Alveolar bone resorbtion – influences on orthodontic dynamics

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Summary

Objective: **to analyze and to compare the behavior of teeth with varying loss of alveolar bone during orthodontic movements.**
Material and method. **Six three-dimensional models for the upper central incisor have been created using the Finite Element Method, a modern computer-based method of analysis. The first model corresponds to the situation of non-resorbtion of alveolar bone while the other 5 models correspond to the progressive resorbtion of alveolar bone of 2, 4, 6, 8, 10 mm. A horizontally orthodontic force by 1 N has been applied in the middle of labial incisor side.**
Results. **The stress and displacements distribution have been analyzed, compared and interpreted from a qualitative and quantitative point of view. The results obtained after computer simulations have been synthesized in a series of graphs.**
Conclusions. **The stress and the displacement depending on the orthodontic force direction increase gradually with alveolar bone loss both on the apical and cervical level.**

Key words: **orthodontic force, biomechanical reactions, bone resorbtion, Finite Element Method.**

Introduction

Orthodontics is playing an extremely important role in the treatment of periodontal affections. Its purpose is to obtain a functional stable occlusion, to improve the anatomic periodontal support and to create the conditions for a long-term maintenance of periodontal health. The number of adult patients who are asking for orthodontic treatment is permanently increasing. Among them, cases with periodontal affections of different gravity are encountered, which react differently than patients with healthy dental-periodontal support, when an orthodontic force is applied.

The Finite Element Method (FEM) is a modern computer-based method of analysis, having some extremely varied applicability fields: aeronautics, structural and industrial engineering, nuclear field, medicine [1,2]. It is generally pursued to determine, within the considered field, the values of one or several unknown functions such as: tensions, pressures, specific deformations, temperatures, displacements and speeds [3]. This method has been successfully used for several years in engineering and it uses the computer in solving certain systems with a big number of equations, in order to determine the tensions and the deformations, on

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the basis of the physical properties of analyzed structures.

This method is being more and more used in medicine too for an extremely precise investigation and identification of structural stress and displacements, under the influence of different external factors on the human body.

In orthodontics, when compared to other methods, FEM has numerous advantages, highlighted by the ability of including the heterogeneity of the dental-periodontal structures and by the irregularity of the dental contour in casting and designing a tooth. In order to obtain a more qualified and rigorous analysis, FEM also allows the application of forces in different directions and with different intensities [4].

This study opted for FEM, due to the **advantages** this method offer:

- The possibility of modeling the irregularity of the dental contour and the structure of the tooth-periodontal ligament (PDL)-alveolar bone ensemble, heterogeneous from the point of view of physical properties [3,5];

- FEM allows quantitative determination and graphical visualization of movements and stress, basically in any point of the tooth-PDL-alveolar bone ensemble;

- FEM is a numeric analysis method, which allows the extremely precise identification of structural stress and movements, based on the physical properties of the analyzed structures [3];

- FEM allows applying the forces on different directions and with different intensities, for a more competent and rigorous analysis;

- Redirecting the study based on human or animal experiments to the non-aggressive simulation methods of the real biological phenomenon, i.e. computer assisted analyzing methods.

Objective

This study suggests an analysis of the biomechanical reactions in the orthodontic

movement during the application of orthodontic forces, in different situations of reduced periodontal support of the tooth. Afterwards, a comparative analysis of biomechanical reactions is made, based on its components, stress and displacements, in the situation of a periodontal support with progressive loss of alveolar bone.

Material and method

The Finite Element Method depends on a fundamental concept, which is based on the discretization of the entire "continuum" into finite elements with the same physical and functional properties, connected each other through points called **nodes** [3].

In this study, all materials used to create the FEM model were considered isotropic and elastic. The values of Poisson's Coefficient (μ) and of Young's modulus (E) for different materials were derived from other investigations [6].

According to the geometry, dimensions and morphological data of the upper central incisor, from the specialty manuals, and using software based on FEM, a **general three-dimensional model** was created, which includes the tooth-PDL-alveolar bone ensemble (*Figure 1*). The model contains 1379 nodes and 976 finite elements (FE).
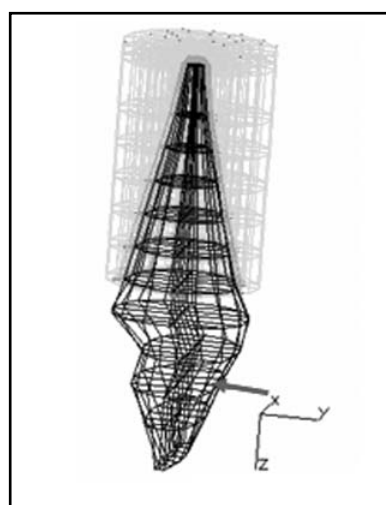

Figure 1. Discretization
(tooth-PDL-alveolar bone ensemble)

Table 1. The parameters of discretization field depending on the specific model geometry

Alveolar bone loss (mm)	Number of finite elements	Number of contact elements	Number of nodes
0	976	225	1379
2	818	193	1186
4	674	160	1010
6	546	128	849
8	434	96	705
10	338	64	576

This first model corresponds to the situation of non-resorbtion of alveolar bone. We also have created five three-dimensional models of the upper central incisor corresponding to the progressive resorbtion of alveolar bone by 2, 4, 6, 8, 10 mm [7].

Depending on the specific geometry, the discretization process has lead to a different number of subdivisions, according to *Table 1*.

The studies were realized using ALGOR software. We have realized the comparative studies concerning teeth behavior with varying loss of alveolar bone in cases when a tipping force by 1 N intensity was applied in the middle of labial incisor side.

Results

The results that give relevance to the studies phenomena after computer simulations are:

1. Displacements depending on the direction of orthodontic force applied;
2. Stress depending on the force direction.

1. Distribution of orthodontic displacements at different levels of alveolar bone loss

The results obtained after computer simulations emphasize the displacement distribution of tooth-PDL-alveolar bone ensemble and allow an overview comparative analysis concerning the movement values which are emphasized through the colored spectrum of the general model.

Alveolar bone resorbtion leads to an increase of the orthodontic displacement values. Thus, in the case of non-alveolar bone loss, the maximum value of tooth movement is 0.0019 mm (*Figure 2*) and in the case of 4 mm alveolar bone loss (*Figure 3*), the maximum value is 0.004 mm (both
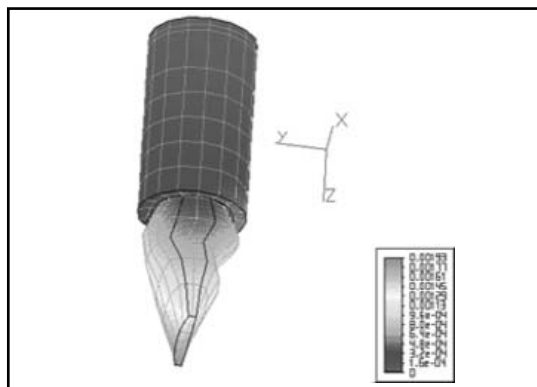

Figure 2. Displacement distribution (mm). Normal alveolar bone height
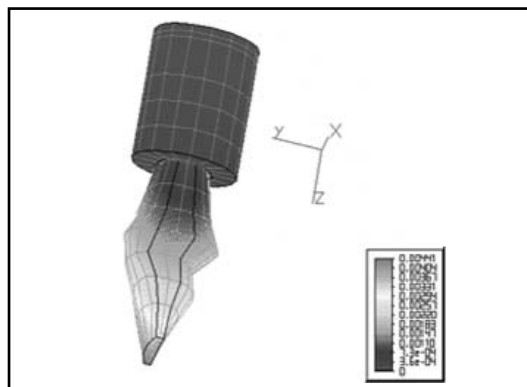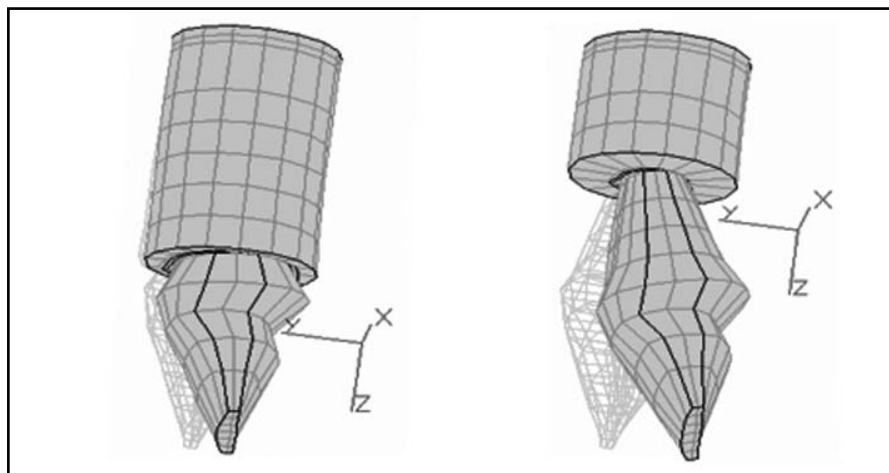

Figure 3

Figure 4

cases are characterized by the same direction and intensity of the orthodontic force).

We also emphasized the initial and final position after orthodontic force application in two situations: non-resorbtion and 6 mm alveolar bone loss. The graphical representation (*Figure 4*) is very suggestive because it indicates in the same time the initial and the final position in both situations.

It is essentially to give emphasis to displacements on PDL in 4 points of the upper central incisor sides: labial (V), mesial (M), distal (D), oral (P). The results obtained are presented and synthesized in a series of suggestive graphs which indicate the displacements distribution on PDL in 4 points, depending on the alveolar bone height, in

two situations:

- 0 mm alveolar bone loss - normal situation (*Figure 5*);

- 4 mm alveolar bone loss (*Figure 6*).

The analysis and interpretation of these graphs lead to the following conclusions:

- The cervical displacement degree is higher than the apical displacement level with two-size orders approximation.

- Regardless of the degree of alveolar bone resorbtion, the displacements at the apical and cervical levels have approximately the same values.

- The displacement of the distal incisor side presents higher values than the other sides in all situations, with or without alveolar bone loss.
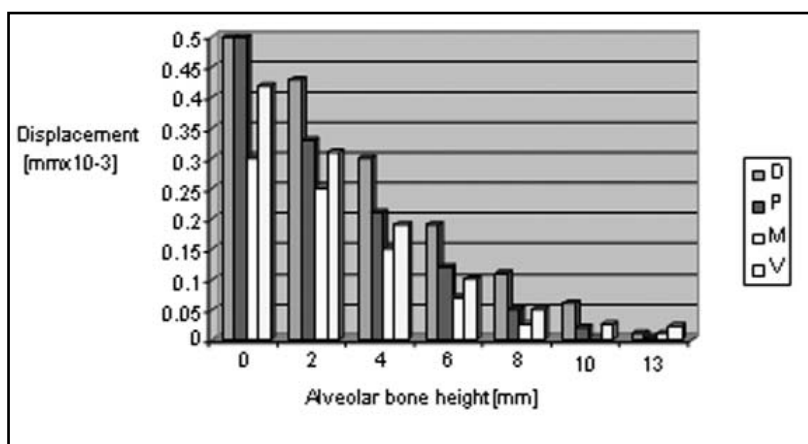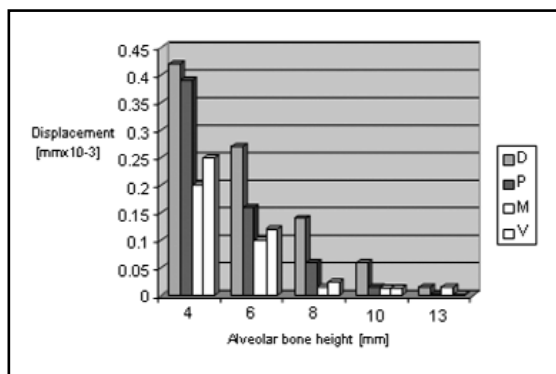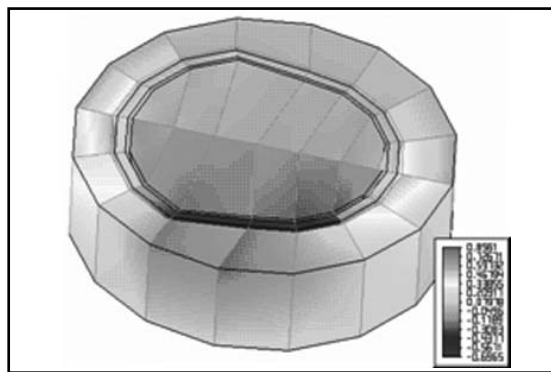

Figure 5

Figure 6

Figure 7

2. Stress depending on the force direction: distribution at different levels of alveolar bone loss

2.1. Results at the cervical level

The increase of alveolar bone resorbtion level leads to higher stress values in all PDL points, at cervical incisor area. For example, the stress value on the oral incisor side at cervical level is -0.14 N/mm² (negative – compressive stress) in the situation without alveolar bone resorbtion. The stress value is -0.4N/mm² when the alveolar bone loss is 2 mm (*Figure 7*) and -0.7 N/mm² when the resorbtion is 4 mm.

The stress depending on the orthodontic force direction, on PDL, increases gradually with alveolar bone loss at the cervical incisor level.

2.2. Results at the apical level

The stress depending on the orthodontic force direction increases gradually with alveolar bone resorbtion at the apical level. For example, it is positive (tensile stress) on the oral incisor side at the apical root level with a value of +0.05 N/mm² (2 mm of alveolar bone loss) and a value of +0.18 N/mm² in a situation with 4 mm loss of alveolar bone support (*Figure 8*).

The stress depending on the force direction, on PDL, at the apical level, is positive on the oral, mesial and distal sides and negative on the labial incisor side (tipping phenomenon).
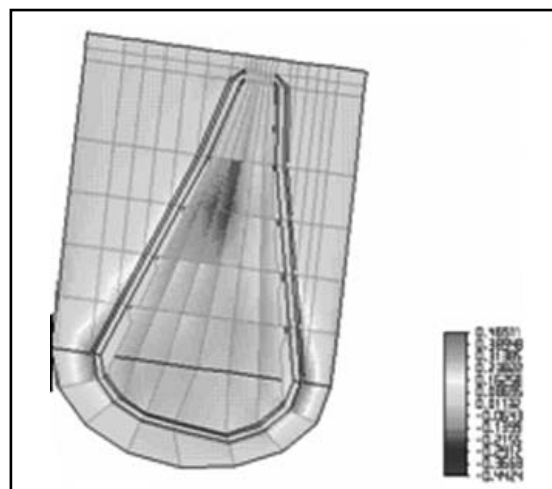

Figure 8

2.3. Stress depending on the force direction: comparison between the cervical and apical levels

The results give emphasis to high stress values on the cervical level and low stress values on the apical level in all PDL points. For example, the stress on the distal incisor side, on PDL, has a value of +0.2 N/mm² at cervical level and a value of +0.001 N/mm² at apical level (*Figure 9*) in the situation of 2 mm alveolar bone loss. The stress has a value of +0.5 N/mm² at the cervical level and 0.1 N/mm² at the apical level (*Figure 10*) in the situation of 6 mm alveolar bone loss, on the distal side too.

On the labial incisor side (V), the stress depending on the force direction is positive ("+", tensile stress) at the cervical incisor
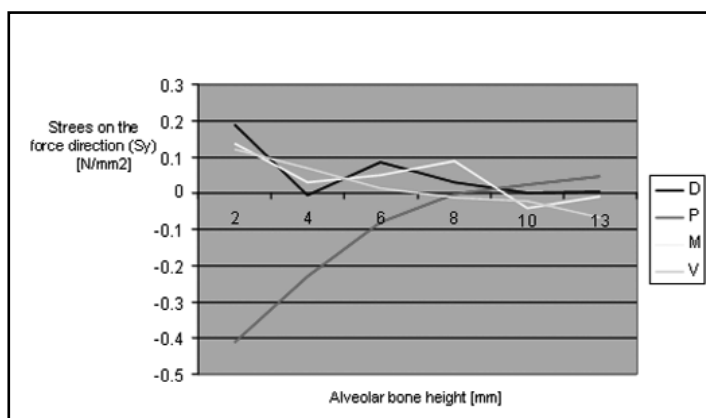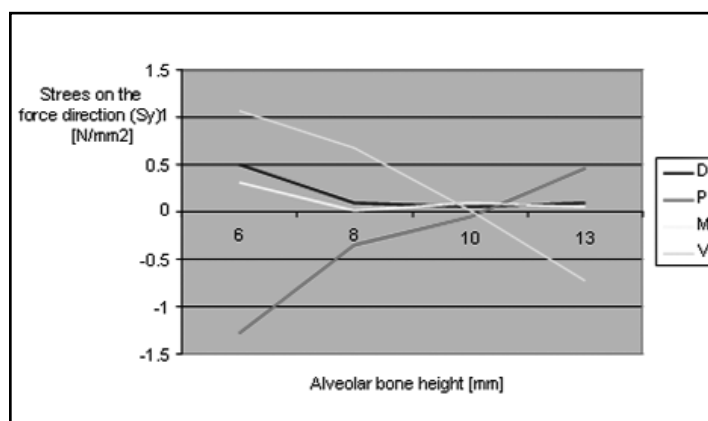
Figure 9

Figure 10

level and negative ("-", compressive stress) at the apical level.

On the oral incisor side (O), the stress is negative at the cervical level and positive at the apical level. So, the stress depending on the force direction, on PDL, changes the sign on the labial and oral sides: on the upper root level, the stress is negative on the oral incisor side, positive on the labial side; on the lower root level, the stress becomes positive on the oral side, negative on the labial side. The tipping orthodontic movement is characterized by the inversion of the stress sign.

The stress evolution on the mesial and distal sides is very similar: a positive kind of stress at all resorbtion levels, on all root height. The stress values increase gradually with alveolar bone loss.

Discussion

The results obtained after computer simulations emphasize the displacements distribution of tooth-PDL-alveolar bone ensemble and allow an overview comparative analysis concerning the displacement values which are emphasized through the colored spectrum model.

The stress depending on the orthodontic force direction increases gradually with alveolar bone resorbtion both at apical and cervical level.

The tipping phenomenon is very suggestive illustrated by the displacement values, the stress values and by the graphs.

Although 0.017 mm/year of bone resorbtion can be considered quite normal [8], increased resorbtion can be detected in patients referred for orthodontic fixed treat-

ment. Melsen suggested applying a mild intrusive force in the treatment of adult patients with reduced bone height [9]. On the other hand, there are authors who believe there is an increased risk of root resorbtion in adult patients when large orthodontic forces are applied to produce continuous bodily and intrusive movement [10,11,12,13].

Thus, with the help of FEM it has been proved that the loss of alveolar bone lowers the center of tooth resistance and modifies the stress distribution at the apex level [14,15,16].

Lee, in a study to find the so-called optimum stress for tooth movement, reported an optimum in the range from 0.00165 to 0.00185 N/mm² (1.65 to 1.85 gf/ mm²) [17]. In a recent study, Lee reported an increased stress value of 0.0197 N/mm² (1.97 gf/ mm²) to be optimal for tooth displacement.

Tanne [18], in a 3D FEM study, reported a cervical margin stress of 0.012 N/mm² when a lingually directed tipping force of 1 N was applied to the center of first upper premolar model. McGuiness reported a stress value of 0.132 N/mm² at the cervical margin and a stress value of 0.002 N/mm² at the apex [19]. Also, McGuiness studied the maximum principal cervical stress and reported a value of 0.072 N/mm², while that at the apex was 0.0038 N/mm².

Conclusions

1. Using FEM in the analysis of dental orthodontic displacement and of stress distribution is justified and proves its efficiency due to the geometrical irregularity of the tooth on one side and to the heterogeneous structure of the tooth-PDL-alveolar bone ensemble, from the physical properties point of view, on the other side.

2. FEM allows the quantitative determination and the graphical visualization of displacements and stress, practically in any point of the tooth-PDL-alveolar bone ensemble; the programming medium that is used permits the modeling and simulation of biomechanical reactions in the conducted case studies.

3. The analysis of the results regarding the displacements and tensions in three-dimensional space stated that the relevant values are those which correspond to the direction of force action.

4. The results obtained after computer simulation using the Finite Element Method, emphasize the displacements distribution on the tooth-PDL-alveolar bone ensemble. Alveolar bone loss leads to an increase of the orthodontic displacement values.

5. The stress depending on the force direction, in PDL, increases gradually with alveolar bone resorbtion, both on the apical and cervical level.

6. The loss of alveolar bone support lowers the tooth resistance center and modifies the stress distribution at the apex.

Acknowledgements

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