Ref: Ro J Stomatol. 2018;64(2)
DOI: 10.37897/RJS.2018.2.6

Finite Element Method Study: Determination of the center of rotation in the phenomenon of orthodontic tipping depending on the position of the bracket

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ABSTRACT

The purpose of the study is to determine through a FEM (Finite Element Method) analysis, the position of the center of rotation of a tooth belonging to a complex structure made of enamel – tooth – pulp – periodontal ligament – alveolar bone, subjected to an external load through a bracket, a component of a fixed orthodontic appliance that produces the tipping phenomenon.

Simulations were performed maintaining the same value of the orthodontic force but modifying the position of the bracket along the crown of the tooth. The aim is displacing the position of the center of rotation of a tooth by changing the position of the bracket and the possibility to achieve a controlled tipping, respectively, a tooth rotation at the apical or coronal level.

Keywords: Finite Element Method, uncontrolled tipping, controlled tipping, center of rotation, orthodontic force, displacements

INTRODUCTION

The center of rotation is an arbitrary point located at a distance from the center of resistance – the center of mass of the tooth – around which the tooth rotates with the application of a force applied to the crown. The position of the center of rotation never coincides with the position of the center of resistance (1,10,14,17-19).

The position of the ***center of resistance*** C_{rez} and of the ***center of rotation*** C_{rot} differs depending on the geometry and the morphology of the tooth, but also changes depending on the location of the application of the force, respectively the positioning of the bracket on the tooth.

Similarly to a lever, the point around which a rotation occurs behaves as a ***joint*** with zero displacements, both along the direction of the axis Oy - $\boldsymbol{\delta_{yy}} = \mathbf{0}$, and the direction of the axis Oz - $\boldsymbol{\delta_{zz}} = \mathbf{0}$. The only possible move around this point will be the rotation around the axis Ox, which will occur in plane Ozy.

The position of the center of rotation could be defined as a certain point on the vertical axis of the tooth with ***zero displacement*** $\boldsymbol{\delta_{yy}}$ following the direction of the force.

The center of rotation C_{rot} will be determined according to the values of the displacements following the direction of the force, the axis Oy, $\boldsymbol{\delta_{yy}}$ in the nodes of the vertical axis of the tooth.

On a side of the node, with zero displacement in the direction of application of the force, the periodontal fibers will be stretched – positive values of displacements, and on the other side the periodontal fibers will be compressed – negative values of displacements.

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Article History:
Received: 2 June 2018
Accepted: 21 June 2018

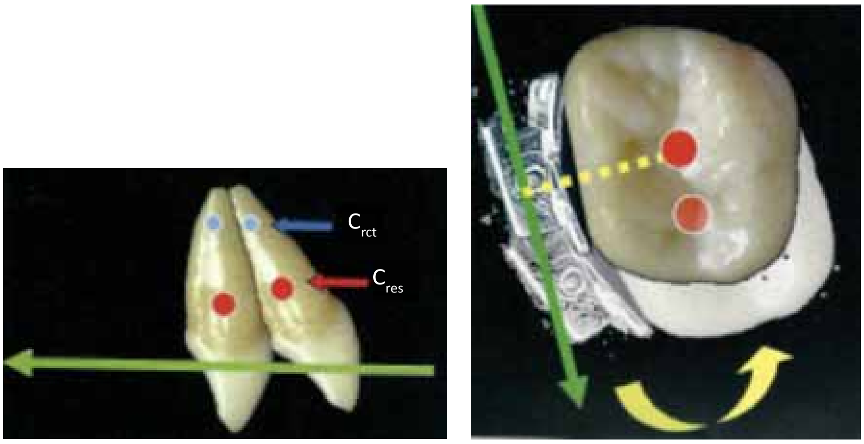


FIGURE 1. *The center of rotation (18)*

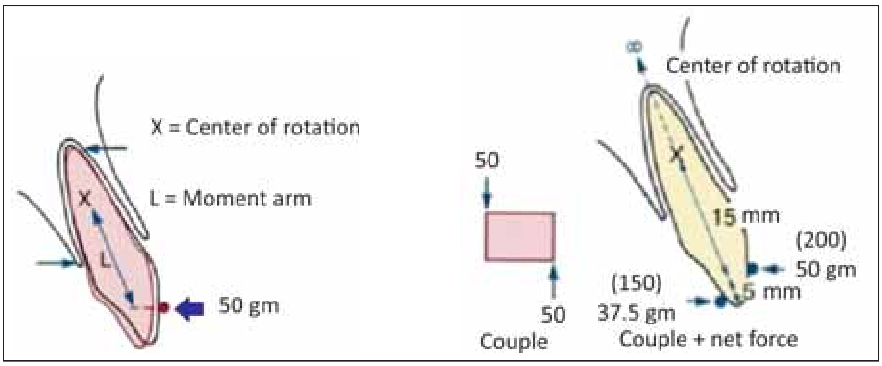


FIGURE 2. *The center of rotation (10,17,19)*

MATERIAL AND METHODS

Modeling

The periodontal structure studied is an ***incisor*** with all its constituent elements: enamel – tooth – periodontal ligament – alveolar bone – pulp, subjected to an orthodontic tipping from the vestibular to the oral.

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 – periodontal ligament – alveolar bone – pulp (Fig. 3).

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

Characteristics of the material: 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: (3) Geramy A. (2000), (4) Gurbuz T. (2008), (8) Ichim I. (2007), (12) Rees J.S., (2004), (16) Tanne K. (1998).

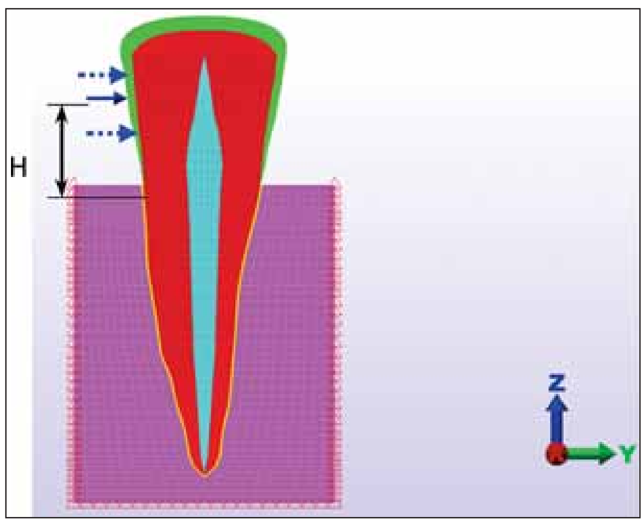


FIGURE 3. *Incisor*
Modeling – meshing – loading

Loads – Simulations

Defining the center of rotation $\boldsymbol{C}_{rot}$ as located in the node of the tooth section with zero displacement following the direction of the force $\boldsymbol{\delta}_{yy} = \mathbf{0}$, on the created tooth model, simulations of the tipping phenomenon with the same force values were performed – for various positions of the application of the force, respectively various positions of the bracket.

The center of rotation $\boldsymbol{C_{rot}}$ was determined according to the values of the displacements following the direction of the force, the axis *Oy*, $\boldsymbol{\delta_{yy}}$ in the nodes of the vertical axis of the tooth.

On a side of the node, with zero displacement in the direction of application of the force, the displacement values are positive – the periodontal fibers will be stretched, and on the other side the displacement values are negative – the periodontal fibers will be compressed.

Simulations were performed for the same value of the force applied, but for three different positions of the bracket: H = 2 mm, H = 4.63 mm and H = 6.58 mm.

The loading of the model was performed by a nodal force, with the amplitude of 300 g, respectively F = 3N, applied at a height of the tooth crown – corresponding to the various positions of the bracket, placed in the plane *Oyz*, on the vestibular or lingual side.

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

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

RESULTS

The results considered to be relevant for the phenomenon studied are the values for: ***displacements*** $\boldsymbol{\delta_{yy}}$ following the direction of the force – axis *Oy* of the nodes on the vertical axis of the structure.

The displacement values are obtained from simulations performed for the same force value F = 3 N, but for three different positions of the bracket: H = 2 mm, H = 4.63 mm and H = 6.58 mm.

The displacement values are measured in the nodes on the vertical axis of the tooth, predominantly assigned to the pulp structure.

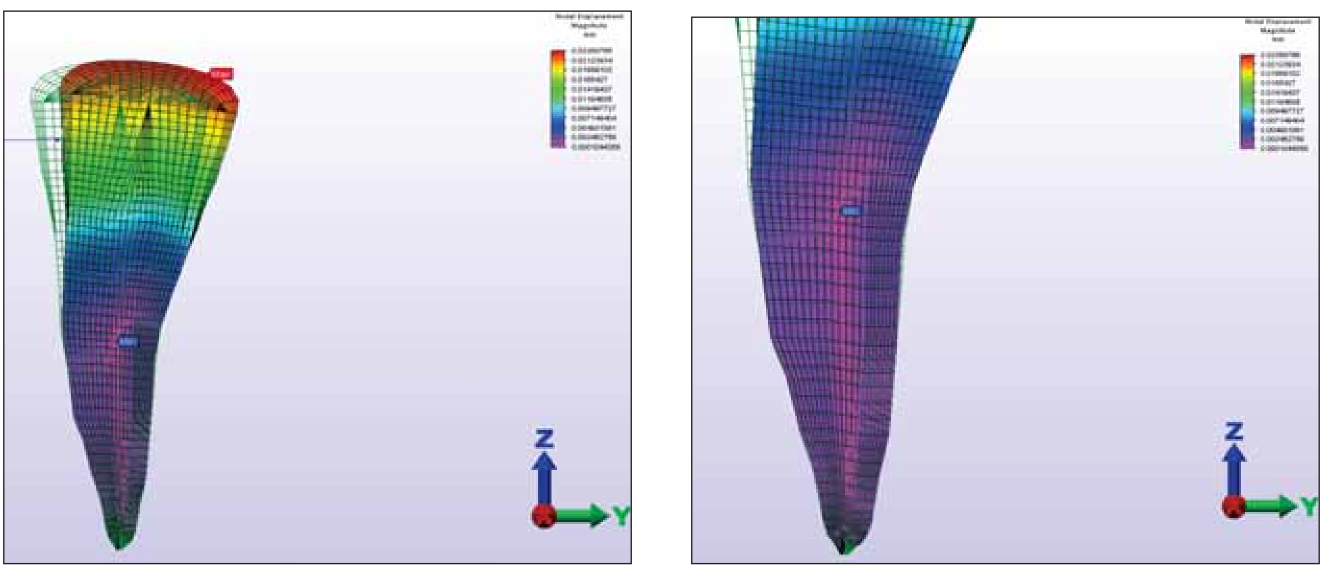
Representations of displacement variations by axis *Oy* – $\boldsymbol{\delta_{yy}}$, depending on the position of the bracket for F = 3 N, can be viewed in the charts in Fig. 7, Fig. 8.

DISCUSSIONS AND CONCLUSIONS

In principle, the ***center of resistance*** $\boldsymbol{C_{rez}}$ – the ***center of mass***, for a free corpus does not change its position. Therefore, the free corpus composed of enamel – dentin – pulp will have, according to its morphology and geometry, a ***center of mass*** (7, 11,18).

Considering, however, that the tooth enters the complex dento-periodontal structure, towards the center of mass of the free corpus – the tooth embedded mechanically in the ALVEOLAR BONE will become a structure whose center of mass will displace in the sense of the mass added – there will be a downward displacement of the center of mass.

From a mechanical point of view, the tooth embedded in the alveolar bone will behave, under the action of the external force – the force in the brack-



a. The distribution of the displacements resulting on the tooth **δ**   *b. Detail*

FIGURE 4. *Deformed tooth position for F = 3 N and H = 4.63 mm*

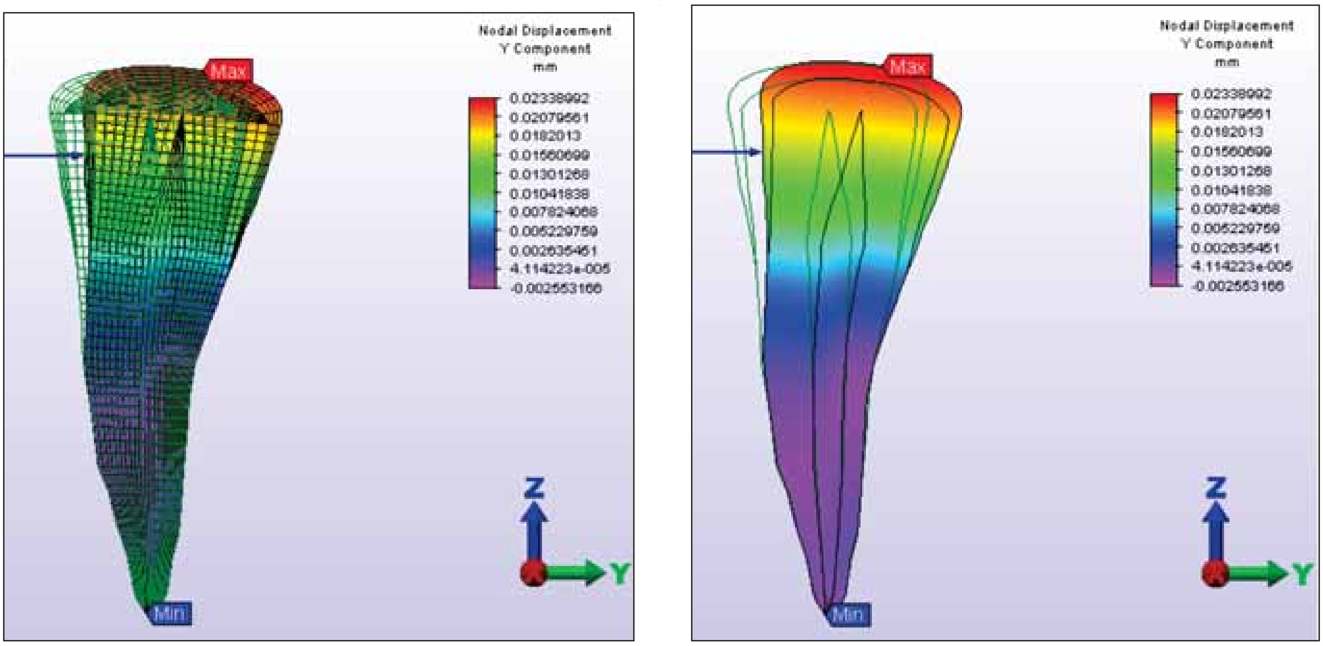


FIGURE 5. *Deformed tooth position – Displacement distribution in the direction of the force* δ_{yy} *for F = 3 N and H = 4.63 mm*

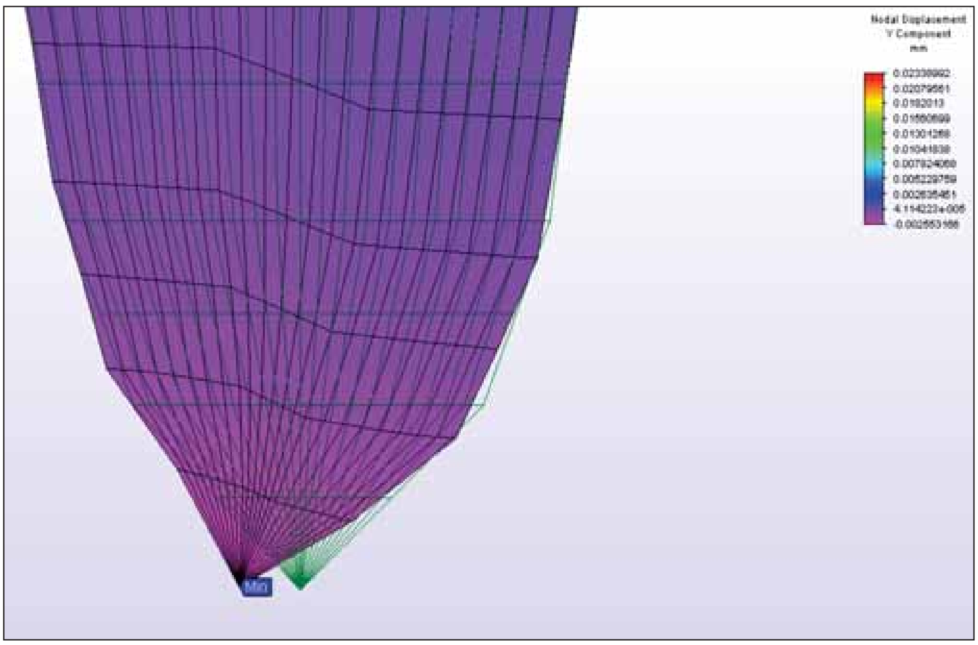


FIGURE 6. *Detail - Displacement distribution in the direction of the force* δ_{yy} *in the tooth apex for F = 3 N and H = 4.63 mm*

et – as a bar embedded along the root length in the alveolar bone – at a bending request in the direction of the force applied.

The movement of the root in the alveolar bone at the apex level will be possible due to the extremely low rigidity of the periodontal ligament within its small thickness.

The displacement of the root is also possible by compressing the alveolar bone – a structure with higher rigidity, only in time, through a progressive application of the external force.

The position of the ***center of rotation*** C_{rot} may slightly vary due to the position changes of the force applied on the crown of the tooth. The force produces towards the center of rotation a moment, with different values equal to the result of multiplication of the force with its arm – the distance from the direction of the force (the position of the bracket) to the center of rotation.

Corresponding to the simulations performed with various positions of application of the force on

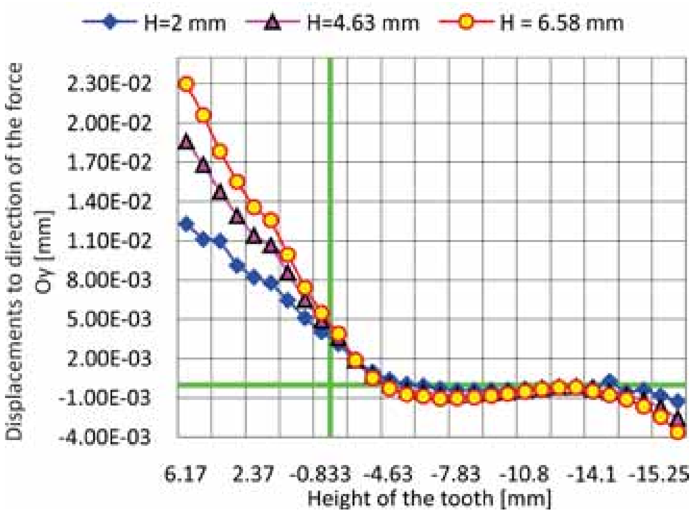


FIGURE 7. *Variation of displacements in the direction of the force, axis Oy -* δ_{yy} *depending on the position of the bracket for F = 3 N*

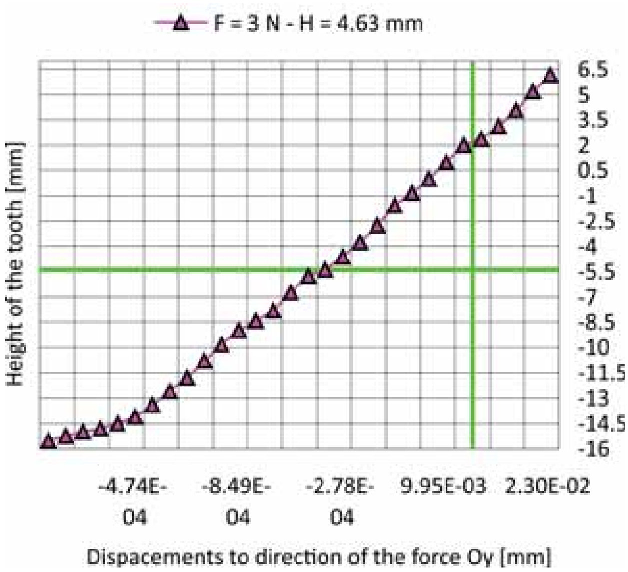


FIGURE 8. *Position of the center of rotation* C_{rot} *for the position of the bracket H = 4.63 mm and loading with F = 3 N*

the crown height, minor changes occur in the position of the ***center of rotation*** C_{rot}.

Thus:

- The position of the ***center of rotation*** C_{rot} – section in which $\delta_{yy} = 0$ – is configured as follows (Fig. 7):
  - for H = 2 mm, between sections: -5.38 mm and -5.75 mm; which represents a position of C_{rot} at 33.6% of the length of the root of the tooth from the alveolar crest;
  - f or H = 4.63 mm, between sections: -4.63 mm and -5.38 mm; which represents a position of
    C_{rot} at 28.9% of the length of the root of the tooth from the alveolar crest (Fig. 7, Fig. 8);
  - for H = 6.58 mm, between sections: -3.77 mm and -4.63 mm; which represents a position of
    C_{rot} at 23.6% of the length of the root of the tooth from the alveolar crest.
- It can be noticed a slight variation in the displacement of the position of C_{rot} for various positions of the bracket on the crown of the tooth **in the direction of the proximity of C_{rot} to the alveolar crest, as the bracket is fixed at a greater distance from the alveolar crest.**
- For **a displacement of C_{rot} towards the apex**, it is necessary to place the bracket on the lower level of the crown.
- The displacement of the extreme node in the **apex** at z = 15.5 mm is configured as follows (Fig.6):
  – for H = 2: δ_{apex} = **-0.001255 mm**
  – for H = 4.63 mm: δ_{apex} = **-0.00255 mm**
  – for H = 6.58 mm: δ_{apex} = **-0.00361 mm**

- As the bracket is placed closer to the alveolar crest, the displacement of the node in the apex is smaller;
- **A rotation of the apex is difficult to achieve**; this would entail the placement of the bracket very close to the alveolar crest – or even on the root of the tooth.
- The displacement of the node in the **apex** is negative – in the opposite direction of the force applied (there is a rotation of the tooth around C_{rot} – and the displacement value increases as the position of the bracket on the crown is at a greater distance from the alveolar crest, H = 6.58 mm;
- The values of the displacements following the direction of the force δ_{yy} are positive – stretching in the direction of the force applied – until C_{rot} , where $\delta_{yy} = 0$, then they become negative – compressed fibers – under C_{rot} (Fig. 7, Fig. 8).

In conclusion, obtaining **a controlled orthodontic tipping of the tooth** depends on the positioning of the bracket on the dental crown.

Conflict of interest: none declared
Financial support: none declared

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