

EFFECT OF ABUTMENT AND IMPLANT SHAPES ON STRESSES IN DENTAL APPLICATIONS USING FEM

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Abstract - In this study, the effect of abutment and implant shapes on stresses in dental applications was investigated, numerically. During the numerical analysis, finite element method (FEM) was used due to a powerful stress analysis method. The three different abutment-implant systems based on producing from different commercial firms were modeled. The Nextengine and Rhinoceros programs were used for three dimensional tooth scan and creation of the solid models. Additionally, Algor Fenpro analysis program was used for three dimensional stress analyses. According to obtained results, the Von Mises stress distributions on abutment, implant and cortical bone are affected from abutment and implant shapes, clearly. If it is possible, the using of any hole in the implant should not be used. Additionally, the bigger collars on the abutment provide to reduce of Von Mises stresses.

Key Words- Abutment shape, Dental implant, FEM, Stress distribution.

1. INTRODUCTION

Since the late 1960s, when dental implants were introduced for rehabilitation of the fully edentulous patient, an awareness and subsequent demand for this type of therapy has increased [1]. In 1988, the NIH consensus development conference on dental implants reported that among the factors involved in the design of an implant are the force components produced during loading, the dynamic nature of loading, and the mechanical and structure properties of the prosthesis in stress transfer to tissues [2]. Resistance of implant to the functional forces and ordering these forces to obtain biomechanical stability in denture-implant and implant-supporting bone system is very significant. Since, the stresses generated as a consequence of functional forces affect the masticatory system and biomechanical properties of dentures. However, these stresses can be controlled by idealization of geometry, material properties, supporting bone, and loading conditions [3-5].

Using of implants for the partially edentulous condition requires adequate implant support to render the restoration independent of tooth connection. In a restorative condition where a raise in implant support is untenable, the option of implant-tooth connection remains. A number of abutment designs and materials have been developed for facilitating restoration and connection to osseointegrated implants [6-9]. Nevertheless, clinical studies have shown that a frequently reported complication

of implant-supported prostheses is the loosening or fracturing of abutment or retaining screws [10]. Therefore, improvement of an ideal substitute for missing teeth has been one of the long-term scopes of dentistry. A dental implant is a biocompatible screw-like titanium “fixture” that is surgically placed into the jawbone. Some detail of a typical implant design is shown in Figure 1 (Neoss Australia Pty Ltd.) and its orientation within the jawbone is presented in Figure 2 (University of Southern California) [11].

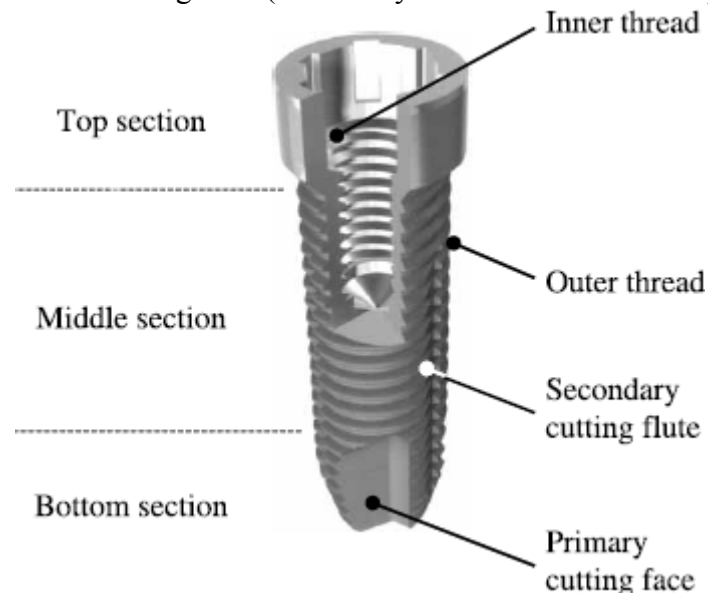


Figure 1 The view of a dental implant produced by Neoss [11]

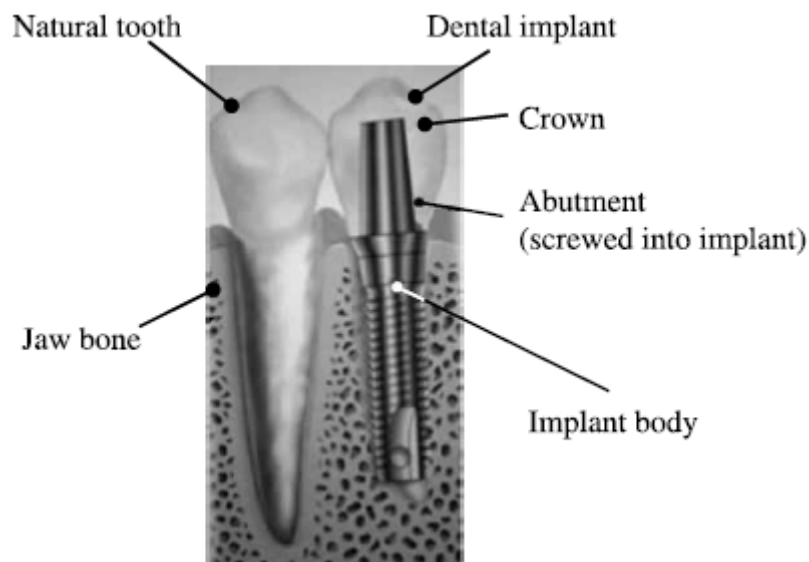


Figure 2 Cross-sectional view of a naturel tooth and a dental implant [11]

Meanwhile, during the last three decades, the finite element method (FEM) has been the prevalent technique used for analyzing physical characteristics of materials in the field of structural, solid and fluid mechanics. In biomedicine too, the FEM has been used with substantial advancements. Certain facts can be found out only by using the

FEM [12]. Recently, FEM is also a popular numerical method in stress analysis [13]. FEM shows the internal stresses and on that basis predictions can be made about failure [14]. However, the jawbone and implants are very complicated structures. For this reason, it is difficult to establish accurate and valid three-dimensional (3D) FEM using conventional modeling techniques. Two-dimensional (2D) representations of implants and jawbone structures were often assumed in preceding studies [11].

Some researchers have investigated various abutment and implant system previously. Bozkaya et al. [15] studied the stress transfer properties of five currently marketed implants that differ significantly in macroscopic geometry. Five systems were evaluated under increasing load levels using FEM. This approach allowed not only the evaluation of load transfer characteristics under regular masticatory forces, but also under the extreme load levels, such as those that occur during parafunction. Koca et al. [16] determined the quantity and localization of functional stresses in implants positioned in different bone levels (4, 5, 7, 10, or 13 mm) in the atrophic posterior maxilla using FEM. The hypothesis tested was that the amount and localization of functional stresses in implants placed in different bone levels in the posterior maxilla is similar. According to FEM study results, high stresses occurred within the implants for all bone levels. Tepper et al. [17] designed to simulate the fate of implants in highly atrophic maxillae under loading conditions with the assist of 3D-FEM. Eight models were used for 3D-FEM to account for the changeable quantity of bone regenerated by the sinus lift and the different implant dimensions. The results show that more extensive peri-implant packing reduces implant displacement, intrabony stresses and stresses at the bone-implant interface. Lisa et al. [2] examined the dynamic nature of developing the preload in an implant complex using FEM. The implant was modeled in accordance with the geometric designs for the Nobel Biocare implant systems. A thread helix design for the abutment screw and implant screw bore was modeled to make the geometric design for these units of the implant systems. The stress distribution pattern clearly demonstrated a transfer of preload force from the screw to the implant during tightening.

In this study, the stress distributions on three different commercial abutments-implants are investigated numerically. The shapes of both abutments and implants on Von Mises stress distributions are evaluated using 3D-FEM.

2. MATERIALS AND METHODS

It is assumed that the implant-abutment systems were created for second premolar tooth. For this reason, the dimensions of real tooth was supplied from Wheeler' Atlas [18]. The dimensions of modeled tooth are given in Table 1. The view of 3D-modeled second premolar tooth is shown in Figure 3. 3D-FEM models were created for three different commercial dental abutments-implants systems. Because of the similar structures, they were selected as Friadent, SPI and Zimmer. The preferred three different implant-abutment systems are presented in Figure 4. The materials are assumed as linear elastic and isotropic. The mechanical properties of materials are given in Table 2 [19-22]. The diameters and heights of implants were chosen as similar to be comparable in size. Therefore, the diameter and height of all implants are designed as 4 mm and 10 mm, respectively. The creating of 3D-CAD model, firstly, both implants

and abutments were scanned using Nextengine laser scanner (NextEngine, Inc. 401 Wilshire Blvd., Ninth Flor Santa Monica, California 90401). After the scanning process, a cloud included points were obtained. The solid CAD model was created from this point cloud using Rhinoceros software (3670 Woodland Park Ave N, Seattle, WA 98103 USA). Furthermore, the mesh generation process and stress analysis were carried out using Algor Fenpro software (ALGOR, Inc. 150 Beta Drive Pittsburgh, PA 15238-2932 USA). The numbers of nodes and elements for each implant-abutment systems are listed in Table 3. Meanwhile, the implant was needed to design into a cortical bone structure. Therefore, a cortical bone was modeled. The view of 3D-modeled cortical bone is illustrated in Figure 5. Then, implant was positioned into the cortical bone.

Table 1 The dimensions of modeled tooth

Tooth	Total length	Crown length	Root length	M - D Kron Ekvator	M - D Kole	B - L Kron Ekvator	B - L kole
Second Premolar	26,734	8,094	18,640	7,715	6,172	8,643	7,982

Table 2 The mechanical properties of materials

	Modulus of Elasticity (N/mm ²)	Poisson Ratio
Titanium	110000	0.33
Chrome-Cobalt	206000	0.30
Cortical	15000	0.30

Table 3 The numbers of nodes and elements for each implant-abutment systems

	Element number	Node number
Friadent	117883	522885
SPI	98467	498046
Zimmer	105789	516123

FEM model with boundary conditions are shown in Figure 6, a) Cortical bone b) Implant-abutment system. It is seen clearly from this figure, cortical bone was fixed from all outer surfaces. As seen from Figures 1 and 4, implants were designed from many screw threads. Therefore, during the mesh generation process all threads had to be meshed carefully for a good meshing. All in all, the high-quality mesh structure was made successfully as seen from Figure 6. Furthermore, the force was applied from upper surface of the abutment as 300 N, vertically. The Von Mises yield criterion was carried out for determining the plastic deformation. The equivalent Mises stress is presented by the expression:

$$\sigma_m = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}} \quad (1)$$

where, σ_1 , σ_2 and σ_3 are the three principal stresses. When σ_m reaches the yield strength, the material begins to be injured plastically.

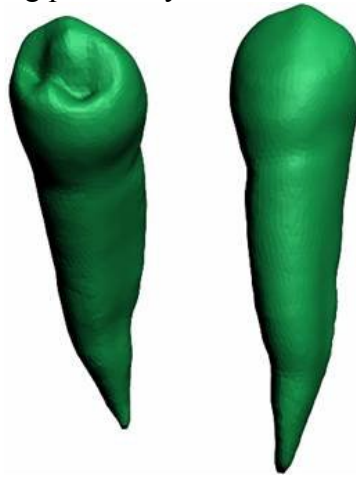


Figure 3 The view of 3D-modeled second premolar tooth



a) Friadent

b) SPI

c) Zimmer

Figure 4 The three different implant-abutment types with commercial names

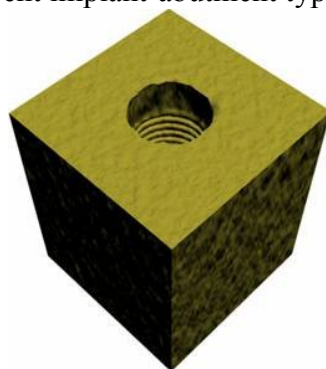


Figure 5 The view of 3D-modeled cortical bone

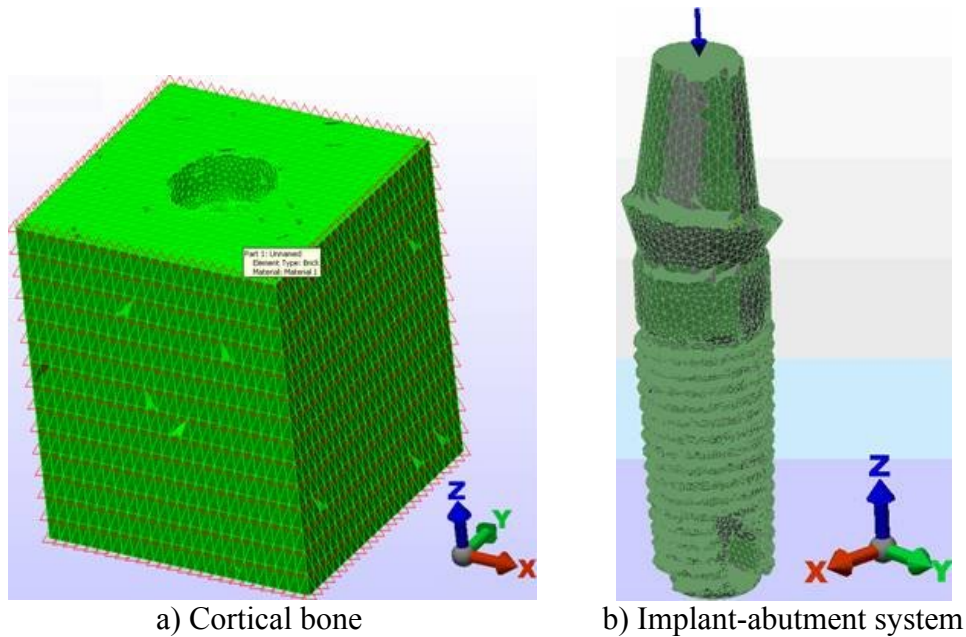


Figure 6 FEM model with boundary conditions

3. RESULTS AND DISCUSSION

The Von Mises stress distributions on three different implant-abutment systems without cortical bone are illustrated in Figure 7. Additionally, the Von Mises stress distributions on three different implant-abutment systems with cortical bone are shown in Figure 8. Firstly, it is clearly seen that the distributions of Von Mises stresses both abutment and implant differ from each other for three systems. The concentrations of stresses on abutment are seen higher than implant. The highest values of stresses are obtained both abutment and top section of the implant.

The stresses on collar which are formed abutment and top section of the implant are lower than mentioned areas. This is an appropriate result, since the collar area is biggest section of the abutment-implant system. Therefore, according to general engineering rule, the stresses are decreased if the area is increased. Meanwhile, the magnitudes of stresses on collar of Zimmer are seen lower than others, whereas the highest values of stresses for collar are observed for SPI. The main of this result, the force is applied on the abutment as vertical. Meanwhile, the maximum values of Von Mises stresses are calculated as 817.36, 863.29 and 976.91 N/mm² for Friadent, SPI and Zimmer systems, respectively.

Briefly, the highest value is obtained Zimmer system. Nevertheless Figure 7 point out that the minimum values of Von Mises stresses are 0, 4.44 and 2.77 N/mm² for Friadent, SPI and Zimmer systems. It is figure out that any stress didn't come into being on some areas of implant for Friadent system. The minimum values of stresses are seen as zero for all systems in Figure 8, since this figure is drawn with cortical bone. In other words, the stresses are calculated as zero on some areas of cortical bone. The magnitude of stresses are decreasing from top section to bottom section of implants, but a stress concentration are seen in the Zimmer implant because of its construction with

hole. It is known that any hole positioned a structure cause stress concentration on its around.

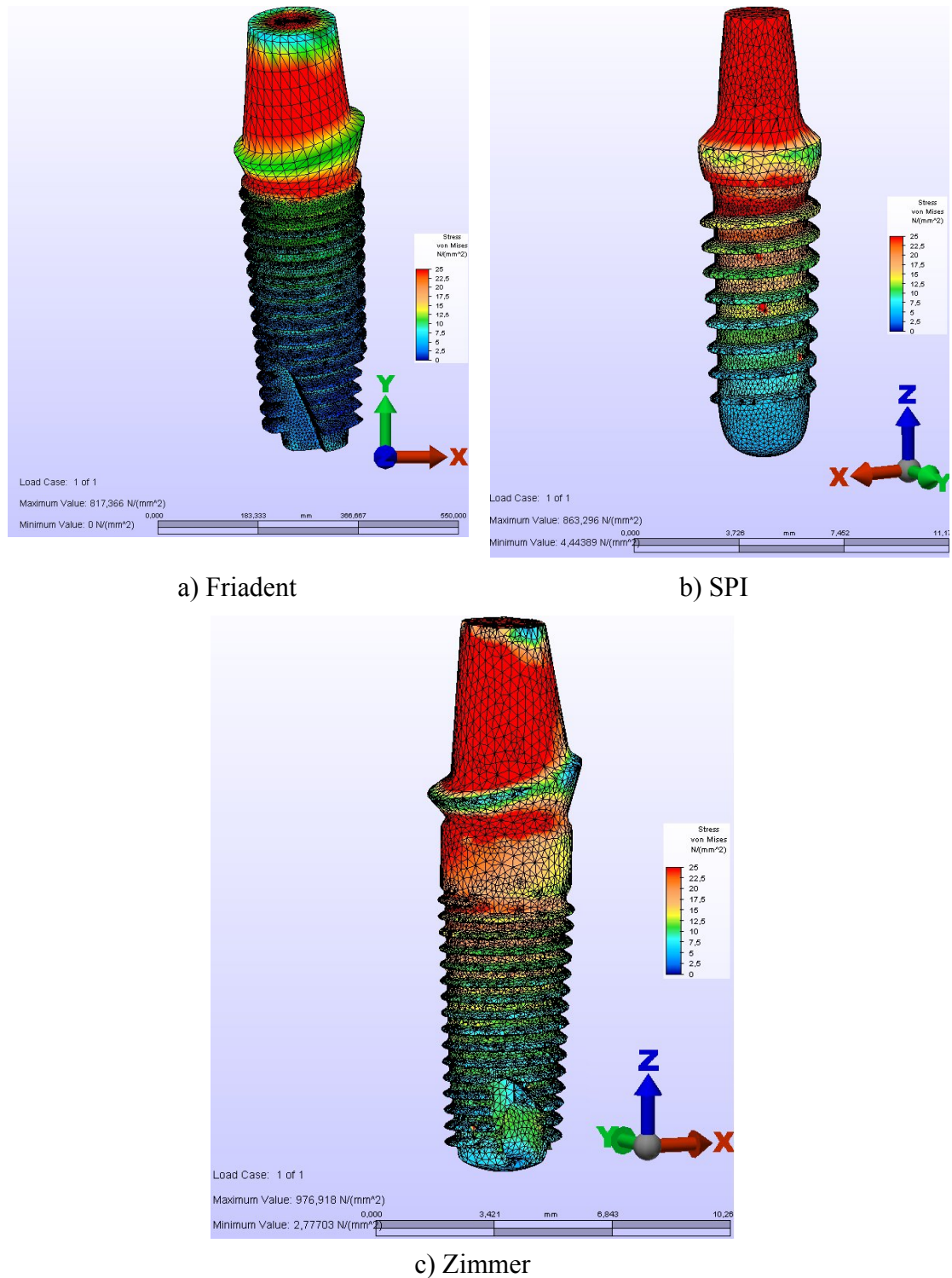


Figure 7 Stress distributions on three different implant-abutment systems

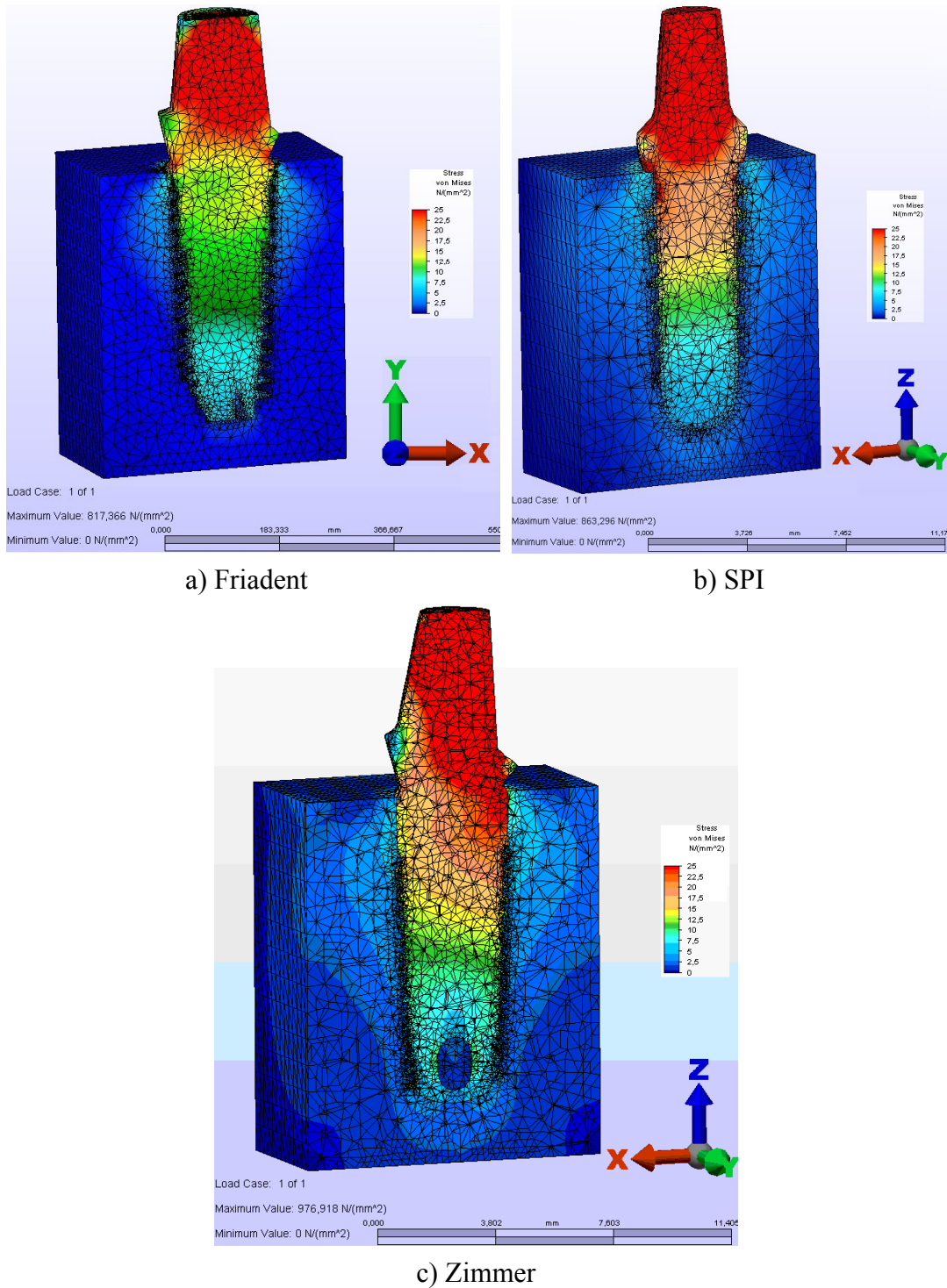


Figure 8 Stress distributions on different implant-abutment systems with cortical bone

According to Figure 8, implant-abutment systems cause stress zones on cortical bone which are surroundings of implant. The zone is very limited for Friadent and SPI, whereas it is spread out a large area for Zimmer on the cortical bone. Additionally, the magnitudes of stresses are decreased from upper surface to bottom of the cortical bone. The lowest stress distribution in cortical bone is obtained for Friadent implant system.

4. CONCLUSIONS

According to 3D-FEM stress analysis results some important points can be concluded. The Von Mises stress distribution on abutment, implant and cortical bone are strictly effected from abutment and implant shapes. The using of any hole in the implant design should not be used. The using of any hole in implant cause to produce stresses on a large part of cortical bone like Zimmer system. The highest values of Von Mises stresses are observed upper section of both abutment and implant. The using of bigger collars on the abutment provides to reduce of stresses.

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