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THE RISK OF FRACTURE OF AN ENDODONTICALLY TREATED TOOTH IN OSTEOPOROTIC BONE

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Abstract. *A new approach using the Finite Element Method (FEM) was applied to analyze the stress distribution in an endodontically treated tooth in the presence of healthy and osteoporotic bone correlating with the use of fiberglass posts. Four three-dimensional models were developed and tested to evaluate the possible reduction of the risk of cortical bone fracture. The results showed that there is no direct relationship between the fiberglass endodontic posts and bone strain. However, the post was effective in reducing stress peaks in structures such as enamel and dentin, reducing the risk of fractures.*
Keywords: *fracture, FEA, osteoporosis, dental posts*

1. INTRODUCTION

Osteoporosis is an osteometabolic disorder characterized by a decrease in bone mineral density, with deterioration of the bone microarchitecture, leading to an increase in skeletal fragility and the risk of fractures (Kanis, 1994; Heaney, 1998). Women exhibit increased risk after menopause due to a decline in bone mass, furthermore, before menopausal estrogen levels are protective. Osteoporosis is known as a "silent disease" being that only loss of bone mass causes no symptoms. However, once the fracture occurs, pain, loss of function and even deformities may result. (Jeffcoat, 1998).

Finite Element Analysis (FEA) is a commonly used method in osteoporotic bone analyses (Rhee *et al.*, 2009; Imai, 2015). This method is an advanced computational technique of structural stress analysis (Imai, 2015). By this method, it is possible to determine the stress and strain distribution when a structure is exposed to a load (Hughes, 2012). In dentistry, this method has been used to model various clinical situations, as fixation of the sagittal split ramus osteotomy in mandibular advancement (Sato *et al.*, 2012), mechanical behavior of restorative materials (Gurbuz *et al.*, 2008), orthodontic tooth movement (Cattaneo *et al.*, 2005), use of endodontic posts (de Castro Albuquerque *et al.*, 2003) e fracture of endodontically treated teeth (Udoye *et al.*, 2014; Franco *et al.*, 2017).

About tooth fracture, this it is still an important complication in endodontically treated teeth. The use of dental posts in this teeth has been extensively discussed in the literature, once its use improves the stress distribution, substantially increasing fracture resistance (Udoye *et al.*, 2014; Prado *et al.*, 2015; Clavijo *et al.*, 2008; Kaizer *et al.*, 2009; Cecchin *et al.*, 2010; Newman *et al.*, 2003). Considering that there is no study evaluating the use of dental posts in patients with osteoporotic condition, it is relevant to evaluate, using Finite Element Method (FEM), the biomechanical behavior under occlusal loading of an endodontically treated teeth. Thus, the objective of this paper is to evaluate the stress-strain state in both dental and bone structures of a patient with osteoporosis, in order to investigate the feasibility of fiberglass dental post in patients with this condition.

2. MATERIAL AND METHODS

2.1 Pre-processing

In some cases, simplified bi-dimensional models can be used to analyze plane strain and stress problems. In this cases, the plane strain-stress formulation can accurately represent the mechanical behavior of some structures. However, not all problems can be treated as plane stress or strain, being necessary the use of three-dimensional models to obtain more precise and reliable results, as the dental structures.

In this study, was used a model of the maxillary right first premolar (element 24), having the following structures:

dental enamel, dentin, pulp, periodontal ligament (PDL), cortical bone and medullary. The model used was modified from a maxilla constructed from a tomography computed tomography (CT). Vasco *et al.* (2015) gives more details on the parameters used to construct these structures. This model was modified, using a CAD software, to simulate an access opening. It was made a conventional access, where a cavity with the opening positioned at the center of the occlusal of the 1st upper premolar was modeled. The abrasion was executed until the wider portion of the pulp chamber. Based on this, four different models was created:

Model 1 (**M1**): First endodontically treated upper premolar with healthy bone constitution.

Model 2 (**M2**): First endodontically treated upper premolar and osteoporotic bone constitution.

Model 3 (**M3**): First endodontically treated upper premolar with dental post and healthy bone constitution.

Model 4 (**M4**): First endodontically treated upper premolar with dental post and osteoporotic bone constitution.

To simulate root canal instrumentation and obturation, CAD tools were used. This obturation was held until the apical boundary. On the models with dental posts, the palatine canal was opened 5 mm above the apical boundary, where the post was introduced (Fig. 1). The pin has an apical diameter of 5 mm, a cervical diameter of 1.3 mm and a length of 14 mm. To model the masticatory load, the load was divided into an axial and oblique load. For the axial loading, a rigid structure was used at three points on the palatal and buccal cusps, with diameter of 1 mm. For the oblique load, a rigid structure at 45 degrees of occlusal, in the buccal cusp, was used (Fig. 2).

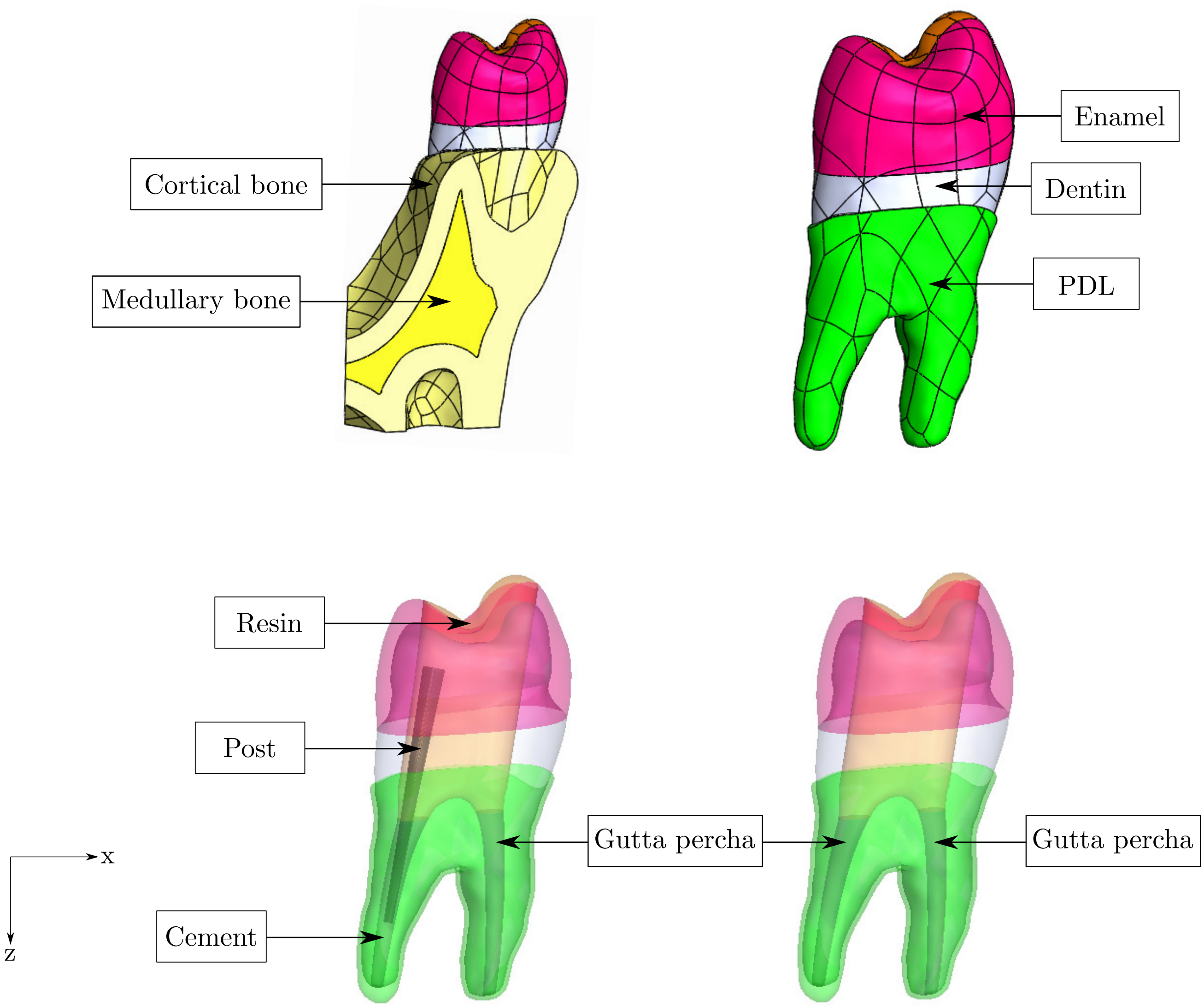


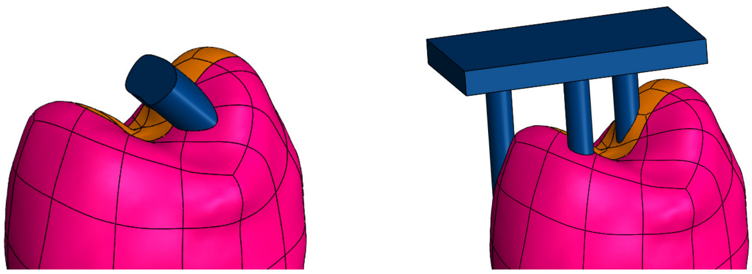
Figure 1. Modeled Structures

Table 1. Isotropic materials mechanical properties

Material	Young's modulus [GPa]	Poisson's ratio
Enamel (Mezzomo *et al.*, 2011)	84,1	0,33
Dentin (Mattos *et al.*, 2012)	18,45	0,29
PDL	0,006 (Pini *et al.*, 2002)	0,45 (Mattos *et al.*, 2012)
Cortical bone (Mattos *et al.*, 2012)	11,17	0,45
Medullary bone (Mattos *et al.*, 2012)	0,0962	0,3
Gutta percha (Mattos *et al.*, 2012)	0,14	0,4
Cement (de Oliveira Franco *et al.*, 2017)	6	0,31

Table 2. Fiberglass mechanical properties (Silva *et al.*, 2015)

E_z [GPa]	E_x [GPa]	E_y [GPa]	ν_{xz}	ν_{xy}	ν_{yz}
40	9	9	0,34	0,27	0,27



(a) (b)

Figure 2. Rigid structures for oblique **(a)** and axial load **(b)**

2.2 Processing

All models were exported from CAD software to finite element simulation software. Gutta percha was the material used to filling, however, in the models that has dental posts, in the palatine root was consider only filling only with resin cement. In all models, was used a composite resin to the tooth restoration. The mechanical properties of this materials are shown on Tab. 1. In models with osteoporotic bone constitution, was used a 15% reduction on bone density (Haugeberg *et al.*, 2000). To quantify the elastic modulus reduction of cortical and medullary bone, used the Eqs. (1) e (2), respectively, according to Helgason *et al.* (2008).

$$E = 1.904\rho^{1.64} \quad (1)$$

$$E = 2.065\rho^{3.09} \quad (2)$$

where E is the Young's modulus and ρ the bone density,. Both axial and oblique load, was applied a 100 N force (Powers *et al.*, 2012). The contact between the structures was modeled like bonded. The mesh was refined until present a 5% chance in stress peaks. The models has, in turn, 424111/240410 nodes/elements. All materials was consider as much as linearly elastic materials. The mechanical properties of isotropic materials are shown on Tab. 1. The fiberglass post was modeled such as an orthotropic material ans its mechanical properties are shown on Tab. 2.

3. RESULTS AND DISCUSSION

3.1 Axial load

The enamel under axial load is shown on Fig. 3. By this figure is possible to observe that there was no significant difference in stress distribution between the 4 models. However, regarding the stress peaks computed (maximum stress value), was possible to conclude that there was a 28.1% reduction in peak stress when using the dental posts. Knowing that the enamel is a brittle material and more likely to fail due tensile stress, only tensile stresses were analyzed (Pashley *et al.*, 2011). According to Giannini *et al.* (2004), its tensile strength is 42,7 MPa. Junction points between the different dental structures, in this case, enamel-dentin junction, have peaks stress greater than the tensile strength, characterizing a possible failure.

Failures in this region occur frequently due to the difference in the Young's modulus between the structures, inducing stress concentrations. (White *et al.*, 2005). Another important observation is that in the enamel-resin junction there was a stress increase, as well as in the enamel-dentin region, but with less expression. Another point to be mentioned was the reduction of 49.5% in the stress peak in the enamel-dentin region, in the M4 model in relation to the M3 model.

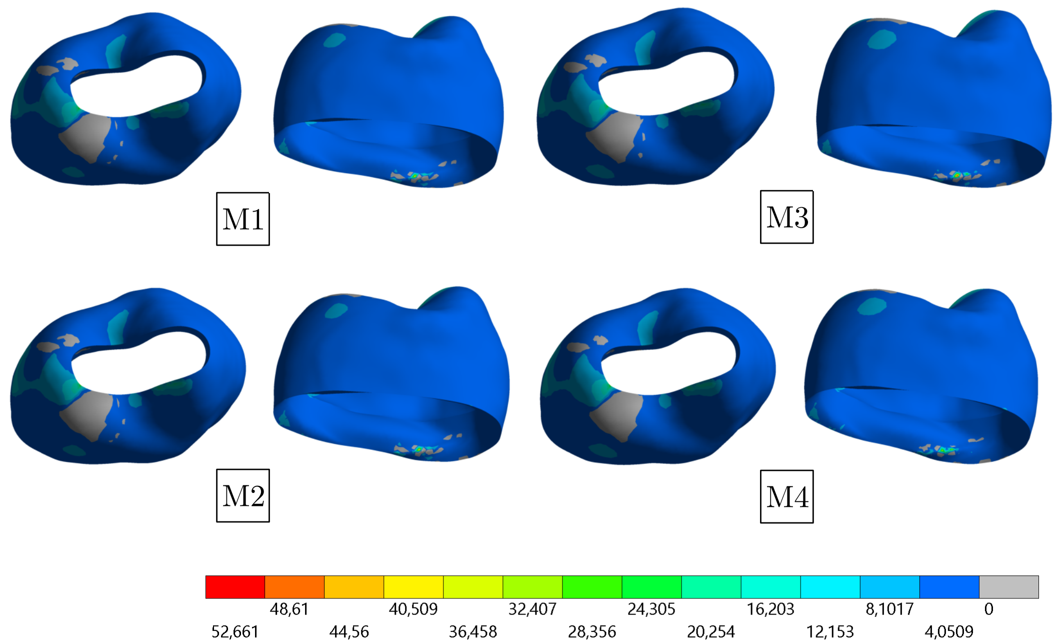


Figure 3. Maximum Principal Stress on enamel under axial load in Mpa

Dentin under axial load (Fig. 4), as well as enamel, do not show large variations in stress state. Stress peaks concentrated in the bifurcation region. Like enamel, dentin also shows brittle behavior, this way, only tensile stresses were evaluated (Sim *et al.*, 2001). Its tensile strength is 105 MPa (Sano *et al.*, 1994). In view of this value, no region of dentine under axial loading showed stress peaks close to this value. Therefore, there is no probability of failure in the models. Regarding the presence of dental posts, in healthy bone models, M1 and M3, there was a reduction of 30.4 % in the stress peak. However, in models with osteoporotic bone, there was no significant stress reduction.

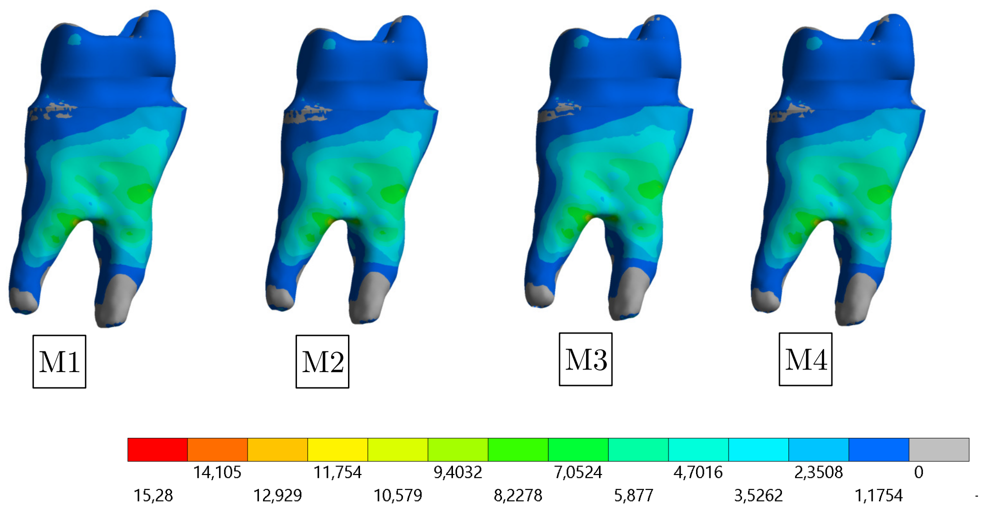


Figure 4. Maximum Principal Stress on dentin under axial load in Mpa

To evaluate the cortical bone, it used as a reference the strength to tensile strain according to the study of Bayraktar *et al.* (2004). The data from this study are related to the femoral bone. This reference was used because there are no studies for the maxillary bone. The result for cortical bone is shown on Fig. 5. According to Bayraktar *et al.* (2004), its tensile strain strength is 7300 $\mu\epsilon$. For axial loading, there was no model that presented deformation above bone strength. Regarding the dental posts, there is no improvement in the results. As expected, in models with osteoporotic bone (M2 and M4), there were higher values of deformation. The results of the medullary bone were not considered because this structure did not present any variation in any of the models under axial loading.

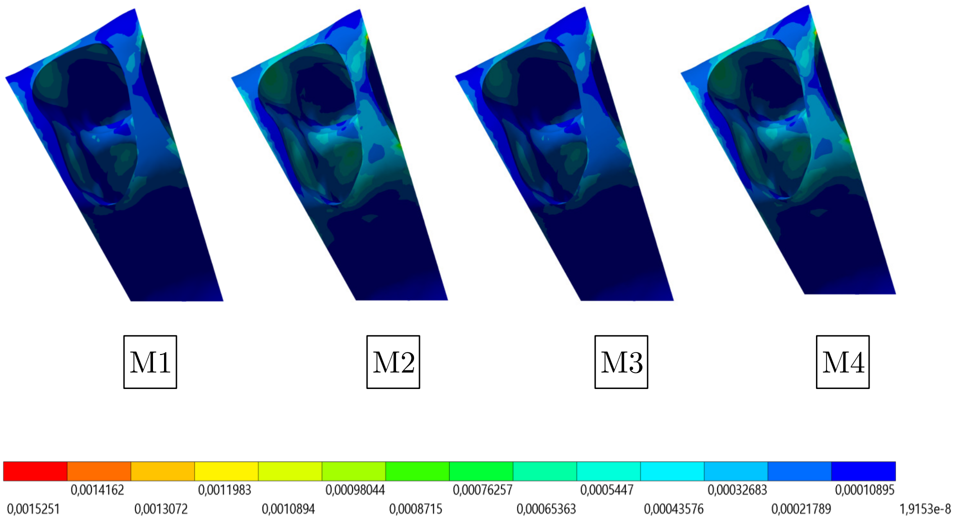


Figure 5. Maximum Principal Elastic Strain on cortical bone under axial load

3.2 Oblique load

The oblique loading on the enamel showed higher stress peaks compared to the axial loading. An increase of 21.43% was observed among the models with higher peaks. It can be observed that there was a decrease in peak stress when compared to models with healthy bone with and without the use of posts (M1 and M3), with a reduction of 22.5%. In models with osteoporotic bone (M2 and M4) this reduction was 2.45%. By the Fig. 6, can be noted that the highest stress concentrations are present in the junction regions between enamel and resin, with a higher propensity to fracture.

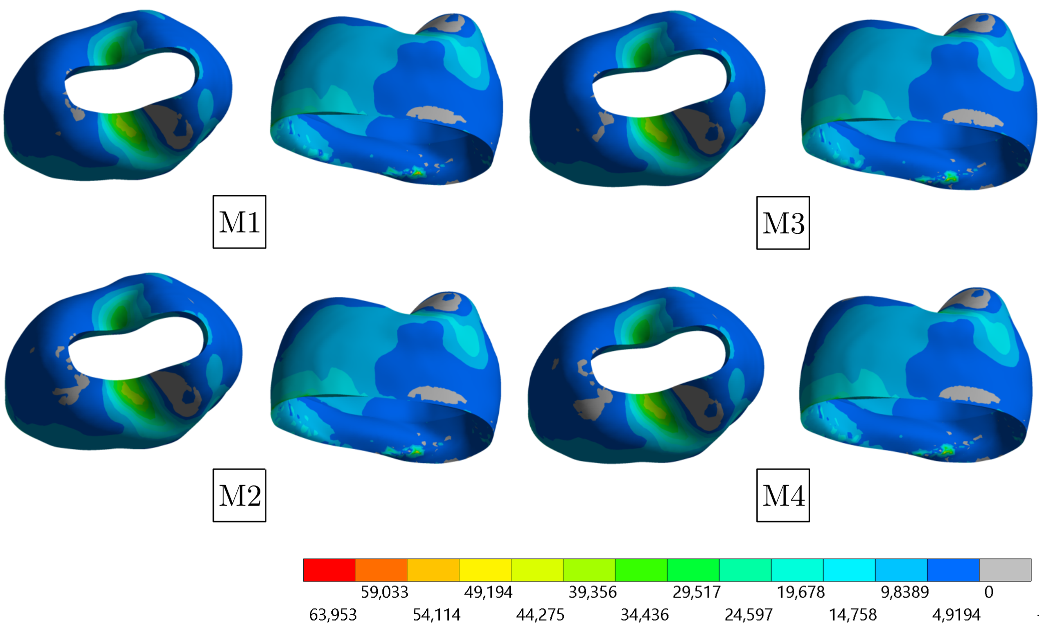


Figure 6. Maximum Principal Stress on enamel under oblique load in Mpa

Unlike enamel, dentin under oblique loading showed a large difference in stress peaks, about 5 times higher, as can be observed in the Fig. 7. Even so, the stress peaks are below the fracture resistance value. The highest peaks are observed in the bifurcation region, closest to the buccal root. This occur due to bending caused by the oblique force, which causes a high tensile stress in this region. Regarding the dental post, there was a reduction of 4.46% in the stress peak between the M2 and M4 models. Between the M1 and M3 models, there was no significant change.

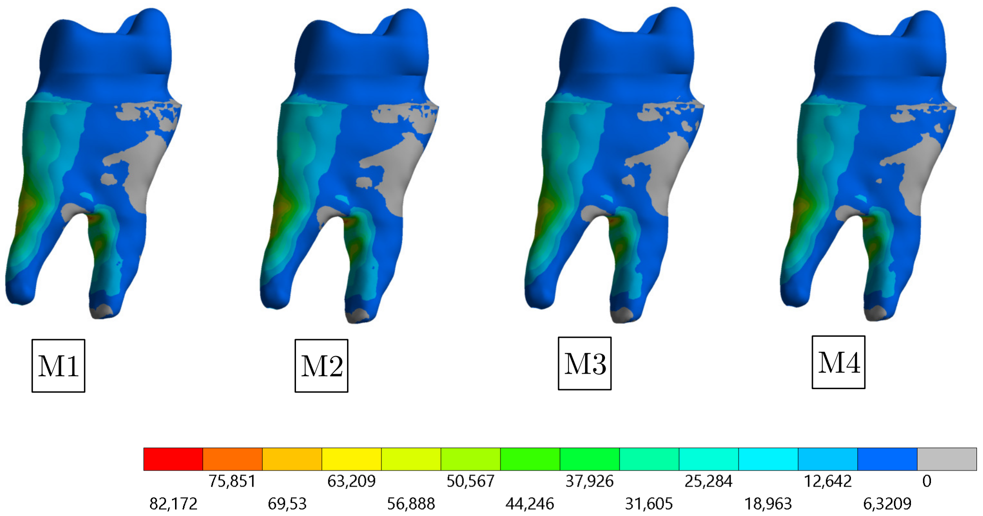


Figure 7. Maximum Principal Stress on dentin under oblique load in Mpa

Similar to the axial loading, the presence of the dental posts did not cause changes in the strain state of the cortical bone. The region that bear the greatest strain was on the buccal bone face of the models with osteoporotic bone constitution. This was due to the moment caused by the oblique force that tends to cause a rotation at this point, as can be seen in Fig. 8. Thus, the bone of a patient with osteoporosis is more likely to fracture than healthy bone under the same type of loading.

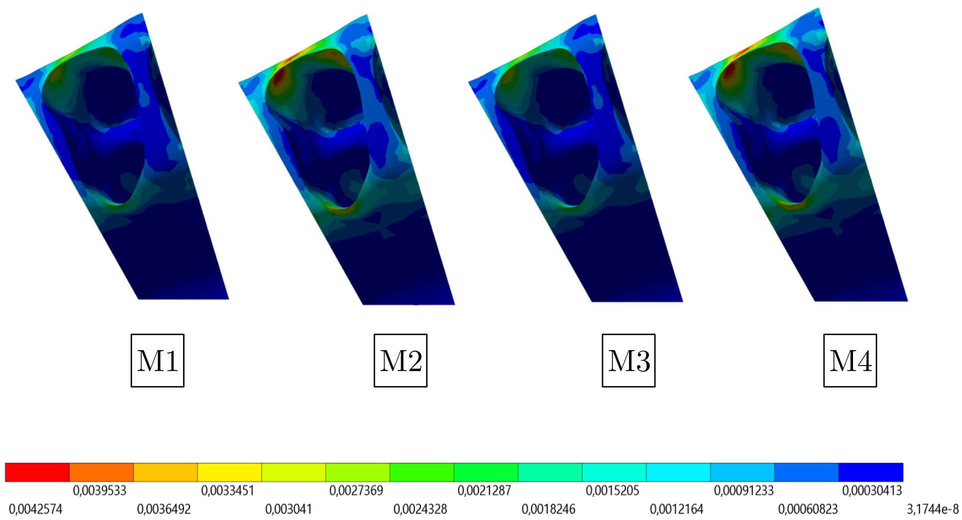


Figure 8. Maximum Principal Elastic Strain on cortical bone under oblique load

4. CONCLUSION

As a preliminary study, the results showed that there is no direct relationship between the use of dental posts and the mechanical behavior of osteoporotic bones. Thus, according to this study, this type of endodontic post is not contraindicated in patients with this condition. In either model, using the axial and oblique loading, it was noted a reduction in bone strain in the presence of posts. However, in structures with enamel and dentin, the post was effective in reducing stresses and consequently reducing possible fractures of these structures. It should be noted that this study is not sufficient to state that the use of dental posts are irrelevant in reducing the possibility of bone fractures in patients with this condition. To have a better understanding, further studies and new approaches of modeling bone structures are needed.

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