Biomechanics of Noncarious Cervical Lesions

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Abstract— **Noncarious cervical lesions (NCCLs) restoration represents a unique clinical situation due to their multifactorial etiology. Though the mechanical theory of cervical lesions formation is widely accepted, its mechanism is not fully understood. The incidence of NCCL refers to the facial and oral aspects of the teeth. Finite Elements Method (FEM) were drawn up, applied with various occlusal forces and analyzed in order to observe the stress distribution. The standard biomechanical unit involves restorative material, tooth structure and interface between the restoration and tooth. The purpose of this study was to examine the NCCL formation caused by occlusal forces and the behavior of restored and unrestored lesions.**

Keywords— **Finite Element Analysis, abfraction, cervical lesion, stress, displacement, restorative material.**

I. INTRODUCTION

Noncarious cervical lesions (NCCL) are considerable restorative challenges for the dentist. NCCL are defined as the loss of tooth structure at the cement-enamel junction. However, literature also describes other destructive processes that originate on the external surface of the tooth and affect it causing irreversible damage to the tooth structure, such as erosion, abrasion, attrition and abfraction. Dental erosion represents the physical results of loss of hard tissue caused by acid attack. Abrasion represents the pathological loss of hard tissue through abnormal mechanical processes. The term of dental attrition is used to describe the physiological wear of hard tissue. The term of abfraction describes a special type of wedge shaped defect in the cervical region of the tooth.

The tooth has not a rigid structure, hence it can suffer strains when various forces/loads are applied. Intraoral loads vary from 10N to 430N, the normal clinical values being considered of 70N [9]. One current hypothesis is that the tensile or compressive strains gradually produce micro fractures.

Loads applied under various angles result in different flexures of the tooth: lateral flexure at occlusal loads of 40º or axial flexure at occlusal loads directed axially to the tooth (Fig.1).

Lately, the numerical analysis methods have become indispensable in solving engineering and biomechanical problems mainly due to their increasing reliability and accuracy. In the field of biomechanics, the finite element methods are able to address a wider range of problems than the conventional methods, because of their structural and material complexity. However, both conventional and FEM present a major shortcoming concerning their inability to predict failure by fracture.

The bulk of dentistry papers address the influence of dental materials used in NCCL restorations focusing mainly on their retention/loss rates. Thus, there are few studies treating the biomechanical mechanism of NCCL and the selection of that restoration material which best exhibits the most appropriate elastic characteristics.

The purpose of this study was a radical approach to the behavior of an intact and restored/unrestored tooth undergoing a mechanical load of various values.

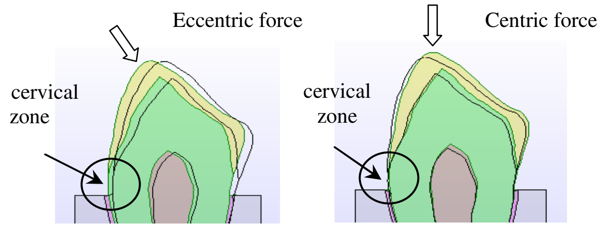

Fig. 1 Diagram of tooth flexure creating cervical stresses

II. MATERIALS AND METHODS

A 2D mathematical finite elements analysis model was generated, using an intact normal human mandibular canine. The quality of the analysis results depends on the accuracy of the model.

Properties of dental tissue are shown in Table 1.

Table 1 Properties of dental tissue

Materials	Young's modulus E [MPa]	Poisson's ratio μ
Enamel	$6{,}9.10^4$	0,30
Dentine	$1{,}67.10^4$	0,31
PDL	12	0,45
Bone	$1{,}47.10^4$	0,3
Pulp	2	0,45

S. Vlad and R.V. Ciupa (Eds.): MEDITECH 2011, IFMBE Proceedings 36, pp. 270–275, 2011.
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All materials were considered elastic (right proportion between stresses and specific strain and Hooke law valability) and isotropic (with identical elastic characteristics on all directions). Longitudinal elastic modulus (Young's modulus *E*) and Poisson's ratio μ values for the materials used in the model were derived from standard texts [3].

Numerical analysis was carried out using ALGOR-Fempro solver. A plan model reproducing a vestibular and lingual section of the lower canine was created. A denser mesh with a large number of EF was built in the area of interest in order to obtain the best replica of the tooth and the most faithful analyses of the situation. To simulate material continuity, all the parts of the dental structure are considered connected and forming whole body (Fig.2).

Two situations of tooth loading were considered:

a. Oblique nodal force at 40 degrees to vertical applied onto the vestibular aspect at h=8.993mm from cervical area of increasing magnitudes: 40, 80, 120, 160, 200N (Fig.1.a.);
b. Vertical nodal force of increasing magnitudes: 40, 80, 120, 160, 200N applied onto the tip of the tooth (Fig.1.b.).

The values of the loadings (40-200N) are considered "study loads" that cover the whole range of the clinical situations. The forces applied were of the same values, both for the vertical and tensile stress, in order to obtain the most accurate results by means of comparison of the two situations.

The study sets off from the working hypothesis that there are various differences in stress profile between healthy teeth and teeth with cervical enamel damage.

III. RESULTS

The results of the present study are shown in the following significant values:

- Equivalent stress Von Mises σ_{ech};
- Stress following tooth direction Z-Z;
- Minimum main stress (compression effect) σ_2;
- Resultant displacement.

Model I. Healthy tooth - lesion mechanism

The present study used simulations of different values and positions of the loads, both vertical and oblique, on a healthy tooth. The result show that the most stress-prone area with the highest risk of mechanic damage is the cervical area of the tooth (Fig.1).

A maximum stress at 0,1mm above the cervical line for an oblique load was noticed (Fig.3).

The variation graphs for equivalent stress values of the eccentric and centric forces applied on the cervical interface were created (Fig.4, Fig.5).

Model II. Tooth with cervical lesion

Loads of different positions and magnitudes applied on a tooth with cervical lesion will lead to an increase of stress in the area.

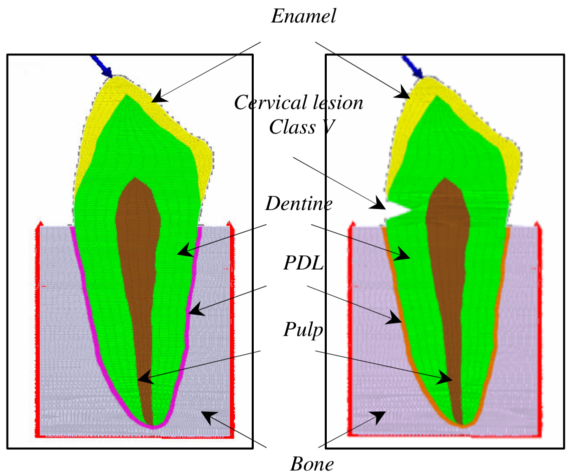


Fig. 2 2D model of the lower canine.
Healthy tooth and tooth with lesion

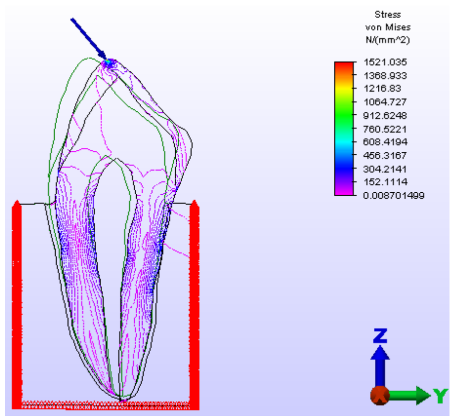


Fig. 3 Equivalent stress Von Mises distribution
Curves of equal values corresponding to an eccentric force of F=160N

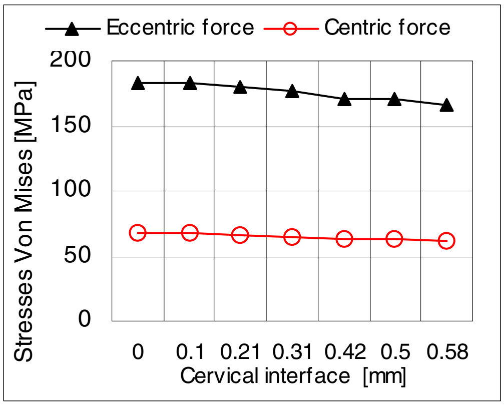


Fig. 4 Von Mises equivalent stress variation in the cervical interface for different position of a force: F=160N

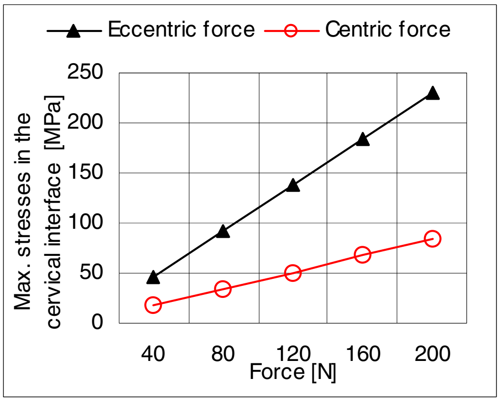


Fig. 5 Comparison: eccentric force – centric force The node with maximum stress Von Mises values (0,1 mm from colet)

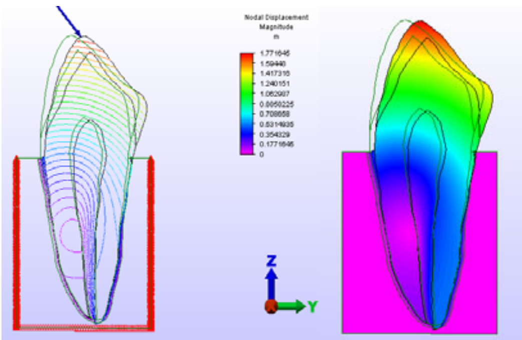


Fig. 6 Displacements distribution for eccentric force of F=160N (curves and areas of equal stress)

The lesion will become a stress concentrator with cracks propagating onto and into the tooth, ultimately leading to tooth fracture (Fig.7).

The results obtained after simulations on a tooth lesionned on the cervical area were compared to those obtained following simulations on a healthy tooth (Fig.8).

The same values were considered of significance both for the healthy and lesionned tooth.

Model III. Tooth with restored lesion

Simulations on a restored lesion showed that after restoration the values of the stress in all the elements of the dental structure exhibited slight differences similar to those noticed in the healthy tooth (Fig.3, Fig.15).

After restoration, both the stress concentrator in the bottom of the cavity (Fig.16) and the displacement of stress towards the apex of the restoration will disappear (Fig.18).

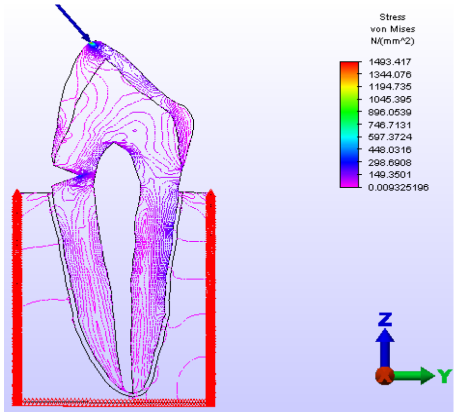


Fig. 7 Equivalent stress Von Mises distribution. Curves of equal values corresponding to a eccentric force of F=160N

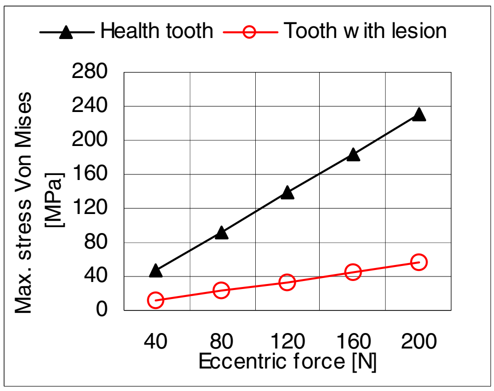


Fig. 8 Comparison: intact tooth – tooth with cervical lesion for oblique force The node with maximum stress Von Mises values (0,1 mm from colet)

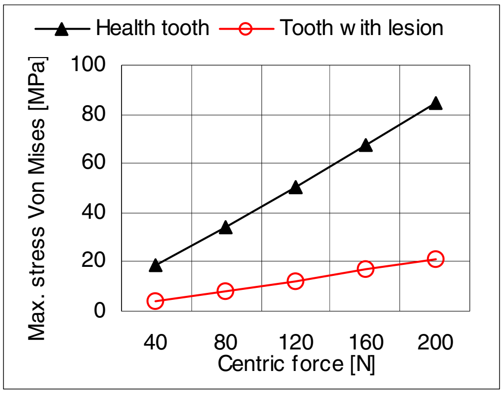
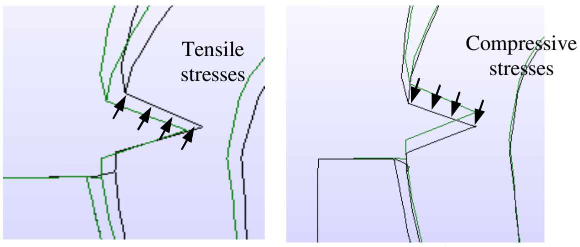


Fig. 9 Comparison: intact tooth – tooth with cervical lesion for centric force. The node with maximum stress Von Mises values (0,1 mm from colet)

Since the quality of any material is defined by its elastic characteristics (Young's modulus E and Poisson's ratio μ) it is extremely important to use those restoration materials which present the closest elastic characteristics to the material to be restored.



a. b.

Fig. 10 Deformed position of the lesion:
a. eccentric force; b. centric force

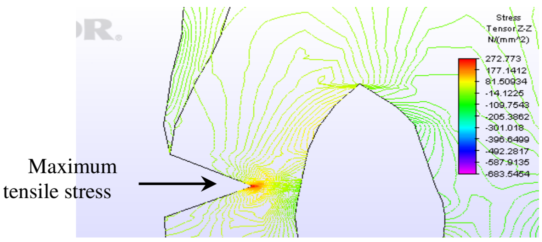


Fig. 11 Stress distribution following vertical axes of the tooth Z-Z in the bottom of the lesion for the eccentric force (positive values in the lesion)

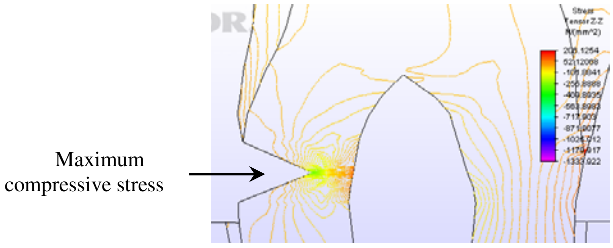


Fig. 12 Stress distribution following vertical axes of the tooth Z-Z in the bottom of the lesion for the centric force (negative values in the lesion)

IV. Discussion

Our study is based on the golden rule in engineering according to which any stress will always follow the direction of the most rigid material, that is to say, of the material with the highest elastic modulus.

The results obtained showed that:

a. *in the healthy tooth*

- maximum stress occurs in the cervical area irrespective of load direction (Fig.4);
- maximum stress values occur at 0,1mm above the cervical line (Fig.4.);
- stress values in the cervical area increase with occlusal loads values (Fig.5);
- Von Mises equivalent stress values for the same value of the load are higher for oblique loads (Fig.5).

The results show that from a mechanic stand point, the maximum strain appears in the cervical area at 0,1 mm above the cervical line, irrespective of load direction. This is the area were the tooth is most exposed to flexure leading to a concentration of stress which increases with the occlusal forces, ultimately leading to cracks.

b. *in the tooth with cervical lesion*

- Von Mises equivalent stress values are higher in the lesionned tooth than in the healthy tooth (Fig.8, Fig.9);
- oblique loads lead to lateral flexure of the tooth and vertical loads lead to axial compression;
- vertical direction of occlusal loads result in higher values of the stress in the lesionned area (Fig.13);
- as a result of load direction on the tooth, a stretching of the tooth appears at oblique loads and a compression of the tooth appears at vertical loads (Fig.10); the phenomenon determines positive maximum strain values in the bottom of the lesion (stretching strain) at oblique loads, respectively negative maximum strain values in the bottom of the lesion (compressive strain) at vertical loads (Fig.13);
- maximum stress values appear in the bottom of the lesion which becomes a stress concentrator (Fig. 11, Fig.12);

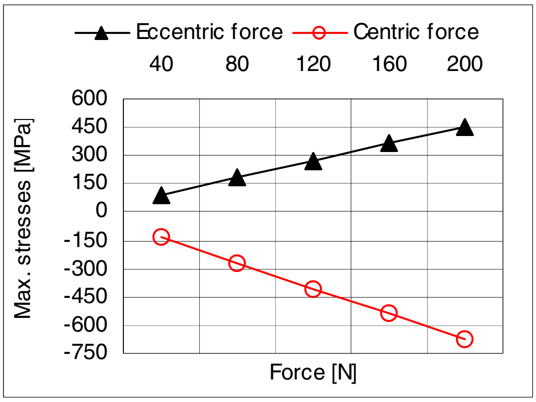


Fig. 13 Variation of maximum stresses Von Mises values stress in the concentrator at various values of both eccentric and centric force

- maximum stress values in the bottom of the lesion increase with external loads (Fig.13);
- the stress concentrator in the bottom of the lesion will lead, in time, to cracks and their propagation onto and into the tooth; this constitutes a risk factor for fracture

c. *in the restored tooth*

- after reconstruction, stress values in all structure elements register differences similar to those in the healthy tooth (Fig.3, Fig.14, Fig.16, Fig.17);
- stress values in the dentine exhibit very close figures, indicating that the reconstruction material undergoes the same distribution of stress as the healthy tooth (Fig.17);
- maximum strain in the reconstruction appears in the bottom of it irrespective of the material used, direction and magnitude of loads;
- considering that maximum strength for dentine ~ $\sigma_{a\ dentine}$ = 105,5 MPa [5], it became clear that loads higher then F=80N will damage the tooth structure.

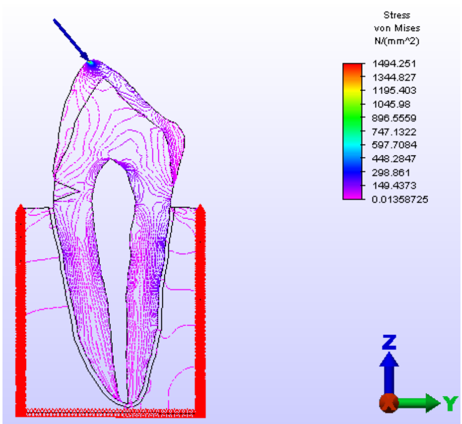


Fig. 14 Equivalent stress Von Mises distribution
Curves of equal values corresponding to a eccentric force of F=160N

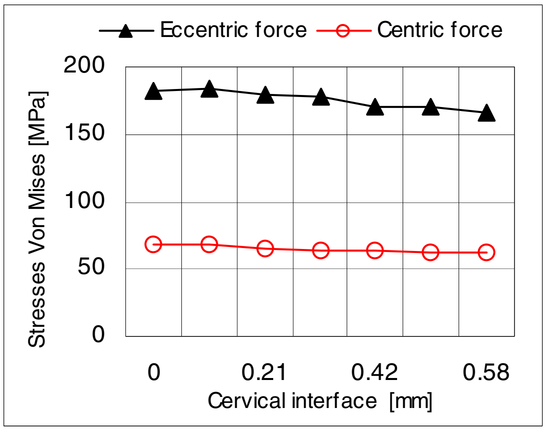


Fig. 15 Von Mises stress values in the cervical interface for different positions of a oblique force F=160N

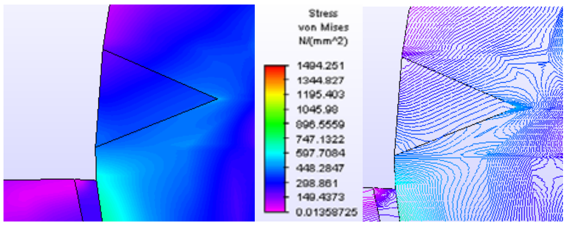


Fig. 16 Detail - Equivalent stress Von Mises distribution
Areas and curves of equal values corresponding to a eccentric force of F=160N

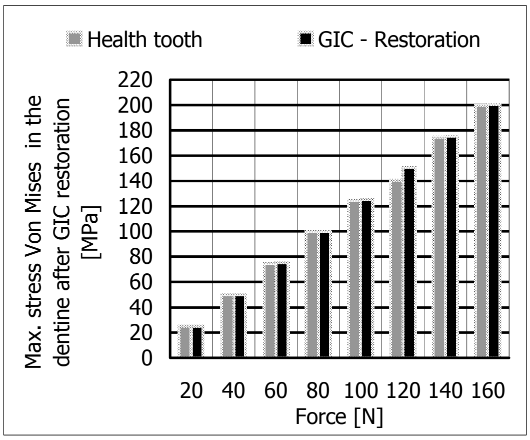


Fig. 17 Maximum Von Mises Stresses in the dentine.
Comparison: healthy tooth - tooth with restoration

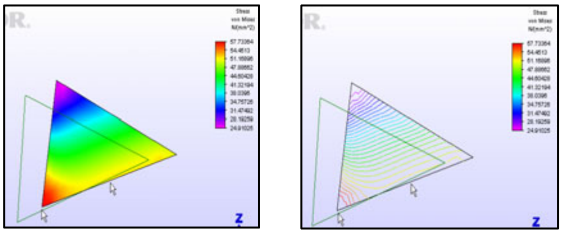


Fig. 18 Von Mises Stress along the cervical interface

V. CONCLUSIONS

We appreciate that Finite Elements Method is a valuable complementary method which offers accurate images of the behavior of the structure under study, while being a noninvasive method of analysis.

With all the limitations of this numerical study, the following conclusions can be drawn:

1. Any load applied on a tooth can result in enamel damage on the cervical area leading to NCCL and modest possibilities of preventing the restart of the process.
2. The cervical lesions induce a stress concentrator, which, in turn, leads to cracks on the surface of the enamel and even fracture of the tooth in the cervical area.
3. As materials of choice in NCCL restorations, we suggest those with the closest elastic characteristics to the dental tissues to be replaced.

FEM was also applied to analyze the behavior of restored lesions. The material fracture formulation is based on rotating crack model and propagation. The modeling technique presented offers an insightful understanding of the nonlinear relationship between loading capacity, damage and softening in multiple materials possible.

The finite element code adopted allows an automatic insertion of cracks, enables remeshing and accommodates self contact between the cracked interfaces.

Numeric simulation of a NCCL process and its restorations can became both an alternative to the clinical and experimental studies on the tooth behavior and a major part in selecting and developing biomaterials.

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