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Masticatory tensile developed in upper anterior teeth with chronic apical periodontitis. A finite-element analysis study

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Abstract

Commonly is accepted that a non-vital tooth has a higher risk of root fracture but there is a relatively little knowledge about the specific biomechanical behavior of non-vital frontal teeth with chronic apical periodontitis. The aim of our study was to evaluate the deformation and tensile generated in these teeth while vertically loading them because it is crucial to assess the moment when the absorbed occlusal forces exceed the elasticity of root dentine. Using the method of finite-element analysis, we highlighted the distribution patterns of the compressive and tension tensile, as well as their concentration areas. The vertical forces of 100 N generate deformations of no clinical risk in teeth with chronic apical periodontitis. The tensile developed in these teeth are higher than those in the vital teeth are but do not exceed the value of the elastic modulus of the radicular dentin. By increasing the force to 300 N occur elastic deformations, which cannot be neglected anymore. Even so, the 300 N forces do not generate deformations of the alveolar bone. The highest tensile at loading with 300 N was generated in vertical direction but in the cervical area of the tooth also developed tensile in lingual and mesiodistal direction that must be taken into consideration because they are near the risk limit of the elasticity modulus. The crack lines or fractures can appear both in case of excessive or even usual but accumulative occlusal forces that gradually alter the mechanical resistance of the tooth.

***Keywords*:** chronic apical periodontitis, occlusal loading, finite-element analysis, risk of root fracture.

Introduction

It is recognized the decrease of the dental hard tissue elasticity after losing the vitality of the tooth [1]. The weakening of the mechanical resistance of the tooth leads to the risk of a vertical root crack or even fracture, which clinically would mean its loss [2]. That is the reason why the current therapeutic protocol recommends in case of a chronic apical periodontitis an appropriate full crown protection, as final preventive procedure after the conservatory orthograde endodontic treatment [3].

For the posterior teeth, this recommendation is compulsory, whereas for the anterior ones it becomes optional. Depending on the depth of access preparation, the amount of the dentin removal during the root canal shaping, wedging forces that might be developed by preformed or cast posts, the occlusion or the presence of oral habits, such as bruxism, we may choose between crown filling and appropriate cusp protection by an onlay or full crown [2, 4, 5].

Clinically the distribution patterns of deformation and tensile on the tooth root is likely to be variable, depending on its morphology and hard tissues structure but usually the highest tensile concentration was in the bucco-lingual direction [6].

Using a mathematical method for the numerical analysis of complex structures based on their material properties, the finite-element analysis (FEA), the aim of the current paper was to evaluate the tensile developed under occlusal loading in an untreated upper anterior non-vital tooth with chronic apical periodontitis.

Materials and Methods

We have designed two models of an upper anterior tooth for FEA: one healthy vital upper anterior tooth (Figure 1) and the same non-vital tooth with chronic apical periodontitis (Figure 2). The vital tooth was embedded in the cancellous bone all along the root (Figure 1). Concerning the non-vital tooth, the apical area of its root was not embedded in bone in order to simulate the resorption cavity generated by the peri-radicular granulation tissue (Figure 2). The periodontal ligament (PDL) and the root cementum (RC) were considered too thin in order to be appropriately simulated for FEA [6].

The mathematical model was constructed according to the anatomical dimensional norms of an upper anterior tooth [5]. The tooth structure has been considered as homogenous, isotrope and having linear elasticity. In order to evaluate the effect of the occlusal loading on

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tooth mechanical resistance we respected the already used values of Young's modulus of elasticity and Poisson's ratio for root dentin, cancellous and cortical bone (Table 1) [6].

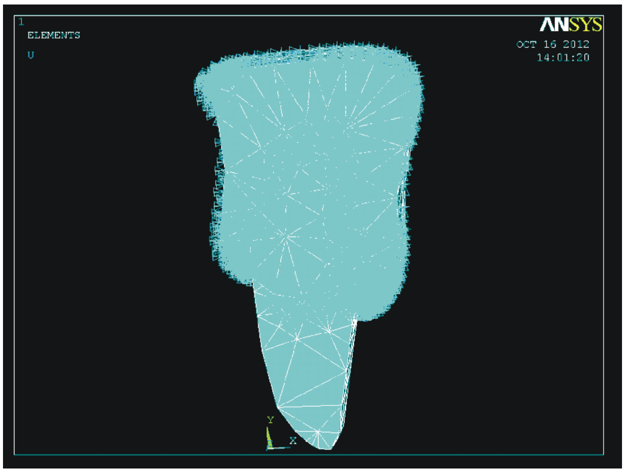

Figure 1 – ***Model of the upper anterior tooth. Healthy status.***

Figure 2 – ***Model of the upper anterior tooth. Chronic apical periodontitis.***

Table 1 – ***Material properties of the tooth hard tissues [6]***

Material	Young's modulus of elasticity [N/mm^2]	Poisson's ratio
Dentin	1.54×10^4	0.31
Cancellous bone	1.37×10^3	0.38
Cortical bone	3.38×10^4	0.23

The material properties of PDL and RC have not be taken for analysis as their values were under Young's modulus of elasticity of dentine.

The simulation of the occlusal masticatory loading has been done in both tooth models with two values of forces, F_1=100 N and F_2=300 N. Using ANSYS software, there were calculated the deformations of the structure (tooth-alveolar bone) in three directions, lingual (*OX* axis), vertical (*OY* axis) and mesiodistal (*OZ* axis), as well as the adjacent developed tensile.

Results

In the first load case, when F_1=100 N (Table 2), the deformations registered on the three axis, vertical, lingual and mesiodistal for the non-vital tooth with chronic apical periodontitis (Figure 3) are approximately of the same size order with the deformations corresponding to the structure of the vital tooth, which is clinically normal (Figure 4).

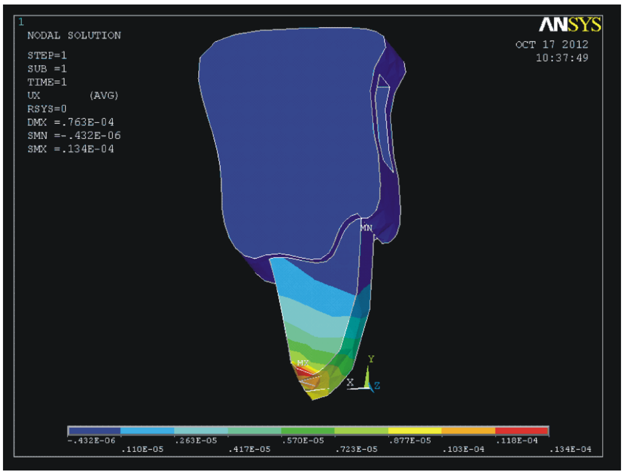

Figure 3 – ***Deformations on OX axis. Chronic apical periodontitis. F_1=100 N (UX = 0.013 mm)***

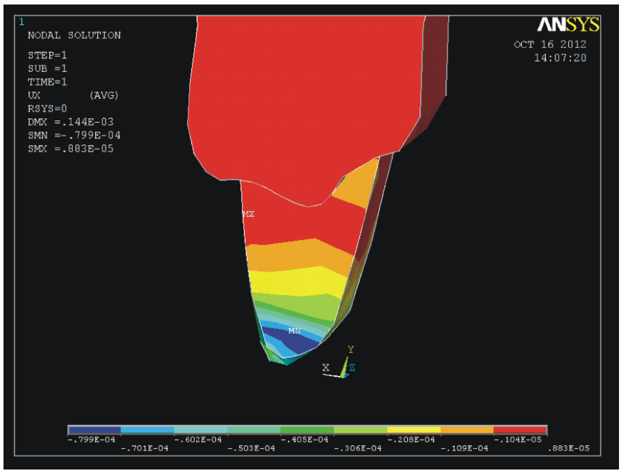

Figure 4 – ***Deformations on OX axis. Healthy tooth. F_1=100 N (UX = 0.07 mm).***

Table 2 – ***Deformations of the structure when loading with force F_1=100 N***

Direction	Healthy vital tooth	Non-vital tooth with chronic apical periodontitis
Lingual (OX axis)	UX = 0.07 mm	UX = 0.013 mm
Vertical (OY axis)	UY = 0.12 mm	UY = 0.058 mm
Mesiodistal (OZ axis)	UZ = 0.056 mm	UZ = 0.047 mm

In chronic apical periodontitis, when loading with the force F_1=100 N, the vertical tensions, representing compression tensions, reach their maximum in the area of applying the loading force and approximate the value of the Young's modulus of the tooth (Figure 5). Even the behavior still remains elastic, as compared to the healthy vital tooth (Figure 6), the tensile developed the tooth-bone structure investigated are higher because of the weakening its rigidity (Table 3).

Table 3 – *Tensions in the structure when loading with force F_1=100 N*

Tension	Healthy vital tooth	Non-vital tooth with chronic apical periodontitis
Lingual	SX = 0.43×10^8 N/m^2	SX = 0.73×10^8 N/m^2
Vertical	SY = 0.27×10^9 N/m^2	SY = 0.5×10^9 N/m^2
Mesiodistal	SZ = 0.3×10^8 N/m^2	SZ = 0.9×10^8 N/m^2

The tensile in lingual direction, which exceed its value in a healthy tooth, but not the level of the elasticity modulus of the material (Table 3), reveal a slight weakening of the resistance of the studied assembly. That is the consequence of the periapical bone resorption produced by the inflammatory tissue, which typically accompanies the chronic apical periodontitis.

The tensile registered in the mesiodistal direction, although having a maximum, which exceeds the value met in the case of a healthy bone structure, might describe the structure behavior in terms of an elastic domain (Table 3).

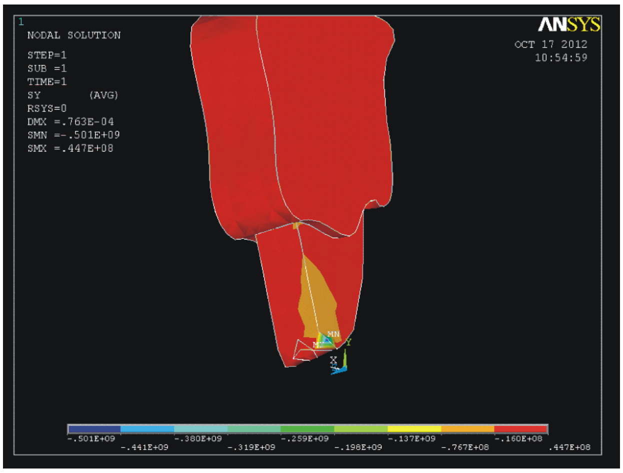

Figure 5 – *Tensions on OY axis. Chronic apical periodontitis. F_1=100 N (SY =0.5×10^9 N/m^2).*

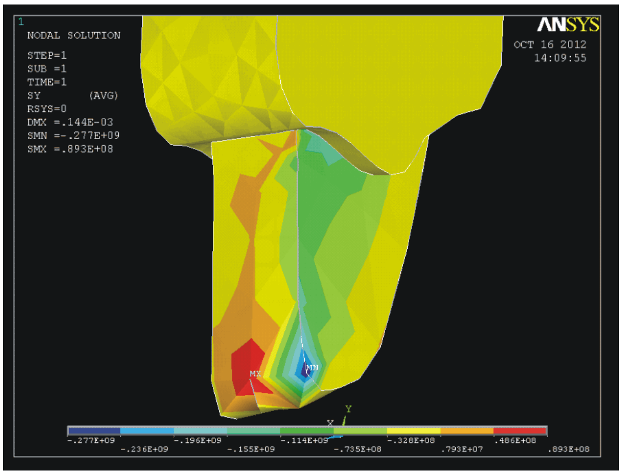

Figure 6 – *Tensions on OY axis. Healthy tooth. F_1=100 N (SY = 0.27×10^9 N/m^2).*

The von Mises tensions, higher than those developed in the clinically normal tooth, reach the σ_{max}= 0.67×10^9 N/m^2 maximum value in the area the occlusal loading force is applied.

In case of a non-vital tooth affected by chronic apical periodontitis, which is under a static loading of F_1=100 N force, FEA shows that the deformations remain almost equal to those of the healthy tooth whereas the structure tensions are increasing.

In the second load case, when F_2=300 N, that is much higher as compared to the previous F_1=100 N loading force, the deformations generated in the structure of a non-vital tooth with chronic apical periodontitis in lingual direction are not important, being in range of hundredths of a millimeter (Table 4).

Table 4 – *Structure deformations when loading a non-vital tooth with chronic apical periodontitis*

Direction	Force: F_1=100 N	Force: F_2=300 N
Lingual (OX axis)	UX = 0.013 mm	UX = 0.04 mm
Vertical (OY axis)	UY = 0.058 mm	UY = 0.17 mm
Mesiodistal (OZ axis)	UZ = 0.047 mm	UZ = 0.14 mm

However, in vertical (Figure 7) and mesiodistal (Figure 8) directions, the values of the deformations of tenths of a millimeter might become important for the behavior of the tooth structure under masticatory forces or dynamically expressed oral habits (Table 4).

Yet at the bone level, there is no risk because the deformations are considerably reduced.

Loading the model with F_2=300 N, the tensile registered in lingual direction do not exceed the value of the tooth elastic modulus (Figure 9) but is important and must be taken into consideration (Table 5).

Table 5 – *Tensions generated in the tooth structure under F_2=300 N loading*

Tension	Healthy vital tooth	Non-vital tooth with chronic apical periodontitis
Lingual	SX = 0.12×10^9 N/m^2	SX = 0.21×10^9 N/m^2
Vertical	SY = 0.83×10^9 N/m^2	SY = 1.5×10^9 N/m^2
Mesiodistal	SZ = 0.93×10^8 N/m^2	SZ = 0.27×10^9 N/m^2

On the other hand, in vertical direction there are compression tensile which approximate the value of the tooth elastic modulus (Figure 10), so that it could be stated that the abovementioned applied force becomes risky for keeping the anatomical integrity of the non-vital tooth with chronic apical periodontitis (Table 5).

Commonly in the mesiodistal direction, both compression and stretching tensions have pretty similar maximum values (Figure 11). However, the highest value of tension was registered as stretching tension. Increased values can also be found at the loading point of the occlusal surface of the tooth but important compression tensions are still evident at its cervical area where the tooth is embedded in bone.

Von Mises tensions reach the maximum value σ_{max}= 2.01×10^9 N/m^2 (Figure 12) but, since the structure behavior is elastic, there is no deformation under static loading.

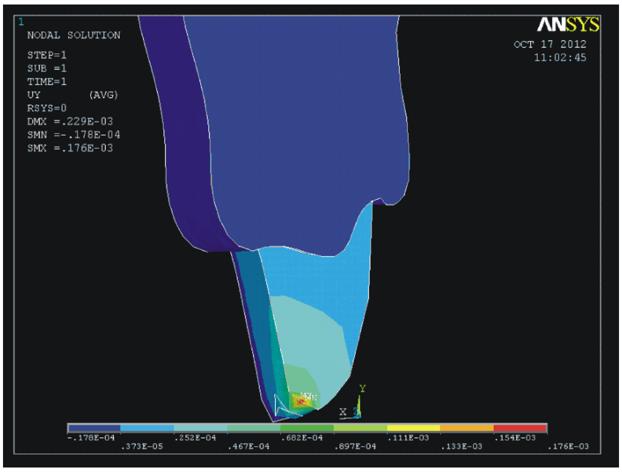

Figure 7 – ***Deformations on OY axis. Chronic apical periodontitis. F_2=300 N (UY = 0.17 mm).***

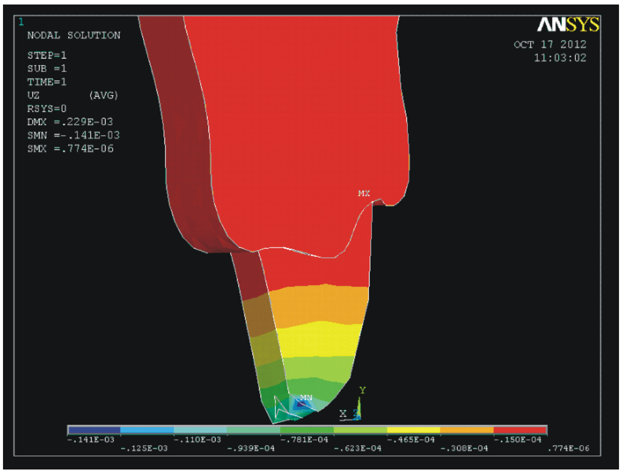

Figure 8 – ***Deformations on OZ axis. Chronic apical periodontitis. F_2=300 N (UZ = 0.14 mm).***

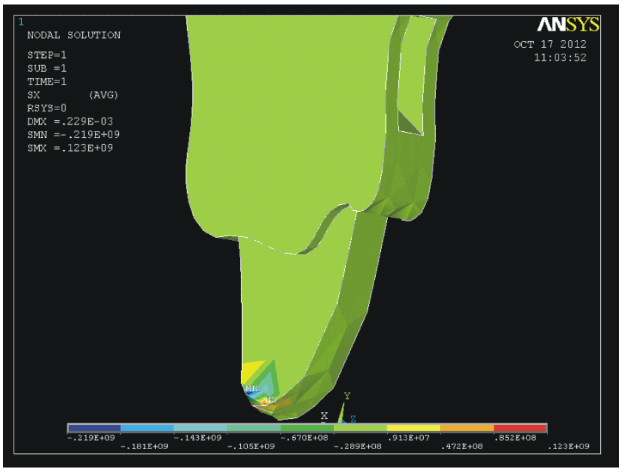

Figure 9 – ***Tensions on OX axis. Chronic apical periodontitis. F_2=300 N (SY = 0.21×10^9 N/m^2).***

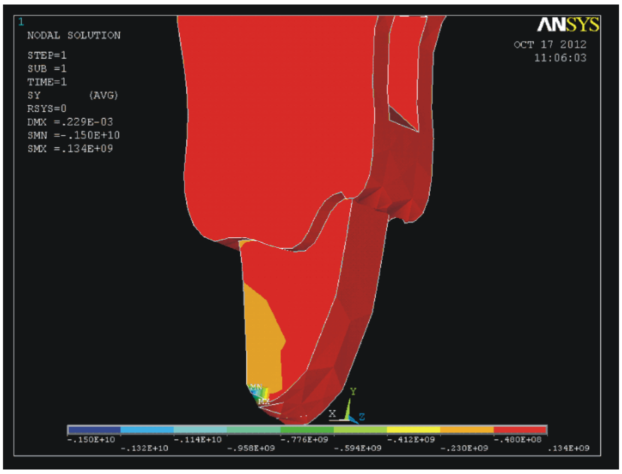

Figure 10 – ***Tensions on OY axis. Chronic apical periodontitis. F_2=300 N (SY = 1.5×10^9 N/m^2).***

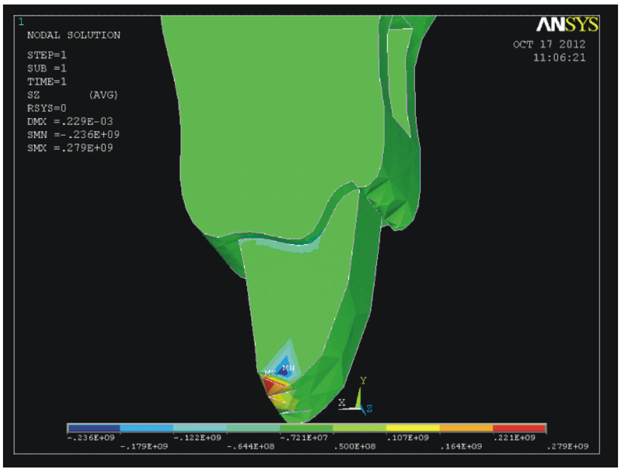

Figure 11 – ***Tensions on the OZ axis. Chronic apical periodontitis. F_2=300 N (SZ = 0.27×10^9 N/m^2).***

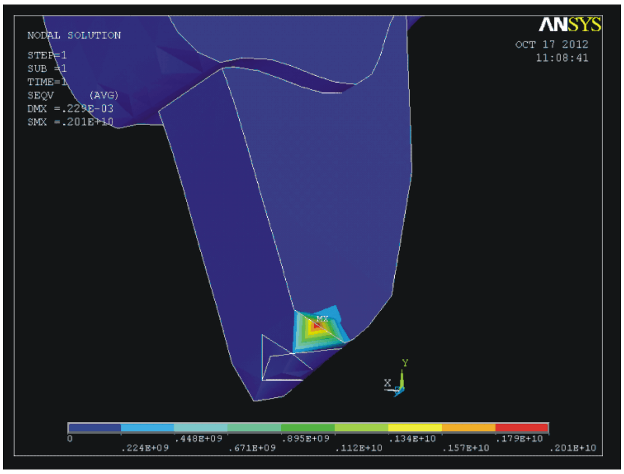

Figure 12 – ***von Mises tensions. Chronic apical periodontitis. F_2=300 N (σ_{max}=2.01×10^9 N/m^2).***

Discussion

The chronic apical periodontitis (the apical granuloma) represents a disease of the apical periodontal tissue generated by the loss of the vitality of the tooth and the further infection of the root canal. Chan CP *et al.* (1998) [7] highlighted the fact that untreated teeth, such as chronic apical periodontitis, due to the weakening of their biomechanic resistance, are prone to more frequent vertical root fractures which compromise their existence, demanding surgical extraction.

The literature does not present differences in the composition of dentinal collagen, comparing the non-vital teeth to the vital ones but the water content of the dentin is reduced by 10% [1]. The consequence is the slight modification of its elastic modulus [8], without weakening their resistance to stretching or compression [9].

Tamse A *et al.* (1998) [10] believe that the main change in tooth biomechanical behavior under the masticatory pressure is induced by the inherent dentin loss produced by the enlargement of the root canal during endodontic treatment.

For this reason, the literature approaches almost exclusively the consequences of root canal enlargement and obturation upon the teeth fracture resistance and less on the primary modifications induced by the loss of vitality, including that of the chronic apical periodontitis [11–14].

In addition, it is necessary to be mentioned that the morphological elements such as the conical shape of the root, the root canal dimension or the root external contour are mainly involved for explaining the vertical root fractures [4, 6, 13, 15, 16].

Starting from the impossibility of direct assessment of the biomechanics of endodontically untreated non-vital teeth as compared to the vital ones, in this study was used a FEA method in order to make the difference concerning their elastic properties.

Using occlusal loading forces, which cover both, the increased (100 N) and the excessive stress (300 N), we have registered the patterns of stretching and compression and mostly the tendencies for the stress concentration which, from a biomechanic point of view suggest possible areas of tooth resistance breaking, which may cause crakes or even fracture lines.

In vertical crown-apex direction, the non-vital tooth with chronic apical periodontitis develops maximum compression stress under 100 N loading, both in the occlusal area where the force is applied and in the cervical area of the tooth crown, in the proximity of the alveolar ridge bone.

In the lateral lingual direction, most of the tensions in the tooth are represented by stretching, except from the cervical area, where there is also compression stress. In the same lateral direction, but mesiodistal, the two types of stress, compression and stretching, reach approximately equal maximum values within the tooth. We must highlight that the area of the alveolar ridge bone adjacent to the cervical area of the tooth crown is similarly under stress, our data confirming the patterns of vertical root fracture suggested by Lertchirakarn V *et al.* (2003) [15].

In similar occlusal loading conditions (100 N), the structure deformations of non-vital teeth with apical granuloma are of the same size order with those of the vital teeth but, on the other hand, the tensions generated within the tooth and the alveolar bone increase.

Comparing to the vital teeth, because of the peri-apical bone resorption produced by the forming of the granulation tissue, which accompanies the chronic apical periodontitis, there is a slight weakening of the studied tooth-bone assembly, by the reduction of the structure rigidity. Even though there is no exceed of the elastic modules values, in certain circumstances of dynamic loading, there is a probability of higher tooth deformation that might generate crakes in its structure.

Increasing the loading of a vital tooth to 300 N generates elastic deformations, which may no longer be negligible because they reach tenths of a millimeter. In the same size range, the non-vital teeth with apical granuloma deformations become important in the structure behavior, only under the action of mastication forces or dynamically expressed parafunctional activities. On the other hand, there are not the same problems at the level of the bone, the deformations being much more reduced.

The tensions generated by a vital tooth loaded with 300 N are more evident vertically, almost reaching the elastic modulus value. Increasing vertically is risky for the morphological integrity of the structure of the non-vital teeth, being expressed as compression stress.

In the lingual direction, the stress generated in a devital tooth loaded with 300 N reach the maximum value at the cervical level. Increasing stress in the non-vital tooth with chronic apical periodontitis, although under the value registered by the one generated in the vertical direction, is important, from lingual as well as from mesiodistal view, reason why they must be taken into account. It must be noticed that in the mesiodistal direction the compression and stretching have approximately the same level, and in the non-vital tooth there is especially compression stress in cervical area.

Under the 300 N static loading, the von Mises tensions in the non-vital tooth with chronic apical periodontitis do not generate deformations. Considering that their maximum value calculated by FEA for von Mises tensions is almost similar to that of the elastic modulus of the tooth-bone structure, it might be possible to occur a structure deformation at dynamic loading of the same range, either masticatory or traumatic.

Dietschi D *et al.* (2011) [1] believe that in many cases the structural deterioration or even vertical fractures of the untreated non-vital tooth root may be caused also by tissue fatigue biomechanically explained by the repetitive long-term occlusal pressures accumulated during mastication or exercising parafunctional activities, although they do not exceed the elastic modulus of the structure.

In this context, the problem of the tensions generated during mastication by static or dynamic loading for endodontically untreated teeth with chronic apical periodontitis should be regarded not only from the perspective of its conventional connection to the teeth elastic modulus but also to the acknowledgement of the risk of long-term accumulations of the under threshold values of those tensions, either of stretching or of compression.

Conclusions

Loading an upper anterior tooth with a static loading of 100 N there are deformations of the non-vital teeth with chronic apical periodontitis which do not have effects on the biomechanical resistance of the radicular dentin or the alveolar bone because are of the same size order with those of the vital teeth. The tensions generated by the 100 N static loading for the non-vital upper anterior teeth with chronic apical periodontitis, higher than those of the similar vital teeth, illustrate only a slight weakening of their biomechanical resistance because do not exceed the values of the elastic moduli of the dentine and bone. Loading a frontal tooth with 300 N generates structure deformations of the non-vital teeth with chronic apical periodontitis but not in the alveolar bone. These deformations cannot be neglected in case of dynamic occlusal pressure because there are of the size order of tenths of a millimeter. The tensions induced in the non-vital upper anterior teeth with chronic apical periodontitis by the 300 N static loading have the tendency to accumulate at the cervical level, becoming risky for their morphological integrity because it register values similar to the dentin modulus of elasticity.

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