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Chewing Stress Developed in Upper Anterior Teeth with Root end Resection. A Finite Element Analysis Study

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Rezumat

Tensiunile masticatorii dezvoltate în dinţii frontali superiori cu rezecţie apicală. Studiu de analiză a elementelor finite

Scop: Intrucât dinţii devitali prezintă un risc crescut de fractură radiculară verticală, acest studiu a investigat efectul adiţional al rezecţiei apicale asupra rezistenţei lor mecanice.
Material şi metodă: Determinarea prin analiza elementelor finite (AEF) a deformaţiilor şi tensiunilor în dinţii frontali superiori cu rezecţie apicală la încărcarea cu forţe de 100N şi 300N.
Rezultate: Incărcarea cu 100N a dinţilor cu rezecţie apicală crează o stare de tensiuni uşor crescută faţă de statusul pre-operator. Deşi tensiunile von Mises confirmă o comportare elastică, întreaga zonă a structurii dinte-os este tensionată în cursul masticaţiei. Crescând încărcarea la 300N apar deformaţii în sens axial şi mezio-distal care nu pot fi neglijate deaoarece sunt de rangul zecimilor de milimetru. Tensiunile maxime, care apar în sens axial cuprinzând întreaga suprafaţă vestibulară a coroanei rămân în domeniul comportamentului elastic dar se apropie apreciabil de limita modulului Young, atingând un maxim de compresiune SY = $2{,}8 \times 10^9$ N/m^2.
Concluzii: Incărcarea de 100N a frontalilor superiori cu rezecţie apicală slăbeşte modic rezistenţa mecanică. Tensiunile induse la încărcarea cu 300N, la limita de risc a modulului de elasticitate, au tendinţa de concentrare la coletul dintelui generând deformaţii ale structurii dinţilor dar nu şi ale osului alveolar.

Cuvinte cheie: rezecţie apicală, analiza elementelor finite, tensiuni masticatorii, deformaţii

Abstract
Aim: Because pulpless teeth have a higher risk of vertical root fracture, the present study investigated the additional effect of root end resection upon their mechanical resistence.
Methods: Finite element analysis (FEA) was used to evaluate the stress and deformations of upper anterior teeth after root end resection while loading them at 100N and 300N.
Results: Loading teeth with root end resection at 100N generates a mild increase of dentin stress. Even though von Misses stress is within the elastic range the whole tooth-bone structure is stressed while chewing. At higher load of 300N the vertical and mesiodistal deformations cannot be any longer neglected. The highest stress occurs in vertical direction and involves the whole labial surface of the tooth crown. It is expressed as a compression stress (SY = 2.8×10^9 N/m^2) and comes close to the value of dentine Young's modulus.
Conclusion: Loading the upper anterior teeth with root end resection at 100N lowers in a mild manner their mechanical resistance. A load of 300 N induces tooth deformations and a risky stress, mostly focused at tooth cervical area. The stress in the alveolar ridge bone is under the risk threshold of Young's modulus.

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Key words: root end resection, finite element analysis, chewing stress, deformations

Introduction

Root end resection is a procedure of surgical endodontics usually indicated nowadays in chronic apical periodontitis refractory to the conservatory orthograde conventional treatment of root canals (1), or in persistent chronic apical periodontitis associated with irretrievable materials in the canal as previous adequately cast post whose de-cementation can compromise the anatomic integrity of the root or procedural errors, horizontal apical fractures and even rarely for biopsies (2).

Apart from lowering of elasticity, a common issue for any pulpless tooth (3), in case of root end resection there are additional factors that change the biomechanical properties of the root. Among them we have to note the procedures of canal enlargement and filling (4,5,6), the monoblock effect of canal filling materials (7,8,9,10), the post-surgical reduced length of the root (with 3-4 mm), root end 3 mm deep cavity preparation with parallel walls and its filling in order to get an apical seal of the root canal (11,12).

Accordingly, our expectations for a long time success of the root end resection depends on our clinical ability to avoid any risk factors of vertical root fracture (13) and to get an efficient apical seal for preventing bacterial microleakage (14,15).

In the present paper, by using the method of finite elements analysis (FEA), we studied the stress and deformations developed in upper anterior teeth with root end resection while loading them with forces of 100N and 300N. It needs also be reminded that in our mathematical model we have considered as parameters of risk for vertical root fracture only three abovementioned factors and namely root canal enlargement, root canal filling and root end resection.

Method

Two 3D mathematical models of an upper anterior tooth were created. One model reproduced a chronic apical periodontitis (*Fig.1*) and the other an upper anterior tooth with root end resection (*Fig. 2*).

Both models have respected the anatomical dimensional norms (16) and the tooth-bone structure has been considered as uniform, isotrope and having linear elasticity. The typical values of Young's modulus of elasticity and Poisson's ratio of dentine, cancellous and compact alveolar bone that we introduced in this study to evaluate the loading effect (*Table 1*) were identical to those already used in other surveys (17). The same parameters of the periodontal ligament and root cementum have not been introduced in analysis because their values were lower than Young's modulus of dentin.

The simulation of occlusal chewing loading was done with two values of forces, F_1 = 100N and F_2 = 300N. The deformations and stress of the tooth-bone structure induced by simulated loading have been calculated in three directions, lingual (OX axis), vertical (OY axis) and mesiodistal (OZ axis) using ANSYS software.

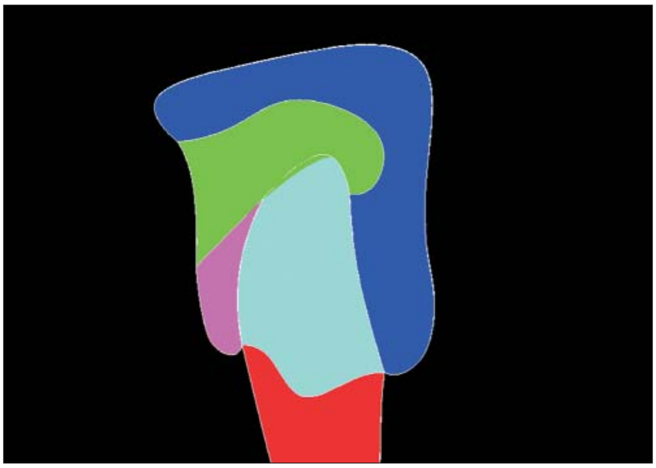

Figure 1. *Geometry of an upper anterior tooth Chronic apical periodontitis*

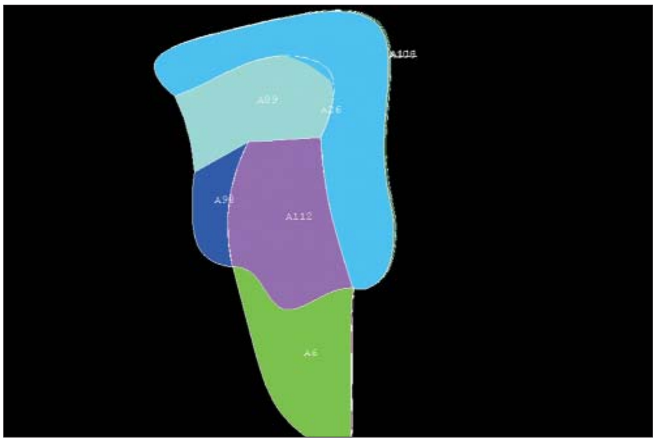

Figure 2. *Geometry of an upper anterior tooth Root end resection*

Results

Loading a tooth with root end resection by a force F_1 of 100N, the peak of deformations appears around the occlusal application point. The values, within the range of hundredths of a millimetre gradually, go down towards the cervical area of

Table 1. *Material properties of hard tissues*

Hard tissue	Young's modulus of elasticity (N/mm^2)	Poisson's ratio
Root dentin	1,54 x 104	0,31
Cancellous alveolar bone	1,37 x 103	0,38
Compact alveolar bone	3,38 x 104	0,23

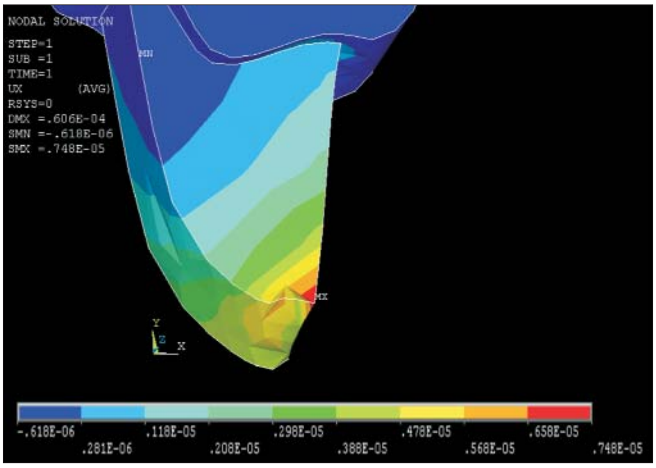

Figure 3. *Root end resection. Deformations in lingual direction (OX axis) F_1 = 100 N (UX = 0.07 mm)*

Table 2. *Comparative deformations of the tooth-bone structure at a loading force F_1 = 100N*

Directions	Chronic apical periodontitis	Root end resection
Lingual (OX axis)	UX = 0,013 mm	UX = 0,0074 mm
Vertical (OY axis)	UY = 0,058 mm	UY = 0,039 mm
Mesiodistal (OZ axis)	UZ = 0,047 mm	UZ = 0,045 mm

Table 3. *Stress generated in the simulated structure at a loading orce F_1 = 100N*

Directions	Chronic apical periodontitis	Root end resection
Lingual (OX axis)	SX = 0,73x10^8 N/m^2	SX = 0,14x10^9 N/m^2
Vertical (OY axis)	SY = 0,5x10^9 N/m^2	SY = 0,46x10^9 N/m^2
Mesiodistal (OZ axis)	SZ = 0,9x10^8 N/m^2	SZ = 0,99x10^8 N/m^2

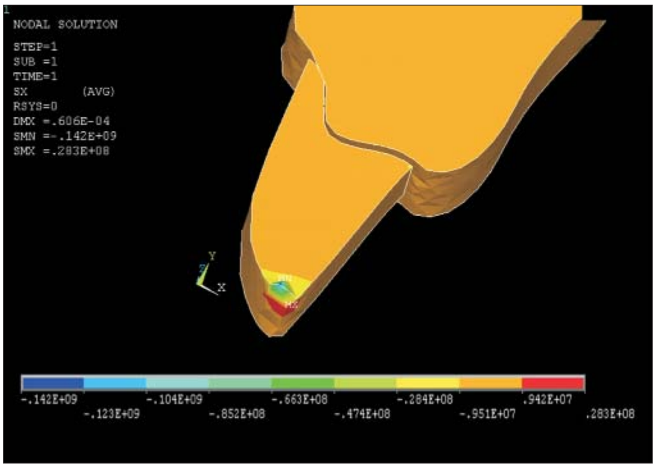

Figure 4. *Root end resection. Stress in lingual direction (OX axis) F_1 = 100 N (SX = 0.14x10^9 N/m^2)*

Figure 5. *Root end resection. Stress in mesiodistal direction (OZ axis) F_1 = 100 N (SZ = 0.99x10^8 N/m^2)*

the tooth and have no importance for the structure resistance both in lingual direction (*Fig. 3*) as well as in the other studied directions, vertical and mesiodistal, because they are even lower than in an unresected tooth root with chronic apical periodontitis (*Table 2*).

The vertical stress (SY = 0.46 x 10^9 N/m^2) after the root end resection, to some extent alike with the pre-surgical value of a tooth with chronic apical periodontitis, are still in the limits of the elastic properties of the structure (*Table 3*).

The stress related to the lingual axis (SX = 0.14x10^9 N/m^2), although it does not exceed the value of the elasticity modulus, still reaches a level that needs to be taken into consideration (*Fig. 4*).

The other lateral stress (mesiodistal) is uniformly distributed. The peak value, expressed as a tensile stress (SZ = 0.99 x 10^8 N/m^2) is focused on the application point of the occlusal loading, but the entire tooth-bone simulated structure has still elastic properties (*Fig. 5*).

In case of von Mises stress the peak value that was recorded (σ_{max} = 0.62 x 10^9 N/m^2) lies still within the elastic

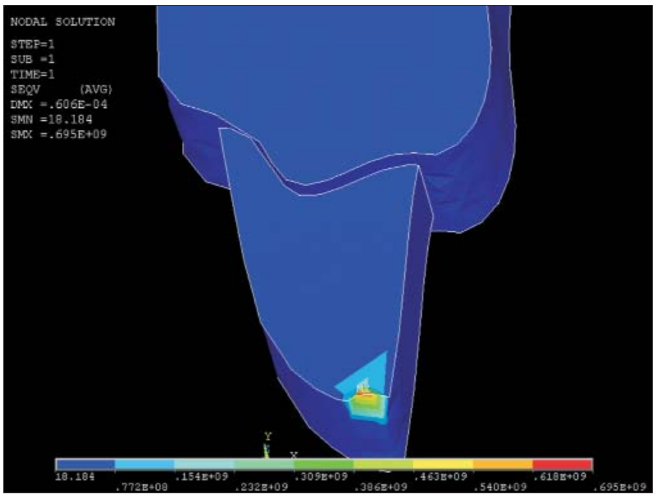

Figure 6. *Root end resection Von Mises stress F_1 = 100 N (σ_{max} = 0.62x10^9 N/m^2)*

Table 4. Deformations of the simulated structure at a loading force F2 = 300N

Directions	Chronic apical periodontitis	Root end resection
Lingual (OX axis)	UX = 0,04 mm	UX = 0,032 mm
Vertical (OY axis)	UY = 0,17 mm	UY = 0,20 mm
Mesiodistal (OZ axis)	UZ = 0,14 mm	UZ = 0,15 mm

properties of the structure (*Fig. 6*), but the value developed in the alveolar bone (σ_{max} = 0.77 x 10^8 N/m^2) should not be neglected as it makes the entire area be stressed while chewing.

In the second load case, when applied chewing force is F_2 = 300N, the FEA has shown in lingual direction deformations that involve the cusps area (UX = 0.032). Even though they increased as compared to the first case of loading with F_1 = 100N (UX = 0.0074 mm) this issue has no significance during the occlusal loading because the values are restricted to the range of hundredths of millimetres (*Table 4*).

At the same chewing load of 300N the deformations generated in the structure that mainly involve the cusps area, since they are expressed in tenths of millimetres, cannot be neglected neither in the vertical (*Fig. 7*) where UY = 0.20 mm nor in the mesiodistal direction (*Fig. 8*) where UZ = 0.15 mm (*Table 4*).

At the loading force of F_2 = 300N the stress developed within the tooth structure increased significantly (*Table 5*). In lingual axis a peak of the compression stress (SX = 0.5 x 10^9 N/m^2) is recorded in the cusp tip. However, the stress value does not exceed the elastic properties of the simulated tooth structure. Excepting the mentioned cusp area the lingual oriented stresses SX are pretty uniformly distributed (*Fig. 9*).

A similar issue arises in mesiodistal axis, because the peak value of stress is located in the area of load application. Excepting this peak area, the mesiodistal stress is uniformly distributed within the tooth structure (*Fig. 10*). Because after the root end resection the stress in mesiodistal axis has increased (SZ = 0.46 x 10^9 N/m^2) the tooth is prone to the weakening of its mechanical resistance.

In vertical direction (crown-apex) are recorded the highest values of stress at a tooth with root end resection. Although the structure properties remains still within the elasticity area, it has to be highlighted that the peak value registered for the compression stress (SY = 2.8 x 10^9 N/m^2) is extremely close to the value of Young's modulus of the structure. While loading the structure with the force F_2 = 300N a particular issue of stress has been described only in vertical direction because the

Table 5. Stress generated in the simulated structure at a loading force F2 = 300N

Directions	Chronic apical periodontitis	Root end resection
Lingual (OX axis)	SX = 0,21x10^9 N/m^2	SX = 0,5x10^9 N/m^2
Vertical (OY axis)	SY = 1,5x10^9 N/m^2	SY = 2,8x10^9 N/m^2
Mesiodistal (OZ axis)	SZ = 0,27x10^9 N/m^2	SZ = 0,46x10^9 N/m^2

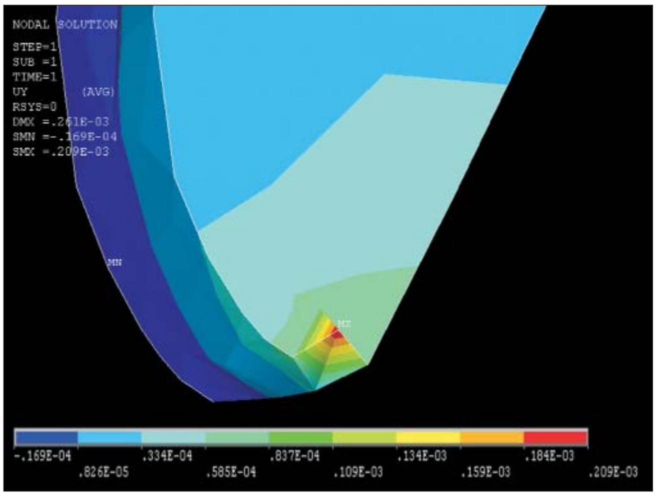

Figure 7. Root end resection. Deformations in vertical direction (OY axis) F2 = 300 N (UY = 0.20 mm)

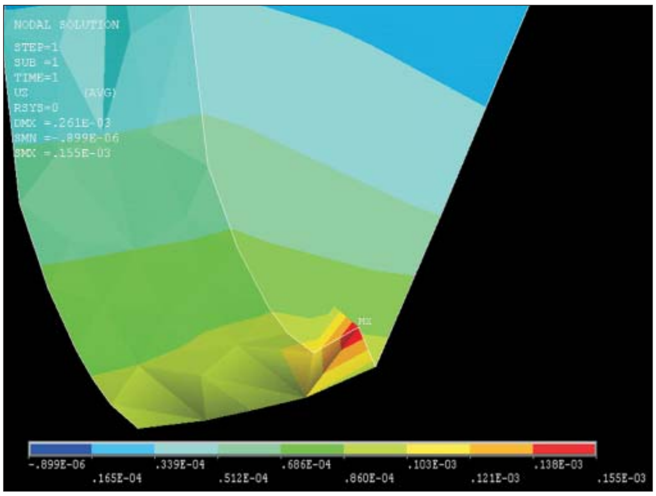

Figure 8. Root end resection. Deformations in mesiodistal direction (OZ axis) F2 = 300 N (UZ = 0.15 mm)

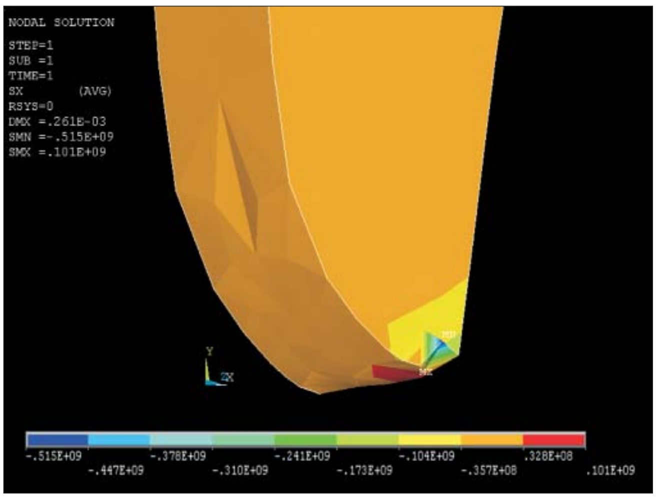

Figure 9. Root end resection. Stress in lingual direction (OX axis) F2 = 300 N (SX = 0.5x10^9 N/m^2)

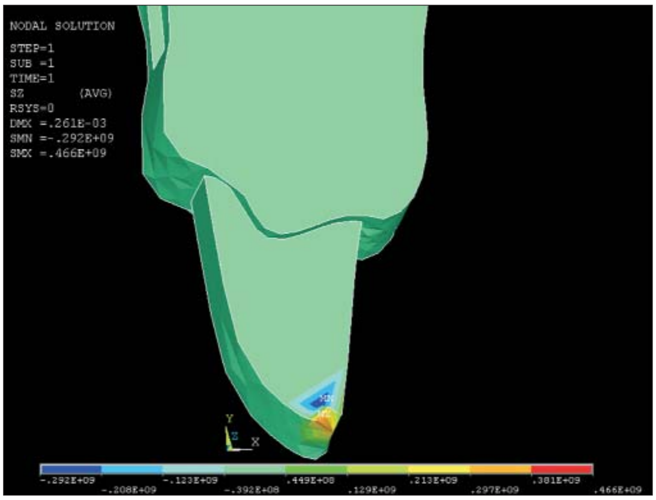

Figure 10. *Root end resection. Stress in mesiodistal direction (OZ axis) F_2 = 300 N (SZ = $0.46 x 10^9$ N/m^2)*

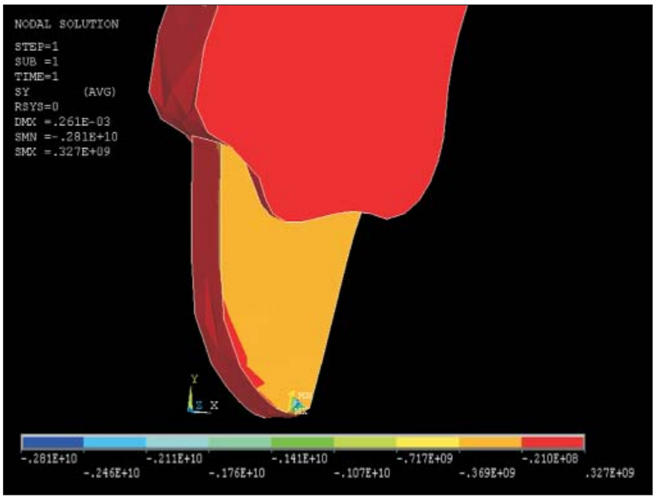

Figure 11. *Root end resection. Stress in vertical direction (OY axis) F_2 = 300 N (SY = $2.8 x 10^9$ N/m^2)*

stress involved the whole buccal surface of the tooth crown (*Fig. 11*).

The von Mises stress reached while loading at 300N (*Fig. 12*) a maximum value (σ_{max} = 3.2 x 10^9 N/m^2) in the cusp tip area of the tooth. However, during the simulated chewing load the rest of tooth structure has been under persistent stress of an important level (σ = 0.35 x 10^9 N/m^2).

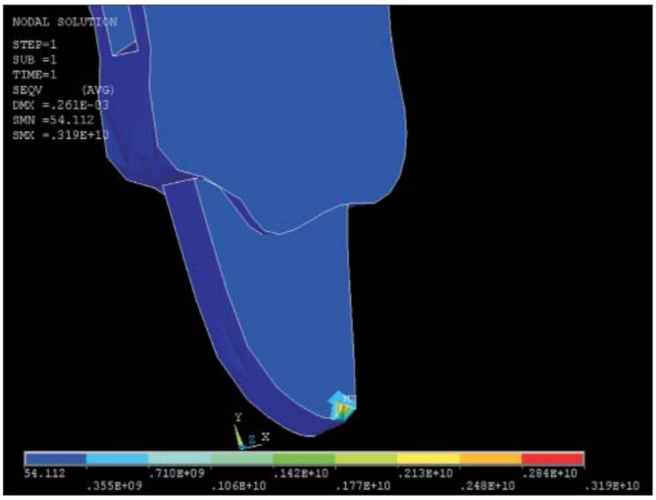

Figure 12. *Root end resection Von Mises stress. F_2 = 300 N (σ_{max} = $3.2 x 10^9$ N/m^2)*

Discussions

FEA has been used in the field of endodontology for the numeric evaluation of the biomechanical properties of teeth whose parameters cannot be directly measured during the occlusal chewing loading (3).

In case of root end resection we are facing with such parameters like the loss of preexistent crown hard tissue, usually as a consequence of the caries' progression or cavity preparation, endodontic access cavity, chemo-mechanical root canal treatment, root canal filling, shortening of the root after root end resection with or without an apical cavity and retrograde root canal filling.

There are also other additional factors involved in any endodontic treatment that compromise to some extent the biomechanical properties of teeth with root end resection, like chemical effect of the usual solutions for root canal irrigation, sodium hypochlorite and the EDTA, and not least the endodontic antiseptic dressing with calcium hydroxide, that modifies the elasticity module of root dentin, its microhardness and resistance to flexion as a consequence of their deleterious effect concerning the dentin collagen framework (3).

In that respect, the present study aimed to assess the developed deformation and stress induced by the occlusal loading of an upper anterior tooth that was conventionally treated (mechanical root canal enlargement using copious irrigations with sodium hypochlorite and orthograde filling) and then shortened by root end resection.

It has been ascertained that the deformations induced in teeth with root end resection are maximal in the crown area where the force of occlusal loading is applied. Starting from this recorded peak the deformation values are gradually reduced as they are approaching the cervical area of the tooth.

If in the load case with the force F_1 = 100N the values of the deformations do not influence the biomechanical resistance of the tooth regardless of the spatial direction in which they are expressed (lingual, vertical or mesiodistal), concerning the other case load case with a higher force F_2 = 300N the deformations of the structure in vertical and mesiodistal direction can no longer be neglected because they are in the range of tenths of millimetres.

It has been ascertained that the orthodontic forces of intrusion generate significantly reduced stress in teeth with a blunt apex (0.0039 MPa) as compared to teeth with normal apical morphology (0.0201 MPa) (18).

Regarding the value of stress at chewing force F_1 = 100N it can be easily seen that it is slightly higher in case of root end resection as compared to the pre-surgical stress value described in the same loading conditions in teeth with chronic apical periodontitis.

According to Geramy's study (2007) at a much lower occlusal loading (18) as compared to the forces of 100 N or 300N used in the present study, by extrapolation it might be speculated that the surgical shortening of the tooth root by changing its apical extremity in a flat surface would have biomechanical advantages. The reason is that at this level the stress value becomes lower than in an anatomically intact root apex.

The values of von Mises stress highlight the maintenance of the elastic properties of the tooth-bone simulated structure but, unlike the pre-surgical status of a tooth with chronic apical periodontitis, in our study it has been evidenced that in the case of root end resection the entire abovementioned structure is stressed during the masticatory loading at 100N.

As it was expected, by loading the teeth with root end resection at 300N a significant increase of stress has been induced, both in the lateral and axial directions of the structure. The stress distribution in lingual and mesiodistal axis is relatively uniform, excepting the cusp tip area where a peak was observed. Overall the maximum value of stress at 300N loading has been recorded in vertical direction. However, in this axis it has to highlight a special issue of the stress distribution that involved the whole buccal surface of the tooth crown.

Our FEA study has shown that the chewing stress developed in teeth with root end resection induces the weakening of their biomechanical resistance as far as their masticatory loading is increasing. Despite the fact that the stress pike is considerably close to the elasticity module the overall stress values remain within the elastic properties of the simulated tooth-bone structure.

Even though Lang et al. (5), Grande et al. (8) and Ou et al. (9) have demonstrated that the access cavity for the orthograde conventional endodontic treatment lowers the tooth resistance by 5 %, it has to be underlined that at this percentage a further reduction generated through the subsequent loss of dentin during the mechanical enlargement of the root canal is added, as the effect of the procedures of root canal filling.

However, Dietschi et al. observed that the elasticity of a tooth with root end resection is most severely affected by some preparation of proximal cavities of the tooth crown, particularly of MOD type, at a rate of up to 44-63% (3).

It has also been mentioned by Johnson et al. that the modern procedure of preparing the retrograde cavity in root end resection by using ultrasonic inserts, although extremely efficient, seems to be equally risky by generating root fractures of different types: internal, external or mixed (12).

On the other hand, the biomechanical resistance of an endodontically treated tooth such as one with root end resection is also highly influenced by the materials and root canal filling techniques. Belli et al. (7) and Tay & Pashley (10) have proven that the stress within the root increased proportionally with the contact surfaces, either between the root canal filling materials as gutta-percha and sealer or between the filling materials and the walls of the root canal.

If the elasticity modules within the tooth-bone system are different, during the chewing loading these abovementioned interfaces represent the weak point of the structure. That is the reason why using only compatible materials for root canal filling, with an elasticity modulus similar to that of dentin, a biomechanical stability of the tooth with root end resection might be assured. In this context one of the treatment suggestions to reduce the risk of root fracture in pulpless teeth should be the primary monoblock as root canal filling (7,10).

Even though root end resection does not lead to substantial changes in the structure deformation at a major occlusal load as it was used in this study (300N), there is still the developing risk of crake lines because the stress peak is very close to the value of dentin Young's modulus. Because the dentin ductility is low, from an already generated crake line to the vertical root fracture is only one step.

The vertical root fracture is an issue of a paramount clinical importance. First of all, the dentist has to use his or her skill to preventing its occurrence during a dental treatment. To the same extend an early diagnosis also is needed because, especially in patients with systemic disorders, the additional local bone inflammation and infection facilitaded by the vertical root fracture may lead either to chronic maxillary sinusitis in case of upper premolars and molars, or regardless the tooth anatomical position, to septic metastases of suppuration at distance (19,20).

Conclusions

The structure deformations of an upper anterior tooth with root end resection at 100N loading are negligible but could became a risk factor in vertical and mesiodistal direction because they can cover tenths of millimetres while loaded with 300N. At 100N chewing load the entire tooth-bone system of an upper anterior tooth with root end resection is stressed without exceeding its elastic properties. Increasing the loading at 300N the structure deformations are evident mainly in the cusps area, becoming risky in the vertical and mesiodistal axis because they have tenths of millimetres. At the same chewing load of 300N the stress of the upper anterior teeth with root end resection is very close to the value of Young's modulus and hence a high risk of developing crack lines in the tooth structure because of its reduced ductility exists.

References

1. Siqueira JF. Treating failures: retreatment and periradicular surgery. In: Siqueira JF, editor. Treatment of endodontic infections. Berlin: Quintessence Publishing; 2011. p.341-60.
2. McDonald NJ, Torabinejad M. Endodontic surgery. In: Walton RE, Torabinejad M, editors. Principles and practice of endodontics. 3rd ed. Philadelphia: W.B. Saunders; 2002. p. 424-44.
3. Dietschi D, Bouillaguet S, Sadan A. Restoration of the endodontically treated toth. In: Hargreaves KM, Cohen S, editors. Cohen's pathways of the pulp. 10th ed. St. Louis: Mosby-Elsevier; 2011. p.777-807.
4. Hong J, Xia W, Zhu Y, Wang X, Wiong H. Finite element

analysis of the stress variations on the root canal wall of pulpless tooth by different root canal preparations. Int Chin J Dent. 2003;3(4):111-4.
5. Lang H, Korkmaz Y, Schneider K, Raab WH. Impact of endodontic treatments on the rigidity of the root. J Dent Res. 2006;85(4):364-8.
6. Rundquist BD, Versluis A. How does canal taper affect root stresses? Int Endod J. 2006;39(3):226-37.
7. Belli S, Eraslan O, Eskitascioglu G, Karbhari V. Monoblocks in root canals: a finite elemental stress analysis study. Int Endod J. 2011;44(9):817-26.
8. Grande NM, Plotino G, Lavorgna L, Ioppolo P, Bedini R, Pameijer CH, et al. Influence of different root canal-filling materials on the mechanical properties of root canal dentin. J Endod. 2007;33(7):859-63.
9. Ou KL, Chang CC, Chang WJ, Lin CT, Chang KJ, Huang HM. Effect of damping properties on fracture resistance of root filled premolar teeth: a dynamic finite element analysis. Int Endod J. 2009;42(8):694-704.
10. Tay FR, Pashley DH. Monoblocks in root canals: a hypothetical or a tangible goal. J Endod. 2007;33(4):391-8.
11. Arens DE, Torabinejad M, Chivian N, Rubinstein R. Practical lessons in endodontic surgery. Chicago, Quintessence Books; 1998. p. 93-8.
12. Johnson BR, Fayad MI, Witherspoon DE. Periradicular surgery. In: Hargreaves KM, Cohen S, eds. Cohen's pathways of the pulp. 10th ed. St. Louis, Mosby-Elsevier; 2011. p.720-776.
13. Berman LH, Hartwell GR. Diagnosis. In: Hargreaves KM, Cohen S, eds. Cohen's pathways of the pulp. 10th ed. St.Louis, Mosby-Elsevier; 2011. p.2-39.
14. Baek SH, Plenk H, Kim S. Periapical tissue responses and cementum regeneration with amalgam, superEBA, and MTA as root-end filling materials. J Endod. 2005;31(6):444-9.
15. Kontakiotis EG, Lagoudakos TA, Georgopoulou MK. The influence of root-end resection and root-end cavity preparation on microleakage of root filled teeth in vitro. Int Endod J. 2004; 37(6):403-7.
16. Lindhe J, Karring T, Araújo M. Anatomy of the periodontium. In: Lindhe J, Karring T, Lang NP, eds. Clinical periodontology and implant dentistry. 4th ed. Oxford, Blackwell-Munksgaard; 2003. p.3-49.
17. Lertchirakarn V, Palamara JEA, Messer HH. Anisotropy of tensile strength of root dentine. J Dent Res. 2001;80(2):453-6.
18. Geramy A. Apical third morphology and intrusive force application: 3D finite element analysis. J Dent Tehran Univ Med Sci. 2007;4(3):130-4.
19. Onişor-Gligor F, Lung T, Pintea B, Mureşan O, Pop PB, Juncar M. Maxillary odontogenic sinusitis, complicated with cerebral abscess – case report. Chirurgia (Bucur). 2012;107(2):256-9.
20. Juncar M, Popa AR, Lung T, Onişor F. Septic metastases of suppuration of odontogenic origin. Chirurgia (Bucur). 2011; 106(3):359-64. Romanian