Different Bone Resorption Levels Effect on Stresses Distribution for Different Implant Design

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Abstract: Aim :Different bone resorption levels effect, and better understanding of the effect of implant design parameters such as implant length on the stability of implants, stress values and distribution in surrounding bone are targeted in this study. **Materials and Methods**: Nine cases (implant-bone conditions) were numerically analyzed in 3D by Finite Element Method (FEM). Three bone levels were tested versus three implant lengths, while one type of loading was applied. **Results** showed that implant stability decreases as bone level decreases. The level of instability depends on implant design parameters. Bone stresses increase as bone level decreases with varying values depending on implant parameters. Approximate design curves were obtained.

[Mohamed M. EL Zawahry[1], Mohamed I. El-Anwar[2], and Ahmed F. El-ragi. Different Bone Resorption Levels Effect on Stresses Distribution for Different Implant Design. Journal of American Science 2010;6(12):1521-1525]. (ISSN: 1545-1003). http://www.americanscience.org.

Key words: Bone resorption ,implants,

Introduction:

The resorption of the dental bones after the dental implant surgery is one of the main factors that lead to biological and/or mechanical failure of implant-supported dental restorations.

From the biomechanics point of view, bone resorption decreases the bone density, therefore leading to the reduction of the overall stiffness of the bone. This could worsen the stress/strain distribution and the bone's role as the support to the implant, and in some cases, cause bacteria to be trapped in the resorbed notch area, therefore further worsening the resorption phenomenon. Clinically, two factors are primarily identified and associated with the incidence of bone resorption: bacterial infection due to the plaque in the bone/implant interface; and occlusal overload in the newly formed bones in the gap between the implant surface and the hosting bone, thereby damaging mineralized cellular tissues and their responses, thus preventing proper osseointegration, Daniel et al., (2009).

The exact reason for bone resorption varies between patients and has not been pinpointed yet. In general, the crestal bone level remains more or less the same and does not change much. Nevertheless, several literature studies have reported the marginal bone loss following the dental implantation surgeries, Nowzari et al., (2006). It was reported the alveolar bone loss occurs at an average rate of 0.17mm per year after implantation, Corn et al .,(1989). While Kol et al (2003);Nowzari et al .,(2006) reported the alveolar bone loss between 0.2 and 0.4mm over the first twelve months of implantation, followed by an additional 0.1mm bone loss between months 12 and 18.Overall, it can be seen that the average dental bone loss due to resorption is approximately around 0.2-0.4mm over the first twelve months, and can be said to reach a more stable status after months 12 to 18. Clinically, the bone resorption usually occurs in the cortical region surrounding the neck of the implant. Micro-damage and macro-damage may be differentiated in such construct of artificial (implant) and natural (bone) biomaterials. A certain level of micro-damage in bone tissues could promote positive bone remodeling, while excessive micro-damage may lead to certain local micro-cracking of mineralized tissues and the loss of bone strength, consequently weakening the implantation as a whole. Thereafter, the damage could reduce the magnitude of stress and strain induction in such bone tissues. Bone remodeling on the other side is a damage repair process, Li et al.,(2007). Bone resorption can therefore be viewed as the result of excessive damage in the bone tissues, where the damage takes place at a rate too rapid for the bone to repair and remodel, McNamara et al.,(1997).

Currently, placement of dental implants is a gold standard for replacement of missing teeth. Although successful clinical treatments by dental implants have been reported Andersen et al.,(2002). failure of osseointegration still sometimes occurs Chee and Jivraj (2007). In contrast to natural teeth, there is no periodontal ligament between dental implants and their surrounding bone. The periodontal ligament acts as a shock absorber between a root and surrounding bone and it also contains mechanoreceptors.

Without the periodontal ligament, mechanoreceptors will also be absent. The absence of mechanoreceptors results in poor detection of bite forces with small magnitudes.

This subsequently increases the tendency of occlusal overloading, which can cause peri-implant bone loss and implant failure, Kim et al.,(2005). When dental implants are used, it is therefore advisable to remove the sources of occlusal overloading as much as possible.

The Finite Element Method (FEM) is frequently used to determine stresses in bone around dental implants, Dejak and Mlotkowski(2008). Complex FE analysis methods such as the FE contact analysis can be very beneficial for modeling different clinical situations,Lin et al.,(2008).

Modeling of a bone resorption level problem, can actually be done by employing FE contact analysis. With having the maxilla, mandible, periodontal ligament and all teeth placed in the actual positions. The main reason may be that the FE contact analysis is expensive since it needs both large human and computational resources. Nevertheless, studies of bone resorption levels by experiments, both in humans and animals, are even more difficult and more expensive. In fact, some information, such as stresses in human bone, can be very difficult to obtain from experiments. To obtain stresses in bone from experiments, strains in bone must be first measured and, after that, stresses can be computed from the measured strains. The measurement of strains in bone is complex and can be quite expensive. The difficulties in performing experiments discourage studies of premature contacts with varied parameters, Takayama et al.,(2001)

2.Material and Methods:

2.1.Materials:

2.1.1.Implant designs:

Fixed implant diameter of 3.9 mm, and three different implant lengths: 9, 11 and 13 mm were modelled. Vertical load of 100 N perpendiculars in the middle for implant head top surface and coincident with bone (cortical and spongy) centreline were applied. Cortical and spongy bones were modelled as two co-axial cylinders of 24 and 22 mm diameter, and 16 and 14 mm height respectively. Where cortical bone cylinder is hollow, and has a constant thickness of 1 mm.

2. 2. Methods:

2.2.1.Experimental design

-Three different bone resorption levels at: 0, 2, and 4 mm were studied.

-Four types of stresses: Tensile stress, Von Mises stress, Compressive stress and Shear stress were obtained and focused by this study.

-The modulus of elasticity and possion ratio for the cortical and spongy bone besides the titanium implant was provided to the F.E.package,Table (1).

-Boundary condition was just supporting the bottom level of the cortical bone cylinder.

-The solid modeling (Figure 1) and finite element analysis were performed on a personal computer Intel Pentium IV, processor 2.8 GHz, 1.0GB RAM. The meshing software was ANSYS version 9.0 and the used element in meshing all three-dimensional models is 8 nodes Brick element (SOLID45), which has three degrees of freedom (translations in the global directions) Peter Kohnke (1994)
Figure (2).

Table 1. Material properties used in the analysis

Material	Modulus of Elasticity (MPa)	Poisson's Ratio
Cortical bone [Ishigaki etal.,2003]	14,500	0.323
Spongy bone [Caglar etal.,2006]	1,370	0.3
Titanium [Mellal etal.,2004]	110,000	0.3

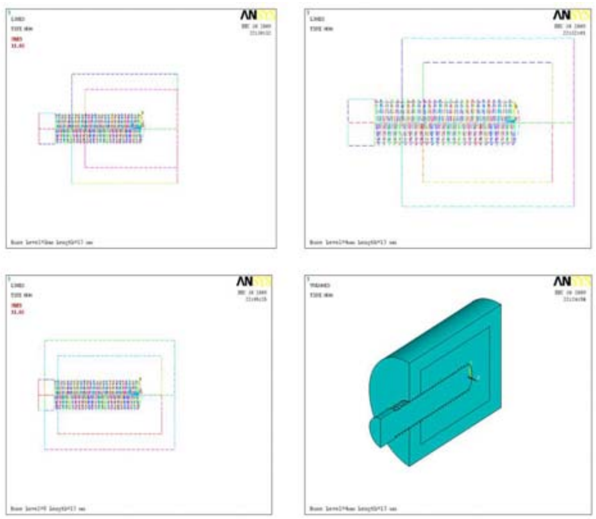


Figure 1: Different levels of bone resorption (screen shots from FE package)

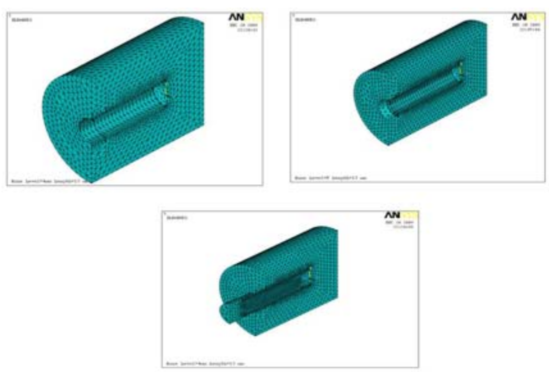


Figure 2: Meshed models for different bone resorption level

3.Results:

3.1. Running the F.E. package for the nine planned cases

This resulted in tons of data, and screen shots for the detailed analysis.

Figure(3)showed the maximum tensile stress generated on the 13mm implant at resorption level of 4mm. The maximum stresses were localized at implant-cortical bone interface. Generally all cases showed safe implant stresses levels, therefore, no further demonstrations for implant results presented in this study.

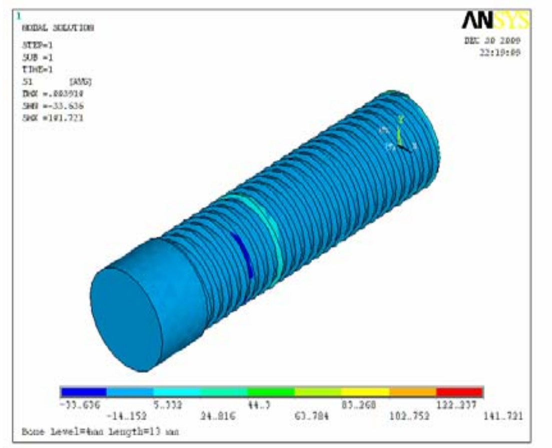
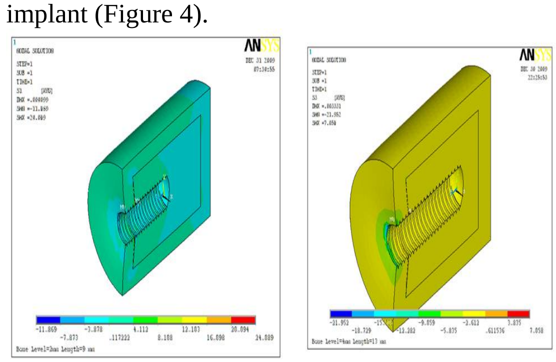


Figure 3: Maximum tensile stress in 13mm implant length, bone level 4mm

3.2. Bone stresses distributions and levels:

Bone stresses distributions and levels resulted on fixed stresses distribution where the maximum stresses were found at cortical bone interface with the implant (Figure 4).



(a) **(b)**

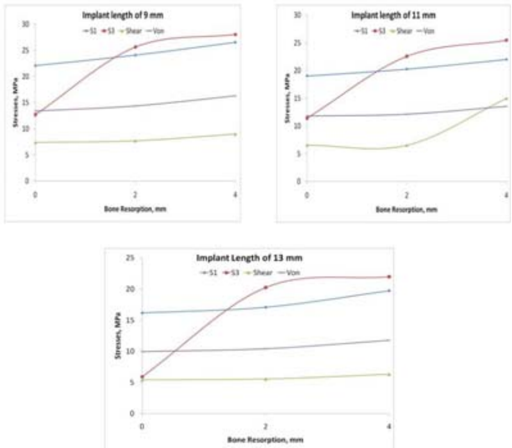
(a) 9mm implant length / 2mm bone level
Maximum tensile Stress

b) **13mm implant length / 4mm bone level**
Maximum compressive Stress

Figure 4: Spongy and Cortical bones stresses distribution

3.3.**Comparing stresses values with different resorption levels** :

This comparison could lead to approximate design curves, and solid conclusions. Figure (5) showed these comparisons between bone maximum tensile, maximum compressive, shear, and Von Mises.



Bone maximum stresses are generally increased with bone resorption level increase

Figure 5: Comparison between the nine cases

4.Discussion:

Consistently, the most prominent stress peaks occured in the bone (either cancellous or compact) near the protruding part of the stem. The values were probably under-estimated, since slip might occur between implant and tissue - contrary to the models' assumptions-thus at the least reducing amount of load transmitted by shear and tension. The resulting compressive stressed in the mandible were still locally approaching the upper limit of temporarily-acting physiological stresses, Borchers and Reichart(1983).

Crestal bone resorption primarily occurred during the first 4 weeks after uncovering, and although the cellular mechanism has not yet been identified, the micro-gap elicited an inflammatory response and subsequent bone loss, Xavier et al.,(2006). Pattern of stresses showed the distributions of stresses within the implant and the bone highlighting the location of the maximum and minimum values. An increase of all types of stresses occurred with higher bone resorption proportionate to degree of resorption. The compression stress showed an increased stress more than the others. For all bone levels the locations of maximum stresses were the same. On the other hand increasing implant length (in other words implant side area) ensured more stable fixation, and less stresses values which was preferred for weak bone patients. All stresses types could be said that it increased linearly with resorption level except maximum compressive stress (S_3). Which dramatically increased, by 100 to 400%, when resorption level increasing from zero to four millimetres.

Conclusions:

In the present study, the influence of a premature contact on stress and strain distributions in bone around an STDI was investigated. Bone resorption increased stresses for both implant & bone with all types of stresses namely, tension, Von Mises, shear & compression; with the later showing maximal increase. The increase of compressive stress in the bone showed more than one hundred percent increase. The location of the maximum stresses in the bone was the same for all levels of resorption in all implant designs. The increase of the implant lengths reduced the rate of increase in bone stresses with increasing bone resorption.

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11/9/2010