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ALVEOLAR BONE LOSS: AN ENERGY ANALYSIS USING FINITE ELEMENT METHOD

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Abstract

Introduction: The number of adult patients seeking orthodontic treatment has increased and the esthetic demand is a much more important factor for this group. Periodontal problems and loss of alveolar bone crest could occur frequently in adult patients and bone loss is one of the important factors that could influence treatment outcome. The aim of this study was to evaluate the effects of bone loss on tooth movement mechanics and also to analyze the PDL energy input change in various alveolar bone heights when trying to produce bodily movement concerning M/F ratio using finite element method.

Methods: Nine 3D computer models of a central incisor were designed. Models were the same except for the alveolar bone height that ranged between normal and 8 mm of bone loss. Bodily movement was produced and the strain energy changes, distance of center of resistance (CRes) to the alveolar crest, moment to force ratio (M/F) increase and the changes in distance of CRes to cemento-enamel junction (CEJ) were analyzed.

Results: The center of resistance shifts from 7. 295 mm to the crest in normal bone height to 2. 872 mm to the crest in 8 mm of bone loss. An increase of 12% in 1 mm of bone loss to a 49% of increase in 8 mm of bone loss was shown necessary to maintain bodily movement. The distance of CRes to CEJ decreases from 7. 295 mm in normal bone height to 10. 827 mm in 8 mm of bone loss. An increase of energy input was also shown from 0. 027 mJ to 0. 035 mJ in normal and 8 mm of bone loss respectively.

Conclusion: The result of this study revealed that in alveolar bone loss, the M/F ratio to produce bodily movement increased. There is an increased input energy in PDL of cases with more than 3 mm of bone loss when following M/F ratio increase to produce bodily movement. Decreasing the force magnitude as a method of reducing the energy input is also suggested.

Keywords: Alveolar bone loss, Finite Element Method, Center of Resistance,

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Strain energy analysis.

Introduction

Demand of esthetic is higher nowadays than before. In past decades, the major problem of adult patients was their health status while the aim of adults seeking orthodontic treatments has shifted towards esthetic considerations.[1-5] Improved life style, increased quality of life and life expectation are among the reasons for this shift. The importance of getting a better face and smile in social relations can be added to the list. The psychosocial benefits of orthodontic treatment would include an enhancement of self-esteem.[6, 7] Alveolar bone resorption can be found due to different reasons in an adult patient like periodontal surgery and senile changes.

Increased number of adults looking for orthodontic treatments necessitates new considerations among which producing given tooth movement types in reduced bone height cases is an important one. The older is the patient, the higher degrees of bone loss is expected.[8-10] Studies reveal that ageing procedure can diminish resistance of periodontal tissues to break down.[11] There is no evidence of relationship between the duration of the treatment, extraction or non-extraction and the amount of bone loss.[12] The influence of sex in bone loss is controversial. A greater distance of bone from CEJ to alveolar crest has been reported in untreated males in comparison to females but the difference has no longer remained after orthodontic treatment.[13-14]

A combination of tooth movement types are needed in a treatment procedure which produce different amounts of stress in various levels of periodontal ligament (PDL).[15] The bodily movement is a favored one among others due to a more harmonious stress levels in PDL. This movement is produced by a force system which is equivalent to a force passing through the center of resistance (CRes). This point is believed to be approximately 40% of distance from alveolar crest to the apex or in furcation of a molar in a healthy periodontal level.[16-17]

The CRes position is modified in gradual alveolar bone loss. The force system to produce bodily movement should be modified to adapt the changes in the CRes location.[18-19] An increase of the needed M/F to produce bodily movement in various stages of alveolar bone loss is reported by Geramy.[20] An increased level of stress produced in gradual levels of bone loss under the same force system is also reported by Geramy.[21]

The finite element method (FEM) subdivides a system into individual components or 'elements' whose behavior is readily understood and enables one to rebuild the original system so that its behavior can be understood.[22] New advances in FEM and its analyses have been helpful to perform and assess a system from the energy point of view. In this way, involved systems can be evaluated from the changes in energy point of view during the loadings.

The FEM has been used to study a number of different problems in orthodontics, such as alveolar bone resorption during tooth movement, extra oral force application and orthodontic mechanotherapy.[23-29]

Materials and Method

Nine 3D computer models of a central incisor were designed in SolidWorks 2006 (SolidWorks, Concord, Massachusetts, USA). The tooth was modeled according to Ash's dental anatomy.[30] The models contained compact and cancellous alveolar bone, central incisor, and its PDL. The models were the same except for their alveolar bone heights. It was normal in the first model and showed degrees of bone loss between 1 and 8 mm in other models. The 3D models were designed to be as realistic as possible, without using any symmetry in modeling.

Table 1. Mechanical properties of the materials

	Young's Modulus (MPa)	Poisson's Ratio
Tooth	20300	0.26
PDL	0.667	0.49
Spongy Bone	13400	0.38
Cortical Bone	34000	0.26

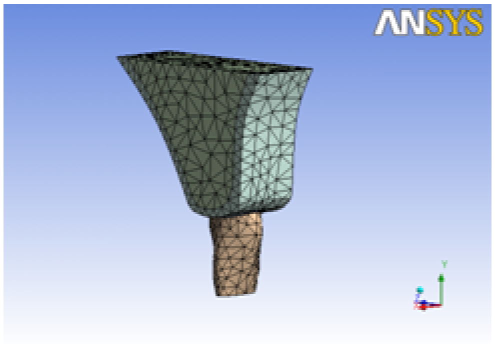
Table 2. Node and element number of different models

	Node	Element
Normal alveolar bone height	26533	21138
-1 mm of bone loss	21322	16470
-2.5 mm of bone loss	25067	15958
-5 mm of bone loss	26638	14618
-6.5 mm of bone loss	23962	13557
-8 mm of bone loss	24228	13224

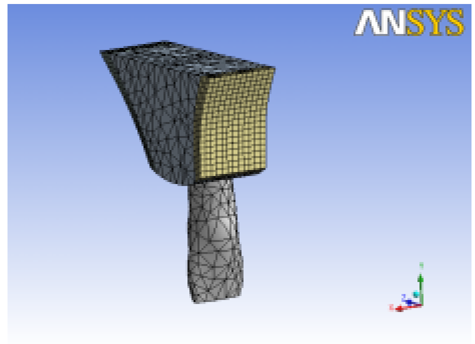
The models were transferred to the ANSYS Workbench Version 10 (Ansys Inc. , Southpointe, Canonsburg, PA, USA). Boundary conditions restricted displacements of the nodes at the base of the models. The rigid body motion was restricted by preventing definite nodes from moving along the 3D space axes. The manner of restriction was based on the anatomy of maxilla. Mechanical properties (Table 1) were then applied and the models were meshed. (Figure 1a-c) Table 2 lists the node and element numbers used in different meshed models.

A suitable force system was then applied to each model to produce bodily movement. The force system contained a 1-Newton force vector to the center of the crown being 5. 827 mm incisal to the CEJ and the moment was applied so that the amount of displacements in two nodes in different tooth heights were the same, showing a bodily movement of the tooth.

Modification of CRes position and its effects on tooth movement were assessed. An energy analysis was also conducted in each model and the change of the strain energy input was assessed in PDL based on the fact that tooth movement is a PDL based event.



a)



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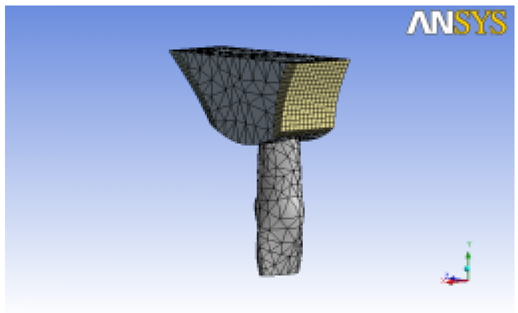

c)

Figure 1. The meshed models a) normal alveolar bone height, b) 5 mm of bone loss, c) 8 mm of bone loss.

Results

a. The distance of CRes to the crest of alveolar bone

In normal alveolar bone height, it is 7. 295mm apical to the crestal bone and a gradual decrease is noticed while the bone loss progresses and reaches 2 872 mm. (Table 3) Figure 2 presents the shift of the CRes in relation to the crestal bone.

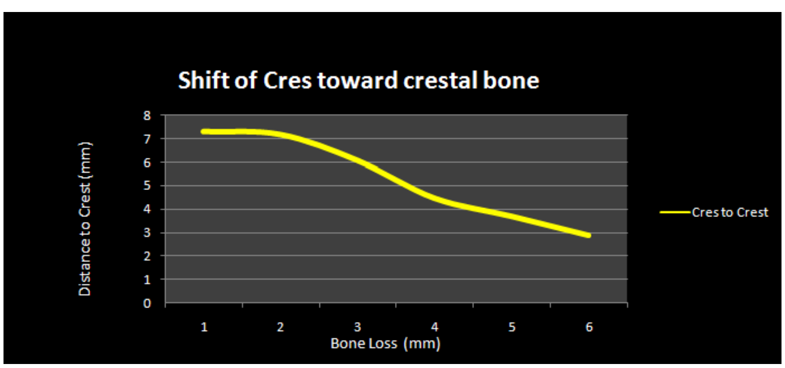

Figure 2. Modification of CRes position with gradual stages of bone loss.

Table 3. Modification of CRes position in different stages of bone loss

	CRes to Crest	Crest. to CEJ	Percent of M/F change*	Strain Energy (mJ)**
Normal	7.295	7.295		0.027315
-1	7.172	8.172	12	0.027471
-2.5	6.072	8.572	17.5	0.027535
-5	4.472	9.472	29.8	0.028981
-6.5	3.695	10.1953	39.7	0.031498
-8	2.872	10.872	49	0.035001

*= the percent of M/F change to maintain bodily movement.

**= Change of energy input in bodily movement.

b. Percent of M/F increase in bodily movement

Gradual bone loss caused an increase in M/F ratio to maintain bodily movement and started with 12% of increase in 1 mm of bone loss and reached 49% in 8 mm of bone loss and are summarized in Figure 3. (Table 3)

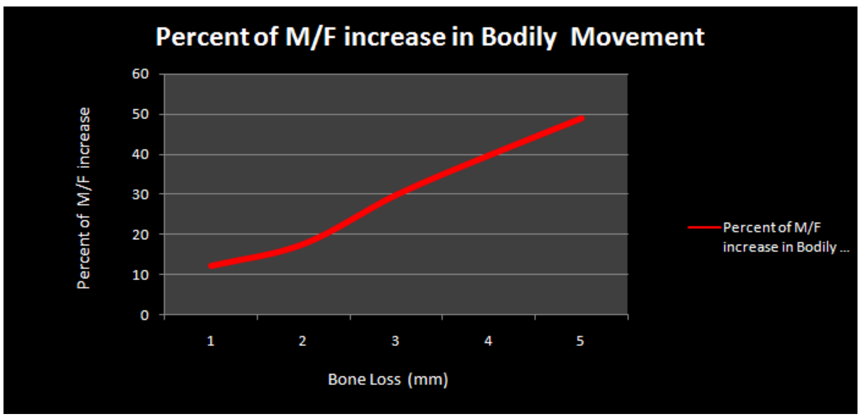

Figure 3. Increase of M/F needed to maintain bodily movement in gradual stages of bone loss.

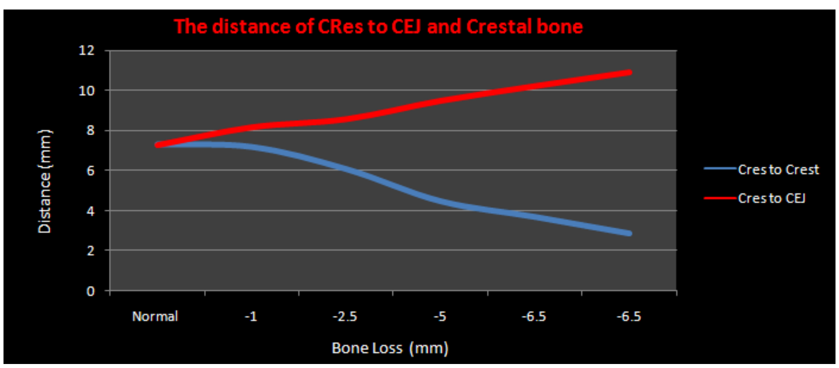

Figure 4. Modification of CRes position in different stages of bone loss.

c. The distance of CRes to CEJ

It starts with 7. 295 mm in normal alveolar bone height and increased to 10. 872 mm in 8 mm of bone loss. (Table 3) and (Figure 4)

d. Strain energy

In normal alveolar bone height, the energy input to produce bodily movement was 0. 027315 mJ and increased to 0. 035001 mJ in 8 mm of bone loss. (Table 3) Figure 5 shows the energy changes.

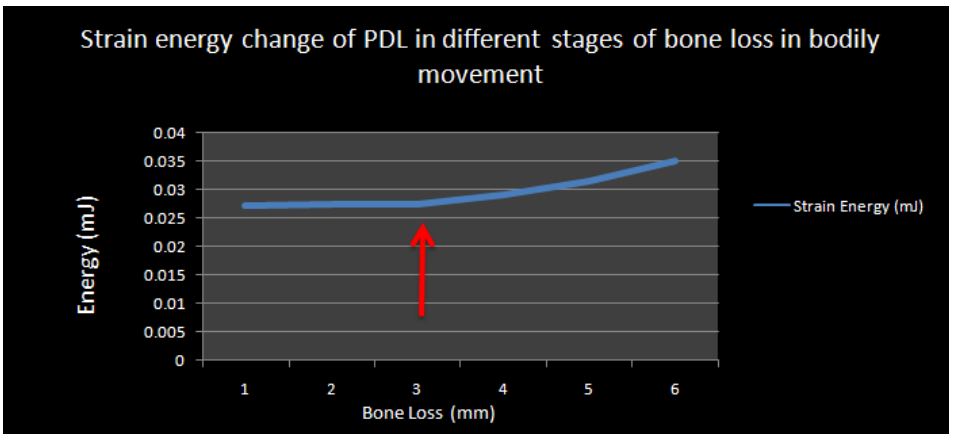

Figure 5. Modification of Strain energy in PDL in bodily movement while alveolar bone height is reduced.

Discussion

The biomechanical consequences of bone loss were assessed three-dimensionally by finite element method.

Generally, the findings were in accordance with previous studies.[20,21,31] The models used in previous studies were designed by defining nodes one by one (bottom – up) while the new models are designed in a top-to-bottom method. The similarities found in output data made it clear that changing the method of modeling cannot influence the accuracy of the models but saves the time needed in designing phase. It should be mentioned that not all the models can be designed in a top-to bottom method and there are still models that need to be modeled in a bottom-up method.

Alveolar bone height is one of the major determinants in orthodontic tooth movement. In this study, different distances from CRes to alveolar crest in various bone loss models were found. This is in accordance with other authors outcomes.[32] Geramy[19] reported a shift in CRes position toward alveolar crest with alveolar bone loss which is in accordance with Tanne[20]. Cobo[33] concluded that decreasing alveolar bone height could diminish the distance of CRes to alveolar crest and it could be located above the alveolar crest which is against Geramy[20]and this study. Different M/F ratios could induce different type of tooth movement. To achieve bodily tooth movement, it is important to sele ct an optimum moment to force ratio which is simplified as 10:1[34] but is believed to depend on different parameters including root length. Tanne reported that even small difference in the M/F ratio leads to clinically significant changes in the center of rotation. He also reported 8. 39 as the optimum M/F leading to bodily movement in normal alveolar bone height[35]. Alveoalr bone loss makes it necessary to increase M/F to retain bodily movement. [36] According to the results of this study, a 12% of M/F increase is needed in 1 mm of bone loss situation. This increase was 49%in 8 mm of bone loss and is in agreement with other studies.[19,32] Bantleon reported 20% increment of M/F ratio necessary to maintain bodily movement in 3mm alveolar bone loss.[37]

The amount of M/F increment for 2. 5 mm of bone loss in our study is 17. 5%which is in accordance with Geramy who reported a 17. 35% of increase under the same condition.[20] In 5 mm of bone loss, preserving bodily movement needed a 29. 8% of M/F increase which is nearly in accordance with Siatkowski who reported this as 38%[38] and to Geramy whose data showed this change as 32. 1%.[20] An apical movement of the CRes in bone loss cases also was shown. This increment is 10. 872 mm in 8mm bone loss cases while in normal bone condition this distance is 7mm.

A new consideration in finite element analysis is assessing the strain energy which seems to provide new information in analyzing situations. We consider work and energy to be equal. Increase of energy in a system can be interpreted as the work done in loading and can be an indicator of the events in the system while unloading.

The result of this study showed an increase in strain energy (0. 035001 mJ) in 8 mm of bone loss compared to a healthy situation whic h is 0. 02731 mJ when bodily movement occurred. The energy finding in a normal bone level can be considered as an optimum one and increases found in different levels of bone loss may be considered as unnecessary or harmful. The energy change accelerates after 2. 5-3 mm of bone loss. The findings suggest decreasing the force magnitude in a case with more than 3 mm of bone loss.

According to Tanne the amount of stress level in bodily tooth movement is approximately 0. 29 times as that in simple tipping of a tooth and showed the importance of controlling stress levels for inducing optimal tooth movement.[36] Cobo *et el.* reported an increased stress production in gradual stages of alveolar bone loss.[33] Results of the other study describe that in samples with normal bone height level up to 8 mm of bone loss the stress level in periodontal membrane is increased.[20] Rudolph show that in bodily tooth movement stress was distributed throughout the root but was more concentrated at the alveolar bone.[39]

During orthodontic tooth movement, the level of hydrostatic pressure increase. When hydrostatic pressure exceeds more than systolic pressure (120 mm of mercury) areas of necrosis could be found in PDL.[40]As mentioned earlier, in alveolar bone loss cases the level of strain energy is more than normal ones leading to possible unwanted events like areas of hyalinization and necrosis in PDL. Interpretation of data reveal that in orthodontic treatment, especially in adult patients with compromised periodontal status and alveolar bone loss, not only the M/F ratio but also the force magnitude should be considered to control unwanted tooth movement and prevention of inducing more bone loss. It is in completion of literature and to consider force magnitude in addition to the M/F increase in bone loss and adult patients.

Conclusion

1. An increase of M/F ratio to produce bodily movement in different stages of bone loss was shown.
2. Reduction of the distance of CRes to the alveolar crest and also increase of its distance to CEJ in stages of bone loss was shown.
3. Three millimeter of alveolar bone is the point beyond which the energy input of PDL to produce bodily movement increases rapidly.
4. It seems acceptable to reduce the force level in cases with more than 3 mm of bone loss to retain the input energy.

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