

# EFFECTS OF NON-CARIOUS CERVICAL LESIONS AND CORONARY STRUCTURE LOSS ASSOCIATION ON BIOMECHANICAL BEHAVIOR OF MAXILLARY PREMOLARS

## ABSTRACT

**PURPOSE:** Analyze the influence of tooth structure loss associated to non-cariou cervical lesions (NCCLs) and coronary preparations on biomechanical behavior of maxillary premolars, restored or not, using finite element analysis (FEA). **MATERIAL AND METHODS:** Virtual models were generated using a longitudinal cut image of a maxillary premolar, exported to a finite element software (Ansys 12.0) and analyzed as follows: sound tooth (S); MOD preparation (P); MOD preparation restored with composite resin (PR); cervical lesion (L); cervical lesion restored with composite resin (LR); and combinations, PR+LR; P+L; PR+L; P+LR. The areas corresponding to each structure were plotted and then meshed with eight-node isoparametric plane elements (PLANE183) in accordance to mechanical properties of each structure and materials. The materials and structures were assumed elastic, isotropic, homogeneous and linear, except for enamel and dentin, considered orthotropic. Oblique load (45N) was applied on buccal and palatal cusps, simulating an experimental tooth-sphere contact. Von Mises (VM) and maximum principal stress (S1) criteria were applied for analyzing the results. **RESULTS:** FEA using VM criterion revealed similar stress distribution patterns for groups S, PR, LR and PR+LR. Models L, P+L, P+LR and PR+L presented the highest stress at the center of NCCLs, with S1 levels of 0.22, 0.2, 0.25 and 0.31 MPa, respectively. For groups P and P+LR, Von Mises stress concentration was observed at internal angles of preparation and at base of cusps. **CONCLUSION:** NCCLs and intracoronal structure loss associated promoted high stress concentration in dental structure and at center of lesion. The load application influenced the stress distribution, and the models of groups restored with composite resin tend to mimic the biomechanical behavior of sound tooth model.

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## KEYWORDS

Non-cariou cervical lesion. Dental preparation.  
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## INTRODUCTION

As a typical non-carious cervical lesion (NCCL), which involves dental structure loss on cervical region in absence of caries<sup>1</sup>, abfraction is a common clinical occurrence which requires restorative treatment in most of cases, especially due to loss of tooth structure.<sup>2</sup> This dental structure loss reduces the resistance of tooth by increasing the possibility of fractures of the element in question.<sup>3-4</sup> So, the formation of a cervical wedge-shaped lesion adversely affects the dental biomechanical behavior, inducing an alteration in stress-strain distribution pattern when the tooth is loaded.<sup>5</sup>

A number of theories have been postulated to explain the etiology of NCCLs. However, the real causes still remain obscure, as reflected by contradictory terminology found in the literature.<sup>6</sup> Acidic and abrasive processes have been documented as the main etiological factors<sup>7</sup>, but common aspect seems to be the presence of high occlusal loads leading to cuspal flexure.<sup>8-12</sup> During tooth deflection, tensile and compressive stresses are generated at cervical region, causing cohesive rupture between hydroxyapatite crystals, leading to the formation of cracks and eventually to enamel loss.<sup>7,13</sup> The teeth more commonly affected by non-carious cervical lesions are the premolars.<sup>14-17</sup>

Premolars have the highest rate of clinical fractures among posterior teeth.<sup>18</sup>

Probably, due to the anatomical disadvantage of having the furcation adjacent to the cervical region<sup>19</sup>, marked grooves on root and crown, as well as cervical constriction of the crown.<sup>20</sup>

The association of these factors, probably makes premolar teeth more susceptible to fracture. In addition, tooth structure loss resulting of carious processes, traumas, cavity preparation and endodontic treatment are additional weakening factors<sup>8</sup>. Some authors showed that presence of coronary amalgam restorations in premolars increases the stresses at cervical region, as compared to sound tooth and suggested that these teeth should be restored with composite resin to prevent flexion of the cusps.<sup>21</sup>

The evolution of computer numerical analysis methods, like finite elements and their accuracy, has made them essential in solving engineering and also biomechanical problems.<sup>2</sup> Finite element analysis (FEA) has recently become a powerful technique in dental biomechanics, and several authors have employed this method for analysis of cervical lesion formation, and to establish the best restorative approach to NCCLs.<sup>6,9,21-23</sup>

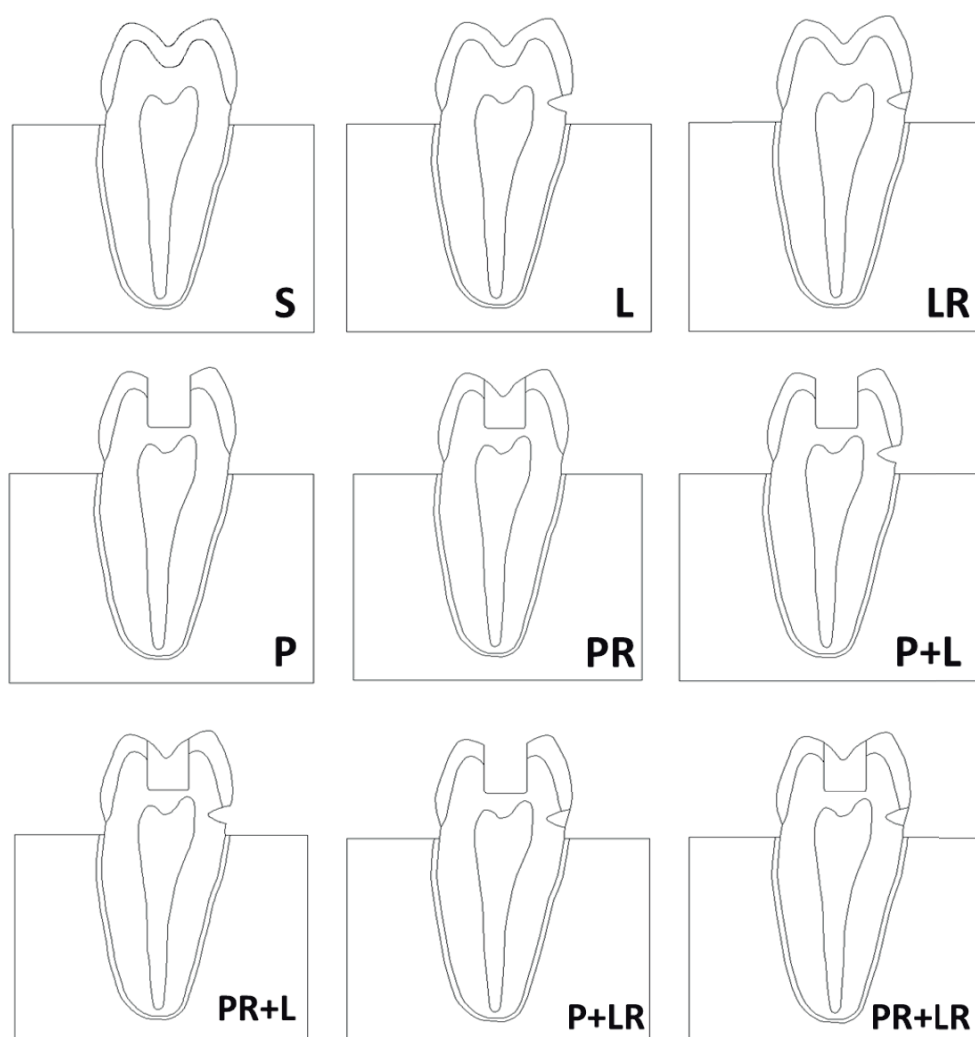
Thus, the aim of this study was to assess the influence of tooth structure loss associated to non-carious cervical lesions and coronary preparations on biomechanical behavior of maxillary premolars, restored or not, by using finite element analysis.

## MATERIAL AND METHODS

Bi-dimensional numerical models were created from a longitudinal cut of a sound maxillary premolar<sup>4,8</sup> using computer aided design software (Autodesk Mechanical Desktop 6; Autodesk Inc, San Rafael, Ca) (Figure 1), and the dimensions of dental structures, cervical lesions, mesial-occlusal-distal (MOD) preparations, and restorations were simulated according to each group. The outlines of tooth specimen, including the

polystyrene resin base and the simulated periodontal ligament were traced on this software either.<sup>4,8,24</sup> Researches have examined the characteristics of non-carious cervical lesions<sup>25</sup>, reporting many diversity of morphology between the NCCLs.<sup>26-27</sup> In this present study, authors consider the angle of lesion with a more rounded geometry, with internal line of C our U shape, described as saurce.<sup>27</sup>

Figure 1: Description of 2D-finite element models groups. S= Sound Tooth, L= Cervical Lesion, LR= Cervical Lesion restored with composite resin, P= MOD preparation, PR= MOD preparation restored with composite resin, P+L= MOD preparation + Cervical lesion, PR+L= MOD preparation restored with composite resin + Cervical lesion and PR+LR= MOD preparation restored with composite resin + Cervical lesion restored with composite resin.



Nine individual models were obtained according to the testing groups as described in Figure 2. The data obtained were exported to a software application (ANSYS 12.0; ANSYS Inc., Canonsburg, Pa) using the IGES format (Figure 1).<sup>4, 8, 28, 29</sup> The areas of each structure/material were identified, plotted, and then meshed with eight-node isoparametric plane elements (PLANE183), in accordance to mechanical properties of each region (Tables 1 and 2), assuming plane strain condition. The meshing process involves division of the system to be studied into a set of small discrete elements defined by nodes.<sup>4,8,29</sup> Tooth structure and materials used in the models were considered isotropic, elastic, linear, and homogeneous, except for dentin and enamel, which were considered orthotropic. To develop models restored with composite resin restorations (models R), the areas corresponding to the adhesive restorations were bonded at interface of adjacent areas of

enamel and dentin, simulating perfect union between the structures. In all the cases, two oblique loads with static characteristics, a 45° inclination in relation to the long axis of tooth and an intensity of 45 N were applied to the models at buccal and palatal cusp slopes, simulating a tooth-sphere contact in eight adjacent nodes in accordance to the previously described experimental/numerical set-up (Figure 1).<sup>4,8,29</sup> The displacement of models was restricted at external lateral outline and at cylindrical specimen support base. Stress distribution was assessed qualitative and quantitatively by using von Mises and maximum principal stresses (S1) criteria. Quantitative analysis's model was performed by selection of five nodes on NCCL (initial point, superior wall, deeper point, inferior wall and final point, respectively), or the corresponding region in the absence of lesion.

In restored lesion, points chosen were located on restoration interface (Figure 3).

Figure 2: Generation of bi-dimensional finite element models: (A) longitudinal cut of sound maxillary premolar; (B) external contours traced by computer-aided design software; (C) plotted areas in FE software; (D) mesh creation in FE software; (E) load application simulating tooth-sphere contact and displacement restriction; and (F) stress distributions in FEA.

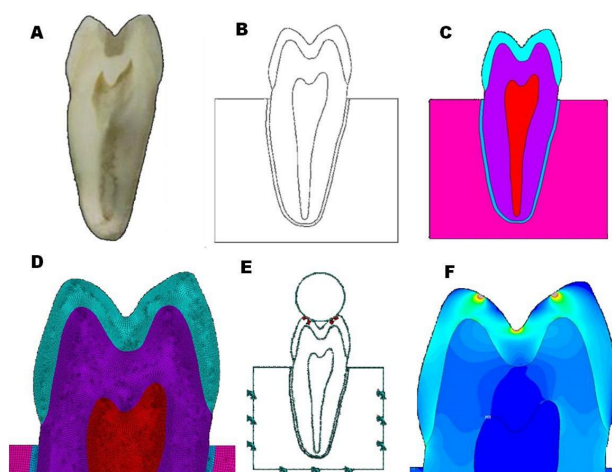


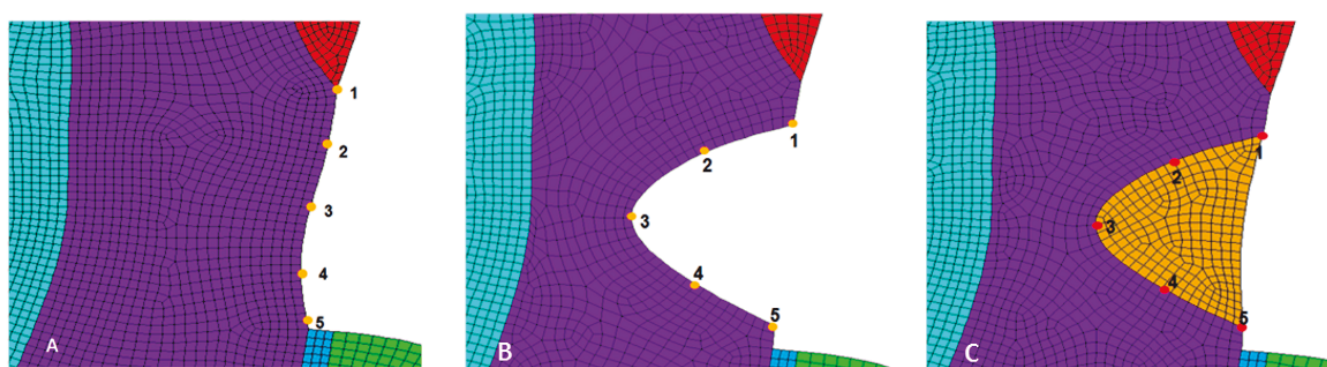
Table 1: Mechanical properties used to develop finite element models.

Structure/ Material	Elastic Modulus (MPa)	Poisson Ratio
Pulp <sup>50</sup>	0.003	0.45
Polyether <sup>51</sup>	50	0.45
Polystyrene resin <sup>52</sup>	13.5 X 10 <sup>3</sup>	0.31
Composite resin <sup>53</sup>	16.5 X 10 <sup>3</sup>	0.24

Table 2: Mechanical properties used to perform linear elastic orthotropic FEA models<sup>54</sup>.

Structure	Elasticity Modulus (E) (GPa)		Shear coefficient (G) (GPa)		Poisson ratio	
	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
Enamel	73.72	63.27	20.89	24.07	0.23	0.45
Dentine	17.07	5.61	1.7	6	0.3	0.33

Figure 3: Points chosen for specific analysis of different groups. 1: Initial point; 2: Superior wall, 3: Center of lesion; 4: Inferior wall and 5: Final point. A. Absent cervical lesion; B. Present cervical lesion; C. Present cervical lesion and restored with composite resin. In restored lesion, points chosen were located on restoration interface.



## RESULTS

The FEA of using von Mises and S1 criteria showed critical zones with great stress concentration for the models P, P+L and P+LR.

These results are depicted in Figure 4 and 5 for von Mises and S1 analysis. A false-color nonlinear scale for stress was used in the figures. The von Mises equivalent stress

criterion showed clear difference for stress distribution among the models analyzed. The models from groups S, PR, LR and PR+LR showed distribution patterns similar tensions at center of possible cervical lesion. The models of groups L, P+L and PR+L had the

highest stress levels on the center of cervical lesion (Figure 4 and 5). For groups P, P+L and P+LR, the models showed stress concentration at internal angles of preparation and at the base of cusps.

Figure 4: Stress distribution by von Mises criterion on maxillary premolars models.

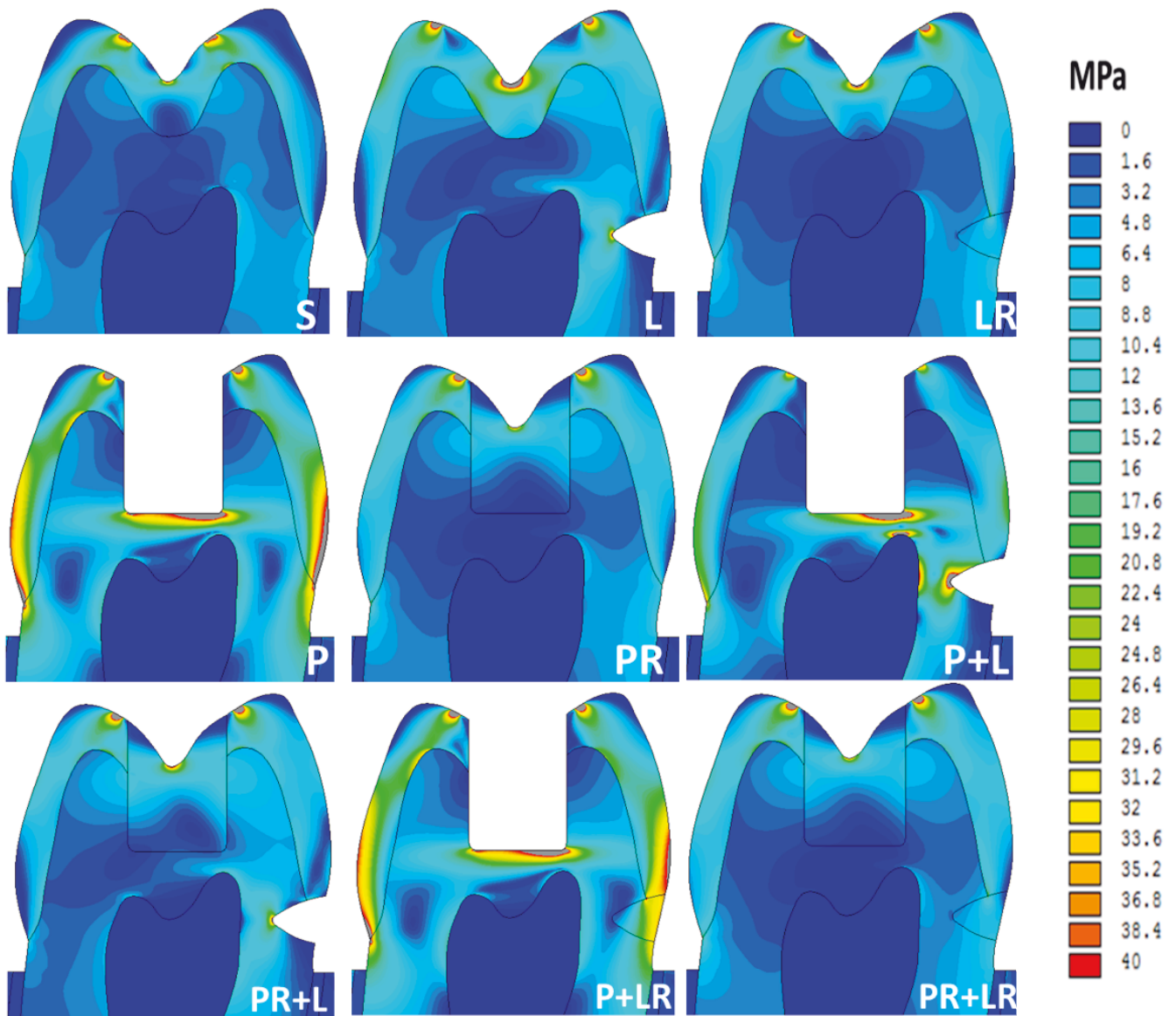
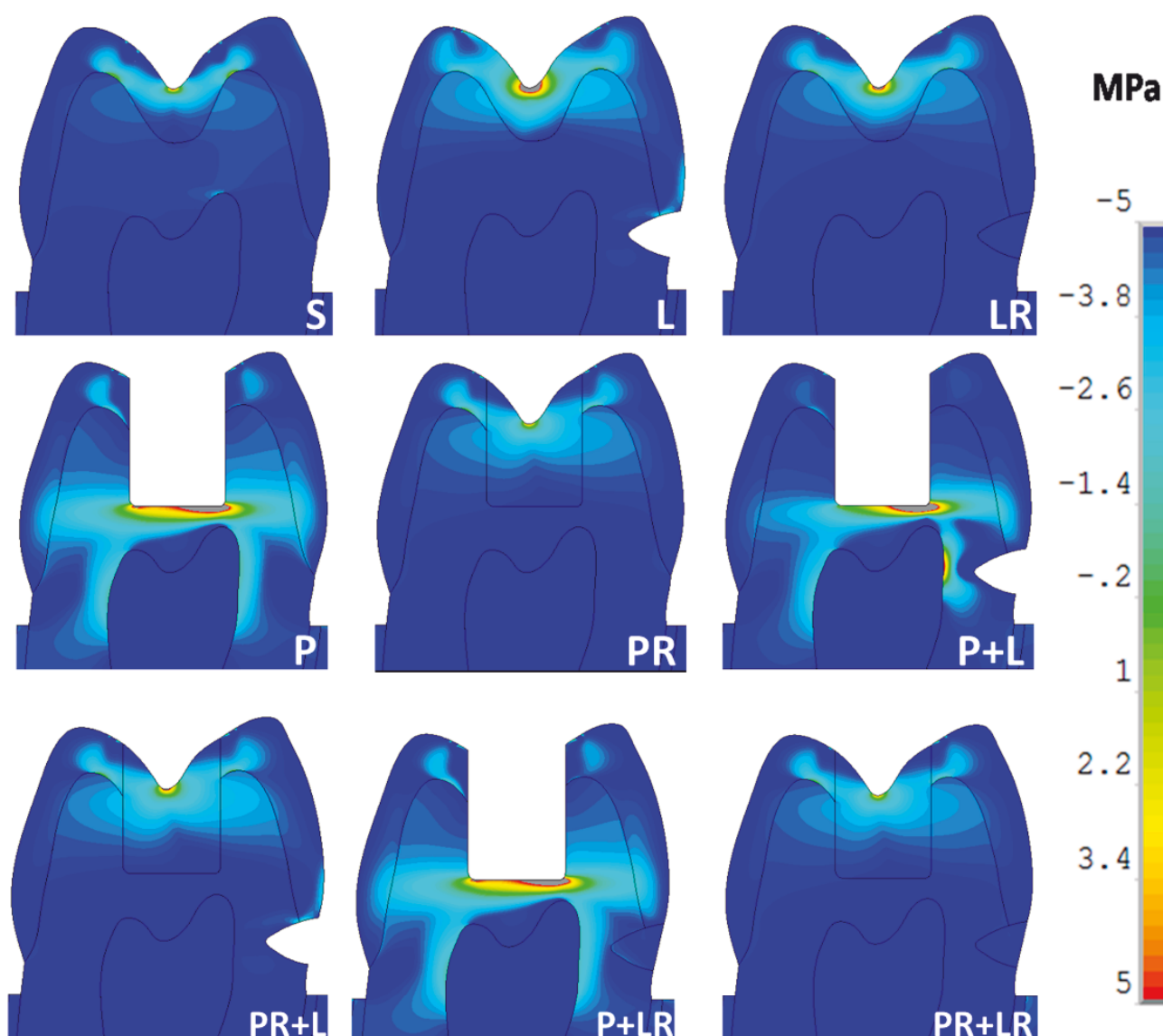


Figure 5: Stress distribution by S1 criterion on maxillary premolars models.



The models restored with composite resin (PR, LR and PR+LR) presented similar biomechanical behavior to the model simulating the sound tooth (S). The model P+L presented the higher stress concentration between all groups. The groups with only cavity preparation (P and P+LR) showed similar stress concentration pattern, affected mainly by flexion of the cusps. Quantitatively analyzing the stresses in the cervical region by von Mises criterion, of sound tooth model and

at deeper point of lesions in models with NCCLS present or restored, allows observe results with significantly high stress, especially on models with lesion not restored (Figure 6).

For maximum principal stress criterion, it is checked that the models with not restored MOD cavity (P, P+L and P+LR) showed high tensile stress concentration on the pulpal wall (Figure 5). Moreover, the models with restored lesions (P+LR, LR and PR+LR) present the

values of tensile stress on the NCCL walls close to the S model (Figure 7).

Figure 6: Quantitative analysis by von Mises criterion. Stress values are shown by standardized point of each numerical model.

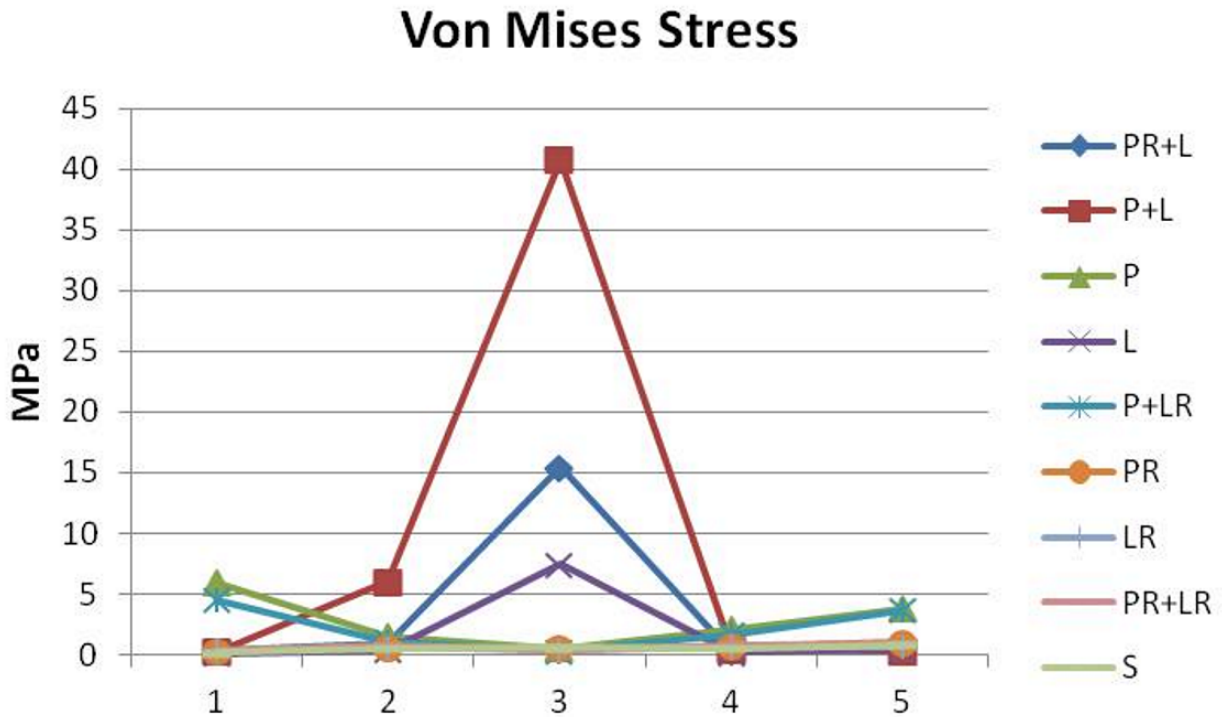
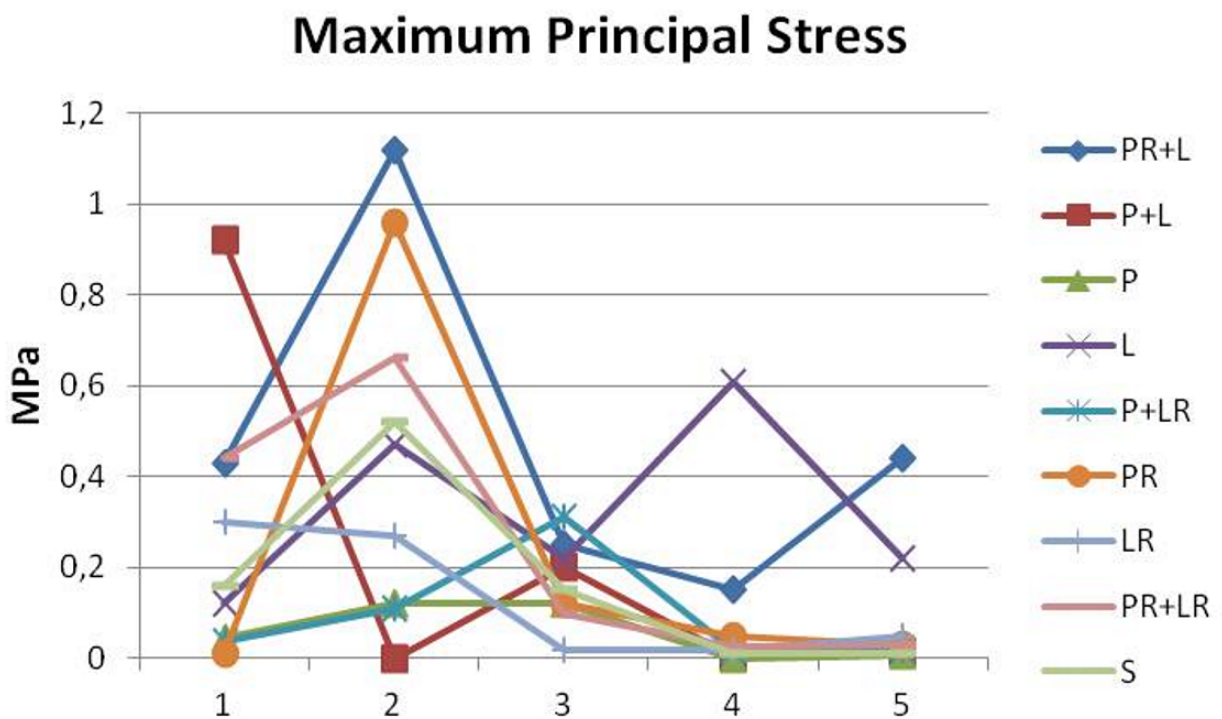


Figure 7: Quantitative analysis by S1 criterion. Stress values are shown by standardized point of each numerical model. These points were localized at the end of cervical lesion.





## DISCUSSION

Finite element analysis is a versatile tool to study stress conditions within complex structures, and technology improvement and better modeling techniques promoted this methods reliable and accurate for biomechanical applications.<sup>4,8,23,28-29</sup> The conducting of studies that simulate the behavior of oral structures, such as bi-dimensional or tri-dimensional finite elements analysis, entails a very complex approach due to the singular characteristics of components constituting the stomatognathic system. This study considered the application of forces to simulate chewing; loss of structure such as NCCLSs and MOD cavities; even tooth restored with composite resin. The options to represent a model of premolar was based on the evidence from recent studies, which demonstrates that cervical lesions are most frequently found on these teeth; also confirming that one in three premolar was affected by some form of NCCL.<sup>14-17,30</sup>

This research came about through controversial scientific evidence, which was correlated occlusal loading with presence and progression of NCCLs. The formation of these lesions has long intrigued researchers and clinicians. Several hypotheses have been proposed for its etiology, but except for multifactorial nature, there is no consensus about its initial mechanism. One of these theories is based on a biomechanical concept in which the

cervical area of a tooth becomes a fulcrum during occlusal function, premature contacts, bruxism or other parafunctional activities, developing tensile stresses in cervical region area where NCCLs occur.<sup>31</sup> The models (P+L, P+LR and P) clearly represent this theory, showing tensile stresses next to lesion area (Figure 4 and 5).

On the other hand, abfraction has been theoretically proposed as the primary etiological factor in the formation of NCCLs because of off-axis loading that occurs on tooth cusps, leading to a flexure at cervical area.<sup>32-33</sup>

It has been proposed that the tensile and compressive stresses from mastication, abnormal occlusal forces and malocclusion would result in weakening of enamel and dentine.<sup>33-34</sup> Initiation and dissemination of enamel cracks in cervical region for NCCLs formation depend on the presence of stresses induced by high occlusal loads.<sup>31</sup> Considering the fact that stress concentration in dentin-enamel junction exceeded the tensile strength of enamel under masticatory force, probably NCCLs will occur<sup>6</sup>, and it was observed in models L, P+L, P+LR, PR+L (Figure 4 and 5). So, these forces would then cleave thin enamel crystals and the subjacent dentine at tooth cervical area.<sup>33-37</sup> These findings are consistent with our study, because all models presented occlusal loading and consequently stress concentration in cervical region (Figure 6 and 7). Also, some groups have shown tendency to

loss of dental hard tissue in this region (L, P+L, P+LR, P, PR+L).

Several biomechanical studies have demonstrated the weakening effect of cavity preparations on teeth.<sup>3-4</sup> As the size of occlusal restoration gets larger, the dental structure weakens, and more stresses are seen on tooth.<sup>38</sup> Levels of cusps deformation and stress distribution patterns are directly influenced by amount of tooth structure removed and restorative material presence.<sup>3-4</sup> Evaluating the stress distribution at the center of cervical lesion, it could be seen that stress concentration was influenced, especially by tooth structure loss and weakening of remaining tooth structure (Figure 4 and 5). It was noted in models with only MOD cavity preparation (P and P+LR), which showed similar stress concentration affected by the cusps flexion. The results of the model simulating structural loss with MOD preparation and cervical lesion (P+L) are qualitatively observed on equivalent researches<sup>3-4, 8, 29, 39</sup>, which the progressive removal of tooth substance during cavity preparation led to increase cuspal flexure under occlusal loads.

Additionally, literature shows that amalgam restorations have similar behavior on non-restored teeth.<sup>3-4,40</sup> The failure to form a single body from amalgam fillings, tooth structure and deformation capacity of material when subjected to occlusal loading reduces the

fracture toughness of tooth restoration complex to levels comparable to those found in groups with no direct preparations restored.<sup>3-4</sup>

Therefore, the similarity was considered in this study to provide comparison and discussion among studies of amalgam, which behave similarly to non-restored teeth with preparations, one of the factors involved in this study. So, it was also seen that in the presence of an occlusal amalgam restoration, cuspal flexure increased and the maximum shear stresses at cervical region increased together<sup>41-42</sup>, what was also noted in this study through the model P+L. Similar pattern was observed in study which evaluated the stress profile in cervical region of mandibular first premolars varying occlusal loads, and compared the stress profile between sound and occlusally restored tooth, using two-dimensional finite element models.<sup>21</sup> These authors suggested that high occlusal loading and the presence of an occlusal amalgam restoration (or non-restored teeth) increased the stress concentration at cervical area, which may lead to enamel breakdown at this region; and this situation was found in models P, P+L and P+LR.

Clinically, many patients have occlusal and class V restorations associated in the same tooth<sup>43</sup>. The occlusal restoration can reduce the integrity of tooth and allows flexing of the cusps under occlusal load.<sup>44</sup> This fact would generate high stresses in cervical region and

further stress on class V tooth–restoration interface, contributing to failures in this region.<sup>44</sup> These findings should be analyzed carefully, since a restoration will not always weaken the tooth. In this study, we found that the model with the occlusal and NCCL cavities restored with composite resin (PR+LR) presented similar behavior to the model simulating the sound tooth (S). In addition, the model with NCCL not restored\_but MOD with composite resin restoration (PR+L), also showed similar behavior to the sound model (S).

Mechanical properties of restorative materials may affect the behavior and fracture propagation inside the tooth restoration complex.<sup>3-4,8,45,46</sup> The results of the present investigation are in agreement to the results of previous studies<sup>32,47</sup>, which showed that composite resin restoration of NCCLs (LR, PR+LR) significantly reduces stresses induced in tooth tissues around them, simulating the sound tooth (S), possibly preventing further lesion enlargement. Accordingly, this study demonstrated reconstruction of NCCLs with composite resin (LR, PR+LR), revealing similarity of stress concentration between the restored groups and the model simulating the sound teeth (S). Correlations may be noted with the studies reported by some authors, where it can also be suggested that whether the occlusal restoration were composite instead of silver amalgam, the cuspal flexure would further be reduced due to the bonding

ability of composites and their elastic modulus, similar to the tooth structure, especially dentin.<sup>41, 42,48,49</sup> This relationship was noted when comparing models with cavity preparation (which theoretically simulate amalgam restoration) and restored with composite resin, especially PL e PR+LR. This mechanical property is important with respect to both the stress-strain ratio of tooth-restoration complex during occlusal load application, and behavioral differences between tooth structure and restorative materials.<sup>48</sup>

Despite, this study provides a biomechanical viewpoint explanation for NCCLs, cavity preparation and restorations, the results must be viewed with some reservations. Since this study was a two-dimensional plane strain analysis, so it was not possible to model any small twisting movements of the tooth in z direction, whereas teeth are three-dimensional (3D) objects, because this models show better anatomical details. Additionally, the inclusion of all factors that occur intraoral is impracticable for computer simulations. Other methodologies, such as laboratory methods and clinical longitudinal researches are also very important and should be evaluated and studied further to better understand the biomechanical factors related to the NCCL.

## CONCLUSION

Within the limitations of this *in vitro* study, the following conclusions were drawn:

- Tooth structure loss increases the stress concentration at center of NCCLs;
- There is flexion of cusps in cavities preparations (P, P+L and P+LR);
- Sound tooth (S) showed most homogenous stress distribution;
- Composite resin restorations (LR, PR and PR+LR) tend to mimic the mechanical properties of sound teeth, especially regarding the stress distribution;
- No restored cervical lesions (P+L, PR+L and L) showed higher stress concentration on center of lesion, respectively.

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