Single molar restoration

Wide implant versus two conventional

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_The single-tooth restoration has become one of the most widely used procedures in implant dentistry.[1] In the posterior region of the oral cavity, bone volume and density are often compromised. Occlusal forces are greater in this region and, with or without parafunctional habits, can easily compromise the stability of the restorations (Fig. 1).[2,3]

The single-molar implant-supported restoration has historically presented a challenge in terms of form and function. The mesiodistal dimensions of a molar exceed that of most standard implants (3.75 to 4.0 mm), creating the possibility of functional overload resulting in the failure of the retaining components or the failure of the implant (Figs. 2 & 3).[4] Wider-diameter implants have a genuine use in smaller molar spaces (8.0 to 11.0 mm) with a crestal width greater than or equal to 8 mm (Fig. 4 a).[5] Clinical parameters governing the proposed restoration should be carefully assessed in light of the availability of implants and components that provide a myriad of options in diameter, platform configurations and prosthetic connections. Many of the newer systems for these restorations are showing promising results in recent clinical trials.[6-8] It has further been suggested by Davarpanah and others,[9] Balshi and others,[2] English and others[10] and Bahat and Handelsman[11] that the use of multiple implants may be the ideal solution for single-molar implant restorations (Figs. 4 b & c). Most standard implants and their associated prosthetic components, when used to support a double implant molar restoration, will not fit in the space occupied by a molar unless the space has been enlarged (12 mm or larger).[4] Moscovitch suggests that the concept of using 2 implants requires the availability of a strong and stable implant having a minimum diameter of 3.5 mm. Additionally, the associated prosthetic components should ideally not exceed this dimension.[2]

Finite element analysis (FEA) is an engineering method that allows investigators to assess stresses and strains within a solid body.[10-13] FEA provides calculation of *stresses* and *deformations* of each element alone and the net of all elements. A finite element model is constructed by breaking a solid object into a number of discrete elements that are connected at common nodal points. Each element is assigned appropriate material properties that correspond to the properties of the structure to be modeled. Boundary conditions are applied to the model to stimulate interactions with the environment.[14] This model allows simulated force application to specific points in the system, and it provides the resultant forces in the surrounding structures. FEA is

Fig. 1_Load distribution during mastication shows marked increase in the molar and premolar area.[23]
Fig. 2_Occlusal view showing a missing first molar. The mesio-distal width is very wide and restoration couldn't compensate it leaving a space distally.
Fig. 3_Proximal cantilever shown radiographic view of maxillary right first molar on standard Brånemark implant with standard abutment (Nobel Biocare).[1]

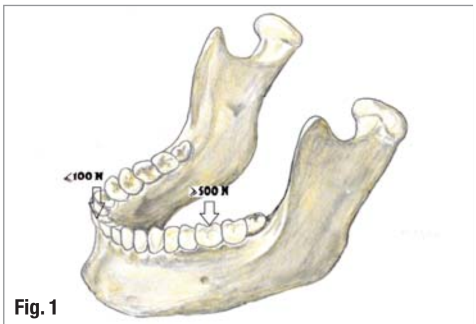

Fig. 1

Fig. 2

Fig. 3

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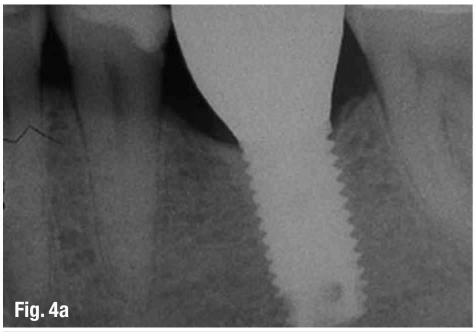
Fig. 4a


Fig. 4b

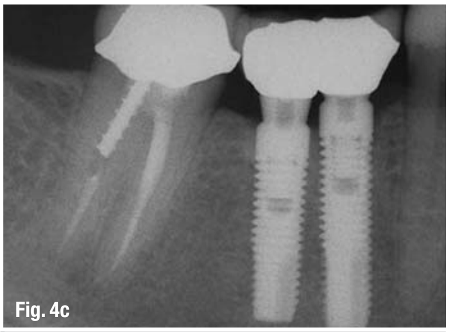
Fig. 4c

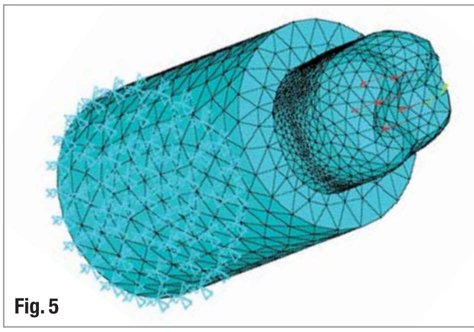
Fig. 5

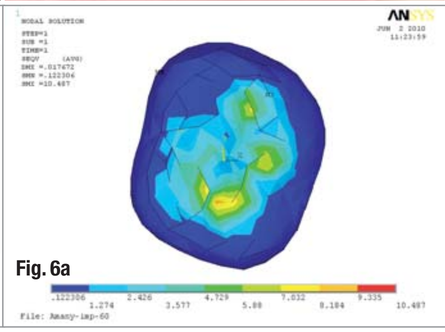
Fig. 6a

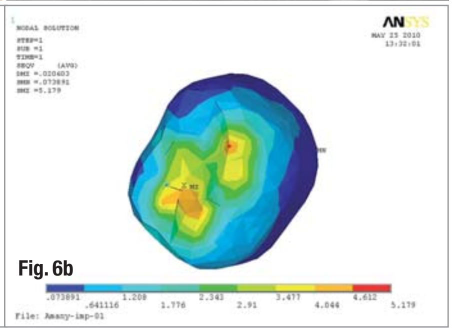
Fig. 6b

Fig. 4a_Radiographic view of wide implants used to restore missing lower first molars.[1, 24]

Fig. 4b_Buccal view of 2 standard 20-degree abutments on 3.5 mm Astra Tech implants for restoration of mandibular right first molar.[1, 24]

Fig. 4c_Radiographic view of the restoration.[1, 24]

Fig. 5_Crown, implants and bone assembled in a model (FEA software).

Figs. 6a & b_Von Mises stress on crown (a. wide implant; b. two implants).

particularly useful in the evaluation of dental prostheses supported by implants.[13-16] Two models were subjected to FEA study to compare between a wide implant restoration versus the two implant restoration of lower first molar.

_Material and Methods

Three different parts were modeled to simulate the studied cases; the jaw bones, implant/abutment assembly, and crown. Two of these parts (jaw bone and implant/abutment) were drawn in three dimensions by commercial general purpose CAD/CAM software "AutoDesk Inventor" version 8.0. These parts are regular, symmetric, and its dimensions can be simply measured with their full details.

On the other hand, crown is too complicated in its geometry therefore it was not possible to draw it in three dimensions with sufficient accuracy. Crown was modeled by using three-dimensional scanner, Roland MDX-15, to produce cloud of points or triangulations to be trimmed before using in any other application.

Tab. 1_Material Properties.

Material	Poisson's ratio	Young's modulus MPa
Coating (porcelain)	0.3	67,200
Restoration (gold)	0.3	96,000
Implants (titanium)	0.35	110,000
Spongy bone	0.3	150
Cortical bone	0.26	1,500

The second phase of difficulty might appear for solving the engineering problem, is importing and manipulating three parts one scanned and two modeled or drawn parts on a commercial FE package. Most of CAD/CAM and graphics packages deal with parts as shells (outer surface only). On the other hand the stress analysis required in this study is based on volume of different materials.[3] Therefore set of operations like cutting volumes by the imported set of surfaces in addition to adding and subtracting volumes can ensure obtaining three volumes representing the jaw bone, implant/abutment assembly, and crown.[2] Bone was simulated as cylinder that consists of two parts. The inner part represents the spongy bone (diameter 14 mm and height 22 mm) that filling the internal space of the other part (shell of 1 mm thickness) that represents cortical bone (diameter 16 mm and height 24 mm). Two implants were modeled one of 3.7 mm diameter and the other of 6.0 mm. The implants/abutment design and geometry were taken from Zimmer dental catalogue (Fig. 5).

Linear static analysis was performed. The solid modeling and finite element analysis were performed on a personal computer Intel Pentium IV, processor 2.8 GHz, 1.0 GB RAM. The meshing software was ANSYS version 9.0 and the used element in meshing all three dimensional model is eight nodes Brick element (SOLID45), which has three degrees of freedom (translations in the global directions). Listing of the used materials in this analysis is found in Table 1. The two models were subjected to 120 N vertical load equally distributed (20 N on six points simulate the occlusion; one on each cusp and one in the central fossa). On the other hand, the base of the cortical bone cylinder was fixed in all directions as a boundary condition.[17-21]

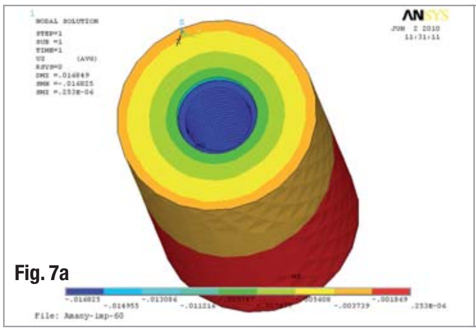

Fig. 7a

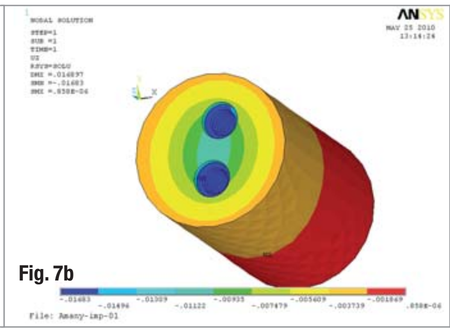

Fig. 7b

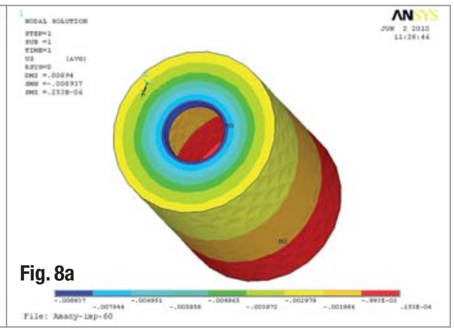

Fig. 8a

_Results and Discussion

Results of FEA showed a lot of details about stresses and deformations in all parts of the two models under the scope of this study. Figures 6a & b showed a graphical comparison between the crowns of the two models which are safe under this range of stresses (porcelain coating, gold crown, and implants showed the same ranges of safety). No critical difference can be noticed on these parts of the system. All differences might be found are due to differences in supporting points and each part volume to absorb load energy (equation 2).** Generally a crown placed on two implants is weaker than the same crown placed on one implant. This fact is directly reflected on porcelain coating and the two implants that have more deflections. Comparing wide implant model with the two implants from the geometrical point of view it is simply noted that cross sectional area was reduced by 43.3 % while the side area increased by 6.5 %. Using one implant results as a reference in a detailed comparison between the two models by using equation (1) resulted in Table 2 for porcelain coating, gold crown, implant(s), spongy and cortical bones respectively.

*Difference % = {One implant Result–Two implants Result}*100/One implant Result...(1)*

Spongy bone deformation and stresses (Table 2) seems to be the same in the two cases. Simple and fast conclusion can be taken that using one wide implant is equivalent to using two conventional implants. On the other hand a very important conclusion can be exerted that, under axial loading, about 10 % increase in implant side area can overcome reduction of implant cross section area by 50 %. In other words, *effectiveness of increasing implant side area might be five times higher than the increasing of implant cross section area* on spongy bone stress level under axial loading. Starting from Figure 7 a & b, slight differences can be noticed on spongy bone between the two models results. The stresses on the spongy bone are less by about 5 % in the two implants model than the one wide diameter implant. The exceptions are the relatively increase in maximum compressive stresses and deformations of order 12 % and 0.3 % respectively. The bone is known to respond the best to compressive and the least to shear stresses[22], so considering the difference in compressive stresses less significant, the *two implants were found to have a better effect on spongy bone*. Contrarily, Figures 8a & b, showed better performance with cortical bone in case of using one wide implant over using two implants, that, deformations in cortical bone are less by 20 % while the stresses are less by about 40 %. The stresses and displacements were significantly higher in the two implant model due to *having two close holes*, which results in *weak area in-between*.

_Conclusions

This study showed various results between cortical and spongy bone. It was expected that the maximum stresses in the cortical bone was placed in the weak area between the two implants. In addition to be higher than the case of using one wide implant. Although the middle part of spongy bone was stressed to the same level in the two cases, using two implants resulted in *more volume of the spongy bone* absorbed the load energy** which led to reduction of stress concentration and rate of stress deterioration by moving away from implants. That is considered better distribution of stresses from the mechanics point of view, which may result in longer lifetime. Porcelain coating showed less stress in case of two implants, longer life for the brittle coating material

Fig. 7a & b_Spongy bone deflection in vertical direction (a. wide implant; b. two implants).

Figs. 8a & b_Cortical bone deflection in vertical direction (a. wide implant; b. two implants).

Tab. 2_Results.

Differences %	Porcelain coating (1mm)	Gold crown	Implants	Spongy bone	Cortical bone
U_{sum}	-17.86	-16.70	-8.18	-0.28	-19.57
U_z	-11.10	-11.10	-2.72	-0.03	-19.62
S_1	31.59	-179.99	-6.72	5.96	-37.17
S_3	0.71	-33.44	-310.74	-11.24	-70.43
S_{int}	-1.26	-18.08	-166.39	4.75	-31.82
S_{eqv}	0.25	-10.22	-196.86	4.00	-39.17

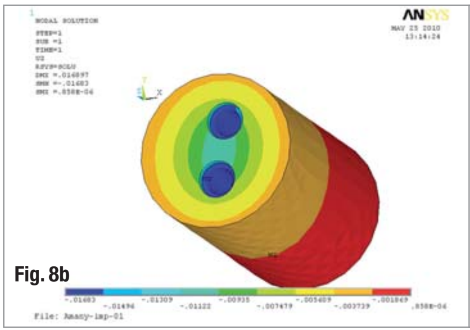

Fig. 8b

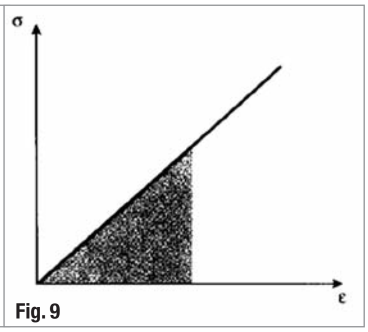

Fig. 9

Fig. 9_Strain energy = area under stress strain curve.

is expected. Contrarily more stresses were found on the gold crown placed on two implants due to its volume reduction (less material under the same load). This is clearly seen in increasing stresses on the two implants, that more load effect was transferred through the weak crown to the two implants. That showed maximum stresses in the area under the crown, while the wide implant showed maximum stresses at its tip. Looking to energy** absorption and stress concentration on whole system starting from coating to cortical and spongy bone, although the stress levels found was too low and far from cracking danger, the following conclusions can be pointed out; the total results favourise the two implants in spongy bone and the wide implant in the cortical layer, but the alveolar bone consists of spongy bone surrounded by a layer of cortical bone. It's also well known that according to the degree of bone density the alveolar bone is classified to $D_{1,2,3,4}$[23] in a descending order. So, provided that the edentulous space after the molar extraction permits, it's recommended in the harder bone quality ($D_{1,2}$) to use one wide diameter implant and in the softer bone ($D_{3,4}$) quality two average sized implants. Therefore more detailed study to compromise between the two implants size/design and intermediate space can put this stress values in safe, acceptable, and controllable region under higher levels of loading.

Fig. 10_Equation 2 (stress energy).

*** The area under the σ_ϵ-ϵ_ϵ curve up to a given value of strain is the total mechanical energy per unit volume consumed by the material in straining it to that value (Fig. 9). This is easily shown as follows in equation 2:*

$$U^* = \frac{1}{V}\int P\,dL = \int_0^L \frac{P}{A_0}\frac{dL}{L_0} = \int_0^\epsilon \sigma\,d\epsilon$$

Fig. 10

_Summary

Restoration of single molar using implants encounters many problems; mesio-distal cantilever due to very wide occlusal table is the most prominent. An increased occlusal force posteriorly worsens the problem and increases failures. To overcome the overload, the use of wide diameter implants or two regular sized implants were suggested. The aim of this study was to verify the best solution that has the best effect on alveolar bone under distributed vertical loading. Therefore, a virtual experiment using Finite Element Analysis was done using ANSYS version 9. A simplified simulation of spongy and cortical bones of the jaw as two co-axial cylinders was utilized. Full detailed with high accuracy simulation for implant, crown, and coating was implemented. The comparison included different types of stresses and deformations of both wide implant and two regular implants under the same boundary conditions and load application. The three main stresses compressive, tensile, shear and the equivalent stresses in addition to the vertical deformity and the total deformities were considered in the comparison between the two models. The results were obtained as percentages using the wide implant as a reference. The spongy bone showed about 5 % less stresses in the two implants model than the one wide diameter implant. The exceptions are the relatively increase in maximum compressive stresses and deformations of order 12 % and 0.3 % respectively. The stresses and displacements on the cortical bone are higher in the two implant model due to having two close holes, which results in weak area in-between. The spongy bone response to the two implants was found to be better considering the stress distribution (energy absorbed by spongy bone**). Therefore, it was concluded that, using the wide diameter implant or two average ones as a solution depends on the case primarily. Provided that the available bone width is sufficient mesio-distally and bucco-lingualy, the choice will depend on the type of bone. The harder $D_{1,2}$ types having harder bone quality and thicker cortical plates are more convenient to the wide implant choice. The $D_{3,4}$ types consist of more spongy and less cortical bone, are more suitable to the two implant solution.

Editorial note: The literature list can be requested from the author.

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