Stress Variation in the Orthodontic Tipping Phenomenon

Analysis through the finite element method

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The purpose of the study is to assess through a FEM (Finite Element Method analysis), the behavior of a complex structure (enamel-tooth-alveolar bone-periodontal ligament-pulp), subjected to an external load through an orthodontic bracket-with forces of various intensities and to determine its influence on the entire structure.It is necessary to analyze the way all elements of the structure take over the external action given by the action of an orthodontic appliance through the brackets and the influence on the inner component -the pulp-inside of which there are the nerve endings.

Keywords: Finite Element Method, uncontrolled tipping, controlled tipping, orthodontic force, stress, displacements

One of the frequent orthodontic movements is dental tipping. The tipping occurs due to the force acting through the bracket, the moment of force producing the rotation of the tooth around the center of rotation (fig.1.A), [1-9].

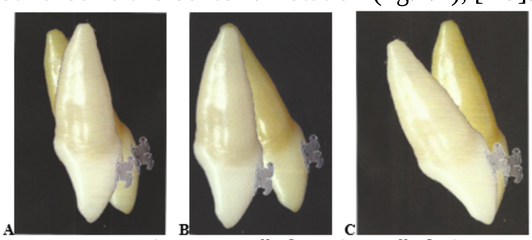

Fig. 1. Tipping: A. uncontrolled; B. Controlled; C. Root displacement [6]

The tipping is uncontrolled when the center of rotation is between the center of resistance - the center of mass- and the tooth apex.

A controlled tipping may be obtained when only the top of the crown rotates under the action of the bracket force; this is only possible if the action of the force would cause tooth rotation at the level of the root apex (fig. 1.B) [6,10].

A rotation of the root only (fig. 1.C), without the displacement of the crown's upper position is difficult to produce, since at the apex the tooth is embedded in the bone, with a relatively small movement possibility, given mainly by the elastic structure of the PDL, but with extremely low thickness.

In figure 2 are presented the uncontroled tipping of incisors [6].

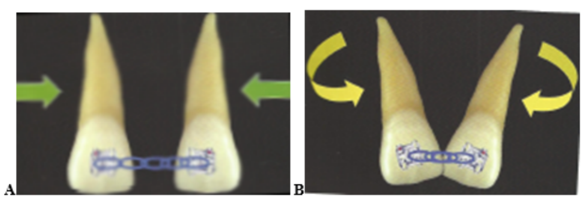

Fig. 2. Uncontrolled tipping of incisors:
The moment applied to the crown produces rotation around the center of rotation [6]

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Finite element analysis is a noninvasive technique for testing a particular design [11].

An uncontrolled, controlled tipping or the rotation of the root only depends on the position of the bracket application on the tooth crown.

Experimental part

Modeling - meshing - loading

The structure studied is an *incisor* with all its constituents and associated elements: enamel - tooth - periodontal ligament - alveolar bone - pulp.

Corresponding to the geometry, dimensions and morphological data in the specialty textbooks of the *incisor*, a two-dimensional plane model was created, representing a median section on the height of the structure, perpendicular to the mesial-distal sides, comprising enamel - tooth - PDL-alveolar bone - pulp (fig. 3).

The used finite elements for the plane model created are bidimensional, 2D-type.

The characteristics of the material are: Young's modulus E and Poisson's ratio (ν), for the materials of the components of the modeled structure, are in accordance with the specialty literature [12-17].

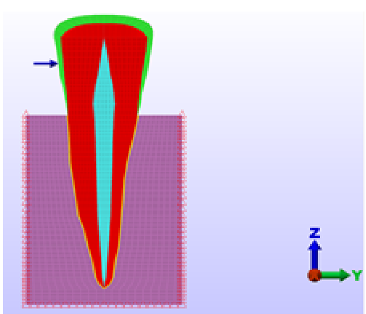


Fig. 3. Incisor: modeling -meshing - loading

Loads -Simulations

For the reproduction of a situation as close as possible to the real one and a less favorable situations analysis, the loading of the model was performed through a nodal force applied at a height of the crown - corresponding to the position of the bracket, in the plane *Oyz*, on the vestibular or lingual side, of various amplitudes, progressively increasing: 100g, 200g, 300g, 400g, respectively: F = 1 N; F = 2 N; F = 3 N; F = 4 N.

It is considered the bracket action given by the nodal force F as resulting from the forces distributed on the bracket-tooth contact surface.

The pursued tipping phenomenon will occur in the plane *Oyz*, perpendicular to the mesial-distal sides.

Loads are considered to act for a bracket position at H = 4.63 mm.

Results and discussions

The results considered to be relevant for the phenomena studied are the values in each of the components of the periodontal structure: tooth - periodontal ligament -pulp-alveolar bone, for:

·*The equivalent stress* (tensions) *based on the Von Mises theory* - $\sigma_{ech\ max}$ that *sums up* all tensions, both normal (perpendicular to the section) - with stretching or compression effect, and tangential (contained in the section plane) – with shearing effect of the section for a certain value thereof;

·*Minimum main stress* $\sigma_{2\ min}$ - the maximum negative values with tissue compression effect;

·*Maximum main stress* $\sigma_{1\ max}$ - the maximum positive values with tissue stretching effect;

·*Maximum stress following the direction of the force applied*, along the axis Oy -σ_{yy}

·*Displacements* δ_{yy} direction of force -axis *Oy*, of the nodes belonging to the vertical axis of the structure.

·Stress values in all elements of the periodontal structure - TOOTH - PDL - BONE -PULP are progressively increasing as the value of the force applied through the bracket increases (fig. 6, fig. 8, fig. 10, fig. 12);

·The values of the minimum main stress $\sigma_{2\ min}$ -with fiber compression effect, for all elements of the structure, are close to the values of stress in the direction of force σ_{yy} - the main phenomenon that occurs is fiber compression in the direction of the force applied (table 1);

·Negative values of the minimum main stress $\sigma_{2\ min}$ - with fiber compression effect, for all elements of the structure, are close to the positive values of the maximum main stress $\sigma_{1\ max}$ - with fiber stretching effect (table 1);

·It results that periodontal fiber compression phenomena in the direction of the force applied are similar to the fiber stretching phenomena in the opposite direction of the force applied;

·In the direction of the force, in the bone - PDL - pulp, the fibers are compressed, and in the opposite direction of the force the fibers are stretched;

·The highest stress values are in the tooth σ_{ech},$\sigma_{1\ max}$,$\sigma_{2\ min}$ - the maximum load occurs in the dentin (table 1);

·The maximum negative values of the stress $\sigma_{2\ min}$ in the tooth are in the apex area;

·The maximum positive values of the stress $\sigma_{1\ max}$ in the tooth are in the crown area;

-The maximum negative stress $\sigma_{2\ min}$ - compressed fibers -is in the apex area in the direction of the force applied;$\sigma_{2\ min}$ = -7.31999 MPa for F = 4 N (fig. 4);

-The maximum positive stress $\sigma_{1\ max}$ - maximum stretched fibers-is still in the apex area in the opposite direction of the force; $\sigma_{1\ max}$ = 8.03301 MPa for F = 4 N;

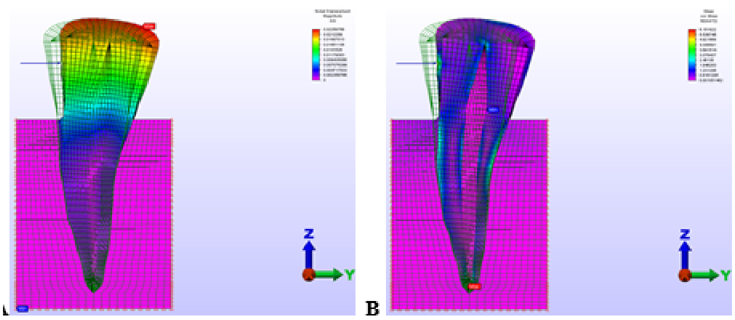
-Close values in the mode for $\sigma_{2\ min}$ and $\sigma_{1\ max}$- the stress in compressed fibers close to that in stretched fibers;

-Maximum stress following the direction of the force, along the axis *Oy*, σ_{yy} - maximum compressed fibers, following the direction of the force is in the apex;σ_{yy} = -1.83257 MPa for F = 4 N;

·Stress values are close in the Bone and PDL structures (table 1) - the explanation would be due to the very small thickness of the periodontal ligament, of approx. 0.25-3mm - practically under the load, the thickness of the PDL

Incisor's components	Force [N]	Stress [N/mm²]			
		$\sigma_{ech\ max}$	$\sigma_{1\ max}$	$\sigma_{2\ min}$	$\sigma_{yy\ min}$
Pulp	1	0.0010236	0.0008333 -apex	-0.000841 - cor.	-0.0008411
	2	0.002047	0.0016666 -apex	-0.001682 - cor.	-0.0015745
	3	0.00105	0.0024998 -apex	-0.002523 - cor.	-0.00787
	4	**0.0040945**	**0.003333** -apex	**-0.003365** – cor.	**-0.003149**
Tooth -in the apex	1	2.05061	2.00825	-1.83	-0.45814
	2	4.10121	4.0165	-3.65999	-0.9311
	3	6.15182	6.02475	-5.48999	-1.37443
	4	**8.20243**	**8.03301**	**-7.31999**	**-1.83257**
PDL -in alveolar crest	1	0.173478	0.197297	-0.175189	-0.149922
	2	0.346957	0.394594	-0.350378	-0.299845
	3	0.520435	0.59189	-0.449767	-0.525567
	4	**0.693914**	**0.78919**	**-0.700756**	**-0.59969**
Bone -in the neck area	1	0.152902	0.163228	-0.138208	-0.12842
	2	0.305805	0.326456	-0.276415	-0.25684
	3	0.458707	0.489684	-0.414623	-0.38526
	4	**0.61161**	**0.652912**	**-0.55283**	**-0.51368**

Table 1
MAXIMUM POSITIVE/ NEGATIVE STRESS VALUES FOR THE BRACKET POSITION H = 4.63mm



B

Fig. 4. Deformed position of the structure for F = 3 N and H = 4.63 mm

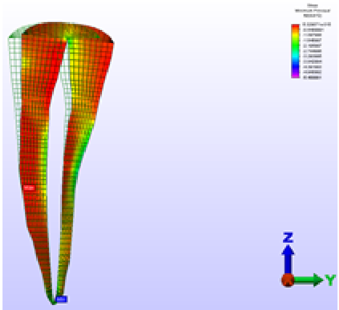


Fig. 5. Distribution of the minimum main stress $\sigma_{2\,min}$ in the tooth for F = 3 N and H = 4.63 mm

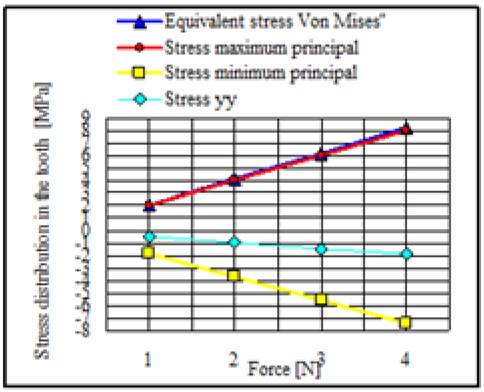


Fig. 6. Variation of stress in the tooth for the bracket position at H = 4.63 mm

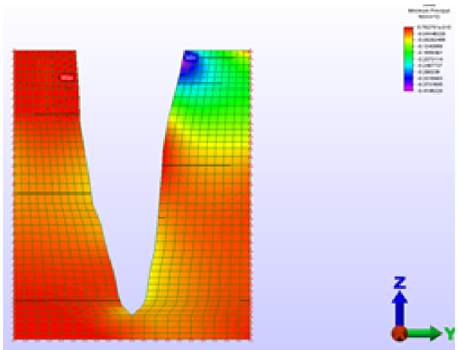


Fig. 7. Distribution of the minimum main stress $\sigma_{2\,min}$ in the bone for F = 3 N and H = 4.63 mm

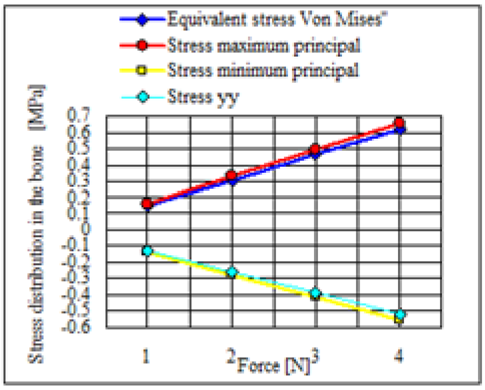


Fig. 8. Variation of stress in the bone for the bracket position at H = 4.63 mm

tends towards a film, and its material characteristics are much weaker than those of the bone;

·The distribution of stress in the Bone and PDL structures is similar with maximum positive/ maximum negative values located in the alveolar crest, on the same side;

Thus, in the PDL:

-The compressed area with maximum negative values $\sigma_{2\,min}$ in the PDL corresponds to the direction of the force applied and is in the alveolar crest (table 1); $\sigma_{2\,min}$=-0.700756 MPa for F = 4 N;

-The stretched area with maximum positive values $\sigma_{1\,max}$ corresponds to the opposite direction of the force applied and is still in the alveolar crest (table 1);$\sigma_{1\,max}$ = 0.78919 MPa for F = 4 N;

-The distribution of stress in the direction of the force, axis *Oy*, suggests the same thing-maximum stress in the alveolar crest area, maximum negative in the direction of the force, maximum positive in the opposite direction of the force (fig. 8); σ_{yy} = -0.59969 MPa for F = 4 N;

-Stress values in the PDL, slightly higher, but close to the stress values in the structure of the alveolar bone, are explainable given the small thickness of the ligament (table 1).

In the *alveolar bone*:

-Minimum main stress $\sigma_{2\,min}$ -maximum compressed fibers – with maximum negative values – are in the alveolar crest area, in the direction of the force applied; $\sigma_{2\,min}$ = -0.55283 MPa for F = 4 N (table 1, fig. 6);

-Maximum main stress $\sigma_{1\,max}$ - maximum stretched fibers - with maximum positive values – are still in the alveolar crest area, in the opposite direction of the force applied; $\sigma_{1\,max}$ = 0.652912 MPa for F = 4 N (table 1);

-Close values in the mode for $\sigma_{2\,min}$ and $\sigma_{1\,max}$ in the alveolar crest area – the stress in compressed fibers close to that in stretched fibers;

-Maximum negative/positive stress following the direction of the force σ_{yy}, are in the alveolar crest area, with fiber compression in the direction of the force and fiber stretching in the opposite direction of the force; σ_{yy} = -0.51368 MPa for F = 4 N (table 1);

·Stress values are minimum in the PULP -explainable, as the pulp is a structure with incomparably weaker material characteristics than the tooth structure and positioned inside the tooth, thereby being protected from it.

Thus, in the pulp:

-Minimum main stress $\sigma_{2\,min}$ in the pulp-fibers compressed all over the pulp height in the direction of the force; maximum negative in the tooth crown area; $\sigma_{2\,min}$ = -0.0033645 MPa for F = 4 N (table 1, fig. 10);

-Maximum main stress in the pulp $\sigma_{1\,max}$ - maximum stretched fibers towards the apex; $\sigma_{1\,max}$ = -0.003333 MPa for F = 4 N (table 1); Close values in the mode for $\sigma_{2\,min}$

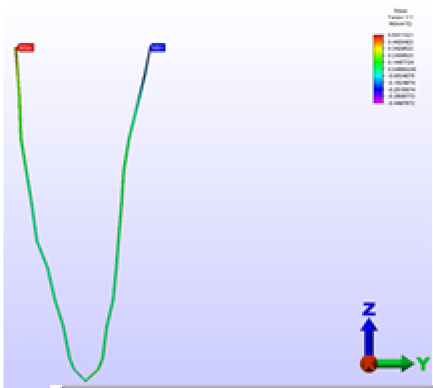


Fig. 9. Distribution of stress in the PDL along the axis *Oy* - σ_{yy} for F = 3 N and H = 4.63 mm

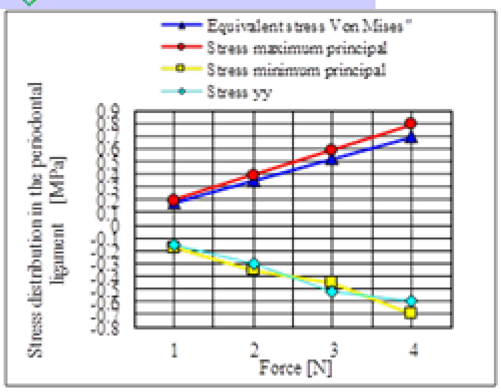


Fig. 10. Variation of stress in PDL for the bracket position at H = 4.63 mm

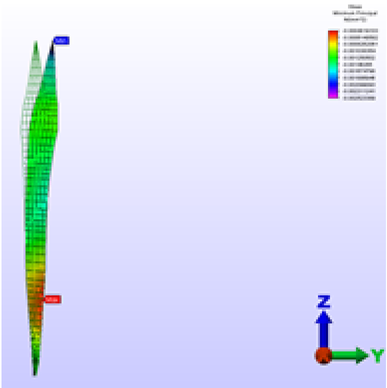


Fig.11. Distribution of the minimum main stress $\sigma_{2\,min}$ in the PULP for F = 3 N and H = 4.63 mm

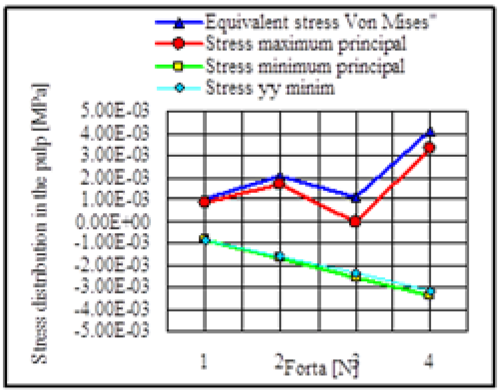


Fig.12. Variation of the stress in the pulp for the bracket position at H = 4.63 mm

and $\sigma_{1\,max}$ all over the pulp height - the stress in compressed fibers close to that in stretched fibers;

After the studies of Jinescu et al [18], the load superposition can have synergetic effect and can be positive or negative according to behavior of loaded matter.

The Finite Element Analysis method has advantages that analyzes are repeatable and there are no ethical considerations [19].

Conclusions

The stress following the direction of the force *Oy* - maximum positive/stretched fibers- towards the *apex*; and maximum negative/compressed fibers *in the tooth crown*.

The stress variation in the orthodontic tipping phenomenon varies in the elements of the structure, the dentin being the most demanded, but due to its material characteristics it can handle the load better and, at the same time, protects the pulp structure.

The highest stress values are in the *tooth*– the maximum load occurs in the dentin structure.

The maximum negative values of the stress $\sigma_{2\,min}$ in the tooth are in the *apex* area and themaximum positive values of the stress $\sigma_{1\,max}$ in the tooth are in the *crown* area.

There are contraindicated, loads with force values higher than F = 200 g = 2 N.

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