BIOSCIENCE JOURNAL

INFLUENCE OF NON-CARIOUS CERVICAL LESIONS, BONE ATTACHMENT LEVEL, AND OCCLUSAL LOAD ON THE STRESS DISTRIBUTION PATTERN IN MAXILLARY PREMOLARS: FINITE ELEMENT ANALYSIS

Thiago Silva PERES[1], Daniela Navarro Ribeiro TEIXEIRA[1], Paulo Vinícius SOARES[2], Lívia Favaro ZEOLA[3], Alexandre Coelho MACHADO[4]

[1] Postgraduate Student and Member of Nucleus Extension, Research and Teaching at NCCL, Dentistry School, Federal University of Uberlandia, Brazil.
[2] Department of Operative Dentistry and Dental Materials, Dentistry School, Federal University of Uberlândia, Uberlandia, Minas Gerais, Brazil.
[3] 3Department of Restorative Dentistry, Dentistry School, Federal University of Minas Gerais and Member of Nucleus Extension, Research and Teaching at NCCL, Dentistry School, Federal University of Uberlandia, Brazil.
[4] Professor at Technical Health School and Coordinator of Nucleus Extension, Research and Teaching at NCCL, Dentistry School, Federal University of Uberlandia, Brazil.

Corresponding author:
Alexandre Coelho Machado
alexandrecoelhomachado@gmail.com

How to cite: PERES, T.S., et al. Influence of non-carious cervical lesions, bone attachment level, and occlusal load on the stress distribution pattern in maxillary premolars: Finite element analysis. *Bioscience Journal*. 2022, **38**, e38072. https://doi.org/10.14393/BJ-v38n0a2022-58132

Abstract

This study aimed to evaluate the influence of different bone attachment levels and occlusal loads on the stress distribution pattern of maxillary premolars with or without non-carious cervical lesion (NCCL), before and after restoration with composite resin by three-dimensional (3D) finite element analysis. From the healthy model, NCCL models were produced and the cavity was restored with composite resin. Models with vertical and horizontal bone loss were also made. For each model, three types of occlusal loads were simulated (100 N): vertical load (VL), buccal load (BL), and palatal load (PL). After processing the models, the data were obtained in MPa for the criteria of Maximum Principal Stress (for all structures) and Minimum Principal Stress (for cortical and medullary bones). Stress values were collected for a node on the cervical buccal surface (Maximum Principal Stress) and the buccal crestal bone (Minimum Principal Stress). As a result, the different bone attachment levels did not affect stress distribution at the amelodentinal junction. The buccal load promoted a higher concentration of compressive stress on the buccal bone surface and the palatal load resulted in greater tensile stress in the buccal cervical third of the tooth. The concentration of tensile stress in the buccal cervical third was exacerbated by the presence of NCCL and it was similar to the healthy and restored models. It can be concluded that stress concentration at the bone level does not depend on the presence or absence of NCCL and the restoration procedure but it is related to the type of occlusal load. However, the presence of NCCL promoted a higher stress concentration in the cervical region, especially when combined with oblique occlusal loads.

Keywords: Dental occlusion. Finite element analysis. Gingival recession. Permanent dental restoration. Tooth wear.

1. Introduction

The worldwide prevalence of non-carious cervical lesions (NCCLs) among adults is 46.7% and it is higher in older populations than younger ones (Teixeira et al. 2020). The NCCLs are pathological conditions characterized by the loss of tooth structure at the cementoenamel junction (CEJ), unrelated to bacterial processes (Borcic et al. 2004; Michael et al. 2009; Reyes et al. 2009; Bhundia et al. 2019; Soares et al. 2021). This tooth structure loss is routinely found and increasingly common in dental clinical practice (Rees 2002; Borcic et al. 2004; Michael et al. 2009; Reyes et al. 2009), with a positive correlation to the presence of gingival recession (GR) (Teixeira et al. 2018) and a multifactorial etiology (Alvarez-Arenal, et al. 2019; Kolak, et al. 2018). The three mechanisms involved in the development of these lesions are stress (abfraction), friction (wear), and biocorrosion (chemical, biochemical, and electrochemical degradation) (Grippo et al. 2012; Rusu Olaru et al. 2019). The NCCLs also increase with age, which suggests a fatigue component in their formation associated with occlusal interferences or any event that changes dental occlusion, such as restorative procedures, occlusal surface wear, tooth position changes, and toothbrushing behavior (Bernhardt et al. 2006).

One of the major factors that contribute to NCCLs and the progression of gingival recession (GR) is excessive loading associated with occlusal forces (Dejak and Mlotkowski 2011; Duangthip et al. 2017). Two types of loading on premolars have been described (Soares et al. 2014; Soares et al. 2015): oblique load (due to oblique or inclined contact with the lingual/buccal surface) and vertical load (along the long axis of the tooth, applied via incisal edge). Dental biomechanical behavior, when submitted to oblique loads, changes the stress/strain distribution pattern (Du et al. 2020), resulting in the fatigue and rupture of rigid structures such as enamel.

Oblique loads can also affect the loss of alveolar bone and represent a pathologic or age-related phenomenon. Although 0.017 mm/year of alveolar bone loss is considered normal (Corn and Marks 1989), greater amounts of bone resorption can be found in some adults without any diagnosable pathologic condition. Several studies have investigated stress distributions and displacement patterns in teeth with different amounts of alveolar bone loss (Cobo et al. 1996; Geramy 2000; Wood et al. 2008; Vandana et al; 2016). However, no study evaluated the relationship between bone loss and the development of non-carious cervical lesions.

The multifactorial characteristics of NCCLs must be considered while developing a multidisciplinary treatment (Teixeira et al. 2018). Although the literature is not clear about the treatment protocol (Kim et al. 2009), it is notorious that rehabilitation longevity consists of the restoration of lost structures, occlusal analysis, and patient education about their habits. Restorations are recommended as a protection against cervical dentin hypersensitivity, prevention of excessive wear, improvement of esthetic standard requirements (Soares et al. 2013; Machado, et al. 2017), and especially to minimize damage to the dental structure due to changes in stress/strain distribution (Poiate et al. 2009; Machado, et al. 2017).

Methods using simulated dental structures are useful to analyze the dental behavior associated with structural loss, occlusal conditions, and the effects of restorative materials, considering their properties (Poiate et al. 2009). The finite element analysis (FEA) method analyzes the biomechanical behavior of teeth in specific clinical situations to understand failure causes, treatment protocols, and pathological changes (Rees 2002; Vasudeva and Bogra 2008; Poiate et al. 2009; Jakupović et al. 2016; Zeola et al. 2016; Machado et al. 2017; Correia et al. 2018; Yang and Chung 2019; Matos et al. 2020).

Thus, this study aimed to evaluate the influence of different bone attachment levels and occlusal load conditions on stress distribution in maxillary premolar models with or without NCCLs, before and after the restorative procedure with composite resin, using three-dimensional (3D) finite element analysis. The null hypothesis is that bone attachment, restorative procedures, and occlusal loads do not interfere with the biomechanical behavior of the tooth.

2. Material and Methods

A three-dimensional, linear, elastic, and homogeneous finite element analysis was performed with anatomically-based geometric representations for pulp, dentin, enamel, periodontal ligament, and cortical and medullary bones (Soares et al. 2013). Nine computer-aided design (CAD) models were made (Rhinoceros 3D software, Rhinoceros, Miami, FL, USA) differing the cervical region (sound tooth-SO, unrestored buccal wedge-shaped NCCL-UN, and NCCL restored with composite resin-CR) and the level of bone loss (normal-NO, vertical-VE, and horizontal-HO).

The models were exported to the processing analysis software (ANSYS 12.0, Ansys Workbench 12.0.1, Canonsburg, PA, USA) using the Standard for the Exchange of Product Data (STEP) format. The following steps were performed in this software: preprocessing (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). Enamel and dentin were considered orthotropic and the other structures were isotropic (Table 1) (Carter and Hayes 1977; Weinstein et al. 1980; Rubin et al. 1983; Shinya et al. 2008; Miura et al. 2009).

Table 1. Mechanical properties used for orthotropic and isotropic structures.

Structures	Orthotropic Structures (Miura et al. 2009)		
	Elastic Modulus (MPa)		
	LONGITUDINAL	TRANSVERSE	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 (Rubin et al. 1983)	2.07	0.45
Periodontal ligament (Miura et al. 2009)	68.9	0.45
Cortical bone (Carter and Hayes 1977)	13700	0.30
Medullary bone (Carter and Hayes 1977)	1370	0.30
Hybrid composite resin (Shinya et al. 2008)	22000	0.27

MPa: Megapascal; v: resulting Poisson's ratio; Z: z axis.

After testing the mesh conversion to define the appropriate refinement level, volumes corresponding to each structure were meshed with controlled and connected elements. The meshing process involved the division of the system studied into a set of small and discrete elements defined by nodes. Solid quadratic tetrahedral elements of 10 nodes were used. The mesh conversion test was initiated using the automatic meshing software and continued by gradually decreasing the size of the elements. For each test stage, the results were generated by an equivalent stress criterion (von Mises) to verify the highest stress values of dentin. The mesh was considered satisfactory when, even by reducing the dimension of elements, the highest stress levels were similar to the results observed in the previous mesh refinement. The number of elements used varied depending on the different volumes so that the final model accurately represented the original geometry. Due to the adhesive properties of the composite resin and adhesive system, the restoration was bonded to the dental structures by considering a mesh connection with dentin and enamel.

After the mesh step, boundary conditions were determined. The models underwent three types of loads (100N) applied to specific surfaces previously defined in CAD software. The vertical load (VL) was distributed equally on both cusps, simulating a homogeneous contact distribution. The buccal load (BL) and palatal load (PL) were applied at 45 degrees to the long axis on buccal and palatal cusps respectively, simulating occlusal interferences (Rees 2002). The models were constrained to the side and base of cortical and trabecular bones to prevent displacement (Zeola et al. 2015; Machado et al. 2017).

The stress distribution analyses were recorded using the Maximum and Minimum Principal Stress criteria, measured in MPa. For the 3D image perspectives, the composite resin was plotted in transparency for a better understanding of the NCCLs walls. In the sagittal analyses, the composite resin was plotted to identify the stress on the restorative material. For analyzing the cervical region, stress values were obtained by Maximum Principal Stress in one mesh node on the buccal cervical surface. Similarly, the stress values by Minimum Principal Stress were obtained in one mesh node for analyzing the buccal crestal bone.

3. Results

The figures 1-4 show the stress distribution among all models under different loading conditions. Maximum Principal Stress may not affect the appearance of NCCLs. The stress distribution was almost the same on axial, buccal, or palatal loads in sound teeth, teeth with NCCL, and restored NCCL. The presence or absence of restorations also did not affect bone strain. However, bone loss modified the stress field, concentrating it closer to the bone and displacing the fulcrum point.

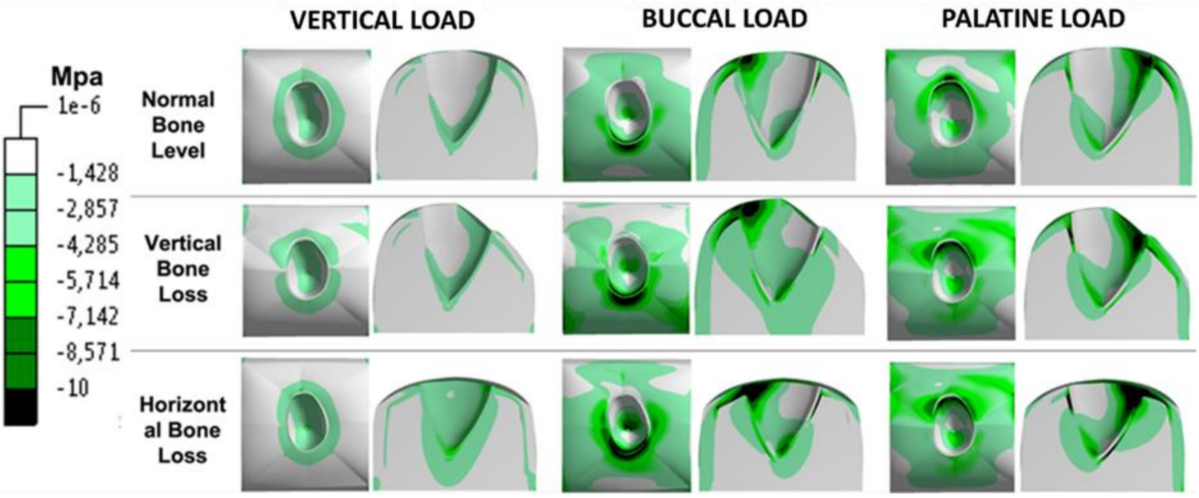

Figure 1. Minimum Principal Stress of the crestal bone.

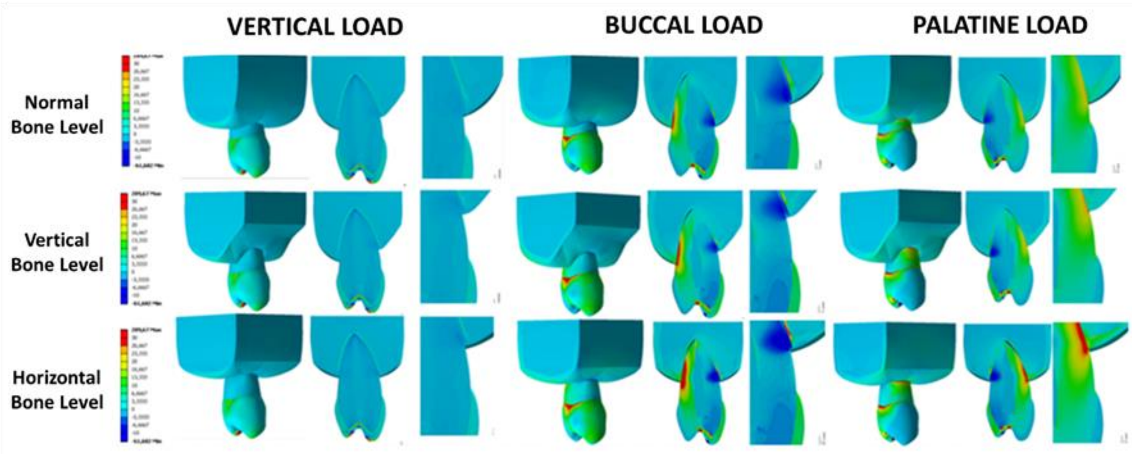

Figure 2. Sound teeth models with different types of loads and bone attachment.

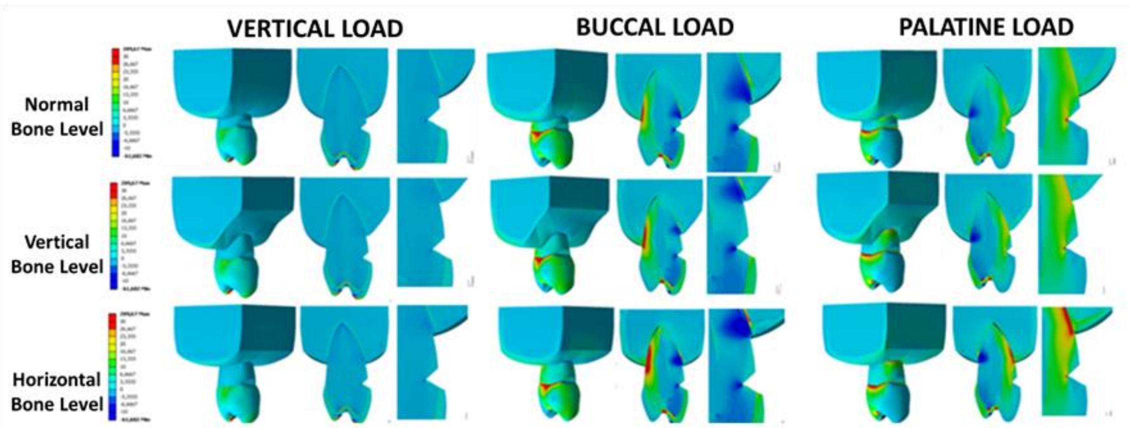

Figure 3. Models of teeth with NCCL with different types of loads and bone attachment.

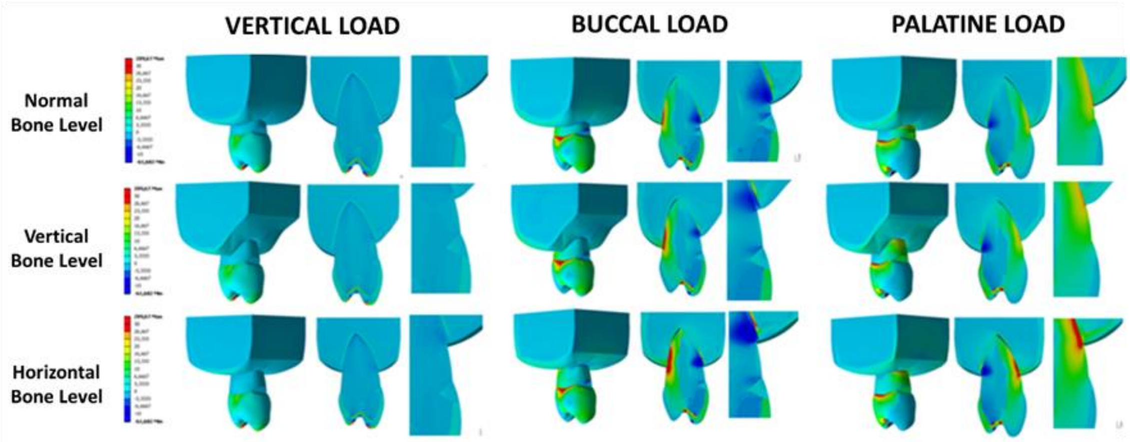

Figure 4. Restored teeth models with different types of loads and bone attachment.

As observed in Fig 5, the palatal load shows higher tensile stress values in the buccal cervical third for all models than the ones that received axial and vertical loads. The results in Fig. 6 showed that the models with horizontal bone loss, when submitted to the vertical load, had higher values of compressive stress on the crestal bone region than the models with NCCL and sound teeth. The loading direction made a significant difference in the stress distribution pattern. The loading type affected bone loss and the progression of NCCL. As observed in the figures, the axial load provides a more homogeneous stress distribution between tooth and bone. The palatal load causes tensile stress on the buccal surface, which increases the likelihood of NCCL progression. However, the buccal load causes compressive stress on both the buccal surface and the crestal bone.

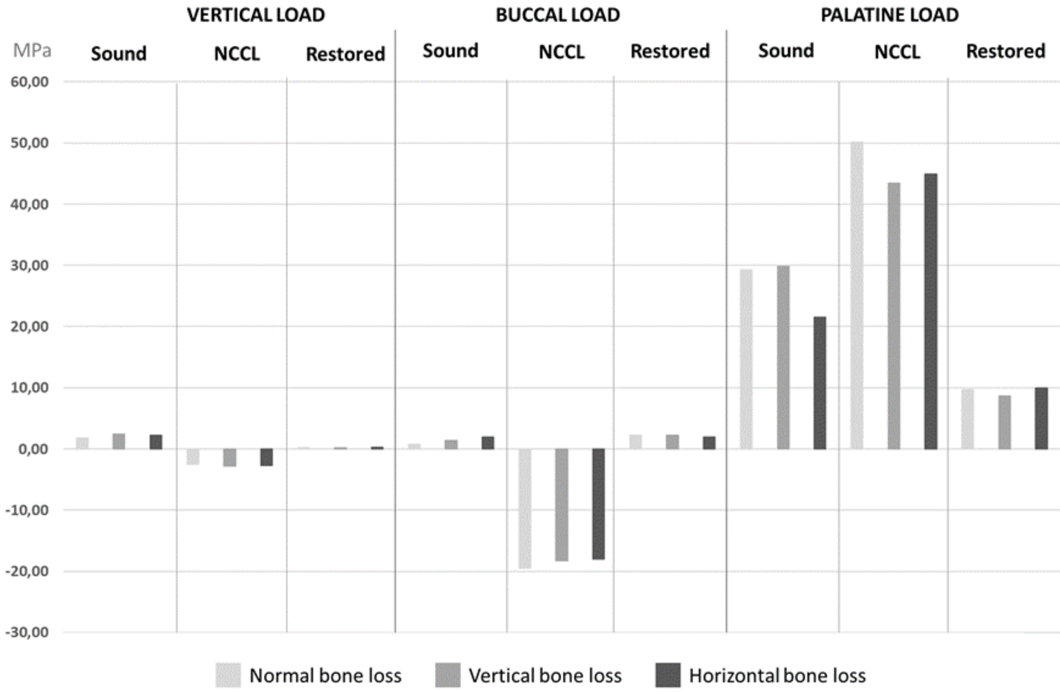

Figure 5. Stress values (MPa) obtained in one mesh node in the cervical region by Maximum Principal Stress.

The bone stress distribution pattern does not depend on the presence or absence of NCCL. The only change occurring with bone loss is the fulcrum point, which will dislocate. The stress distribution of the lesion remains the same. Thus, the major factor to modify the stress field is still the occlusal contact. The presence of restoration also does not interfere with the stress pattern related to bone loss, it only improves the stress distribution in the non-axial loading.

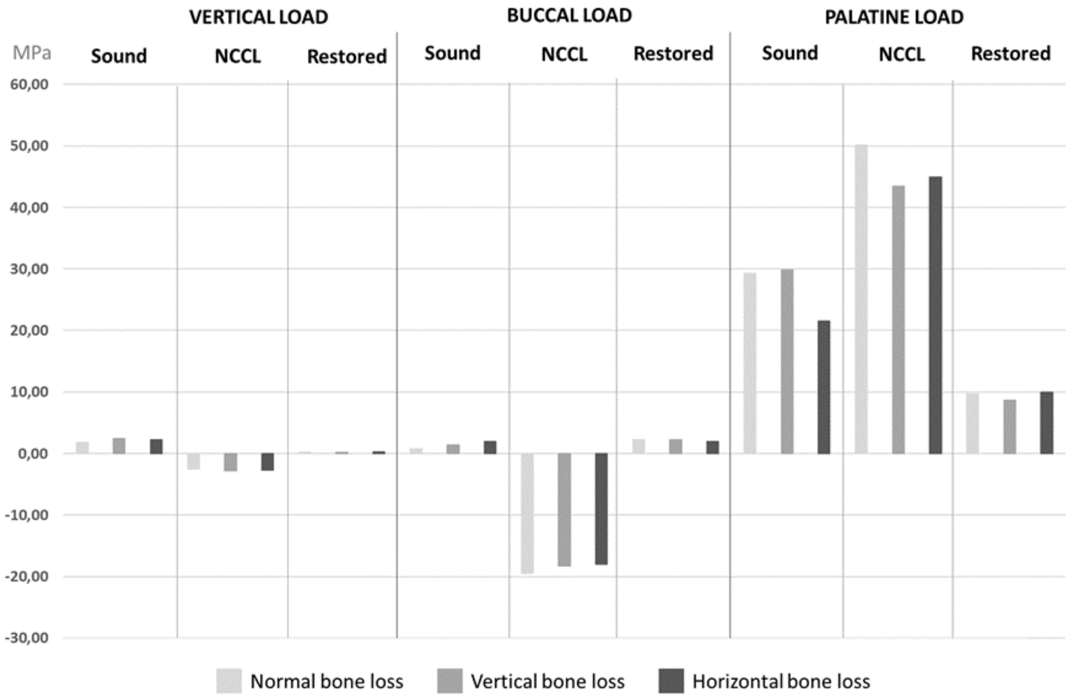

Figure 6. Compressive stress values (MPa) evaluated in one node in the crestal bone by Minimum Principal Stress.

4. Discussion

According to the results, the null hypothesis of this study was rejected. The different bone attachments, NCCL restorative procedure, and occlusal load changed the biomechanical behavior of maxillary premolars. The results showed that the loading type had an influence on the increase of stress concentration in the buccal bone and the cervical region of the tooth, and that it may contribute to the development or progression of gingival recession and NCCL. However, the bone stress distribution pattern does not depend on the presence or absence of NCCL. The restored 3D model also did not interfere with the stress pattern related to bone loss. In the stress pattern analysis of the models that received palatal load, the results showed lower Maximum Principal Stress values in restored models with NCCL than non-restored ones. This occurred because the point evaluated was in composite resin, which has a lower elasticity modulus than enamel, contributing to the better dissipation of tensile stress in the cervical region.

These results agree with another study (Reddy et al. 2012, Jakupović et al. 2016) that showed that any type of stress (tensile, compressive, or shearing), when sufficient in magnitude, can damage the tooth structure. When submitted to oblique loads, the tooth structure suffers a flexure, producing tensile or compressive strain and disrupting the bonds between hydroxyapatite crystals. This leads to crack formation and occasional loss of enamel and underlying dentin, although the loads applied to the buccal surface have lower values, which contributes to the reduction of NCCLs progression (Lee and Eakle 1984; Grippo 1991). However, higher values of compressive stress on the buccal surface of the crestal bone were found, consequently increasing the odds of bone resorption (Machado et al. 2018). These results emphasize the importance of occlusal adjustment and restoration on the treatment of NCCLs and bone loss prevention.

Another study (Madani and Ahmadian-Yazdi 2005; Yoshizaki et al. 2017) investigating the relationship between premature contacts in centric relation and other occlusal discrepancies in teeth with and without NCCLs found a statistically significant correlation between the prevalence of NCCLs and premature occlusal contacts. However, another study (Reyes et al. 2009) found the same distribution for NCCLs and premature contacts in centric relation in first premolars but no correlation between NCCLs and premature contacts. This difference may be explained by the methodology applied in each study and the criterion for data analysis.

In a similar study (Vandana et al. 2016), the authors reported that with decreasing periodontal support, the location of the highest stress concentration tended to shift away from the CEJ, which is supposed to be susceptible to abfraction mechanisms toward the apical dentin region. This means that NCCL with abfraction mechanisms is less likely to occur in a tooth with diminished periodontal support and, if it does, it must be more apically located (Grippo 1992). This also corroborates the findings of the present study, in which bone loss modified the stress pattern but did not affect stress concentration in the cervical region.

In turn, Reyes et al. (Reyes et al. 2009) reported that abfraction lesions are associated with buccal attachment loss but the order of appearance between the two cannot be determined. An abfraction lesion can lead to buccal attachment loss, which in turn can make the tooth surface more susceptible to abrasion or abfraction. This indicates the etiology of NCCLs, which has been extensively discussed and yet presents no consensus in the literature. However, due to the complexity of etiological factors of NCCLs, some factors such as biocorrosion and friction could not be simulated in the FEA. Moreover, the properties of structures and dimensions of the models can be considered limitations in the development of this study, considering the several differences among individuals.

5. Conclusions

Considering the methodological limitations of this study, it can be concluded that oblique loading is the intensifying factor in the stress distribution pattern, which may affect bone loss and NCCL progression. The stress distribution pattern in the bone was not affected by the presence of NCCL. The restoration did not affect the stress distribution pattern in the bone.

Authors' Contributions: PERES, S.T.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article; TEIXEIRA, D.N.R.: acquisition of data, analysis and interpretation of data; SOARES, P.V.: acquisition of data, analysis and interpretation of data; ZEOLA, L.F.: acquisition of data, analysis and interpretation of data; MACHADO, A.C.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, critical review of important intellectual content. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Not applicable.

Acknowledgments: The authors would like to thank the funding for the realization of this study provided by the Brazilian agencies CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior -Brasil), Finance Code 001, and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico -Brasil).

References

ALVAREZ-ARENAL, A., et al. Non-carious cervical lesions and risk factors: A case-control study. *Journal of Oral Rehabilitation*. 2019, **46**(1), 65-75. https://doi.org/10.1111/joor.12721

BERNHARDT, O., et al. Epidemiological evaluation of the multifactorial aetiology of abfractions. *Journal of Oral Rehabilitation*. 2006, **33**(1), 17-25. https://doi.org/10.1111/j.1365-2842.2006.01532.x

BHUNDIA, S., BARTLETT, D. and O'TOOLE, S. Non-carious cervical lesions - can terminology influence our clinical assessment? *British Dental Journal*. 2019, **227**(11), 985-988. https://doi.org/10.1038/s41415-019-1004-1

CARTER, D.R. and HAYES, W.C. The compressive behavior of bone as a two-phase porous structure. *The Journal of Bone and Joint Surgery*. 1977, **59**(7), 954-962. https://doi.org/10.2106/00004623-197759070-00021

COBO, J., et al. Dentoalveolar stress from bodily tooth movement at different levels of bone loss. *American Journal of Orthodontics and Dentofacial Orthopedics*. 1996, **110**(3), 256-262. https://doi.org/10.1016/S0889-5406(96)80008-4

CORREIA, A.M.O., et al. Polymerization shrinkage stresses in different restorative techniques for non-carious cervical lesions. *Journal of Dentistry*. 2018, **76**, 68-74. https://doi.org/10.1016/j.jdent.2018.06.010

CORN, H. and M.H. MARKS Basic biological concepts associated with adult Orthodontics: Lea & Febiger. Edtion ed. Philadelphia: Atlas of adult Orthodontics, 1989.

DEJAK, B. and MŁOTKOWSKI, A. Finite element analysis of strength and adhesion of cast posts compared to glass fiber-reinforced composite resin posts in anterior teeth. *The Journal of Prosthetic Dentistry*. 2011, **105**(2), 115-126. https://doi.org/10.1016/S0022-3913(11)60011-5

DU, J.K., et al. Influence of cavity depth and restoration of non-carious cervical root lesions on strain distribution from various loading sites. *BMC Oral Health*. 2020, **20**(1), 98-98. https://doi.org/10.1186/s12903-020-01083-w

DUANGTHIP, D., et al. Occlusal stress is involved in the formation of non-carious cervical lesions. A systematic review of abfraction. *American Journal of Dentistry*. 2017, **30**(4), 212-220.

GERAMY, A. Alveolar bone resorption and the center of resistance modification (3-D analysis by means of the finite element method). *American Journal of Orthodontics and Dentofacial Orthopedics*. 2000, **117**(4), 399-405. https://doi.org/10.1016/S0889-5406(00)70159-4

GRIPPO, J.O. Abfractions: a new classification of hard tissue lesions of teeth. *Journal of Esthetic Dentistry*. 1991, **3**(1), 14-19. https://doi.org/10.1111/j.1708-8240.1991.tb00799.x

GRIPPO, J.O. Noncarious cervical lesions: the decision to ignore or restore. *Journal of Esthetic Dentistry*. 1992, **4**, 55-64. https://doi.org/10.1111/j.1708-8240.1992.tb00721.x

GRIPPO, J.O., SIMRING, M. and COLEMAN, T.A. Abfraction, abrasion, biocorrosion, and the enigma of noncarious cervical lesions: a 20-year perspective. *Journal of Esthetic and Restorative Dentistry*. 2012, **24**(1), 10-23. https://doi.org/10.1111/j.1708-8240.2011.00487.x

JAKUPOVIĆ, S., et al. Biomechanics of cervical tooth region and noncarious cervical lesions of different morphology; three-dimensional finite element analysis. *European Journal of Dentistry*. 2016, **10**(3), 413-418. https://doi.org/10.4103/1305-7456.184166

KIM, S.Y., et al. Two-year clinical effectiveness of adhesives and retention form on resin composite restorations of non-carious cervical lesions. *Operative Dentistry*. 2009, **34**(5), 507-515. https://doi.org/10.2341/08-006C

KOLAK, V., et al. Epidemiological investigation of non-carious cervical lesions and possible etiological factors. *Journal of Clinical and Experimental Dentistry*. 2018, **10**(7), e648-e656. https://doi.org/10.4317/jced.54860

LEE, W.C. and EAKLE, W.S. Possible role of tensile stress in the etiology of cervical erosive lesions of teeth. *The Journal of Prosthetic Dentistry*. 1984, **52**(3), 374-380. https://doi.org/10.1016/0022-3913(84)904487

MACHADO, A.C., et al. Influência do desequilíbrio oclusal na origem de lesão cervical não cariosa e recessão gengival: análise por elementos finitos. *Revista Odontológica do Brasil Central*, 2018, **27**(83), 204-2010. https://doi.org/10.36065/robrac.v27i83.1271

MACHADO, A.C., et al. Stress-strain analysis of premolars with non-carious cervical lesions: Influence of restorative material, loading direction and mechanical fatigue. *Operative Dentistry*. 2017, **42**(3), 253-265.https://doi.org/10.2341/14-195-L

MADANI, A.O. and AHMADIAN-YAZDI, A. An investigation into the relationship between noncarious cervical lesions and premature contacts. *Cranio: The Journal of Craniomandibular Practice*. 2005, **23**(1), 10-15. https://doi.org/10.1179/crn.2005.003

MATOS, F., et al. Impact of different restorative techniques on the stress distribution of endodontically-treated maxillary first premolars: a 2-dimensional finite element analysis. *Journal of Research and Knowledge Spreading*. 2020, **1**(1), e11761. https://doi.org/10.20952/jrks1111761

MICHAEL, J.A., et al. Abfraction: separating fact from fiction. *Australian Dental Journal*. 2009, **54**(1), 2-8. https://doi.org/10.1111/j.1834-7819.2008.01080.x

MIURA, J., et al. Multiscale analysis of stress distribution in teeth under applied forces. *Dental Materials*. 2009, **25**(1), 67-73. https://doi.org/10.1016/j.dental.2008.04.015

POIATE, I.A., et al. Stress distribution in the cervical region of an upper central incisor in a 3D finite element model. *Brazilian Oral Research*. 2009, **23**(2), 161-168. https://doi.org/10.1590/S1806-83242009000200012

REDDY, S.D., et al. Cervical stress due to normal occlusal loads is a cause for abfraction? - A finite element model study. *Journal Orofacial Science*. 2012, **4**, 120. https://doi.org/10.4103/0975-8844.106204

REES, J.S. The effect of variation in occlusal loading on the development of abfraction lesions: a finite element study. *Journal of Oral Rehabilitation*. 2002, **29**(2), 188-193. https://doi.org/10.1046/j.1365-2842.2002.00836.x

REYES, E., et al. Abfractions and attachment loss in teeth with premature contacts in centric relation: clinical observations. *Journal of Periodontology*. 2009, **80**(12), 1955-1962. https://doi.org/10.1902/jop.2009.090149

RUBIN, C., et al. Stress analysis of the human tooth using a three-dimensional finite element model. *Journal of Dental Research*. 1983, **62**(2), 82-86. https://doi.org/10.1177/00220345830620021701

RUSU OLARU, A., et al. Identifying the Etiological Factors Involved in the Occurrence of Non-Carious Lesions. *Current Health Sciences Journal*. 2019, **45**(2), 227-234. https://doi.org/10.12865/CHSJ.45.02.15

SHINYA, A., et al. Three-dimensional finite element analysis of metal and FRC adhesive fixed dental prostheses. *The Journal of Adhesive Dentistry*. 2008, **10**(5), 365-371.

SOARES, A., et al. Prevalence and severity of non-carious cervical lesions and dentin hypersensitivity: association with oral-health related quality of life among Brazilian adults. *Heliyon*. 2021, **7**(3), e06492. https://doi.org/10.1016/j.heliyon.2021.e06492

SOARES, P.V., et al. Loading and composite restoration assessment of various non-carious cervical lesions morphologies - 3D finite element analysis. *Australian Dental Journal*. 2015, **60**(3), 309-316. https://doi.org/10.1111/adj.12233

SOARES, P.V., et al. Non-carious cervical lesions: influence of morphology and load type on biomechanical behaviour of maxillary incisors. *Australian Dental Journal*. 2013, **58**(3), 306-314. https://doi.org/10.1111/adj.12084

SOARES, P.V., et al. Effect of root morphology on biomechanical behaviour of premolars associated with abfraction lesions and different loading types. *Journal of Oral Rehabilitation*. 2014, **41**(2), 108-114. https://doi.org/10.1111/joor.12113

TEIXEIRA, D.N.R., et al. Prevalence of noncarious cervical lesions among adults: A systematic review. *Journal of Dentistry*. 2020, **95**, 103285. https://doi.org/10.1016/j.jdent.2020.103285

TEIXEIRA, D.N.R., et al. Relationship between noncarious cervical lesions, cervical dentin hypersensitivity, gingival recession, and associated risk factors: A cross-sectional study. *Journal of Dentistry*. 2018, **76**, 93-97. https://doi.org/10.1016/j.jdent.2018.06.017

VANDANA, K.L., et al. A finite element study to determine the occurrence of abfraction and displacement due to various occlusal forces and with different alveolar bone height. *Journal of Indian Society of Periodontology*. 2016, **20**(1), 12-16. https://doi.org/10.4103/0972-124X.168484

VASUDEVA, G. and BOGRA, P. The effect of occlusal restoration and loading on the development of abfraction lesions: A finite element study. *Journal of Conservative Dentistry*. 2008, **11**(3), 117-120. https://doi.org/10.4103/0972-0707.45250

WEINSTEIN, A.M., KLAWITTER, J.J. and COOK, S.D. Implant-bone interface characteristics of bioglass dental implants. *Journal of Biomedical Materials Research*. 1980, **14**(1), 23-29. https://doi.org/10.1002/jbm.820140104

WOOD, I., et al. Non-carious cervical tooth surface loss: a literature review. *Journal of Dentistry*. 2008, **36**(10), 759-766. https://doi.org/10.1016/j.jdent.2008.06.004

YOSHIZAKI, K. T., et al. Clinical features and factors associated with non-carious cervical lesions and dentin hypersensitivity. *Journal of Oral Rehabilitation*. 2017, **44**(2),112-118. https://doi.org/10.1111/joor.12469

YANG, S.M. and CHUNG, H.J. Three-dimentional finite element analysis of a mandibular premolar with reduced periodontal support under a non-axial load. *Oral Biology Research*. 2019, **43**(4), 313-326. https://doi.org/10.21851/obr.43.04.201912.313

ZEOLA, L.F., et al. Effects of non-carious cervical lesion size, occlusal loading and restoration on biomechanical behaviour of premolar teeth. Australian dental journal. 2016, **61**(4), 408-417. https://doi.org/10.1111/adj.12391

ZEOLA, L.F., et al. Influence of non carious cervical lesions depth, loading point application and restoration on stress distribution pattern in lower premolars: A 2D finite element analysis. *Bioscience Journal*. 2015, **31**, 648-656. https://doi.org/10.14393/BJ-v31n2a2015-27837

Received: 11 November 2021 | **Accepted:** 20 April 2022 | **Published:** 9 September 2022