Osteoporosis and Endodontic Access: Analysis of Fracture Using Finite Element Method

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Abstract

Introduction: The aim of this study is to assess the biomechanical behaviour of the first upper premolar, healthy and endodontically treated, with conventional and conservative access, under physiological occlusal load, and that of the surrounding alveolar bone both in normal and osteoporotic conditions. Methods: With this aim, virtual models were developed: M1 - healthy tooth/normal bone; M2 - conservative access/normal bone; M3 - conventional access/normal bone; M4 - healthy tooth/osteoporotic bone; M5 - conservative access/osteoporotic bone; M6 - conventional access/osteoporotic bone. Simulations used Finite Element Method. Results: On the enamel, under axial load, strength peaked around the occlusal contact points and on the sulcus between the cusps under oblique load. On dentin, under axial and oblique loads, peaks were observed in the furcation region, and were more prominent under oblique load. On the bone deformity under axial load, peaks were shown on the furcation region in the normal bone models and on the apical vestibular region in the osteoporotic bone model; under oblique load, peaks were shown in the cervical vestibular region. Greater deformities were found in osteoporotic bone models. Conclusions: The osteoporotic bone showed increased probability of fracture and, if a fracture were to exist, it is likely to occur in the apical and cervical vestibular regions. Simulated dental conditions did not interfere with the occurrence of bone deformities. The type of crown opening had little influence on dental fracture resistance and, if a fracture were to exist, it is likely to occur in the furcation region.

Key Words: Osteoporosis, Root canal therapy, Fractures, Stress, Osteoporotic fractures

Introduction

Osteoporosis is characterized by bone mass reduction and deterioration of bone tissue microarchitecture [1] which leads to increased risk of fracture [1-3]. Finite Element determines the tension distribution and deformation whenever a structure is exposed to strength of various magnitudes [4,5]. Finite Element analysis is commonly used in osteoporotic bone analyses [6], both bone [3] and root fractures [4,7]. Dental fracture is still a major complication in endodontically treated teeth [8]. The impact of a more conservative cavity access has been widely discussed in the literature, since it improves tooth resistance to fracture [9-12].

In the light of the above considerations, it seems relevant to assess, using the Finite Element Method, the biomechanical behaviour under physiological occlusal load of the first upper premolar, healthy and endodontically treated, with conventional and conservative crown opening, and that of the surrounding alveolar bone both in normal and osteoporotic conditions. This aims at providing clinical subventions for treating patients who present such systemic conditions.

Material and Methods

Pre-processing: obtention of the geometric models

The geometrical modifications were applied using the software CAD-like SolidWorks 2015 (DassaultSystemes, SolidworksCorps, USA). The models were modified to keep only the teeth 23, 24 and 25, and the surrounding structures.

The masticatory loads were simulated using two structures representing the contact points of the antagonist teeth. For the axial load, a structure with three circular contact points with diameter of 1mm made contact against the palatine cusp, both on the grinding and smooth sides, and against the vestibular cusp on the grinding side. For the oblique load, a structure positioned on the grinding side of the vestibular cusp was modelled.

The patterns of dental abrasion regarded two endodontic access opening. For the conservative access, a cavity with the opening positioned at the centre of the occlusal of the 1st upper premolar was modelled. The opening had 1.7 mm length to vestibular-palatine, 1.5 mm width to mesial-distal, and rounded angles. The abrasion angle was approximately 7º, and extended until the abrasion was delimited within the pulpal chamber [11].

For the conventional access, a cavity with the opening positioned at the centre of the occlusal of the 1st upper premolar was also modelled. The occlusal opening had 4 mm length to vestibular-palatine, 1.7 mm width to mesial-distal, and rounded angles. The abrasion was executed until the wider portion of the pulpal chamber.

The developed models were named in the following way:

Model 1 (M1 - control): 1st upper premolar healthy with normal bone constitution;

Model 2 (M2): 1st upper premolar endodontically treated via conservative access, and normal bone constitution;

Model 3 (M3): 1st upper premolar endodontically treated via conventional access, and normal bone constitution;

Model 4 (M4): 1st upper premolar healthy with osteoporotic bone constitution;

Model 5 (M5): 1st upper premolar endodontically treated via conservative access, and osteoporotic bone constitution;

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Model 6 (M6): 1st upper premolar endodontically treated via conventional access, and osteoporotic bone constitution.

For the endodontically treated teeth, it was modelled a filling with composite resin until 1 mm to the apical boundary between the pulpal chamber and the canal [13].

Processing: simulation

All models were exported from the Solidworks software to the Ansys Workbench v16.2, the software for Finite Element simulation used in the present study (Ansys Inc., Canonsburg, PA, USA).

Normal masticatory strengths were simulated using 100N intensity loads [14]. The axial load was applied by a vector parallel to the long element axis, and the oblique load was applied by a vector in the palatine-vestibular direction at 45° angle with the occlusal plane.

Results

Axial load on the enamel

On the enamel under axial load, strength peaked around the occlusal contact points (*Figure 1*). This is observed because the compression at the load point generates a deformity towards the internal side of the enamel, leading to traction in the adjacent regions. This concentration is due to the high rigidity of the enamel.

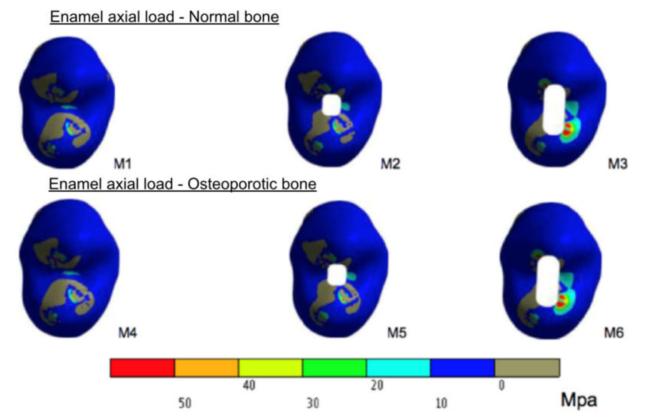

Figure 1*. Occlusal view of the major maximum tensions on the enamel under axial load.*

Quantitatively, the healthy teeth models presented the lowest values, followed by a non-significant increase in the models which conservative access was used, and by a significant increase in the models which conventional access was used. The difference between conventional access models and the other models is due to the fact that the grinding side of the lingual cusp is partially positioned on the resin. This favors local strength peaks of traction.

When comparing normal and osteoporotic models, we obtained very similar results which indicate that the variation of bone rigidity has insignificant influence on the enamel.

The resulting peaks were stronger than the enamel resistance, which could possibly cause enamel fracture or cracking.

Oblique load on the enamel

On the enamel under oblique load, strength peaked on the sulcus between the cusps (*Figure 2*). This is observed because the oblique load caused a tendency of deformation of the vestibular cusp, whereas the lingual cusp offers resistance to this movement which leads to traction in the sulcus region, a local tension accumulation spot.

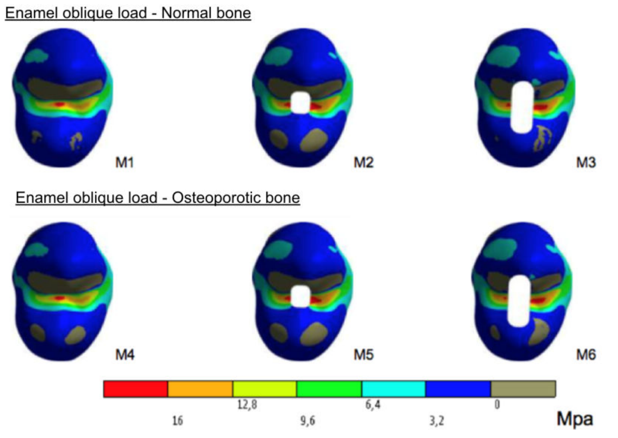

Figure 2*. Occlusal view of the major maximum tensions on the enamel under oblique load.*

Quantitatively, the highest tensions were observed in the conservative access models, flowed by healthy teeth models, and with lower intensity in the conventional access models. However, the difference between the three model types was not significant. The high values observed in the conservative access models to due to the fact that in these models, only a small part of the occlusal contact area that is in contact with the resin, whereas in the conventional access models present a much larger contact area with the resin. This favours the dissipation of tension through the resin body, which decreases the load on the enamel.

Taking into account clinical conditions, the difference of 13-14% between the results observed in the conservative and conventional access models could lead to possible long-term fracture on the enamel due to weariness.

When comparing normal and osteoporotic models, we obtained very similar results which indicate that the variation of bone rigidity has insignificant influence on the enamel.

Axial load in the dentin

On dentin, under axial load, all peaks were observed in the furcation region (*Figure 3*). During the load, there is intrusion of the roots within the alveolus, and the bone in the furcation region offers a greater resistance than the surrounding walls of the alveolus. This creates a tendency of the roots to separate, which generates traction tensions in the furcation region.

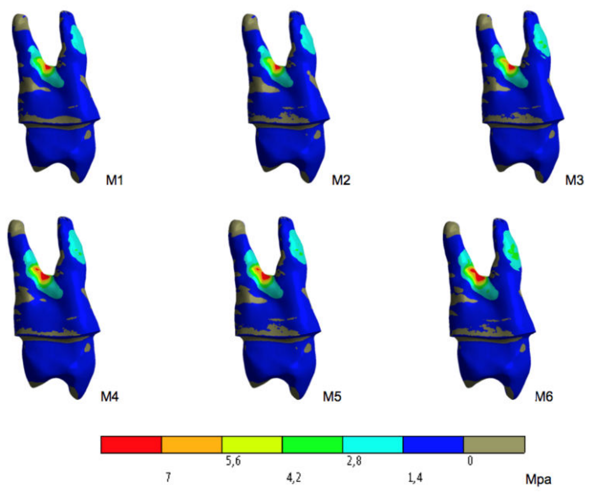

***Figure** 3. External view of the major maximum tensions on the dentin under axial load.*

Quantitatively, the difference between the tension peaks of the healthy, conservative access and conventional access was minimal, which indicates that in premolars with two roots the furcation factor offers a greatest risk of fracture than the presence and types of crown opening analyzed.

When comparing normal and osteoporotic models, we could observe a small increase of the values in the osteoporotic bone models. This occurred due to the lower bone rigidity of the osteoporotic bone models which favors the tendency of intrusion of the roots within the alveolus, and generates higher traction tensions in the furcation region.

Due to the fact that the peaks are located in the furcation region, in case of fracture there will be loss of the dental element in all models.

Oblique load in the dentin

On dentin, under oblique load, the highest tension peaks were observed in the furcation region in all models. During the load, the vestibular region of the tooth has a tendency of moving towards the apical region, while the palatine region offers resistance against this movement. In this case there is a bending of the tooth and a greater intrusion displacement of the vestibular root, with a smaller displacement of the palatine root, leading to the concentration of tension in the furcation region (*Figure 4*).

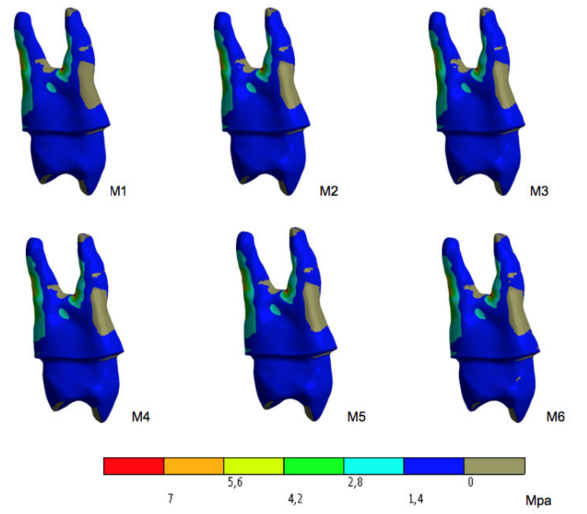

***Figure** 4. External view of the major maximum tensions on the dentin under oblique load.*

Quantitatively, the difference between the healthy tooth, conservative access and conventional access models was minimal, which indicates the greater impact of the presence of two than the type of opening itself in the analysed models. There was a non-significant increase of the values of the osteoporotic bone models when compared to the normal bone models. This is due to the lower bone rigidity of the osteoporotic bone models which favours the movement of intrusion of the vestibular root. However, the difference is rather small and should not affect the useful life expectancy of the teeth in clinical conditions.

Due to the fact that the peaks are located in the furcation region, in case of fracture there will be loss of the dental element in all models.

Axial load on the alveolar bone

On the bone deformity under axial load, peaks were shown on the furcation region in the normal bone models and on the apical vestibular region in the osteoporotic bone model (*Figure 5*). The peaks were observed in the furcation region in the normal bone since there is tendency of intrusion of the two roots which causes traction on the periodontal ligament in this region. In the osteoporotic bone models, the lower bone rigidity leads to lower resistance of the furcation region and greater intrusion of the root, which create the peak on the apical region. There was greater concentration on the apical vestibular region since the apical portion of this root is mainly surrounded by cortical bone whereas the apical palatine is mainly surrounded by medullar bone.

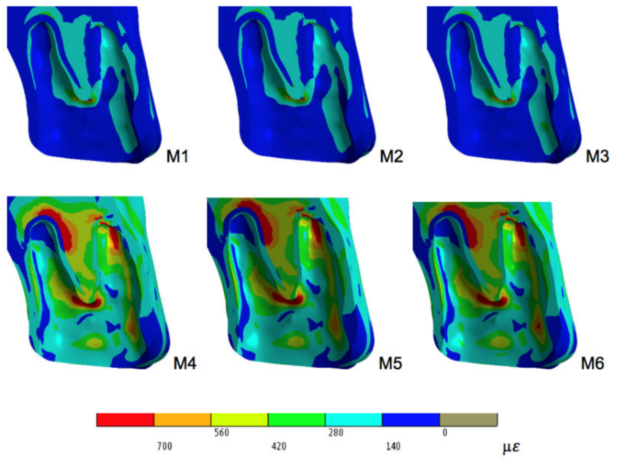

Figure 5. Mesial view of major maximum deformation on the bone under axial load.

Quantitatively, the difference between the healthy tooth, conservative access and conventional access models was almost insignificant, which indicates that, regarding the axial load, the type of opening does not significantly interfere on the values.

Comparing the results of normal bone models and osteoporotic bone models, we observed peaks approximately twice as deformed, and this is due to the difference in bone rigidity.

Oblique load on the alveolar bone

On the bone deformity under oblique load, peaks were shown in the cervical vestibular region for all models (*Figure 6*).

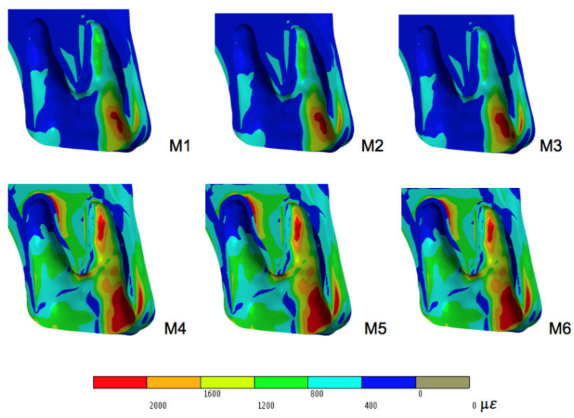

Figure 6. Mesial view of major maximum deformation on the bone under oblique load.

Quantitatively, the lowest values were found in the healthy teeth models, followed by the conservative access models, and the greatest peaks were observed in the conventional access models. However, the differences observed were small. In the case of the teeth with opening, the slightly higher peaks occurred due to the fact that part of the load was transferred in the resin surface which favoured a greater load distribution to the medial portion of the tooth. This caused a greater deformity in the cervical vestibular region.

The results of the normal bone models and osteoporotic bone models show a significant increase of the bone deformities in the osteoporotic models. This is due to the difference in bone rigidity of the cortical bone.

Discussion

Osteoporotic bone presents increases the risk of fracture [1-3]. In the present study, the comparison between normal bone models and osteoporotic bone models revealed an increased risk of deformation in the osteoporotic bone models which increases the risk of fracture. This could be due to the reduced bone mass in the osteoporotic bone model as it is seen in actual conditions, which leads to an decrease of it bone rigidity [15,16].

Besides, the results show that healthy and endodontically-treated teeth models respond with nearly insignificant differences, bone-wise, under axial and oblique load.

Nowadays there is a strong tendency to conservative access opening that improve the tooth resistance to fractures under functional loads [10,12]. In the present study, the type of opening had little influence on the resistance to fracture.

Maximum concentration of tension on the cervical root dentin has been observed in some studies [7]. Therefore, the maximization of the dentin, especially around the furcation region, can protect the roots against the fractures [17]. In the present study, the dentin under axial and oblique loads responded by showing peaks on the furcation region. This causes the tendency of root separation.

Endodontically treated teeth using new models of access are restored with composite resin direct for the ideal function [9,18]. In addition, increase of the cavity wall thickness decreases stress on the enamel [19]. In the present study, oblique load on the enamel led to peaks occurring on the sulcus region between the cusps.

Based on the experimental results, as well as on the theoretical foundations, more research is needed for a reliable assessment of the relation between dental fractures, osteoporotic bone, and endodontically treated teeth.

Conclusion

Based on the simulation results using the Finite Element Method, we conclude the following:

- The osteoporotic bone presents greater probability of fracture when compared to the normal bone under the same occlusal conditions;
- In case of osteoporotic bone fracture, it is likely to occur on the apical and cervical vestibular regions;
- The simulated dental conditions do not interfere in the occurrence of bone deformations;
- The type of crown access opening has little influence on the resistance to dental fracture;
- In case of dental fracture, it is likely to occur on the furcation region.

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