LOADING AND COMPOSITE RESTORATION ASSESSMENT OF DIFFERENT NON-CARIOUS CERVICAL LESIONS MORPHOLOGIES - 3D FINITE ELEMENT ANALYSIS

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Abstract. *The present study aimed to analyze the effect of occlusal loading on premolars presenting different non-carious cervical lesions morphologies, restored (or not) with composite resin, using finite element analysis. Three-dimensional virtual models of maxillary premolar were generated using CAD software. Three non-carious cervical lesions morphological types were simulated: wedged- shaped, saucer and mixed. All virtual models underwent three loading types (100N): vertical, buccal and palatine. The simulated non-carious cervical lesions morphologies were analyzed before and after restoration considering specific regions: occlusal wall, bottom wall and gingival wall. Data summarizing the stress distribution were obtained in MPa, using Maximum Principal Stress. Palatine load was responsible for providing the highest values of tensile stress accumulation on the buccal wall, 27.66 MPa and 25.76 MPa for mixed and wedged-shaped morphologies, respectively. The highest tensile value found among restored lesions was 5.9MPa for mixed type, similar to that found on sound model regardless of lesion morphology and occlusal loading. The different non-carious cervical lesions morphologies had little effect on stress distribution patterns, whereas loading type and the presence of composite restoration influenced on the biomechanical behavior of maxillary premolar.*

Key-words*: Biomechanical behavior, Composite restoration, Finite Element Analysis, Premolar teeth, Non carious cervical lesions.*

1. INTRODUCTION

Non-carious cervical lesions (NCCLs) are pathological process characterized for loss of tooth structure in the cement-enamel junction (CEJ), which is unrelated to dental caries. The occurrence of these lesions is an increasingly common finding in dental clinical practice (Reyes, et al. 2009; Smith et al. 2008, Wood, et al. 2008) most prevalent in maxillary premolars (Wood, et al. 2008; Aw TC et al. 2002). The main factors involving in this process are stress (abfraction-parafunction and traumatic occlusion), friction (wear-toothbrush/dentifrice abrasion) and biocorrosion (chemical, biochemical and electrochemical degradation-extrinsic and intrinsic acids) (Grippo, et al. 2012). Furthermore, the enamel of cervical region has poorer quality and thin thickness, what makes this area susceptible to lesion formation (Walter, et al. 2013).

The multifactorial etiology of NCCLs results in varied anatomic aspects, which are classified in three morphologies for posterior teeth: wedge-shaped, saucer-shaped and mixed-shaped (Hur, et al. 2011). Wedge-shaped lesions are characterized by sharp internal line angle presence, while saucer-shaped lesions present this same internal angle rounded. On the other hand, when a lesion has flat gingival and semicircular occlusal walls with smooth lines and semi-circular shape, it is called mixed-shaped lesion (Hur, et al.2011).

In addition, different types of occlusal load provide changes on stress distribution patterns in cervical enamel (Benazzi, et al. 2013; Rees, et al.2002). Occlusal interferences can lead to weakening of the continuity between the hard tooth structures and cause increased stress in the cervical region (Corte, et al. 1977), resulting in fatigue and possible rupture of cervical enamel (Reyes, et al. 2009; Rees, et al. 2002). The aim of this study was to evaluate the effect of NCCLs morphologies, submitted to three different occlusal loadings and their restorative status in biomechanical behavior of premolars, using 3D Finite Element Analysis.

2. METHODS AND MATERIALS

2.1. Finite Element Analysis

Three-dimensional linear elastic analysis was performed based on anatomical geometric representations of dentine, pulp, enamel, periodontal ligament, cortical bone and trabecular bone. Seven models were generated, simulating sound tooth (SO), three NCCL morphologies: wedge shaped (WS), saucer shaped (SA), mixed shaped (MI),[10] and also the restored models of all lesions types (R) (Fig 1).

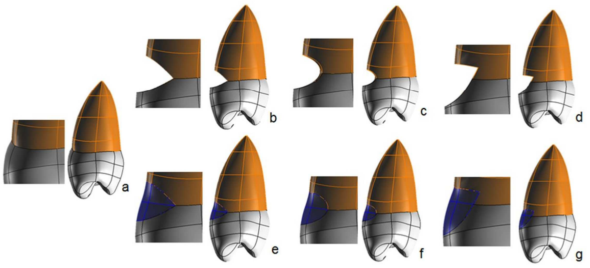

Figure 1. NCCLs morphologies simulated models. a) Sound tooth (SO); b)Wedge Shaped (WS); c)Saucer shape (SA); d)Mixed shape (MI); e)WS restored (WSR); f)SA restored (SAR); g)MI restored (MIR).

The models were exported using the STEP format to the processing analysis software (ANSYS 12.0, Ansys Workbench 12.0.1, Canonsburg, PA, EUA). The following steps were performed in this software: pre-processing (definition of mechanical properties, volumes, connection types, mesh for each structure, and boundary conditions), processing (data calculation) and post-processing (analysis of results by stress distribution criteria). All dental structures and restorative materials were considered homogeneous and linear elastic. Enamel and dentin were considered orthotropic and the other structures isotropic (Tab. 1).

Table 1 Mechanical properties used to perform orthotropic and isotropic structures.

Structures		**Orthotropic Structures**		**Reference**
		Elastic Modulus (MPa)		(Miura et al., 2009)
	LONGITUDINAL	**TRANSVERSAL**	**Z**	
Enamel	73720	63270	63270	
Dentin	17070	5610	5610	
		Shear coefficient (MPa)		
Enamel	20890	24070	20890	
Dentin	1700	6000	1700	
		Poisson Ratio (v)		
Enamel	0.23	0.45	0.23	
Dentin	0.30	0.33	0.30	
Structures		**Isotropic Structures**		
	Elastic Modulus (MPa)	**Poisson Ratio (v)**		
Pulp	2.07	0.45		Rubin et al., 1983
Periodontal Ligament	68.9	0.45		Weinstein et al., 1980
Cortical Bone	13,700	0.30		Carter et al., 1977
Medular Bone	1,370	0.30		Carter et al., 1977
Hybrid Composite Resin	22,000	0.27		Shinya et al., 2008

Volumes corresponding to each structure with controlled and connected elements were meshed after performing conversion mesh test to define the appropriate refinement level. Solid quadratic tetrahedral elements with 10 nodes were used. Meshing process involved division of the system being studied in a set of small discrete elements defined by nodes. Conversion mesh test began with the software automatic meshing and followed by gradual decreasing of elements size (Fig. 2). For each test stage, the results were generated by equivalent stresses criterion (von Mises) to verify the higher stress values on dentin. Mesh was considered satisfactory when even with the decrease in the size of the elements; the higher stress levels verified were similar to the results observed with the previous element dimension. The number of elements generated varied depending of the different volumes, so the final model accurately represented the original geometry.

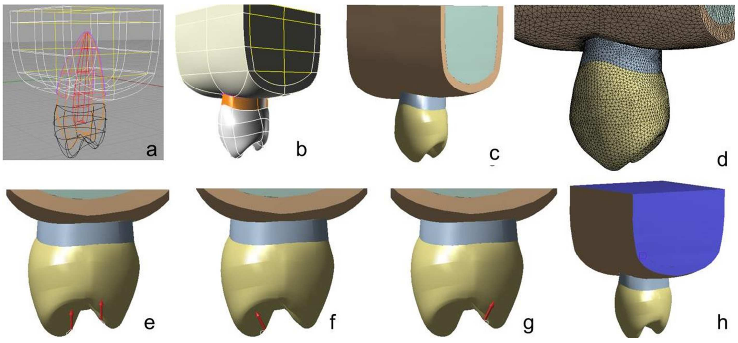

Figure 2. Finite Element models generation. a) CAD software model outlines; b) Volumes created; c) Volumes exported to ANSYS Workbench 12.0; d) Mesh; e) Vertical Loading (VL); f) Buccal Loading (BL); g) Palatine Loading (PL); h) Displacement restriction (on the blue area the displacing was null).

The models underwent three types of loads (100N) applied on specific surfaces previously defined in CAD Software. Vertical Load (VL) was distributed equally on both cusps, simulating homogeneous contact distribution (Fig 2e). Buccal Load (BL) (Fig 2f) and Palatine Load (PL) (Fig 2) applied at 45 degrees to the long axis on buccal and palatine cusps respectively, simulated occlusal interferences. Models were constrained on the lateral and base of cortical and trabecular bone to avoid the displacement (Fig 2h). The stress distribution analyses were recorded using the Maximum Principal Stress criteria, measured in MPa. For analysis of NCCLs specific regions, tensile stress values were obtained on three different nodes of the meshed surface: cavosurface angle of the occlusal wall (OW); deepest point of the bottom wall (BW); and cavosurface angle of the gingival wall (GW).

3. RESULTS

3.1. Finite Element Analysis

The stress distribution presented by all of the models under different loading conditions is shown in (Figs 3, 4, 5 and 6). Positive and negative values indicate that the corresponding regions were subjected to tensile or compressive stress, respectively.

The sound model (SO) presented better stress distribution pattern for all loading types compared with non-restored ones. For vertical loading, tensile stress accumulated in the buccal cervical region, demonstrated the highest values in OW, approximating 1.5MPa (Fig 3). On SO/BL model, stress concentration in buccal cervical region was greater than VL (Fig 4). In addition, BL promoted stress concentration in palatine face. Finally, the PL produced the highest tensile stress levels in buccal cervical region when compared with the others. For SO/BL and SO/PL, BW showed the greatest values of tension, 3.95 and 16.95 MPa, respectively (Fig 6).

The vertical loading (VL) produced lower levels of stress concentration than the other types, independently of lesion morphology (Fig 3). The higher tensile stress values were found at OW, with the highest for MI lesions, 1.65MPa (Fig 7). For compressive stress, the greatest concentration was shown at BW, with -3.39 MPa for MI.

Models loaded on buccal direction (BL) presented the highest tensile stress on the superior wall of NCCL and had dentin on the opposite face (palatine) affected in cervical region (Fig 4). The BL promoted high tensile stress levels at OW, SA and MI models, 5.99 and 6.87MPa, respectively (Fig 6). Compressive stress was shown in the bottom wall, -15.03 MPa, for WS lesion.

Palatine load (PL) presented the highest tensile stress values regardless of lesion geometry. PL was associated with the tensile stress concentration on the cervical region of the buccal face. The dentin of opposite face (palatine) was also affected (Fig 5). The greatest tensile stress levels were found at BW for the MI and WS models, with 27.66 and 25.76MPa, respectively (Fig 6).

Despite of lesion morphology or loading type restored NCCLs shown better stress distribution patterns similar to those found on sound tooth. The restored models present the lowest stress levels on cervical regions, with stress values up to 1.2 MPa, 4.9MPa and 5.4 MPa for VL, BL, and PL, respectively (Figs 3, 4, 5 and 6).

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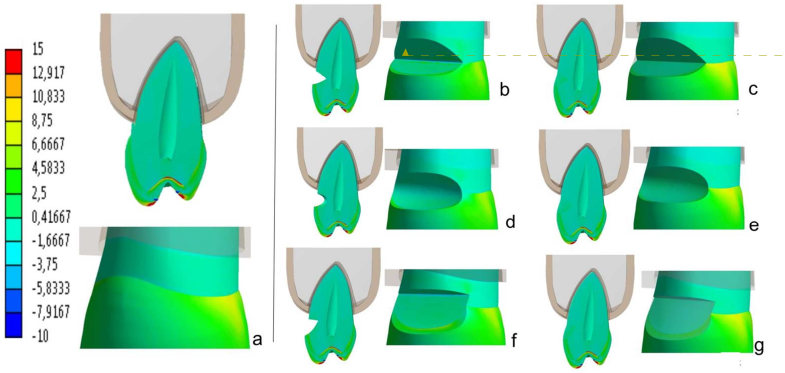

Figure 3. Maximum Principal Stress (MPa) distribution for models that received Vertical Loading: a) Sound Model; b) Wedge Shaped; c) WS restored; d) Saucer shape; e) SA restored; f) Mixed shape; g)MI restored. In perspective view, models with restored lesions, the composite resin was placed on transparency to enable NCCLs walls visualization.

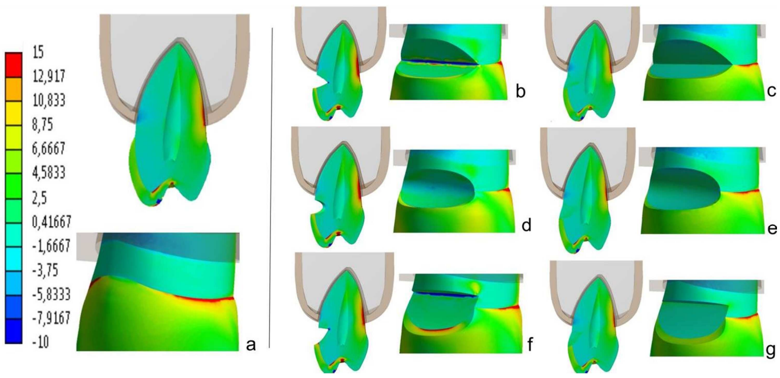

Figure 4. Maximum Principal Stress (MPa) distribution for models that received Buccal Loading : a) Sound Model ; b) Wedge Shaped; c) WS restored; d) Saucer shape; e) SA restored; f) Mixed shape; g)MI restored. In perspective view, models with restored lesions, the composite resin was placed on transparency to enable NCCLs walls visualization.

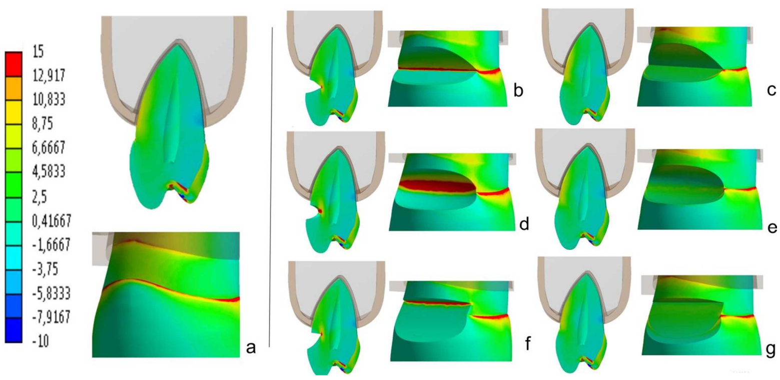

Figure 5. Maximum Principal Stress (MPa) distribution for models that received Palatine Loading : a) Sound Model; b) Wedge Shaped; c) WS restored; d) Saucer shape; e) SA restored; f) Mixed shape; g)MI restored. In perspective view, models with restored lesions, the composite resin was placed on transparency to enable NCCLs walls visualization.

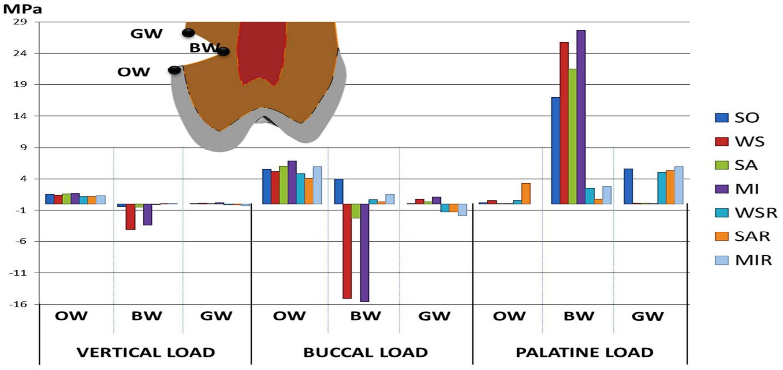

Figure 6. Maximum Principal Stress values (MPa) on NCCLs at specific regions on models: OW (occlusal wall); BW (bottom wall); and GW (gingival wall).

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5. ACKNOWLEDGMENTS

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6. ACCOUNTABILITY OF INFORMATION

All the authors are responsible for the information include on this paper.