THE EFFECTS OF NON CARIOUS CERVICAL LESIONS - MORPHOLOGY, LOAD TYPE AND RESTORATION - ON THE BIOMECHANICAL BEHAVIOR OF MAXILLARY PREMOLARS: A FINITE ELEMENT ANALYSIS

OS EFEITOS DAS LESÕES CERVICAIS NÃO CARIOSAS – MORFOLOGIA, TIPO DE CARREGAMENTO E RESTAURAÇÃO - NO COMPORTAMENTO BIOMECÂNICO DE PRÉ-MOLARES SUPERIORES: ANÁLISE POR ELEMENTOS FINITOS

Paulo Vinícius SOARES[1]; Giovana de Almeida MILITO[2]; Fabrícia Araújo PEREIRA[3]; Lívia Fávaro ZEOLA[4]; Marina Ferreira de Lima NAVES[5]; Vítor Laguardia Guido FARIA[6]; Alexandre Coelho MACHADO[7]; Paola Gomes SOUZA[8]; Bruno Rodrigues REIS[9]

1. Professor adjunto do departamento de Dentística e Materiais Odontológicos da Faculdade de Odontologia da Universidade Federal de Uberlândia - FOUFU, Uberlândia, MG, Brasil. paulovsoares@yahoo.com.br ; 2. Mestre em Clinica Odontológica – FOUFU, Uberlândia, MG, Brasil; 3. Doutoranda, Faculdade de Odontologia, Universidade de São Paulo – USP, São Paulo, SP, Brasil; 4. Mestranda– FOUFU, Uberlândia, MG, Brasil; 5. Graduanda – FOUFU, Uberlândia, MG, Brasil; 6. Graduando – FOUFU, Uberlândia, MG, Brasil; 7. Mestrando – FOUFU, Uberlândia, MG, Brasil; 8. Graduanda – FOUFU, Uberlândia, MG, Brasil; 9. Doutorando, Faculdade de Odontologia – USP, São Paulo, SP, Brasil

ABSTRACT: The aim of the present study was to analyze the effects of different types of non-carious cervical lesions (NCCLs) and their morphologies in premolars, restored (or not) with composite resin, on the application three occlusal loadings. The hypothesis was that differing NCCL morphologies, loading types and restoration with composite resin affect stress distribution patterns. A two-dimensional linear Finite Element Analyses (FEA) simulated a healthy tooth model (H) with dental structures including: dentin, pulp, enamel, periodontal ligament, cortical bone, and trabecular bone. Three NCCL morphological models were examined: Mixed (MI), Sauce (SA) and Wedged-shape (WS). All types of lesions were analyzed with and without restoration. The models were considered homogeneous and elastic. In each model three load types: 100N: vertical load (VL), buccal load (BL) and palatine load (PL) were applied. The Maximum Principal Stress values were analyzed. The quantitative analysis of stress (MPa) was identified at five points of the NCCLs according to the morphology of the lesion type: initial point, superior wall, center of lesion, inferior wall and final point. It was found that NCCLs restored with composite resin exhibited stress distribution patterns similar to the healthy tooth model, independent of morphology and load. The Palatine Load was responsible for providing the highest values of accumulated tensions on the NCCL. The highest values of tensile stress on NCCL areas were found in the models without composite resin restoration, which had received PL. It was concluded that the different NCCL morphologies had little effect on stress distribution patterns. The major factors that affected the biomechanical behavior of premolars presenting NCCL were load type and the presence of composite restoration.

KEYWORDS: NCCL. FEA. Composite resin.

INTRODUCTION

Non-carious cervical lesions (NCCLs) are characterized by the loss of hard tissue in cervical regions with the absence of caries and by a slow and progressive development (MILLER, 1907). This type of lesion is usually located below the CEJ, independent of tooth type, morphology or size of lesion (HUR et al., 2011). NCCLs have a multifactorial etiology that associates stress (abfraction), friction (wear) and biocorrosion (chemical, biochemical and electrochemical degradation) (GRIPPO et al., 2012). These lesions affect both genders and increase in prevalence with the age of patients (AW et al., 2002; WOOD et al., 2008; BRANDINI et al., 2012). The NCCLs are most often found on the buccal face of premolars and canines, with a higher prevalence on the first premolars (AW et al., 2002; WOOD et al., 2008).

Studies have discovered that cervical lesions present varying morphological aspects. HUR et al. (2011) classified NCCLs into three morphologies: wedge-shaped, source-shaped and mixed-shape. A wedge-shaped lesion is characterized by a sharp internal line angle. The saucer-shape lesion has a rounded internal line angle. When the lesion has smooth lines and semi-circular shape, but the cervical wall has a clearly acute angle line, it is called a mixed-shape lesion (HUR et al., 2011). Some authors suggest that, while the morphology can be derived from multifactorial etiology, the

Received: 09/10/12
Accepted: 19/02/13

shape is not associated with the cause of the lesion (WOOD et al., 2008).

Occlusal factors have been identified as the major etiological factors for NCCL formation and growth. Once established, the lesion may present accelerated progression due to tooth brushing with excessive pressure and acidic substances, (TAKEHARA et al., 2008; GRIPPO et al., 2012). Some habits like nail biting, clenching teeth, and temporal-mandibular dysfunctions are factors that may be related to NCCL etiology and progression and should be diagnosed and considered in treatment (BRANDINI et al., 2012).

Different types of occlusal contact create varying patterns of stress distribution on teeth. Contact on the long axis of the tooth may be related to excessive stress generated in the cervical region and with the formation of cervical lesions (REES, 2002). This contact can lead to a weakening of the continuity between the hard tooth structures and cause increased stress in the cervical region (ANDREAUS et al., 2011). These factors, combined with poorly developed enamel and the demineralizing effects of acid biocorrosion, can lead to the emergence of NCCLs (REES, 2002).

The restoration of NCCLs is not considered "treatment" but the removal of etiological factors and the replacement of lost tissue can promote an improvement in aesthetics and a reduction of possible hypersensibility (MICHAEL et al., 2009). Composite resins, glass ionomer cements and Polyacid Modified Composite Resin are useful for the restoration of these lesions (WOOD ed al., 2008; ONAL; PAMIR, 2005; TURKUN e CELIK, 2008). Adhesive predictability promotes successful and satisfactory bonding to tooth structure (BURROW; TYAS, 2008; FRON et al., 2011; CHEE et al., 2012). The resins have an elasticity similar to dentine, which may be considered sufficient to offset the stress generated by occlusal forces (SENAWONGSE et al., 2010).

Methods that use simulated dental structures and their properties are useful to analyze the dental behavior associated with structural loss, occlusal conditions and the effects of restorative materials. The finite element method is a tool that enables analysis of the stress that is generated on teeth in commonly observed situations. This analysis aides the professional in the diagnosis and planning of treatment, providing greater security (DEJAK et al., 2003; REES et al., 2003; CHATVANITKUL; LERTCHIRAKARN, 2010).

The purpose of this study was to analyze the effects of different NCCL morphologies in premolars, restored (or not) with composite resin, applying three different occlusal loadings. It was hypothesized that differing NCCL morphologies, loading types and restoration with composite resin affect the biomechanical behavior of maxillary premolars.

MATERIAL AND METHODS

Finite element analysis (FEA) was used to evaluate the effects of NCCL morphologies, occlusal contact type and composite restoration, on the pattern of stress distribution of premolars. A computerized two-dimensional linear Finite Element Analyses (FEA) simulated a healthy tooth model (H) with dental structures including: dentin, pulp, enamel, periodontal ligament, cortical bone, and trabecular bone (SOARES et al., 2009). Three NCCL morphology models were examined: Mixed (MI), Sauce (SA) and Wedged-shape (WS) *(*HUR et al., 2011*)*. All types of lesions were analyzed with and without restoration (Figure 1).

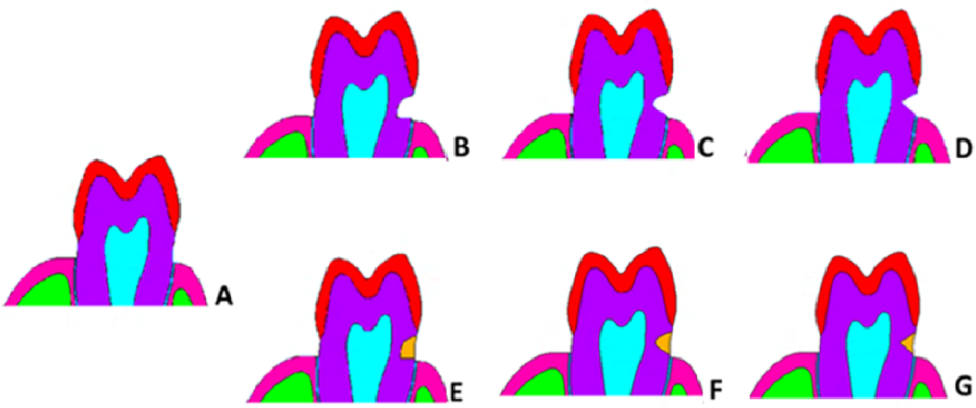

Figure 1. Simulated models. A) Healthy (H); B) Mixed model (MI); C) Saucer model (SA); D) Wedge Shaped model (WS); E) Restored MI model; F) Restored SA model; G) Restored WS model.

The dental structures' geometry was simulated using CAD Software (Autodesk Mechanical Desktop 6; Autodesk Inc., San Rafael, Calif) in order to obtain internal and external structural contours (Figure 2.A). The data obtained were exported to ANSYS 12.0 using the *.iges format (Figure 2.B). The stress distribution patterns were analyzed using ANSYS 12.0 (ANSYS Inc. Houston, USA). This software was used to define the area of the dental structures (Figure 2.C), their mechanical properties, mesh (Figure 2.D), boundary conditions of each model (Figure 2. E-H) and to produce the resulting analysis.

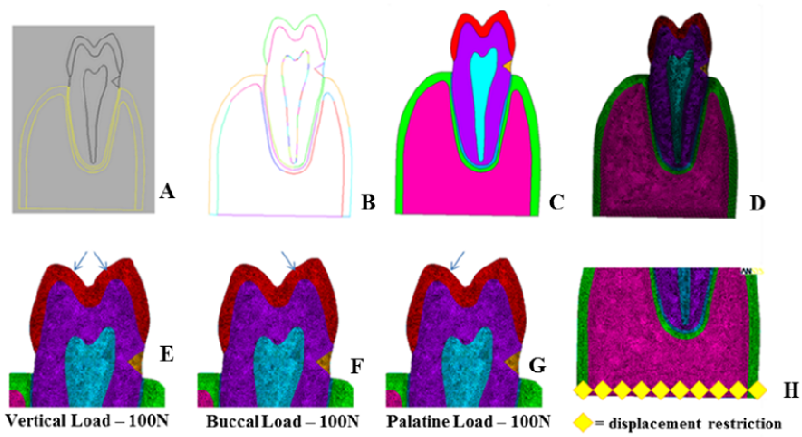

Figure 2. Finite Element models generation. A) CAD software model outlines; B) Outlines exported to ANSYS; C) Created areas of each dental and support structure; D) Mesh; E) Vertical Load (VL) application; F) Buccal Load (BL) application; G) Palatine Load (PL) application; H) Displacement restriction.

Areas corresponding to each structure were plotted by linear associations (Figure 2. B and C). The mesh of the models was elaborated using isoparametric elements of 8- brick nodes with three degrees of freedom per node (PLANE 183) according to the mechanical properties of each structure. The values for mechanical properties were obtained by means of a literature review (Tables 1 and 2). The meshing process involved division of the system being studied into a set of small discrete elements defined by nodes. The number of elements generated varied depending on the different geometries that were meshed, so that the final result accurately represented the original geometry. Enamel and dentine properties were considered orthotropic; the other dental structural properties used were considered isotropic. The models were considered homogeneous and elastic.

Table 1. Mechanical properties used to perform isotropic structures.

Structure/Material	Elasticity Modulus (GPa)	Poisson ratio
Pulp	0.003	0.45
Periodontal Ligament	0.068	0.45
Cortical bone	13.7	0.30
Trabecular bone	1.37	0.30
Composite resin	16.6	0.24

Source**:** JOSHI, 2001; TOPARLI, 2003; SILVA et al., 2009.

Table 2. Mechanical properties used to perform orthotropic structures.

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

Source: MIURA et al., 2009.

Each step of the boundary conditions consisted of the displacement restrictions of the model and load application. The displacement model was restricted in all nodes on the base of the cortical and medullar bone (Figure 2. H). Three different types of load, of 100N each, were distributed and applied on five nodes (Figure 2. E-G): Vertical Load (VL), Buccal Load (BL) and Palatine Load (PL) (REES, 2002). These applied loads simulated occlusal interference on the palatine and buccal slopes of the premolars during occlusion (in maximum intercuspal position). The VL was distributed equally on both cusps so that its result was parallel to the long axis of the tooth (Figure 2. E). The BL was applied in the buccal cusp, at 45 degrees to the long axis (Figure 2. F) and the PL was equally applied in the palatine cusp (Figure 2. G). Maximum Principal Stress (σ1) was analyzed for each model created. The quantitative analysis of stress (MPa) was calculated at five points of NCCL according to morphology lesion types. (Figure 3).

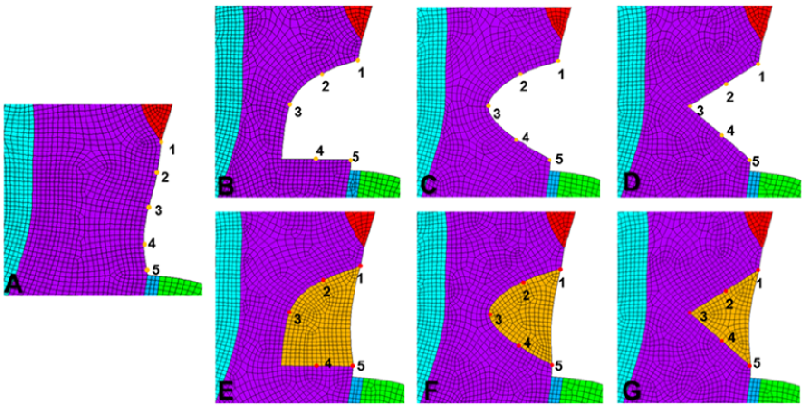

Figure 3. Selected points for calculation of stress values (MPa) in the analysis of NCCL morphologies. Point 1: Initial point; Point 2: Superior wall; Point 3: Center of lesion; Point 4: Inferior wall and Point 5: Final point. A) H model; B) MI model; C) SA model; D) WS model; E) Restored MI model; F) Restored SA model; G) Restored WS model.

RESULTS

The healthy (H) model presented better stress distribution, independently of the load applied, when compared to all of the non-restored models (Figure 4). When load was applied vertically, the tensile stress accumulated in the buccal cervical region demonstrated values approximating 1 MPa (Figure 5). The H/BL model presented similar values for the buccal cervical dentin region, compared to the H/VL model. In the H/BL model, tensile stresses were concentrated in the cervical region of the palatine face. The H/PL model produced the highest concentration of tensile stress in the cervical region of the vestibular face, approaching 7Mpa at point 4 (Figure 4).

The vertical load (VL) produced lower levels of stress concentration than the other types of load, independently of lesion type (Figure 6). Higher values of tensile stress were found at point 2 for MI lesions, 2.80 Mpa (Figure 5).

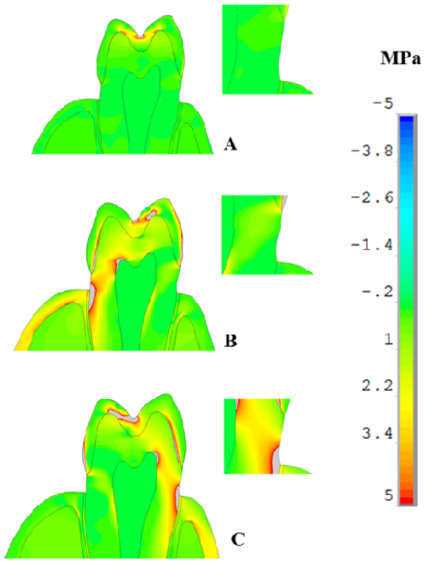

Figure 4. Maximum Principal Stress distribution on the Healthy (H) model. A) H/VL; B) H/BL; C) H/PL.

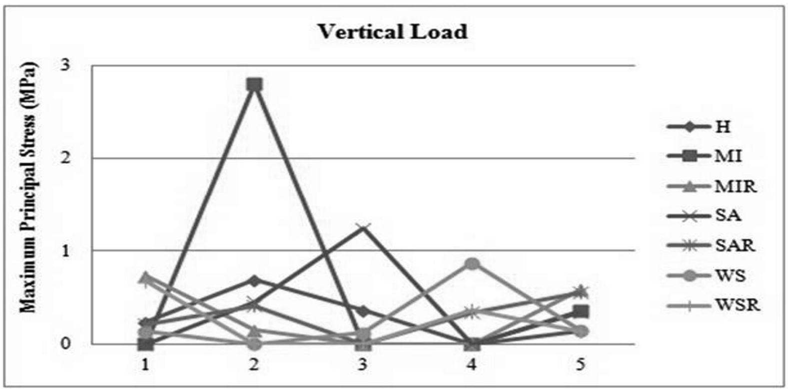

Figure 5. Maximum Principal Stress values (MPa) on NCCLs at selected points on models that received Vertical Load (VL).

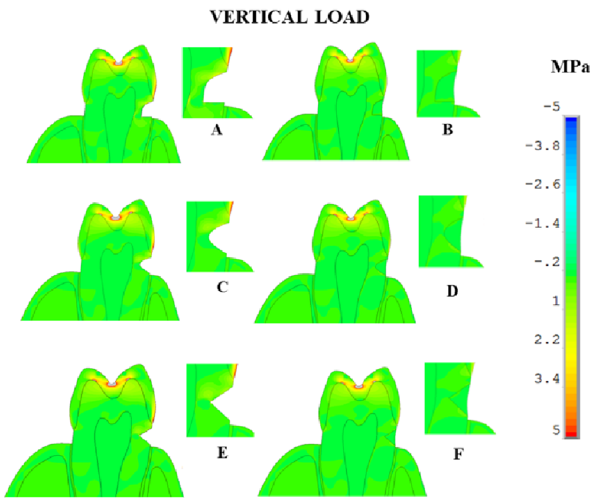

Figure 6. Maximum Principal Stress distribution of NCCL morphology models that received Vertical Load (VL). A) MI model; B) Restored MI model; C) SA model; D) Restored SA model; E) WS model; F) Restored WS model.

Models with buccal load (BL) presented higher tensile stress concentration on the enamel surface of the buccal face and on the cervical region of the palatine face, affecting adjacent periodontal support tissues (Figure 7). The BL promoted higher values of tensile stress at point 2 of the SA and MI models with values of 8.99 and 8.19 MPa, respectively (Figure 8).

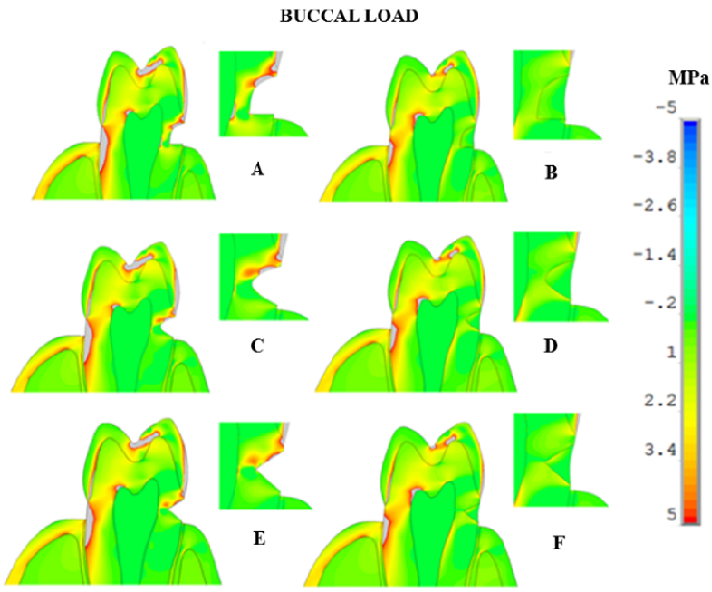

Figure 7. Maximum Principal Stress distribution of NCCL morphology models that received Bucal Load (BL). A) MI model; B) Restored MI model; C) SA model; D) Restored SA model; E) WS model; F) Restored WS model.

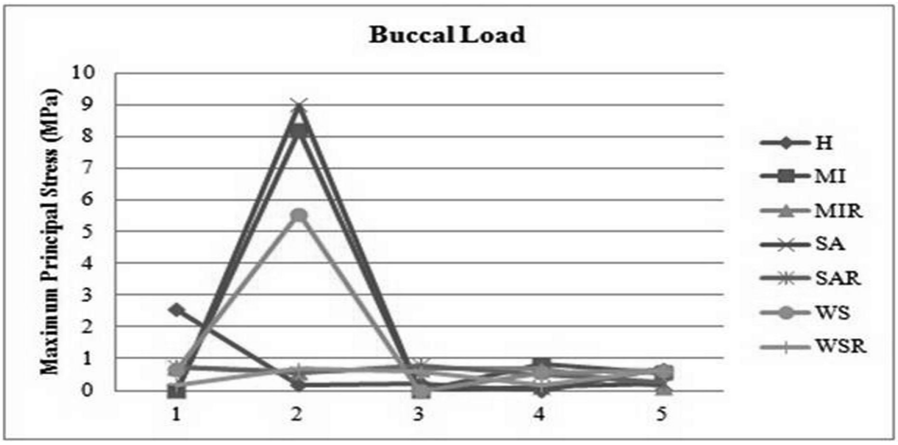

Figure 8. Maximum Principal Stress values (MPa) on NCCLs at selected points on models that received Buccal Load (BL).

Palatine load (PL) presented the highest tensile stress values when compared to the other types of loads, independently of lesion type (Figure 9). PL was associated with the tensile stress concentration on the cervical region of the buccal face and on the enamel surface of the palatine face. The adjacent periodontal support of the buccal face was also affected (Figure 10). Higher values of tensile stress were found at point 3 of the WS and SA models with values of 35.39 and 26.73 respectively (Figure 9).

Independently of lesion morphology or load type, when the NCCLs were restored with composite resin, better stress distribution was identified in the models. Models that had lesions restored, demonstrated stress distribution patterns similar to those of a healthy tooth.

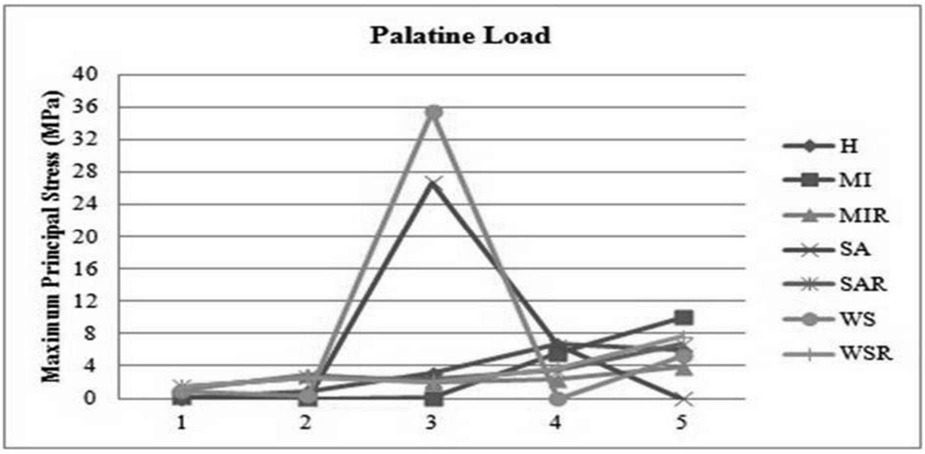

Figure 9. Maximum Principal Stress values (MPa) on NCCLs at selected points on models that received Palatine Load (PL).

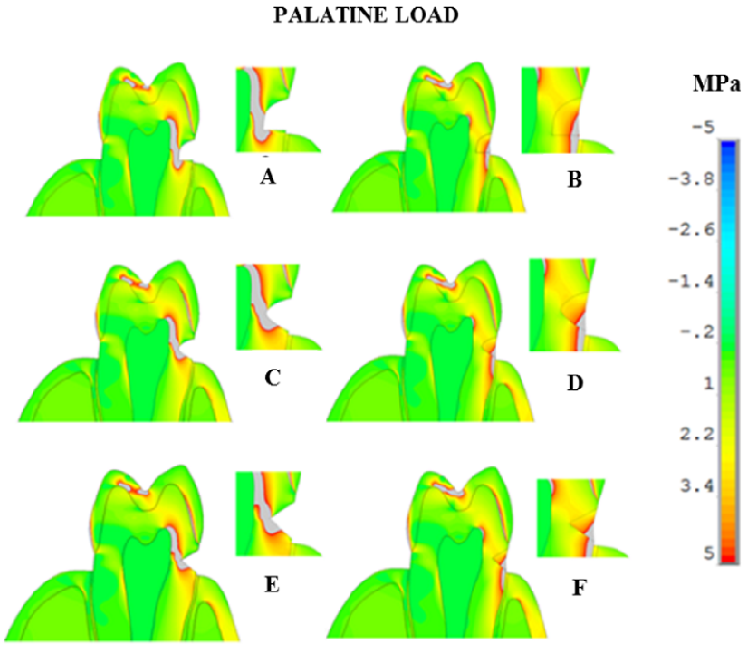

Figure 10. Maximum Principal Stress distribution of NCCL morphology models that received Palatine (PL). A) MI model; B) Restored MI model; C) SA model; D) Restored SA model; E) WS model; F) Restored WS model.

DISCUSSION

Lesion morphology had minimal effect on the biomechanical behavior of maxillary premolars. Load type and the presence of restoration, however, were principal factors associated with the stress distribution patterns.

Buccal load promoted greater concentration of tensile stress in the cervical region of the palatine face and greater stress values at point 2 of non-restored NCCLs, regardless of morphology (Figures 7 and 8). In models with restored NCCLs there was a lower concentration of tensile stress in the cervical region, similar to model H. Stress generated at point 2 of the NCCLs presented a better distribution on restored models.

The results of this study thus demonstrated that the PL produced higher concentrations of stress in the cervical region of the buccal face as compared to the VL and BL concentrations. This finding is in agreement with (REES, 2002), who reported that change in position of the occlusal contact varies the intensity of tensile stress in the cervical region.

In non-restored models, the PL produced a large accumulation of stress at point 4 of the NCCLs, regardless of morphology. These accumulations may be a factor that causes horizontal progression of NCCLs, resulting in an increase in depth of the lesion. When the same load was applied in models with restored NCCLs, stress increased in the buccal cervical region, especially in the root dentin and part of the composite resin restoration. The presence of restoration resulted in a distribution of stress that was similar to the H model and those that received PL.

The occlusal loading along the long axis of the tooth (VL), created stress in the cervical region (PALAMARA et al., 2000) varying according to the amount and size of the NCCLs (MADANI;AHMADIAN-YAZDI, 2005). For this reason occlusal adjustment should be part of NCCL treatment (BORCIC et al., 2005).

Models with SA and WS morphologies that received VL demonstrated a concentration of tensile stress at point 2 of the NCCLs. This stress concentration could produce a longitudinal progression of the lesion leading to increased vertical extension of the lesion. The SA, WS and MI morphologies, when subjected to PL, demonstrated tensile stress concentration at point 4 of the NCCLs which could result in progressive depth of the lesion. Both types of loading, if not adjusted to an adequate occlusion, could result in progression of the NCCL dimensions.

Restoration of lesion is not simply removal of the etiology or treatment. It is a replacement of lost tissue to improve dentine hypersensitivity and aesthetics (MICHAEL et al., 2009). Resin is among the restorative materials currently of choice. It is the most widely used due to its aesthetic and mechanical properties (KIM et al., 2009) as well as being an effective and conservative technique (WOOD et al., 2008). The composite resin restored NCCLs, regardless of the type of loading or morphology of the lesion, demonstrated better stress distribution, similar to the healthy model, due to the mechanical properties of composite resin. There were, however, some cases of failure in class V composite restoration. These may be related to the greater difficulty in achieving adhesion to dentin sclerotic, usually at the base of the NCCL (TAY et al., 2000). Other factors that can affect the longevity of the restoration include marginal staining (straining?) of the restoration, (possibly due to polymerization shrinkage of the composite), the insertion of large volumes of resin or difficult access in the lobby distal area, for finishing the restoration (BURROW et al., 2012).

Point 3 of the MI models was not the area of principal stress concentration. The area of greatest tensile stress concentration was at the internal angle of the lesion. These data were not standardized or compared, however, with the data from the other lesion morphologies.

The finite element analyses simulated a clinical situation. But because of limitations of this method, *in vivo* and *in vitro* studies still need to be performed to elucidate and complete the data.

CONCLUSIONS

The different NCCL morphologies demonstrated minimal effects on stress distribution patterns, while the main factors affecting the biomechanical behavior of premolars were load type and NCCL restoration.

The composite restorations resulted in similar stress distribution patterns and lower values of tensile stress than observed in healthy teeth. This was also the case when restorations were compared with non-restored models for all load types, independently of lesion morphology.

The load applied on the palatine cusp was more harmful for dental structure when compared to loads on buccal or both cusps. Load values on both cusps demonstrated better stress distribution and the lowest tensile stress values.

ACKNOWLEDGEMENTS

The authors express their appreciation to: CNPq-PIBIC/UFU-SAU019 program and the Extension, Research and Teaching Group of Non Carious Cervical Lesions and Dentin Hypersensitivity-LCNC FOUFU for their support, essential for the development of our activities.

RESUMO: O objetivo desse estudo foi analisar a influência de diferentes morfologias de lesões cervicais não cariosas (LCNCs) em pré-molares superiores restaurados ou não com resina composta, aplicando três diferentes carregamentos oclusais. A hipótese é que a morfologia, o tipo de carregamento e a restauração influenciem no padrão de distribuição de tensão. Através do método de elementos finitos, foram simulados modelos bidimensionais, homogêneos, lineares e elásticos. O modelo do dente hígido (H) foi representado com as seguintes estruturas: dentina, polpa, esmalte, ligamento periodontal, osso cortical, osso trabeculado e posteriormente simulou-se três morfologias de LCNCs: Mista(MI), Arredondada (SA) e em forma de Cunha (WS). Todos os tipos de lesão foram analisados com a presença e ausência da restauração. Em cada modelo foram aplicados três diferentes tipos de carregamento, com 100 N cada: carregamento vertical (VL), carregamento vestibular (BL) e carregamento palatino (PL). A análise quantitativa das tensões foi realizada através do critério de Tensão Máxima Principal em cinco regiões de cada LCNC, nos seguintes pontos: ponto inicial, parede superior, centro da lesão, parede inferior e ponto final. Como resultado, as LCNCs restauradas com resina composta apresentaram distribuição de tensão semelhante a do modelo do dente hígido, independente da morfologia e do carregamento. O carregamento palatino foi responsável pelos maiores valores de acúmulo de tensão nas LCNCs. É possível conclui que Os diferentes tipos de morfologia das LCNCs apresentaram pequena influencia no padrão de distribuição de tensão. Os fatores de maior influência no comportamento biomecânico de pré-molares foram o tipo de carregamento e a presença da restauração.

PALAVRAS-CHAVE: NCCL. MEF. Resina Composta.

REFERENCES

ANDREAUS, U.;COLLOCA, M.; IACOVIELLO, D. Coupling image processing and stress analysis for damage identification in a human premolar tooth. **Comput Methods Programs Biomed**, Amsterdam, v. 103, n. 2, p. 61-73, Aug 2011.

AW, T. C.; LEPE,X.; JOHNSON, G.H.;MANCL, L. Characteristics of noncarious cervical lesions: a clinical investigation. **J Am Dent Assoc**, Chicago, v. 133, n. 6, p. 725-33, Jun 2002.

BORCIC, J.;ANIC, I.;SMOJVER, I.; CATIC, A.; MILETIC, I.; RIBARIC,S. P. 3D finite element model and cervical lesion formation in normal occlusion and in malocclusion. **J Oral Rehabil**, England, v. 32, n. 7, p. 504-10, Jul 2005.

BRANDINI, D. A.;PEDRINI,D.;PANZARINI,S.R.;BENETE,I.M.;TREVISAN,C.L. Clinical evaluation of the association of noncarious cervical lesions, parafunctional habits, and TMD diagnosis. **Quintessence Int** , Germany, v. 43, n. 3, p. 255-62, Mar 2012.

BURROW, M. F.; TYAS, M. J. A clinical trial comparing two all-in-one adhesive systems used to restore non-carious cervical lesions: results at one year. **Aust Dent J**, Sidney, v. 53, n. 3, p. 235-8, Sep 2008.

BURROW, M. F.; TYAS, M. J. Comparison of two all-in-one adhesives bonded to non-carious cervical lesions--results at 3 years. **Clin Oral Investig.**, Berlin, v. 16, n. 4,p. 1089-94, Aug 2012

CHATVANITKUL, C.; LERTCHIRAKARN, V. Stress distribution with different restorations in teeth with curved roots: a finite element analysis study. **J Endod**, Chicago, v. 36, n. 1, p. 115-8, Jan 2010.

CHEE, B.; RICKMAN, L. J.; SATTERTHWAITE, J. D. Adhesives for the restoration of non-carious cervical lesions: a systematic review. **J Dent**, Bristol, v. 40, n. 6, p. 443-52, Jun 2012.

DEJAK, B; MLOTKOWSKI, A. Finite element analysis of stresses in molars during clenching and mastication. **J Prosthet Dent**, St. Louis, v. 90, n. 6, p. 591-7, Dec 2003.

FRON, H., VERGNES, J. N.; MOUSSALLY, C.; CAZIER, S.; SIMON, A. L.;CHIEZE, J. B.; SAVARD, G.;TIRLET, G.;ATTAL, J. P. Effectiveness of a new one-step self-etch adhesive in the restoration of non-carious cervical lesions: 2-year results of a randomized controlled practice-based study. **Dent Mater**, Copenhagen,v. 27, n. 3, p. 304-12, Mar 2011.

GRIPPO, J. O.; SIMRING, M.; COLEMAN, T. A. Abfraction, abrasion, biocorrosion, and the enigma of noncarious cervical lesions: a 20-year perspective. **J Esthet Restor Dent**, England, v. 24, n. 1, p. 10-23, Feb 2012.

HUR, B.; KIM, H. C.; PARK, J. K.; VERSLUIS, A.Characteristics of non-carious cervical lesions--an ex vivo study using micro computed tomography. **J Oral Rehabil**, England, v. 38, n. 6, p. 469-74, Jun 2011.

JOSHI, S.; MUKHERJEE, A.; KHEUR,M.; MEHTA, A. Mechanical performance of endodontically treated teeth.**Finite Elem Anal Des**, Amsterdam, v. 37, p. 587-601, 2001.

KIM, S. Y; LEE, K. W.; SEONG, S. R.; LEE, M. A; LEE, I. B.; SON, H. H.;KIM, H. Y.; OH, M. H.; CHO, B. H. Two-year clinical effectiveness of adhesives and retention form on resin composite restorations of non-carious cervical lesions. **Oper Dent**, Seattle, v. 34, n. 5, p. 507-15, Sep-Oct 2009.

MADANI, A. O.; AHMADIAN-YAZDI, A. An investigation into the relationship between noncarious cervical lesions and premature contacts. **Cranio**, United States, v. 23, n. 1, p. 10-5, Jan 2005.

MICHAEL, J. A.; TOWNSEND, G. C.; GREENWOOD, L. F.; KAIDONIS, J. A. Abfraction: separating fact from fiction. **Aust Dent J**, Sidney, v. 54, n. 1, p. 2-8, Mar 2009.

MILLER, W. D.Experiments and observations on the wasting of tooth tissue variously designated as erosion, abrasion, chemical abrasion, denudation, etc. **Dent Cosmos**, Chicago, v. 49, p. 225-247, 1907.

MIURA, J.; MAEDA,Y.;NAKAI,H.; ZAKO, M. Multiscale analysis of stress distribution in teeth under applied forces. **Dent Mater**, Copenhagen, v. 25, n. 1, p. 67-73, Jan 2009.

ONAL, B.; PAMIR, T. The two-year clinical performance of esthetic restorative materials in noncarious cervical lesions. **J Am Dent Assoc**, Chicago, v. 136, n. 11, p. 1547-55, Nov 2005.

PALAMARA, D.; PALAMARA, J. E.; TYAS, M. J.; MESSER, H. H. Strain patterns in cervical enamel of teeth subjected to occlusal loading. **Dent Mater**, Copenhagen, v. 16, n. 6, p. 412-9, Nov 2000.

REES, J. S. The effect of variation in occlusal loading on the development of abfraction lesions: a finite element study. **J Oral Rehabil**, England, v. 29, n. 2, p. 188-93, Feb 2002.

REES, J. S.;HAMMADEH,N.;JAGGER,D.C.Abfraction lesion formation in maxillary incisors, canines and premolars: a finite element study. **Eur J Oral Sci**, Copenhagen, v. 111, n. 2, p. 149-54, Apr 2003.

SENAWONGSE, P.; POMQPRUEKSA, P.;TAGAMI, J. The effect of the elastic modulus of low-viscosity resins on the microleakage of Class V resin composite restorations under occlusal loading. **Dent Mater J**, Copenhagen, v. 29, n. 3, p. 324-9, May 2010.

SILVA, N. R.; CASTRO,C. G. ;SANTOS-FILHO, P. C., SILVA, G. R.,CAMPOS, R. E.; SOARES, P. V.; SOARES,C.J. Influence of different post design and composition on stress distribution in maxillary central incisor: Finite element analysis. **Indian J Dent Res**, Ahmedabad, v. 20, n. 2, p. 153-8, Apr-Jun 2009.

SOARES,C. J.; CASTRO,C. G.; SANTOS-FILHO,P. C.; SOARES, P. V.; MAGALHAES, D.; MARTINS, L. R. Two-dimensional FEA of dowels of different compositions and external surface configurations. **J Prosthodont**, Philadelphia, v. 18, n. 1, p. 36-42, Jan 2009.

TAKEHARA, J.; TAKANO, T.; AKHTER, E.; MORITA, M. Correlations of noncarious cervical lesions and occlusal factors determined by using pressure-detecting sheet. **J Dent**, Bristol, v. 36, n. 10, p. 774-9, Oct 2008.

TAY, F. R.; KWONG, S. M.; ITTHAGARUN, A.; KING, N. M.; YIP, H. K.; MOULDING, K. M.; PASHLEY, D. H. Bonding of a self-etching primer to non-carious cervical sclerotic dentin: interfacial ultrastructure and microtensile bond strength evaluation. **J Adhes Dent,** New Malden, v. 2, p. 9-28., 2000. 28.

TOPARLI, M. Stress analysis in a post-restored tooth utilizing the finite element method. **J Oral Rehabil**, England, v. 30, n. 5, p. 470-6, May 2003.

TURKUN, L. S.; CELIK, E. U. Noncarious class V lesions restored with a polyacid modified resin composite and a nanocomposite: a two-year clinical trial. **J Adhes Dent**, New Malden, v. 10, n. 5, p. 399-405, Oct 2008.
WOOD, I.; JAWAD, Z.; PAISLEY,C.; BRUNTON, P. Non-carious cervical tooth surface loss: a literature review. **J Dent**, Bristol, v. 36, n. 10, p. 759-66, Oct 2008.