crown diameter.

mandibular periimplantar bone, in cases of quality and quantity bone deficit. The analysis is extended for another unfavourable case, when the three-dimensional bone space allows the insertion of only a single implant. It is considered that a proper occlusion of the implant-prosthetic restoration is frequently difficult to obtain, and that the usual methods used to analyse the dental occlusion are often prone to errors [13]. Our study addresses the worst-case occlusal error, the one when the force, having normal and tangential components, is applied eccentrically to the distal extremity of the metal-ceramic crown. The quality and quantity of the periimplantar bone, the mesio-distal edentulous space's dimension and the occlusion's characteristics are determinant factors both for choosing implant's characteristics and for the long-term success of implant-prosthetic restoration. According to Misch, a single implant used in a mandibular molar area must be of minimum 4 mm diameter, ideally 5-6 mm [14]. Considering that the risk of failure for a single mandibular implant is important [15] even when it is possible to insert one with a larger diameter, many authors have concluded that the use of two implants to replace a single molar is more advantageous [16-18]. Saadoun et al. state that the use of two standard implants is possible only if the mesio-distal dimension of the available space is between 12.5 and 14 mm [19]. Unfortunately, that length is not always available and the atrophy of the edentulous ridge does not allow the insertion of an implant with a larger diameter, which is why often we can use only an implant of 3.75 mm diameter [20]; also, because of the pronounced ridge resorption, often there is no satisfactory bone height. According to Misch, especially in conditions of poor bone quality, implant length must be at least 12 mm for the molar area. This study aims to analyze if doing vertical alveolar ridge augmentation offers significant advantages, allowing the insertion of a longer implant. It shows that, for a type III bone, increasing the length of the implant decreases the stresses especially in cortical but also in trabecular bone, and decreases the maximum von Mises stresses in the entire implant assembly, which is equivalent to reducing the risk of bone resorption. In our study, we analyzed both the stress distribution and the maximum stresses which in the cortical bone appear in the implant's neck area. Similar to our results, some studies show that the greatest stresses are located in the bone surrounding the implant's neck and in the junction area between the cortical and the trabecular components [21,22]. Although previous researches showed that by using a longer implant is obtained a more favourable distribution of stresses in bone [23], in this study we obtained the same stress distribution in both cortical and trabecular bone regardless of the implant length. We observed that by increasing the implant length we generally can determine lower values of maximum stresses in the periimplantar bone, but not a more favourable distribution. However, the differences between maximum stress values in the cortical are not so big for the implants of 8, 10 and 11.5 mm length, which means that a procedure of vertical mandibular ridge augmentation would not yield significant benefits. Moreover, according to Esposito et al., inserting short implants without other procedures have similar results compared to using long implants in augmented bone cases.

Other studies affirm that the use of a single implant for replacing a mandibular molar is frequently followed by complications, most of them related to the loss of the abutment screw. The incidence of these accidents is directly proportional with the mesio-distal diameter of the crown and the diameter of the implant [15]. Knowing these disadvantages, the current study aims to determine whether, in addition to the risks brought by the implant components, modifying the mesio-distal diameter of the crown influences the stresses in a particular type of poor quality bone (type III). The average diameter for the first mandibular molar is considered 10,4 mm [14]. We chose two different clinical situations of two crowns of 12 and 7.6 mm (narrow or wide edentulous space). The study shows that, regarding the stresses induced in the bone, a larger edentulous space is more favourable than a smaller one. Although a 12 mm mesio-distal diameter crown has a greater risk of unscrewing, it is inducing less stresses in cortical bone, which is an advantage especially for a poor quality bone type. Moreover, new designs of implants reduced the risk of unscrewing [24].

The use of angled abutments for crowns changes the value of maximum stresses in the bone. Studies in this area have reached different conclusions. Some authors state that the use of these angled abutments is decreasing stress values in bone [25]; on the contrary, others found they are increasing them [22,26-27]. Our study shows that the use of angled abutments is increasing stress values in both bone components, trabecular and cortical, and that by amplifying the abutment's angle we obtain a greater stress in the cortical, surrounding the implant's neck area, which can accelerate the bone resorption.

Conclusion

Increasing the length of the implant is generally inversely proportional with the maximum von Mises stresses in the implant-prosthetic assembly and in both mandibular bone components; though, there are no major differences between the maximum values of von Mises stresses. The distribution of the von Mises stresses in the mandibular bone is independent to the length of the implant. Using angulated abutments increases the von Mises stresses in the bone surrounding the implant; amplifying the angle generates higher von Mises stresses in the cortical bone. Reducing the mesio-distal dimension of the metal-ceramic crown increases the maximum values of von Mises stresses in both bone components.

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