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ARTICLE

Comparison between two low profile attachments for implant mandibular overdentures

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KEYWORDS

Finite element method;
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Implant;
Low profile attachment;
OT Equator

Abstract *Objective:* In this research it was aimed to evaluate stress distribution on the implants supporting a complete overdenture in addition to compare between two different types of low-profile attachments for implant-retained mandibular overdenture with two techniques (with/without using connecting bar).

Materials and methods: Two 3D finite element models were constructed simulating supported lower complete overdenture with two implants and with two implants and bar. Where, models components were modeled in 3D on commercial general purpose CAD/CAM software. Four runs were carried out, two runs on each model, as linear static analysis.

Results: Using bar is generally preferred for mucosa and cortical bone, while its effect can be considered as negligible on overdenture. On the other hand, it slightly increases the stresses on spongy bone. Using bar ensures the same level of energy transfer to the spongy bone and increases its maximum Von Mises stresses by about 50%. In addition, increase in maximum Von Mises stress was noticed by about 1% on cortical bone.

Conclusion: Using bar is not recommended for patients with flat ridge.

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1. Introduction

Millions of people throughout the world are edentulous. Because they have lost a body part, up to 32 body parts to be exact, edentulous people are physically impaired, according to the World Health Organization (WHO) criteria [3,9]. A reduced tooth number can make mastication more difficult. For that reason patients are more likely to practice forms of food avoidance or dietary restriction. In particular they tend to avoid hard and tough foods that are difficult to chew; this has been described in patients with oral impairment [26,31].

The use of dental implants over the past 25 years has significantly influenced treatment planning in dentistry. Successful treatment with dental implants not only includes an esthetic and functional replacement but also treatment that requires minimal maintenance [15]. Removable implant-retained overdentures provide easier access for oral hygiene and easy modification of the prosthesis base [10,22]. The estimated

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interarch space required for an implant-retained overdenture measured from the implant shoulder to the incisal edge is approximately 12–14 mm [19,24,29]. Patients with well-preserved alveolar ridges having lost teeth due to caries may have inadequate interarch space for an implant-retained overdenture. Limited interarch space often restricts the prosthetic armamentarium to low-profile attachments and prevents the use of O-ring attachments [30]. When this happens the patient is no longer able to insert the prosthesis, the dentist must intervene and change the deteriorated plastic material [7,13,23,28].

Occlusion, masticatory force, the number of implants, and implant position within the prosthesis affect the forces acting on the bone adjacent to implants. An applied mechanical force produces stress and strain in the bone causing deformation of its structural arrangement. A hypothesis of the remodeling of cortical bone as a response to mechanical loading, a bone with dental implants demonstrates a higher bone turnover rate during remodeling compared to the dentate situation. Increased bone turnover may result from repair stimuli caused by compressive and tensile loading in tissue adjacent to the implants. The excessive force acting on the implant caused bone reduction in the surrounding area followed by fibrointegration, resulting in possible implant loss [12].

Retention of the mandibular implant-supported overdentures is commonly achieved by ball attachments, clip on bar connecting the implants, or magnetic attachments. These retentive attachments generate forces and stresses that differ from those seen with natural teeth supported by periodontal ligament. If these stresses exceed the physiological limit they may lead to several undesirable results. Also the long-term function of a dental implant system will depend on the biomechanical interaction between; bone and implant [18]. In case of bar system, the forces of occlusion will primarily be transferred to the posterior residual ridge and theoretically cause more resorption in that critical area. In the ball attachment system, however these forces will be distributed more evenly throughout the edentulous arch [6].

The distribution of forces in peri-implant bone has been investigated by finite element analyses in several studies. Recently, stress distribution in bone correlated with implant-supported prosthesis design has been investigated primarily by means of two-dimensional (2D) and three-dimensional (3D) finite element analyses (FEAs). Studies comparing the accuracy of these analyses found that, if detailed stress information is required, then 3D modeling is necessary. The 3D FEA is considered an appropriate method for investigation of the stress throughout a 3D structure, and therefore this method was selected for bone and implants stress evaluation in this study [5,25]. Three-dimensional (3D) finite element analysis (FEA) has been widely used for the quantitative evaluation of such stresses on the implant and its surrounding bone [11]. Current techniques employed to evaluate the biomechanical loads over implants generally comprise photo-elastic stress analysis, two or three-dimensional finite element stress analysis (FEA) and strain gauge analysis (SGA) [5,11,14,25].

Hence, the aim of this study is to evaluate the exerted stresses on the implants comparing between two different types of low-profile attachments for implant-retained mandibular overdenture with two techniques. In-vitro study was shot in this research as the attachments are recently launched in the markets. Thus it is preferred to investigate this new attachment outside the patient's mouth for better understanding of its effect on bone. In addition in-vitro study can be done with less ethical and safety concerns.

2. Materials and methods

Low profile attachments for implant retained mandibular overdenture are used for completely edentulous patients with limited interarch space (the estimated interarch space required for an implant-retained overdenture measured from the implant shoulder to the incisal edge is approximately 12–14 mm), that could be done in two different techniques.

In this study, the first one utilizes two threaded dental implants (Dentium Superline – Dentium Inc., Samsung-dong, Gangnam-gu, Seoul, Korea) with nominal diameter of 3.4 mm, a length of 12 mm where, the root form dental implant had a nominal platform diameter of 3.7 mm, a length of 12 mm and the shape of internal hex with body diameter of 3.4 mm. Two low profile attachments OT Equators square head (Rhein83 srl, Bologna, Italy) with 2.1 mm length and diameter of 4.4 mm that are compatible with the implants were also used.

In the second technique, two threaded dental implants with two low profile attachments OT Equators square head compatible with the implants were used. In addition a nickel-chromium alloy bar was fabricated to connect the two low profile attachments. Finally, the overdenture(s) fabricated from acrylic resin is to be placed over each attachment (with/without bar).

Thus, two 3D finite element models were constructed under ANSYS software (ANSYS Inc., Canonsburg, PA, USA) environment simulating supported overdenture with two implants and with two implants and bar. Where, each model component was modeled in 3D on commercial general purpose CAD/CAM software "AutoDesk Inventor" ver. 8.0 (Autodesk Inc. San Rafael, CA, USA). These components were exported as SAT file format then imported into the finite element package. Meshing and assembly of model components are illustrated in Figs. 1–3, where different colors represent different materials as ANSYS screen shots. All material properties used in this study are tabulated in Table 1. The meshing software was ANSYS version 9.0 and the used element in meshing all three-dimensional models is an 8 node brick element (SOLID45), which has three degrees of freedom (translations in the global directions) (Kohnke P, 1994 [17]). Mesh density is another relevant parameter. As the geometries are complex, improving the mesh has the usual effect of improving the results for the discrete model (increasing the obtained stress levels accuracy in regions of high stress gradients). Another effect of increasing the number of elements is to reduce sharp angles created artificially by the process of substituting the geometric model by the mesh, reducing artificial peak stresses by improving the representation of the actual geometry, mesh density is tabulated in Table 2. A grid sensitivity study was performed to choose the most convenient number of elements (in terms of computational time and results accuracy), which assured an accurate description of sharp angles and curves.

Linear static analysis was performed. The solid modeling and finite element analysis were performed on a personal computer Intel Pentium Core 2 Duo, processor 3.0 GHz, 4.0 GB RAM. Four runs were carried out, two runs on each model (without and with bar). Two types of vertical loading; first one 150 N at the central fossa of lower six tooth (L6), and

Figure 1 Image and meshed parts of the supporting structure.

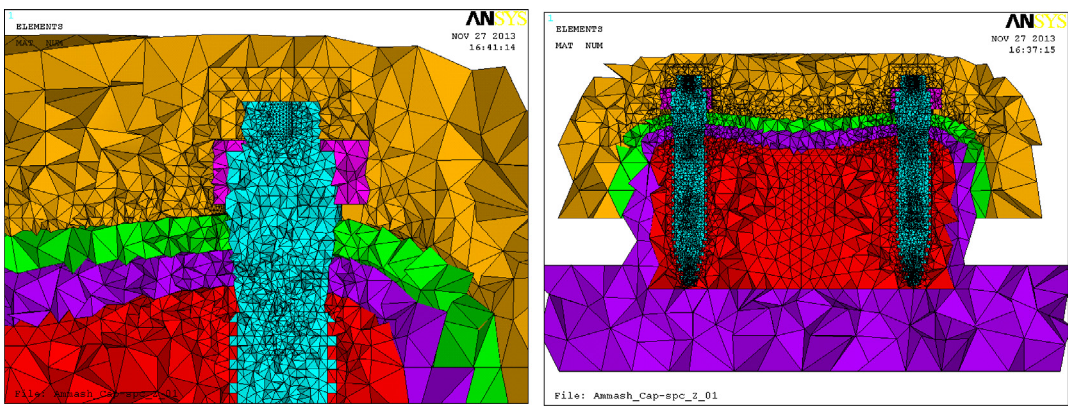

Figure 2 Section view showing implant–abutment complex (with bar).

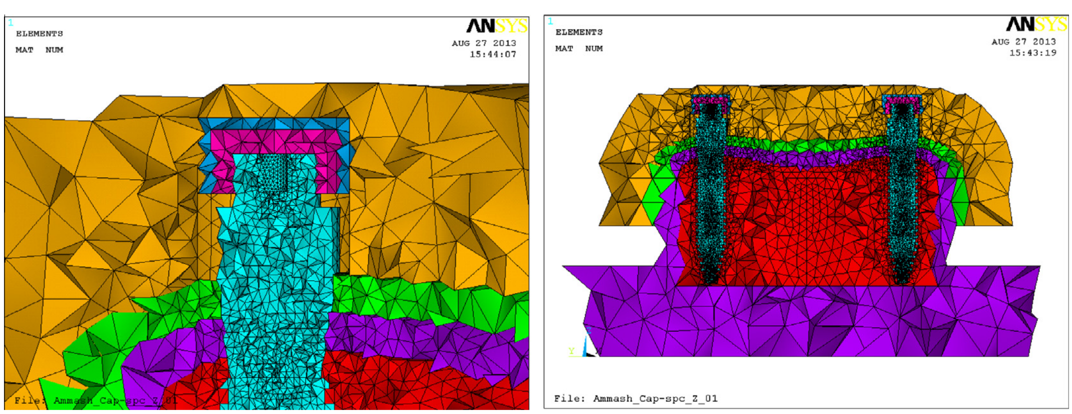

Figure 3 Section view showing implant–abutment complex (without bar).

second one 150 N at the two canines were applied as presented in Fig. 4.

3. Results

Four runs on the constructed models were done, simulating the two supporting structures and vertical/oblique loading prescribed for this study. Graphical comparisons were preferred to show stress and deformation distributions, while tabling the obtained results can indicate extreme values and calculated percentage and differences. Figs. 5–11 represent samples of the obtained results. Fig. 5 shows the total deformation distribution on overdenture in cases with and without bar under a vertical loading of 150 N at lower six tooth (L6). Where the bar increased the overdenture rigidity therefore downward deformation reduced by about 60%, while the far tip moved upward little bit higher than the case of using two implants without bar.

Implant complex stress distribution is negligibly affected by using the bar, where the maximum Von Mises stress is found at

Table 1 Material properties.

Material	Young's modulus [MPa]	Poisson's ratio
Cancellous bone	13,700	0.30
Cortical bone	1370	0.30
Implant/abutment complex	103,400	0.35
Cap	20,000	0.31
Ring	5	0.45
Mucosa	680	0.45
Overdenture	3000	0.35
Bar	182,000	0.30

Table 2 Number of nodes and elements.

	Cases without bar		Cases with bar	
	Nodes	Elements	Nodes	Elements
Cortical bone (base)	29,973	1757	29,844	1764
Cancellous bone	53,126	3837	56,079	4337
Implant/abutment complex	179,824	25,105	133,654	162,072
Cap	1625	42	–	–
Ring	2164	79	–	–
Mucosa 1 mm	27,123	1510	14,850	1510
Overdenture	26,640	2563	51,375	5403
Bar	–	–	5591	349

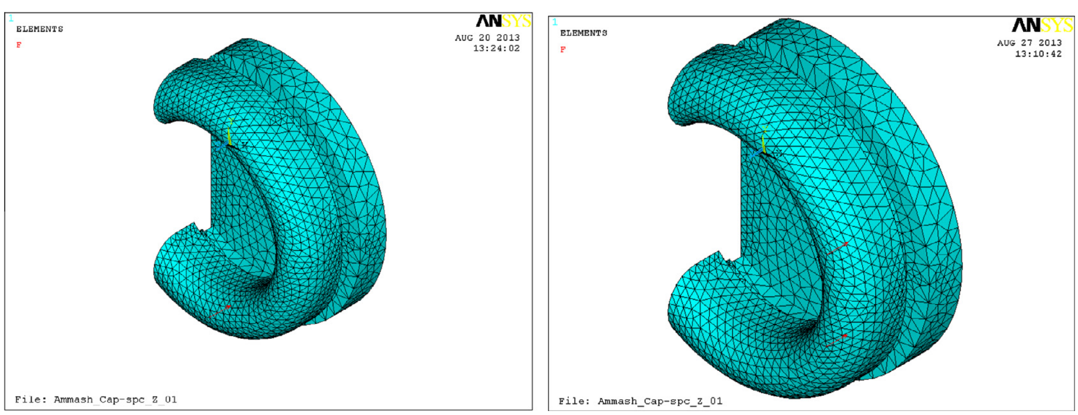

Figure 4 Complete meshed model and cases of applying external forces 150 N at L6 and 2 × 150 N at Canine.

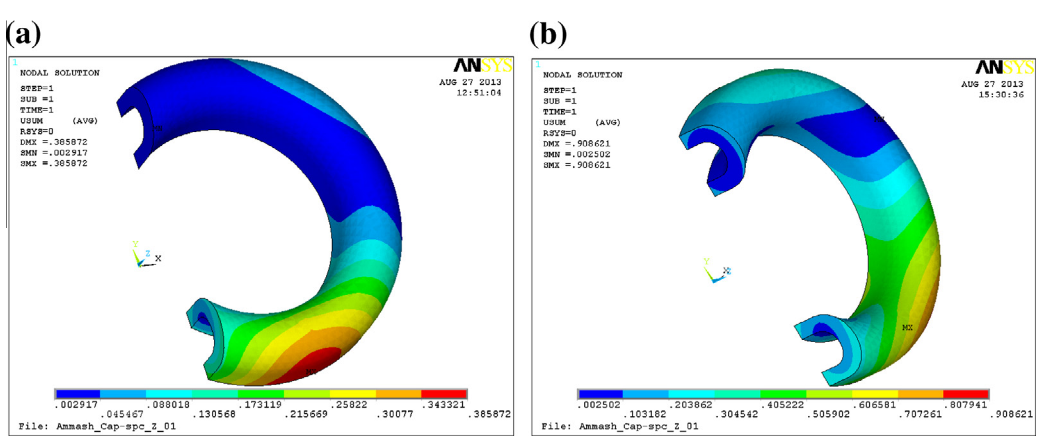

Figure 5 Overdenture sample results, total deformation, L6 loading cases (a) with bar and (b) without bar.

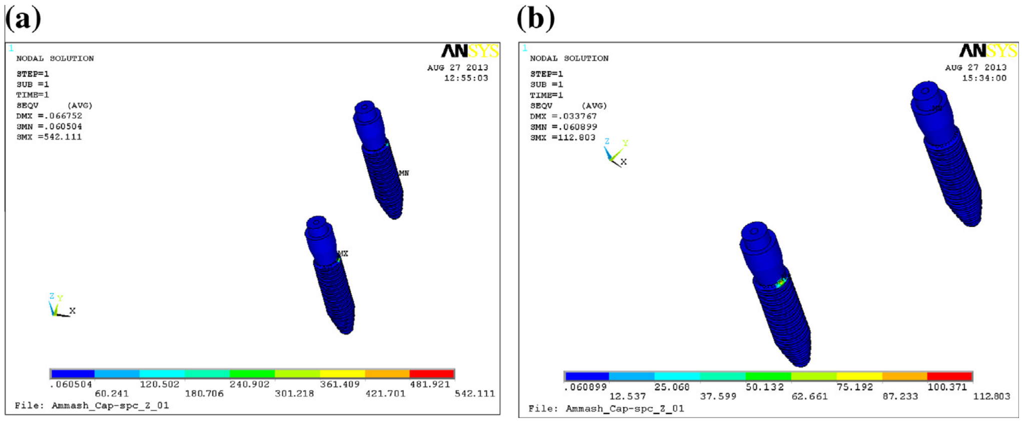

Figure 6 Comparison between implant–abutment complex Von Mises stress distribution under L6 loading cases (a) with bar and (b) without bar.

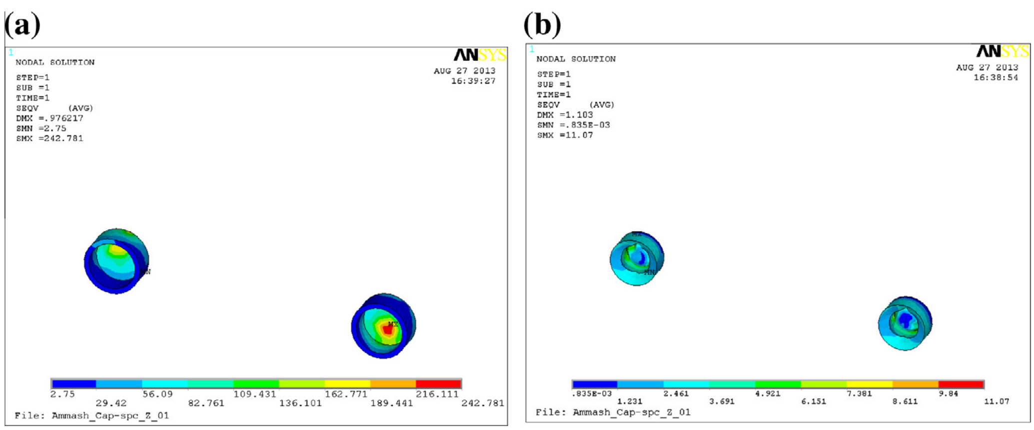

Figure 7 Cap and ring Von Mises Stress distribution under loading at canines – case without bar.

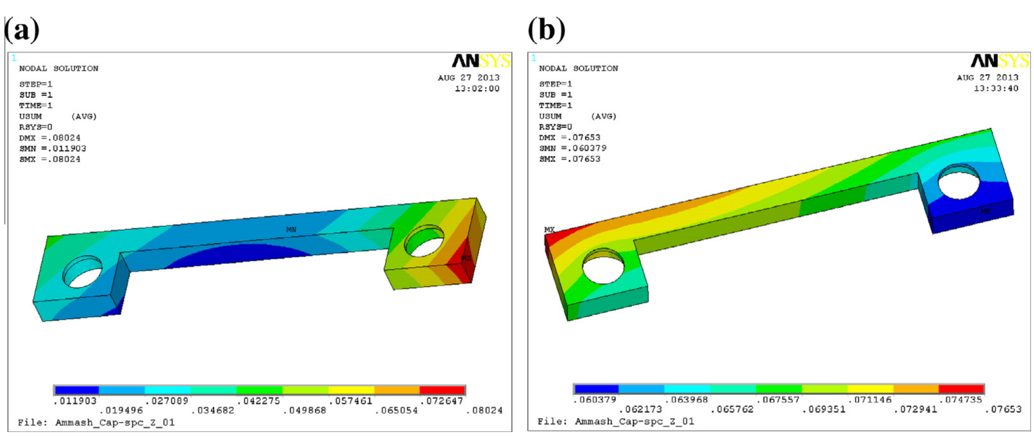

Figure 8 Bar total deformation distribution under vertical loading (a) at L6 and (b) at canines.

the implant neck at the interface with cortical bone. While the values of stresses are dramatically different from those obtained by using the bar, which generally increases stresses on implant complex as illustrated in Fig. 6.

Comparing between ring and cap from one side and the bar from the other side indicated longer life time for the bar. As presented in Figs. 7 and 8, rings and caps are highly stressed and deformed to levels higher than its endurance limit which put a life-time limit for their materials before fatigue failure. On the other hand the bar deformations are in a very low values in comparison with rings and caps for the same loading conditions. In addition the bar stress levels ensure longer life time expectation.

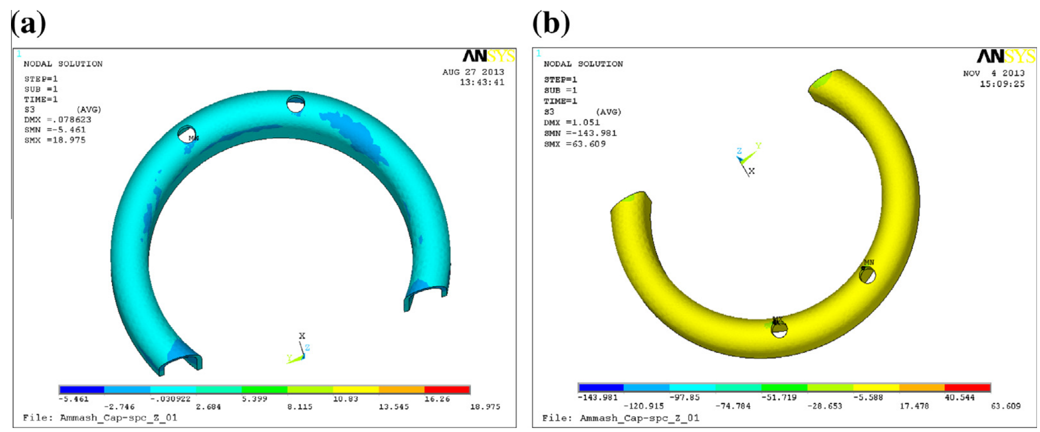

Figure 9 Comparison between mucosa max compressive stress distributions under vertical loading at canines (a) with bar and (b) without bar.

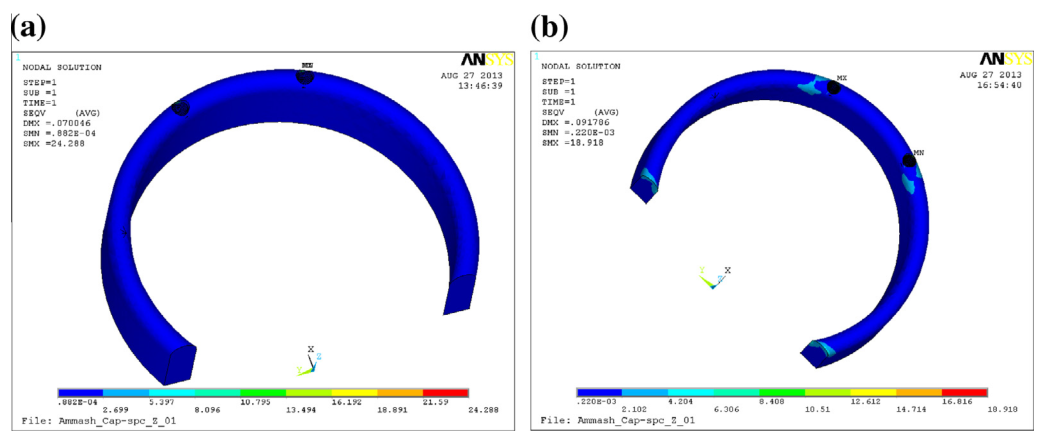

Figure 10 Spongy bone behavior (Von Mises stress distribution) under vertical loading at canines (a) with bar and (b) without bar.

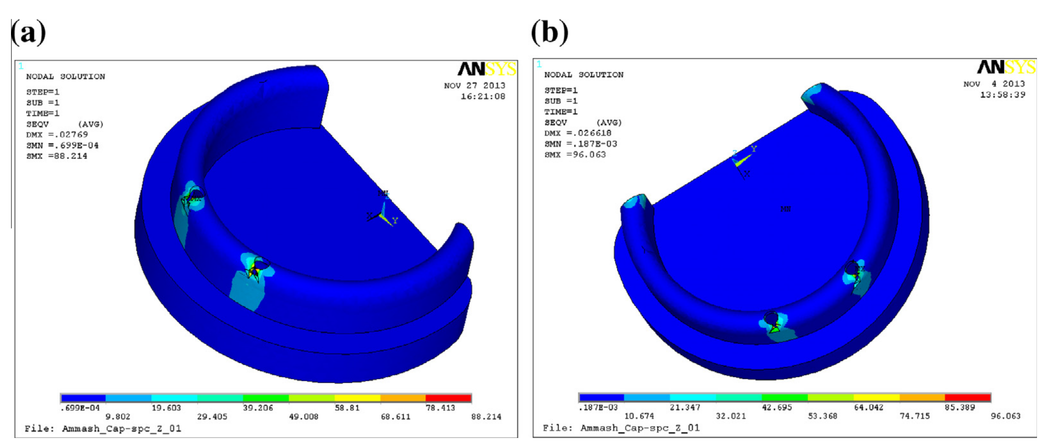

Figure 11 Cortical bone behavior (Von Mises stress distribution) under vertical loading at canines (a) with bar and (b) without bar.

Maximum compressive stresses on mucosa indicated the superiority of using the bar over the case of using two implant complexes only as illustrated in Fig. 9. On the other hand bones (cortical and spongy) are relaxed under two implants than bare usage. In Figs. 10 and 11 Von Mises stress level on spongy is lower by 30% in case of using two implant complexes. Cortical bone maximum Von Mises stress values are comparable between the two cases, but generally it is little bit lower in case of using two implant complexes. Fig. 12 and 13, can summarize the most important results in this research by comparing maximum Von Mises stress and total deformation respectively on all parts of the studied model.

4. Discussion

The finite element method is one of the most frequently used methods in stress analysis in both industry and science. It is used for analyzing hip joints, knee prostheses, and dental implants. The results of the FEA computation depend on many individual factors, including material properties, boundary conditions, interface definition, and also on the overall approach to the model. It is apparent that the presented model was only an approximation of the clinical situation. The application of a 3-D model simulation with the non-symmetric loading by the masticatory force on a dental implant resulted in a more satisfactory modeling of "clinical reality" than that achieved with 2-dimensional models used in other studies [12].

Using bar reduces the overdenture resistance to loading in the canine region and lower six tooth (L6), that is it reduces its cross section at the middle section. Therefore it showed higher level of stress, on the other hand the usage of bar reduces overdenture deformation. Such finding agreed with that obtained by Ahmadzadeh and Fereidoonpoor [1], 2012, during their comparison between four types of different attachment systems; two prefabricated and two castable attachments. The castable bar attachment was less retentive than locator but the difference was not as great [1]. In overdentures, low stress was transmitted to the alveolar support ridge. However, the use of an O-ring attachment better distributed the tension to the ridge/implant [20].

The used type and size of implants are safe for use under such loading conditions. It showed typical maximum stress location at its neck. Baggi et al. in a similar study, maximum stress areas were found to be numerically located at the implant neck [2]. The reduction of bar height and increase in the thickness of acrylic resin base in implant-supported overdentures are biomechanically favorable and may result in less stress in peri-implant bone [8].

Kenney and Richards in 1998 reported that a bar/clip attachment generates higher levels of tension to support implants than ERA or O-ring attachments directly on the implant or the bar [16]. These results are consistent with the current and previous studies [20] and are directly associated with the lower resilience of clips, which transfer the load to the bar and therefore to the implant.

Mucosa gained the highest benefit from using bar. Bar supports the overdenture between canines that reduces transfer loading to mucosa. Cakarer et al., in 2011 performed a clinical study to evaluate the complications associated with the different attachments used in implant-supported overdentures, including prosthetic problems and implant failures. They reported that, the mucosal enlargements were observed in the mandible and only in case of using implants [4].

Cortical bone stresses were relaxed when using bar. The bar reduces the cantilever behavior of implants which dramatically increases stresses at implant nick (connection with cortical bone). Ten percent reduction in stress values may give a reliable confidence to the dentist to use bar in patients with weak bones. Similar results were obtained by Menicucci et al., [21] where, different stress values were also present in the cortical bone between the implants; with ball anchorage, greater peaks (+20%) were reached than with clips/bar anchorage [21].

Spongy bone receives higher level of stresses when bar is used. The expected increase in the stress level due to the bar ranged from 50% to 100%, while such increase in stress level is still fairly safe for spongy bone. As previously presented in literature, the ball anchored mandibular implant-retained overdentures, the two implants are independent and can thus follow the distortion of bone without affecting it. However, with the clips/bar-anchored mandibular implant-retained overdentures, the rigid bar connecting the two implants tends to counteract this movement, therefore more stress reaches the peri-implant bone [21].

Pan in 1999 reported that, most extreme stress values were located at the alveolar ridge crest of the bone around the root of the abutment. In the case of anterior loading, the largest compressive stress (LCS) in telescopic crown overdenture (TOD) was lower. When loaded posteriorly there was no obvious difference between bar attachment overdenture (BOD) and TOD. Generally, using bar is generally preferred for mucosa

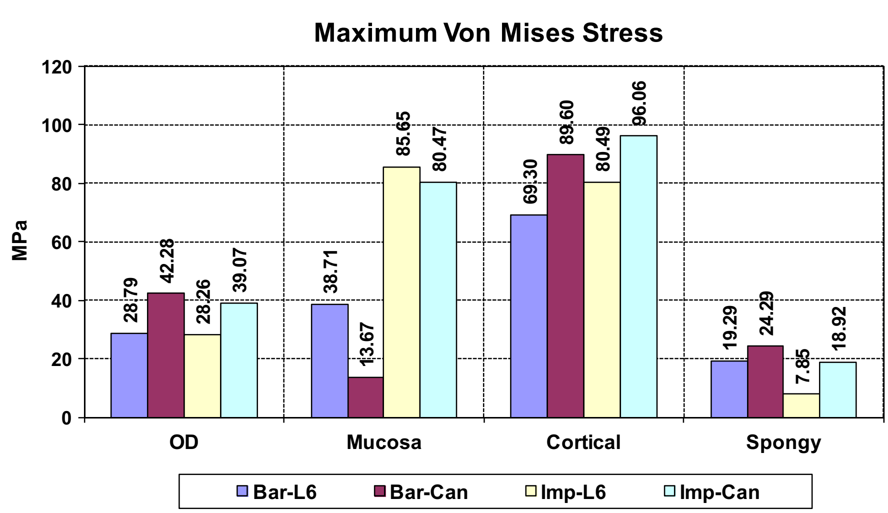

Figure 12 Comparison between maximum Von Mises stresses on OD, mucosa, and bones, in all studied cases.

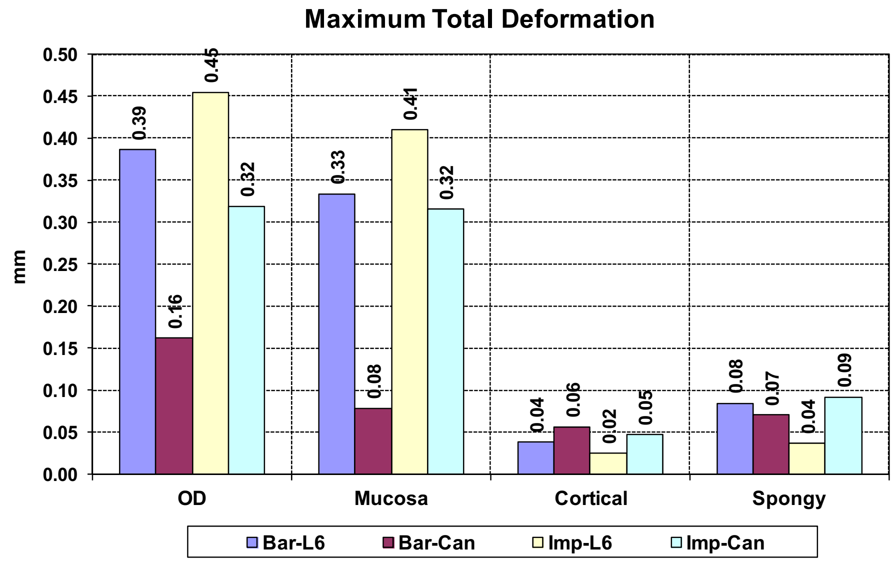

Figure 13 Comparison between maximum total deformation on OD, mucosa, and bones, in all studied cases.

and cortical bone, while it can be considered as in-effective on overdenture. On the other hand, it slightly increases the stresses on spongy bone [27].

5. Conclusions

Within the limitations of this study, the following conclusions can be drawn:

Overdenture: The overdenture is nearly not affected by using the bar, which slightly increases stresses on overdenture.

Implants: The used type and size of implants are safe for use under such loading conditions. It showed typical maximum stress location at its neck. Implant designs, cortical bone geometry, and site of placement affect the load transmission mechanisms.

Caps and rings: The used material types in caps and rings were subjected to high level of stresses that do not ensure long life time. Generally, more rigid cap material is preferred.

Bar: It is safe under the studied loading from the stress analysis point of view.

Mucosa: Mucosa is relaxed by using the bar that is it reduces the overdenture pressing on mucosa tissue.

Spongy bone: Using bar ensures the same level of energy transfer to the spongy bone on both cases of loading. While implants only may keep the level of stress constant, but from the energy point of view, loading at canines transfers more energy by about 15% to the spongy bone. But generally using bar increases spongy bone maximum Von Mises stresses by about 50%.

Cortical bone: About 1% increase in maximum Von Mises stress was noticed in case of using bar. Therefore, using bar can be considered ineffective on cortical bone. And using bar is not recommended for patients with flat ridge.

Ethical approval

This research does not require ethical approval and followed the Helsinki declaration.

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