EFFECTS OF NON-CARIOUS CERVICAL LESION SIZE, OCCLUSAL LOADING AND RESTORATION STATUS ON BIOMECHANICAL BEHAVIOR OF PREMOLAR TEETH

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Abstract: *The aim of this study was to analyze the influence of NCCL size, restorative status and direction of occlusal loading on the biomechanical behavior of mandibular premolars, using finite element analysis (FEA), strain gauge tests and fracture resistance tests. The buccal cusps of 10 teeth were loaded on the outer and inner slopes to calculate the strain generated around the cervical region. Data were collected for healthy (H) teeth at baseline and progressively at three lesion depths (0.5 mm, 1.0 mm and 1.5 mm), followed by restoration of large (1.5 mm) lesions with composite resin. The magnitude and distribution of von Mises stress and maximum principal stress were simulated using FEA. Fracture strength from both loading directions was determined for healthy teeth, large lesions and restored lesions (n = 7 per group). There were significant effects of the lesion size and loading directions on stress, strain and fracture resistance ($p<0.05$). Large lesions exhibited the highest stress and strain levels that returned almost to values for healthy teeth when restored, providing support for restoring NCCLs.*

Key words: *Finite element analysis, Fracture resistance, Non Carious Cervical Lesion, Premolar, Strain gauge test*

1. INTRODUTION

Non-carious cervical lesions (NCCLs) are pathological processes characterized by the hard tissue dental loss at the cement–enamel junction (CEJ) independent of bacterial process (Borcic et al.,2004; Reyes et al., 2009). This tooth structure loss is routinely found and increasingly common in dentistry clinical practice (Borcic et al.,2004; Hur et al.,2011; Rees,2002) and have a multifactorial origin, with the proposed predisposing factors being stress (abfraction), mechanical wear (from toothbrush/dentifrice abrasion) and biocorrosion (chemical degradation) (Grippo et al., 2012). NCCLs also increase with age, which suggests a fatigue component in their formation associated with occlusal interferences or any event that changes the dental occlusion, such as tooth occlusal surface wear, restorative procedures, altered tooth position and tooth brushing behavior, with prevalence reported in the range 5–85% (Bernhardt et al, 2006).

These kinds of lesions are associated with the cusp flexure, and its prevalence is mostly at premolars buccal surface. The literature suggest a relationship between occlusal factors and cervical wear (Takehara et al, 2008), gingival resection and tooth mobility absence seems to contribute to NCCL development (Pikdoken et al, 2011). Despite the great amount of studies searching the formation and progression of NCCLs many doubts still must be solved. The direct relationship between non carious cervical lesion size and occlusal loads remains unknown.

Thus, the aim of this study was to analyze the biomechanical behavior of NCCLs in mandibular premolar teeth as a function of their size, restorative status and the direction of occlusal loading, using a combined assessment involving finite element analysis, strain gauge testing and fracture resistance testing.

2. MATERIALS AND METHODS

2.1. Finite element analysis

Three dimensional, linear and elastic finite element models were performed using anatomically-based geometric representations for pulp, dentin, enamel, polyether and polystyrene cylinder .Five models were generated (Rhinoceros 3D software, Rhinoceros, Miami, FL, USA) (Fig.1A), simulating: H- healthy teeth; three stages of NCCL size: L0.5-small lesion (0.5 mm), L1.0-medium lesion (1.0 mm), L1.5-large lesion (1.5mm); and LR-large lesion restored with resin

The models were exported using the STEP format to the processing analysis software (ANSYS 12.0, Ansys Workbench 12.0.1, Canonsburg, PA, EUA) (Figs.1B and 1C). 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 material were considered homogeneous and linear elastic. Enamel and dentin were considered orthotropic and the other structures isotropic (Tab. 1).

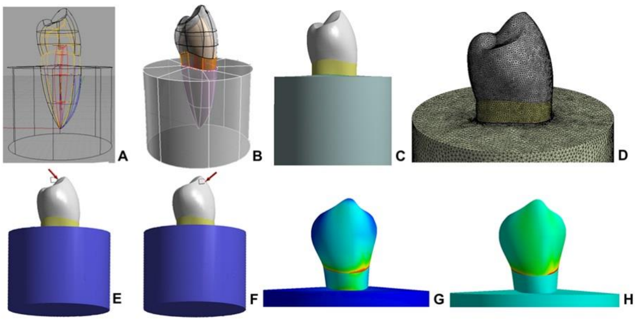

Figure 1. Three-dimensional finite element model generation. (A) Contours, (B) Volumes, (C) Dental tissues and structures in ANSYS software, (D) Mesh, (E) Inner load, (F) Outer load, (G) von Mises Stress distribution, and (H) Maximum Principal Stress distribution

Table 1. Mechanical properties of 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
Polyether	68.9	0.45		Soares et al.,2008
Polystyrene Resin	13,700	0.30		Soares et al.,2008
Hybrid Composite Resin	22,000	0.27		Shinya et al., 2008

After testing the mesh conversion to define the appropriate mesh refinement level, volumes corresponding to each structure were meshed with the controlled and connected elements. The meshing process involved division of the studied system into a set of small discrete elements defined by nodes. Solid quadratic tetrahedral elements of 10 nodes were used (Fig. 1D). The mesh was considered satisfactory when, even reducing the dimension of elements, the higher stress levels were similar to the results observed with the previous mesh refinement. Due to the adhesive properties of the restorative material used, restoration were bonded to dental structures by considering a mesh connection with dentin and enamel.

The boundary conditions consisted of developing a displacement/restriction model using load application. Occlusal oblique loads (100N each) were applied to the buccal cusps of premolar teeth separately on the inner slope (inner load-IL) and the outer slope (outer load-OL) (Figs. 1E and 1F). Models were restrained at the base and lateral surfaces of polystyrene cylinder to avoid displacement. The stress distribution analyses was performed using the equivalent stress criterion (von Mises) and Maximum Principal Stress, measured in MPa (Figs.1G and 1H).

2.2. Strain gauge test

Ten intact mandibular premolars were selected for this step of the study. The teeth were extracted due periodontal problems or orthodontic directions under ethics committee on research by the Federal University of Uberlândia (#092/10) approval.

The NCCLs were prepared on the buccal surfaces of premolar teeth at the cemento-enamel junction with a diamond bur #3118 (KG Sorensen, Barueri, São Paulo, Brazil) using a custom-made machine (Federal University of Uberlandia,

Uberlandia, Minas Gerais, Brazil). Each teeth was prepared with sequential tooth structure reduction and the strain was measured in same sample at five different stages of NCCL development in a longitudinal model: (H) teeth at baseline; after each of the three stages of NCCL preparation (on the same teeth) by cutting 'V' notches at depths L0.5, L1.0, 1.5 mm and after restoration of large lesions with resin composite.

Two strain gauges (PA-06-060BG-350L; Excel Sensores, São Paulo, Brazil) were bonded to the tooth surface with cyanoacrylate adhesive (Super Bonder; Loctite, São Paulo, Brazil) with wires connected to a data acquisition device (ADS0500IP; Lynx Tecnologia Eletronica Ltda., São Paulo, Brazil). One gauge was placed on the buccal surface and the other on the mesial surface. Compressive loads were applied on the inner and outer surfaces of the buccal cusp of each specimen with a metallic-wedge-load device (tip) at a speed of 0.5 mm/min to a maximum of 100 N in a mechanical testing machine (EMIC DL 2000; EMIC Equipamentos e Sistemas de Ensaio Ltda., São José dos Pinhais, Brazil). Data were transferred to computer specific software used for acquisition and analysis of data (AqDados AqAnalisys, Lynx, SP, Brazil).

2.3. Fracture resistance testing

Fracture resistance testing was performed in a mechanical testing machine (EMIC DL 2000; EMIC São José dos Pinhais, Brazil) mounted to a wedge-shaped metallic device (tip) that applied loads on the outer and inner parts of the buccal cusps of premolar teeth (n=42) at a cross-head speed of 0.5 mm/min until they fractured. Fracture patterns were examined under a stereomicroscope and categorized into four types: (i) Type I - a conservative fracture involving a small portion of the buccal cusp, (ii) Type II - a conservative fracture involving a small portion of the lingual cusp, (iii) Type III - a large fracture involving the base of the NCCL and extending above or at the level of the polystyrene, and (iv) Type IV - a severe root and crown fracture extending below the polystyrene.

3. RESULTS

3.1. Finite element analysis

The von Mises analysis showed that there was a direct relationship between NCCL size and stress concentration for both loading directions (Fig. 2). Figure 3 show the results of the maximum principal stress analysis that showed high tensile stress generation around the cemento-enamel junction on the contralateral side of teeth from inner loading. A similar trend was also observed for outer loading on healthy and restored teeth, but tensile stress was also generated on buccal pulp horns of all teeth. Stress concentrations in LR lesions showed similar patterns of distribution to that of healthy teeth, but with relatively lower tensile stresses from outer loading. Compared with NCCLs, stress distribution in LR lesions were generally low for both loading directions.

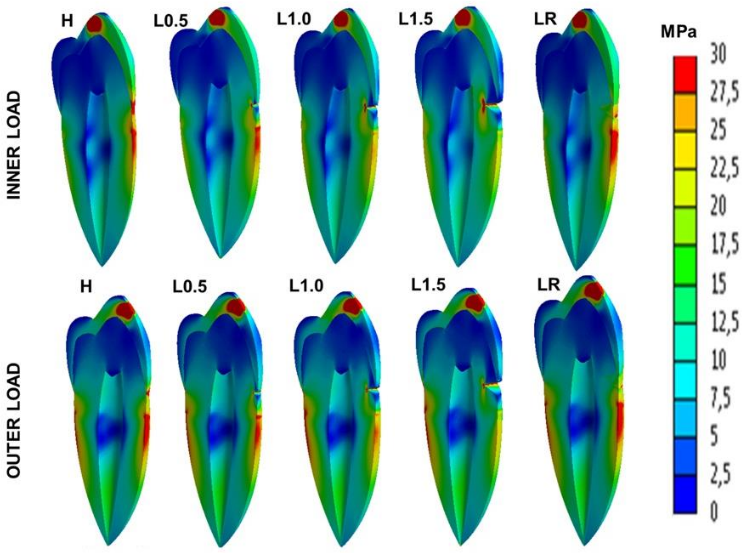

Figure 2. von Mises stress distribution (in MPa) in finite element analysis of different types of non-carious cervical lesions under both outer and inner occlusal loading (blue = 0; red = 30MPa).

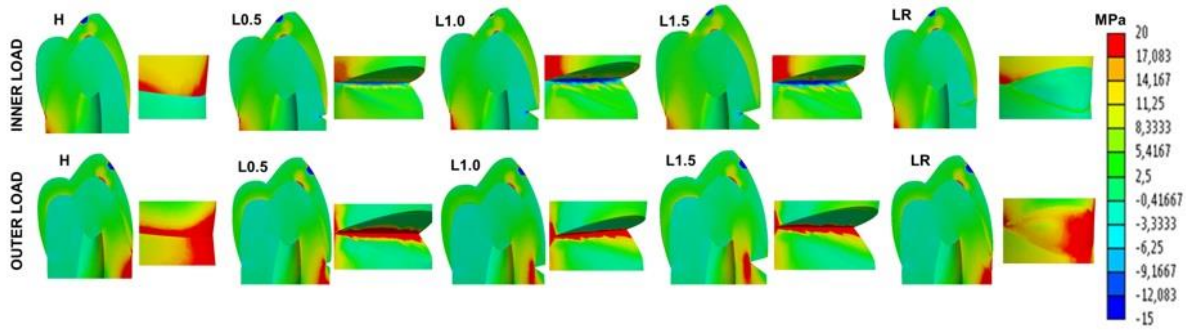

Figure 3. Maximum principal stress distribution (in MPa) in finite element analysis of five different types of non-carious cervical lesions (NCCLs) under outer and inner occlusal loading.

3.2. Strain gauge test

There were no significant differences between the µS values of buccal and mesial strain gauges, so the data were pooled for further analysis. The mean µS and standard deviation values are presented in Table 2. Two-way ANOVA confirmed significant effects of the loading direction and lesion size on µS values ($p<0.05$). The large (L1.5) lesions displayed highest mean µS values and Tukey HSD tests showed significant differences with the other groups for both loading directions ($p<0.05$). There were no significant differences in µS values between healthy (H) specimens and other lesions (i.e. L0.5, L1.0 and LR lesions) for either outer or inner loading. The µS values for outer loading were greater than those for inner loading for all groups ($p<0.05$) (Table 2).

Table 2. Mean micro-strain (µS) (standard deviation) values of different types of non-carious cervical lesions (NCCLs) for both outer and inner occlusal loading

Group	Inner loading	Outer loading
Healthy (H) teeth	527.93 (224.76) Bb	722.79 (299.95) Ba
Small (L0.5) lesion	634.00 (236.92) Bb	743.95 (192.29) Ba
Medium (L1.0) lesion	854.44 (240.13) Bb	934.48 (426.60) Ba
Large (L1.5) lesion	1306.45 (286.34) Ab	1486.03 (361.42) Aa
Large restored (LR) lesion	651.87 (259.08) Bb	790.35 (244.15) Ba

Uppercases represent vertical comparisons and lowercase represent horizontal comparisons.

3.2. Fracture resistance testing

The mean fracture resistance values and standard deviations for the three different groups are presented in Table 3. Two-way ANOVA showed significant effects of NCCL type and loading directions on fracture resistance ($p<0.05$). Tukey tests showed that the fracture resistance values were significantly greater for inner loading compared with outer loading for all three types of NCCLs ($p<0.05$). Large (L1.5) lesions displayed significantly lower fracture resistance values compared with healthy (H) teeth ($p<0.05$), but restored (LR) lesions displayed a significant recovery in fracture resistance ($p<0.05$).

Table 3. Mean fracture resistance (standard deviation) values of different types of non-carious cervical lesions (NCCLs) for both outer and inner occlusal loading

Group	Inner loading	Outer loading
Healthy (H) teeth	1032.71 (420.56) Aa	503.86 (186.33) Ab
Large (L1.5) lesion	641.41 (157.49) Ba	249.57 (99.53) Bb
Large restored (LR) lesion	903.44 (361.86) Aba	352.26 (146.25) ABb

Uppercases represent vertical comparisons and lowercase represent horizontal comparisons

For inner loading, Type I fractures were dominant in healthy (H) specimens (85.7%) whereas Type III fractures occurred frequently in both large (L1.5) lesions (57.1%) and restored (LR) lesions (85.7%). Type II fractures occurred more frequently from outer loading than inner loading in both healthy (H) specimens (57.1%) and restored (LR) lesions (57.1%). Outer loading resulted in similar fracture patterns in the restored (LR) lesions and healthy (H) specimens, with similar distributions on the buccal surfaces (42.9% of combined Type I and IV fractures in H specimens and 42.9% of Type IV fractures in LR lesions) and lingual surfaces (57.1% of Type II fractures in both H specimens and LR lesions).

4. CONCLUSION

In conclusion, the depth of NCCLs increases the magnitude and extent of stress concentration, and outer loading seems to be more destructive to tooth structure compared with inner loading. Furthermore, teeth can flex under occlusal loading, and, if NCCLs are present, there is a greater potential for the occurrence of fracture, possibly leading to non-repairable failure. Furthermore, restoration with a resin composite improved the structural integrity and biomechanical function around the NCCLs almost to the level of healthy state for both loading directions.

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7. ACCOUNTABILITY OF INFORMATION

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