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Etiopathogenic aspects in dental wear
PHD THESIS ABSTRACT

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CONTENTS

Keywords: dental wear, attrition, erosion, non-carious cervical lesions, abrasion, OCT, resistance forces.

INTRODUCTION
Wear is not specific to the oral cavity, it exists in the surrounding environment in various forms.
There is a consensus among which more and more specialists believe that dental wear is not the consequence of a single cause **[Addy 2006].** On the contrary, several factors interact over the life of teeth and are involved in the etiology of dental wear. However, without considering whether there is an association between various etiological factors, it is certain that their effect on teeth over time is simultaneous and irreversible. No matter what factor we choose as the main cause, wear begins immediately after the tooth eruption.
We can be most helpful to our patients by making early diagnosis and by taking early preventative measures after identifying causative factors, especially when wear is progressing rapidly.

CHAPTER 1 - CLASSIFICATION OF DENTAL WEAR
1.1 DEFINITION
Dental wear is the term used for irreversible loss of dental hard tissues, due to interactions with physical and chemical factors, excluding brutal trauma and dental caries. The wear of teeth and prosthetic restoration materials is a common phenomenon in dentistry and occurs when two surfaces glide on each other.
1.2 CLASSIFICATION OF DENTAL WEAR
1.2.1 Classification of Grippo
Grippo, in 2004, has made a classification of non-carious lesions of hard tissue in four categories **[Grippo2004]:**
-Attrition - loss of dental material as a result of interdental contact during parafunction or normal mastication. Incisal or occlusal attrition may occur due to swallowing or gnashing. Proximal attrition may result in a reduction in the mandible arc.
- Abrasion - Pathological wear due to the biomechanical frictional process that occurs during brushing. If the teeth exhibit an occlusal or incisal wear determined by the consistency of the food, then this form of wear is called masticatory abrasion.
-Erosion, originally, was considered a substance loss caused by chemical or electrochemical action. According to the "Consensus Report of the European Federation of Conservative Dentistry: Erosive tooth wear - diagnosis and management" erosion is defined as a chemical-mechanical process resulting in a loss of dental hard tissue without bacterial involvement **[Carvalho2005].** A study done by the OCTs has shown that dental erosion is the most rapidly developing clinical form of tooth wear, the tooth defense capacity being virtually exceeded **[Mercut 2017].**
-Abfraction, a term introduced by Grippo in 1991, occurs when the tooth is subjected to extreme stress or fatigue, in an area distant from the point of application of force during functions and parafunctions. Abrasion causes the appearance of cavity in the tooth (where the prism enamel layer is thinner and thus the tooth is more fragile) of microfractures and small dental loss **[Grippo1991-2].**

CHAPTER 2 - DENTAL ATTRITION
2.1 DEFINITION
Dental wear due to dental contacts during swallowing, mastication and bruxism is called dental attrition **[Grippo 2004].** Wear is located, according to the same author, at the occlusal surfaces, incisal edges and proximal teeth faces with the possibility of reducing the mandible arc.
The major cause of dental attrition is unanimously considered to be bruxism. In addition to bruxism, with a lower weight in the ethyogy of dental attrition, temporomandibular dysfunction has to be mentioned **[Pergamalian 2003].** Most studies in the literature suggest that dental attrition is an exclusive manifestation of bruxism.
2.2 ETHIOLOGY OF ATTRITION
By systematically compiling the literature data and taking into account our accumulated experience from the clinical situations encountered in current practice, we can say that dental attrition is due to the following factors **[Mello 2009], [Carlsson 2003], [Duarte 2008]:**
-Favorite factors:
- The thickness and hardness of the enamel depending on the degree of mineralization;
- Oral Ph, in-vitro experiments showed that atrium in a hydrochloric acid medium (Ph = 1.2) was 10 times higher than in a dry environment;
- Age - Dental wear grows with time.
-Determined factors:
- The bruxism;
- Occlusion disorders: deep covered occlusion, mandibular prognacism (lack of canine guidance predisposes to worsened lateral teeth wear);

- Unilateral osteoarthritis: the occlusal load is distributed on the lateral teeth on the affected part, the meniscus is dislocated and a continuous remodeling occurs;

-Reduction of the number of teeth making occlusal contacts with antagonists;

- Use for prosthetic restorations of materials with higher hardness than dental tissues;

-The presence of improperly processed occlusal restorations;

- Presence of prosthetic restorations that overestimate the vertical dimension of occlusion;

-Forting incorrect prostheses in terms of intermax relationships or having a precarious balance on the prosthetic field.

Paradoxically, dental wear is undoubtedly the sign of bruxism, it is the easiest to identify but is insufficient to establish a diagnosis.

CHAPTER 2 - DENTAL ATTRITION
3.1 DEFINITION

The term erosion describes the process of gradual destruction of a surface, usually by chemical or electrolytic processes. Derives from the Latin word eroder (to erode). In 1970, Pindborg provided the most commonly used definition of dental erosion, considering it to be "a loss of hard dental substance through the existence of a chemical process that does not involve the action of bacteria" **[Pindborg 1970].**

3.1.1 Corrosion or biocorrosion

Corrosion is defined as "metallic damage to a material by chemical or electrochemical attack in a particular environment." **[Perry 1984].** As stated in Perry's Chemical Engineers' Handbook, "metallic materials such as pure metals and their alloys tend to enter into chemical bonds with elements of a corrosive environment to form stable compounds similar those found in nature" **[Grippo 2012].**

3.2 ETHIOLOGY

After Grippo in 2012, there are four types of non-metallic corrosive agents that affect the teeth. These are exogenous (chemical), endogenous (biochemical) acids, proteolytic (biochemical) and / or electrochemical action, and the piezoelectric effect on dentin **[Grippo 2012].**

3.2.1. Exogenous acids

Exogenous acids can be found in the environment, in diet as a whole, and in a range of medicines. It appears that the dental erosion was first described in the case of some workers working at a German automobile battery factory **[Petersen 1991].**

The role of dieting in the production of erosive lesions is very much spoken lately.

Taking into account the publications in the field, as well as our practical experience, we can appreciate that carbonated beverages are the first in the production of dental erosion.

3.2.2 Endogenous acids

Grippo in 2012 states that endogenous acids result from bacterial biocorruption induced by biofilm or plaque acids and have been recognized since 1883 when W.D. Milleri challenged for the first time. These would include acids from crevicular fluid and bacterial plaque. Gingival crevicular fluid has been shown to be acidic and therefore corrosive when it comes into contact with the cervical teeth **[Grippo 2012].**

3.2.3 Proteolytic action

They have proteolytic corrosive action from the enzyme lysate produced in the carious lesions, trypsin produced in the pancreas and pepsin from the stomach **[Schlueter2010].** Proteolytic action would also include protease collagenase **[Kawasaki1997]** and metalloproteinases from crevicular fluid **[Tjaderhane 1998]**, as well as electrochemical piezoelectric effects acting on collagen in dentin **[Habelitz 2007].**

3.2.4 Piezoelectric effect on dentine

Until now, there are few studies on the piezoelectric effect on the teeth. Due to the fact that the organic component in the enamel is very poorly represented, respectively 15%, it has no piezoelectric effect. This piezoelectric effect appears to play a role in the genesis of non-carious cervical lesions, root caries and dental cervical hypersensitivity **[Grippo1987], [Grippo1991], [Grippo2004].**

CHAPTER 4 - NON-CARIOUS CERVICAL LESIONS
4.1 DEFINITION

The loss of dental hard tissue in the cervical vestibular area of the teeth under the influence of factors that exclude dental caries has been termed a non-carious cervical lesion.

4.2 ETIOLOGY

Initially, it was considered that these cervical lesions are due to inadvertent brushing or are of chemical origin, ie erosions. It is believed that dental brushing results in a stress concentration in the cervical area that can initiate non-carious abrasion-friction cervical lesions.

The theory of abrasion is based mainly on engineering analyzes and "Finite element" analyzes, which demonstrate the theoretical stress concentration in the cervical areas of the teeth [Vasudeva 2008]. Few controlled studies demonstrate the relationship between occlusal lesions and abrasion lesions. The role of occlusal loading in these lesions seems to overlap with other factors.

Lee and Eakle described three types of stress resulting from excessive occlusal forces on teeth during mastication and parafunction **[Lee 1996], [Lee 2002]:**

1. compression-compressive strength;
2. tension - stretch resistance;
3. shear - resistant to twisting or slipping.

However, other studies have proposed a combination of occlusal stress, abrasion and erosion in the development of lesions, leading to the conclusion that the etiology of these lesions may be multifactorial.
Moreover, cyclic or continuous stress and tooth flexion can cause loss of amalgam and composite restorations in cervical regions.

After Grippo, static stress biocorosis and cyclic stress biororption (fatigue) occur more frequently in parcel areas as non-carious cervical lesions when these regions are not covered by dental plaque. Conversely, root caries (bacterial biocorrosion) occur in the same areas covered by dental plaque **[Grippo 2004].** A number of other factors, which can be considered as favors, are considered when discussing the etiology of non-carcinogenic cervical lesions. It is the structure of the teeth, their morphology and their position on the dental arches.

Other factors involved in the genesis of non-carious cervical lesions are the change in salivary flow, its ph, viscosity, and saliva composition. Kleinberg claimed that the lingual surface of the teeth is 5 times more saliva than on the vestibular faces **[Kleinberg 2006].**

Certainly, the structure, the teeth composition as well as the intraoral environment are determinant in the production of dental injuries.

CHAPTER 5 - DENTAL ABRAZION
5.1 DEFINITION

The term abrasion is a word derived from the Latin abbreviation (to remove) **[Imfeld 1996].** Friction between an exogenous agent and dental surfaces, resulting in loss of dental substance, is termed *dental abrasion*. The shape and location of dental abrasion lesions are specific to the aetiological factors involved.

5.2 ETHIOLOGY

Consider a number of factors:
- Excessive oral care is considered at this time as the main etiological factor in dental abrasion, including inadvertent brushing, misuse of dental floss and toothpicks.
- The consistency and volume of the food bowl causes abrasion, when the food bowl is pressed through the lips and cheeks on the surfaces of the teeth.
- A series of parafunctions such as pencil, pipe, seed, toothbrush removal, nail raking, chewing tobacco can produce atypical forms of dental abrasion.
- Occupational abrasion occurs among tailors who hold the needle between the teeth, or breaks the tooth with the teeth, among the windmills in the glass, and the musicians blowing the instruments.
- In this category of dental abrasion the tooth wear is also lost thanks to the hooks of the dental prostheses.

CHAPTER 6 - CLINICAL AND STATISTICAL STUDY OF DENTAL WEAR
6.1. INTRODUCTION

Dental wear is the term used for the irreversible loss of dental hard tissues under the action of physical and chemical factors, excluding brutal trauma and dental caries.

6.2. PURPOSE OF THE STUDY

The purpose of the study is to determine the prevalence of clinical forms of dental wear in a group of patients aged 20-80 who presented themselves in the Dental Prosthetic Clinic during 2014-2017. In addition to the prevalence of clinical forms of dental wear, a number of important etiological and clinical factors have been highlighted for this condition.

It is a quantitative descriptive research that will provide data on the prevalence of dental wear and the associated etiological factors in a group of patients in Craiova and rural areas.

6.3. MATERIAL AND METHOD

We conducted a study of 485 patients who presented themselves to the Clinic for Dental Prosthesis and Oral Rehabilitation in 2014-2017. The study was approved by the Ethics Commission of the University of Medicine and Pharmacy of Craiova.

The following parameters were recorded:
- the number of investigated patients (age, sex, background);
-prevalence of dental wear injuries in the group of patients studied;
-distribution of dental wear injuries;
-security of dental wear injuries;
- the etiological factors involved;
- clinical signs;
- complications.

The Microsoft Excel program was used to store, analyze and interpret the data obtained.

6.4 RESULTS

The distribution of patients by age group was as follows:
- age group 20-30 years -117 patients;
- age group 30-50 years -158 patients;
- age group 50-80 years -153 patients.

Of the total of 428 patients, 305 showed dental wear accounted for 71%, and 123 showed no dental wear accounted for 29%.

The prevalence of dental wear injuries in the group of patients studied by age was:
- age group 20-30 years -39 patients, representing 13%;
- age group 30-50 years -113 patients, representing 37%;
- age group 50-80 years - 153 patients, representing 50%.

In the two groups, depending on sex, dental wear was different. Thus, it was found:
- 131 women with dental wear were found for the group of women, representing 43%;
- For the men group, 174 patients with dental wear were found, representing 57%.

Depending on the background, dental wear has been identified differently. Thus, it was found:
- 126 patients with dental wear were found for rural patients, representing 41%;
- 179 dental patients, representing 59%, were found in urban patients.

Distribution of dental wear injuries

Regarding the distribution of dental wear injuries we found:
- in the age group of 20-30 years, 27 patients had wear injuries located on the palatal faces of the upper incisors and the occlusal surfaces of the lower molars (69%), and 12 patients had lesions at the edges of the upper and lower incisors (31) %).
- in the 30-50 age group - 13 patients had wound lesions located on the palatal faces of the upper incisors and the occlusal surfaces of the lower molars (12%), 76 patients had wound lesions in the vestibular cervical area - isolated lesion or associated with wear of the occlusal surface or incisional margin (67%), 69 sufferers suffered from wear on the vestibular face (61%), 113 patients had wear injuries at the level of cusps and incisions (100%) and 61 patients showed wear on edges of incisors and occlusal surfaces (54%).
- in the age group of 50-80 years - 132 patients had wear injuries located on incisors palatal faces and occlusal surfaces of molars (86%), 114 patients had wound lesions located in the vestibular cervical area - lesion isolated or associated with wear of the occlusal surface or incisional margin (75%), 153 patients had wound lesions located on the vestibular face (100%), 113 patients had wear injuries located at the cusp and incisal edges (74%).

For the age group of 20-30 years, 39 patients were scored ranging from 1 to 9 as follows:
- a score less than or equal to 2 to 13 patients (33%) was obtained;
- a score of 3 to 8 in 25 patients (64%) was obtained;
- a score of 9 to 13 in 1 patient (3%) was obtained.

For the age group of 30-50 years, 113 patients were scored ranging from 1 to 14 or more, as follows:
- a score of less than or equal to 2 to 9 patients (8%) was obtained;
- a score of 3 to 8 in 55 patients (49%) was obtained;
- a score of 9 to 13 in 37 patients (33%) was obtained;
- a score of 14 or more was obtained in 12 patients (10%).

For the 50-80 age group, 153 patients were evaluated with a score of 1 to 14 or more, as follows:
- a score of less than or equal to 2 to 5 patients (3%) was obtained;
- a score of 3 to 8 in 47 patients (31%) was obtained;

- a score of 9 to 13 in 72 patients (47%) was obtained;
- a score of 14 or more was achieved in 29 patients (19%).
        Taking into account the **etiological factors involved**, on the basis of completed data sheets, it was found:
- 64 patients are consumers of carbonated beverages (21%);
- 17 patients are consumers of energy drinks (6%);
- 58 patients are wine consumers (19%);
- 116 patients are fruit and vegetable consumers (38%);
- 59 patients had reflux disease (19%);
- 13 patients are drug users (4%);
- 31 patients have bruxism (10%);
- 9 patients were malocclusions (3%);
- 28 patients presented other parafunctions (9%);
- 218 patients had a reduction in the number of teeth (71%);
- 87 patients had incorrect prostheses (29%);
- 72 patients have been brushing badly through inappropriate technique or using abrasive teeth (24%);
- 17 patients had unidentifiable etiological factors (6%).
        Taking into account the **clinical signs**, based on the filled in sheets, it was determined:
- loss of dental tissues of varying degrees was found in all 305 patients (100%);
- Dental sensitivity was found in 53 patients (17%).
- physiological disorders in 211 patients (69%);
- chewing disorder in 143 patients (47%).

6.4.1 Clinical case no.1
        The BI, male, rural, 65-year-old male, was introduced to the clinic in 2011 with left upper left molar pain. The present atrition wear at all teeth. The tooth was extracted and a guard for occlusal protection was made. At the same time, the patient was discussed about the form of wear and tear that he presented and recommendations were made regarding the behavioral issues the patient had to follow (reducing stress, reducing wine consumption and avoiding vicious habits).

Fig.1 Patient with atrition and erosion wear

6.4.2 Clinical case no.2
        The 56-year-old male, GM, from Craiova showed up in the clinic for a deep caries in the left upper left premolar. There was an increased wear, especially at the lateral surfaces of the lower molars and at the level of the cervical area at all teeth.

Fig.2 Patient with erosive wear

6.4.3 Clinical case no.3

The 35-year-old, CI, patient from Craiova presented himself in the clinic in 2013 for multiple carious lesions. Anameza highlighted the fact that it was a patient with bruxism, and the clinical examination revealed multiple carious lesions, chronic gingivitis, atrial lesions located at the upper and lower incisal edges, and the palatal cuspid of the upper left premolar 1 at a patient with deeply occluded occlusion.

6.5 DISCUSSIONS

Dental wear is a dental injury with a high prevalence at this time, and what is worrying is that even greater future growth is expected, directly related to the lifestyle of the population. Vanāt Spijker, in 2009, believes that the prevalence of severely worn-out patients increased from 3 % to 20 la to 17 % to 70 cu with the tendency to increase the wear rate with age **[Van't Spijker 2009].**

6.6 CONCLUSIONS

Analyzing the distribution of dental wear injuries, we can state that the age group 20-30 years predominates erosive wear, in the 30-50 age group the patients presented several forms of wear: erosion lesions, non-carious lesions, lesions of atrition, predominantly occlusal wear and abrasion vestibular wear. For the 50-80 age group, the prevalence of all forms of wear was very high due to the summation of factors acting over time.

CHAPTER 7 - APPLICATIONS OF OPTICAL TOOMOGRAPHY IN COHERENCE (OCT) IN THE DENTAL WEAR DIAGNOSIS

7.1. INTRODUCTION

Teeth wear is a term used in dental medicine, which refers to the various processes that, either individually or in combination, lead to irreversible loss of hard tissue.

OCT could also be useful to diagnose early teeth lesions such as tooth decay and wear, prosthetic restorations and obturations adaptation, progression of periodontal disease and oral cancer detection **[Hsieh 2013].**

The aim of the study was to highlight the quantitative and qualitative morphological changes of dental surfaces that exhibit wear through coherent optical tomography.

7. 2. MATERIAL AND METHOD

147 teeth were selected that were extracted from 98 patients in the Dental Clinic of Dentistry and Oral Rehabilitation of the Faculty of Dentistry, according to a complex treatment plan for which the patient was informed and registered. The study was approved by the Ethics Commission of the University of Medicine and Pharmacy of Craiova. 25 teeth with dental wear were selected from the extracted teeth. Selected teeth were divided into 5 categories, 4 categories, one for each clinical form of tooth wear: erosion, atrition, abrasion and abrasion. The last category was intact teeth (teeth extracted for orthodontic purposes).

The classification of teeth on clinical wear forms was based on the history of the clinical examination, taking into account the abbreviations established by Abrahamsen in 2005, Verrett in 2001 and the consensus of the European Federation of Conservative Dentistry **[Abrahamsen 2005], [Verrett 2001] , [Carvalho 2016-2].**

For each type of lesion, the teeth that showed the most significant traits of the lesion analyzed were selected **[Mercuṭ 2017].**

7.2.1 Optical measurements

For examining the OCT, the teeth were first removed from the solution and dried using absorbent paper. For the experiment, a Thorlabs (OCS1300SS) OCT system powered by a laser source with a 1310 nm core wavelength, a spectral bandwidth of 100 nm and an average power of 12 mW was used for the experiment.

7.2.2 Image processing

Approximately 500 images were obtained for each sample. The images obtained were processed using Image J, an open access program **[Mercuṭ 2017]**.

7.3 RESULTS

7.3.1 Witness test

Among the teeth used as a control, a higher orthodontic premolar is shown. The premolar has an occlusal surface without clinical signs of wear.

Fig.3 OCT aspect of wearless tooth

7.3.2 The erosive wear test

Of the erosion teeth there is a lower molar, with two deep cavities on the occlusal surface, one positioned lingually and one towards the vestibular, separated by a mid-distal central enamel ridge.

At the level of the marginal ridge of the lingo-distal enamel, which delimits the lingual erosive cavity, where the enamel is not supported by the dentin, a very weak signal is observed on the OCT analysis.
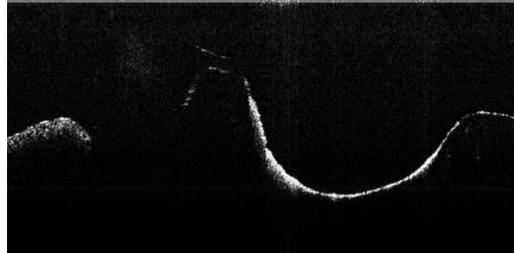

Fig.4 OCT aspect of a tooth with erosion

7.3.3 Attrition wear test

From the tooth group with atrium there is a superior molar with a glossy occlusal surface with the dislocation of the enamel layer on the mid-palatal wall.

It is also noted the presence of cracks, especially in the vertical direction of the enamel-dentine junction. At the level of the occlusal surface on the OCT there is an intense signal, which outlines the outer surface of the atrition lesion very precisely. In the central pocket of the occlusal surface there is a OCT signal similar to the integral teeth [Mercuţ 2017].
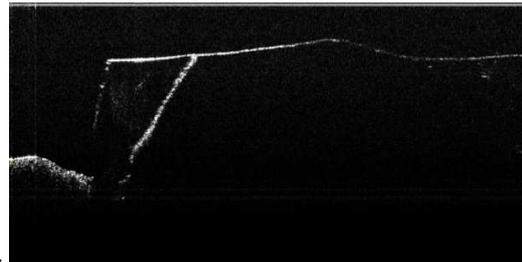
Fig.5 OCT aspect of tooth with dental atrition

7.3.4 Abfraction wear test

For the presentation of abrasion lesions, a lower premolar is presented, in which the lesion of abrasion is associated with an occlusal atrition lesion.

Considerable loss of dental tissue in the occlusal area and cervical area and the presence of vertical and longitudinal cracks in the cement and enamel. At the atrition lesion level, it is noted that the enamel is completely lost on the occlusal surface, with the position of the pulp chamber being emphasized in the central occlusal zone.
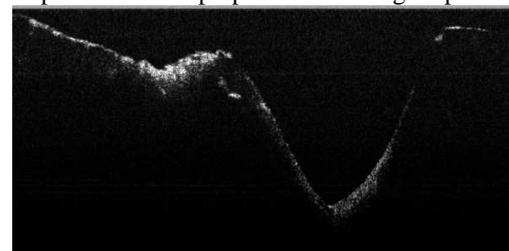

Fig. 6 OCT aspect of a tooth with dental abfraction

7.3.5 Abrasion wear test

From the group of abrasive teeth there is a superior canine on whose vestibular surface there is a matt-like enamel and vertical amplitude cracks.

On the OCT, a homogeneous signal is observed at the external surface of the tooth, and deeply there are vertical and oblique cracks, slightly expressed.
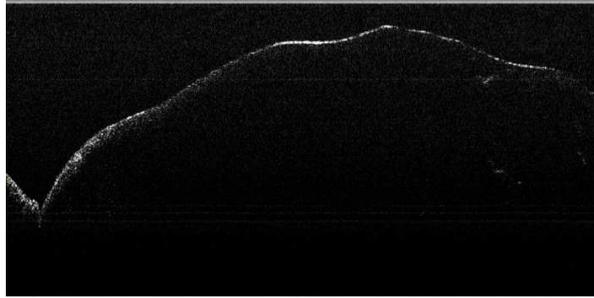
Fig. 7 OCT aspect of a tooth abrasion

7.4 DISCUSSIONS

Through this study, we have tried to highlight specific OCTs for each type of clinical form of dental wear. Although dental wear has accompanied man's evolution throughout its history and there are many publications in this field, there are still gaps in explaining the etiopathogenic mechanisms of dental wear. Exploring the OCTs could make an important contribution in deciphering the mechanisms of producing clinical forms of dental wear **[Mercuţ 2017]**.

7.5 CONCLUSIONS

-The study highlighted each clinical form of dental wear through the features of the OCT signal and, in conjunction with the clinical aspects, highlighted the mechanism by which the main etiologic factor acted in the lesion production.

- OCT analysis may have clinical utility in highlighting the factors involved in each clinical form of dental wear as well as in their detection and monitoring.

-This study presents a high degree of originality in that the OCT aspects of clinical wear patterns have not been described so far, and has also enabled identifying the etiologic factors involved in each lesion.

CHAPTER 8 - DETERMINATION OF RESISTANCE FORCES OF DYNAMIC SIMULATION MANDIBLE MOVEMENTS USING METHODS OF CINEMATIC ANALYSIS AND FINITE ELEMENTS

8.1 INTRODUCTION

Mandibular movements present a number of peculiarities due to the fact that several anatomical elements (determinants) participate in their guiding. These are the two temporomandibular joints (posterior determinant), dental occlusion (anterior determinant) and mandibular mobilizing muscles (middle determinant).

Elevated mandibular movements are rotation and translation and are performed by the two temporomandibular joints. The combination of these movements results in fundamental movements: opening, closing, propulsion, retropulsion and laterality.

Paraphunctional occlusive forces are generated in the same way by the contraction of the masticatory muscles but, in certain situations, may have pathogenic potential. At the level of the dento-maxillary apparatus there is another category of forces called **[Forna 2011]** or "reactive forces" **[Leriche1965]**, **[Prelipceanu 1985]**.

This study aimed to evaluate the resistance forces that develop in the dental structures during mandibular movements through dynamic simulation using the kinematic analysis method and the finite elements.

We sought to highlight these resistance forces and establish their amplitude so that in a later study we could check their possible involvement in the production of dental lesions, especially of non-carious cervical lesions.

8.2 MATERIAL AND METHOD

8.2.1 Obtaining the virtual model of the dentomaxillar system

A first step of the study was to obtain the virtual model of the dento-maxillary system.

A virtual skull was obtained by scanning a corpse skull with the 3DSYSTEMS CAPTURE 3D scanner.

The scanned skull model in the .stl format was obtained, which does not contain the internal components of the skull, but only the surface of the skull. For the internal components of the skull were used several "in vivo" models, respectively magnetic resonance imaging and tomographic images obtained with Emotion16 (Siemens) equipment. Tomographic images from eight patients, six female and two male patients aged 18 years to 75 years were used. Identity, or other personal data, will not be disclosed in this PhD thesis.

Also, in order to be accurate, a scanning scheme based on multiple scanning distances was used, as also used in **[Adam]**, **[Tarnita 2006]**.

For the three-dimensional reconstruction of the dento-maxillar system which involves the transfer of geometric information from the tomographic images to the virtual model, Mimics developed by Materialise, two

Mimics Medical workflows for transforming tomography images into three-dimensional geometry in format.stl, and the 3- Matic Medical for file processing and transformation into editable surface geometries in SolidWorks-type three-dimensional environments.

The model has been corrected and finalized by various software techniques included in the Geomagic for Solidworks program. To obtain the three-dimensional model of the dento-maxillar system, the Assembly module of the SolidWorks program was used.

After the application of a series of procedures and software techniques, the final model of the mandible was obtained. These removal operations of certain components of the model were carried out in order to obtain a simpler model and a high degree of accuracy.

To achieve the Multi-Body model, motion constraints were made such that the joints of this dento-maxillar system were approximated by biomechanical rotation and translational couplings so that the main motions were possible.

The Multi Body Model allows you to estimate the performances of the vertebrate and soft skeleton [Nogue]. It is a simulation technique used to study the behavior of biomechanical systems that have significant flexibility. This simulation method assumes that the deformation of the structure does not affect the dynamic behavior. Even though the structure is somewhat flexible, it is considered rigid, and flexibility is used to evaluate internal forces and deformations.

To determine the amplitude of the resistance forces during occlusal contacts, we started from the assumption that the teeth have occlusal contacts during propulsion, retropulsion, right and left lateral movements, and in the mandible lift movement.

For this, a kinematic simulation of each of the mandibular movements mentioned above was performed and the amplitude of the reaction forces at the level of the upper premolars was determined (24,25). The dento-maxillary model was automatically transferred to the Motion for Motion and Dynamic Motion module. In this program, kinematics (working joints) and free kinetic couplers (non-working joints) were established for each movement. These laws of motion went to the simulation itself for a second.

To simulate these mandibular movements, the strength of the muscle contraction was not taken into account, the amplitude of the forces being determined by the properties of the dental-maxillary and skull tissue [Hsu Ming-Lun 2010], [Ciciu 2015], [Keulemans 2015] [Benazzi 2016].

For the analysis and comparison of the resistance forces that develop from the two upper premolars in the mandibular movements were automatically obtained the Micrsoft Excel files containing the values for the time axis and the results for the force amplitude. Also, in order to be able to compare, for lateral movement, time was halved, and all four studies had a duration of one second.

8.3 RESULTS

Fig.8 Diagram of resistance forces in mandibular movements at the level of 24
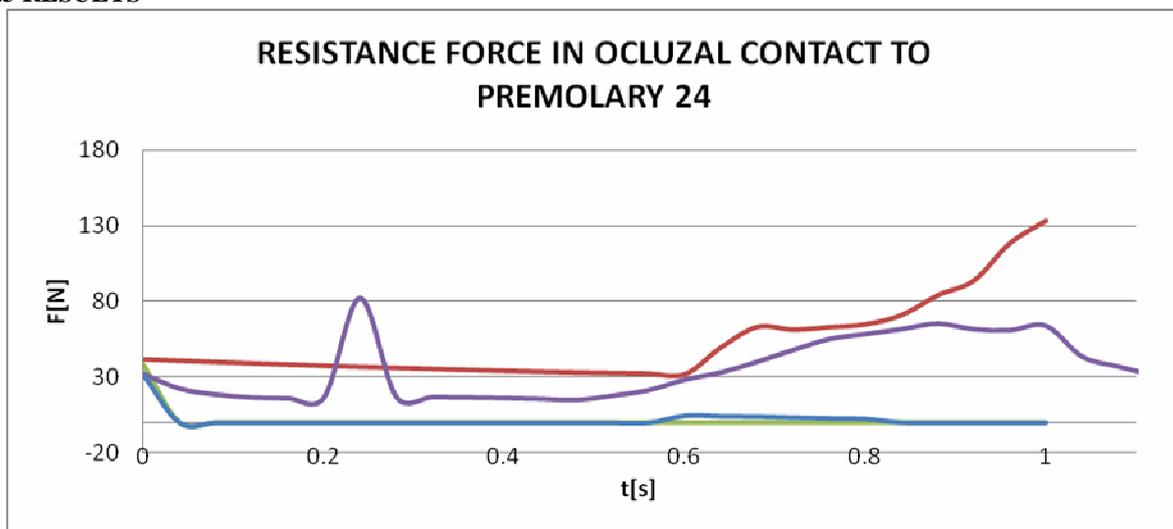
8.4 DISCUSSIONS

This study highlighted the presence of resistance forces [Forna 2011], called by Leriche bioreactive forces [Leriche 1965], and their magnitude in the dental arches in the functional movements of the mandible with occlusal contacts, by simulation, using the finite elements and kinematic analysis. Leriche states that these forces have a

continuous action in the dental arches highlighted by their effects, less known are their production mechanisms. Prelipceanu **[Prelipceanu 1985]** and Forna **[Forna 2011]** claim that their effects are obvious, especially in the case of edentuous fractures, and are represented by vertical and horizontal tooth migrations.

We have not found other studies in the literature to measure or simulate these resistance forces in the human dental-maxillary apparatus.

As we have said, these forces are little studied and their genesis is not well known. They are attributed to the difference in properties (elasticity, plasticity, density) assessed by flexibility of the components of the dento-maxillary apparatus.

8.5 CONCLUSIONS

This study provided a three-dimensional model of the dento-maxillary device by scanning a corpse skull and 1256 CT and MRI images from 8 patients.

Several softwares have been used in the three-dimensional reconstruction of the dento-maxillary device: SolidWorks, Geomatic for Solidworks, AutoCAD, "smoothing" software, Assembly module, Multi-Body module. Simulation of these mandibular movements did not take into account the force of muscle contraction, the amplitude of the forces being determined by the properties of the tissues that are part of the dento-maxillary apparatus and the skull.

This study allowed the simulation and determination of resistance forces occurring in the dental structures (dento-maxillary components) in the functional movements of the mandible with occlusal contacts. The value of these resistance forces was comparable to the value of occlusal forces determined in other studies.

From the balance of the resistance forces with the occlusal forces, the equilibrium state of the dento-maxillar apparatus results.

These resistance forces had approximately the same value at the level of the two upper premolars and a minimum value in the retropulsion movement: 31.78421 N and a maximum value in lateral movement: 174.1045 N.

CHAPTER 9 - HIGHLIGHTING AND EVALUATION OF RESISTANCE FORCES IN DENTAL STRUCTURES USING THE FINITE ELEMENTS METHOD
9.1 INTRODUCTION

This study aims to highlight through the finite element method the effects of resistance forces (stress, displacements and deformations) on the structures of the maxillary bones and the components of the two upper premolars during the functional movements of the mandible. I chose these two teeth because they are the most susceptible to fracture **[Rose 2017], [Bakland 2015], [Khasnis 2014], [Tamse 2006], [Reeh 1989]** followed by the molars one and the other cusp teeth, and also the location of non-carious cervical lesions in the jaw **[Dallongeville 2010], [Lee 1996], [Bader 2008]** is on the vestibular faces of superior incisors, superior premolars, superior canines and molars. Thus, superior premolars have a high susceptibility to both lesions that might be due to excessive forces, they have a very complex morphology through the presence of two cusps placed either orally and the other vestibular, by the presence of a paralysis in the area of the parcel and by the two thin roots (especially the first premolar) arranged one vestibular and one oral.

9.2. MATERIAL AND METHOD
9.2.1 The virtual model of the dento-maxillary apparatus

In the first stage the virtual skull was obtained by scanning a corpse skull with the 3DSYSTEMS CAPTURE 3D scanner. The data was interpreted with a Geomatic Capture software produced by 3D Systems. The scanned skull model in .stl format **[Vatu 2018]** was obtained, which does not contain the inner parts of the skull, but only the surface of the skull. For the internal components of the skull were used several "in vivo" models, respectively magnetic resonance imaging and tomographic images obtained with Emotion16 (Siemens) equipment. In parallel, the disposition of the internal bone components of a skull was studied as a didactic material at UMF Craiova. Tomographic and magnetic resonance imaging have generated a virtual model of the dento - maxillary and skull apparatus to be used for "in vitro" biomechanical simulations. This model shows the inner parts of the skull to which materials have been attached with some flexibility **[Vătu 2018]**.

9.2.2 Experimental virtual simulation using the finite element method of the effect of resistance forces at the level of the two upper premolars in the mandibular movements

It has been chosen as an FEM study method for the following reasons:
• FEM can be applied to linear and nonlinear structural interactions, as well as to solid-fluid contacts.
• Any problem can be divided into fewer problems.
• It is a non-invasive technique.
• Using FEA, it is very easy to simulate any biological state at pre, intra and post-surgical stages to achieve more accurate and safer results.

• Reproducibility does not affect the physical properties involved.
• FEA techniques can replace classical methods for pre-surgical planning, providing an economic solution.

9.2.3. The virtual model of the two superior premolars

To get as close as possible to reality, the two premolars were remodeled and then implanted virtually into the jaw. Thus, each premolar was composed of three components:
- outer enamel pattern;
- the dentine model;
- Simplified pulp pattern.

Using commands and techniques specific to the Assembly module in SolidWorks, the two complete patterns of premolars were positioned and positioned on the jaw.

This virtual model of the jaw was used to perform various simulations using the finite element method. Load mode was used in a dynamic mode, and loadings from the kinematic study performed for the four main movements were automatically transferred, so that for the analyzes presented in this paper the forces and moments previously obtained were used.

9.4 RESULTS

The main results of finite element method simulations are:
- the tension stress state, obtained by the von Mises algorithm, which provides information on loading of the finite element by reporting the force at the surface and expressed in Pascali (1 Pa = 1N / m2);
- Displacement, displaced by displacement maps, which provides information on the variation of the positions of the nodes of the finite elements and is expressed in millimeters (mm);
- the deformation state (deformation) of the biomechanical system which gives the elongation of the finite elements to the unit of length and expressed in millimeters / millimeter (mm / mm - dimensional). The state of deformation was followed by the von Mises criterion.

9.4.1 Experimental virtual simulation using the finite element method of the effects of resistance forces at the upper premolars on the left half for the mandible lifting movement.

It is intended to analyze the biomechanical model of the jaw at the jaw lifting movement for the 2.4 and 2.5 integrals of the premolars. The loading system was similar to the kinematic analysis of the analyzed motion.
To perform the analysis, the model was divided into finite elements.

After running the analysis, different results maps were obtained. By artificially insulating the premolar 2.4 and 2.5, tension, displacement and deformation maps for the enamel, dentin and pulp patterns were obtained.

Similarly, simulations for propulsion, retropulsion, and lateral movement were obtained.

The same simulations were performed for models with 0.5 mm and 1 mm occlusal wear.
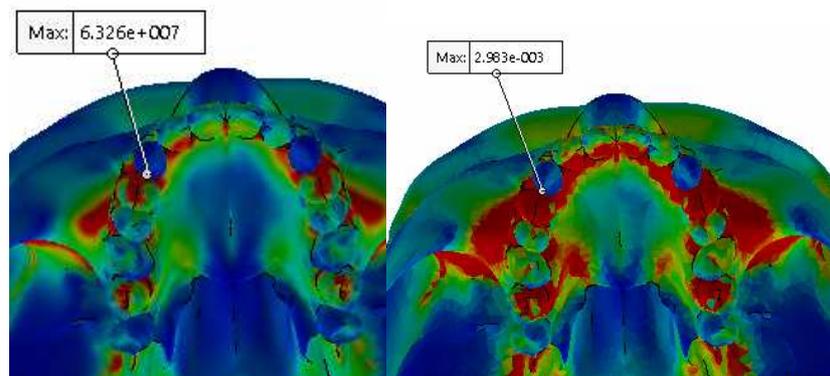
Fig 9. The stress map and deformation map generated by the resistance forces

9.5 DISCUSSIONS

The oral cavity is a complex biomechanical system. Because of this complexity and limited access, most of the biomechanical oral researches, such as restorative dentistry, endodontics, orthodontics, prosthetics and implantology, have been performed in vitro.

Deformation and stresses are generated when tasks are applied to a structure. This is common and is how a structure fulfills its structural function. But if tensions become excessive and exceed the elastic limit, structural failure may occur. These stresses can not be measured directly, and it is not easy to understand why and when the failure process is initiated in complex structures and how we can optimize the strength and longevity of dental

system components. Applying engineering knowledge in dentistry by using computational techniques has contributed to the understanding of oral biomechanical aspects.

The analysis of the mechanical tension of the dental structures has been a subject of interest in recent years in order to determine the state of tension in the dental structures and to improve the mechanical strength of these structures. Such numerical techniques can give a better understanding of reactions and interactions of individual tissues. Finite Element Analysis (FEA) is a mathematical way to solve complex problems in the universe because it provides an easier mathematical solution to biological problems.

9.6 CONCLUSIONS

The human skull and the maxillary bones have a very complicated architecture, determined by the outer walls, by the internal bone structures and their joining. In the structure of the maxillary bones the spongy bone tissue, cortical bone tissue and the dental tissues enter. Each of these tissues have certain properties (elasticity, plasticity, density) assessed by flexibility.

Starting from the virtual skull model obtained in the previous study (CHAPTER 8), the virtual models of the two upper premolars on the left hemiarcade were generated, then the finite element method evaluated the stresses, displacements and deformations generated by the resistance forces, from the level of dental tissues of the two premolars during mandibular movements with occlusal contact.

We believe that these resistance forces that cause tension, deformations and displacements in the bone structures are a reaction to the occlusal forces as long as they are only evident during these occlusal contacts. Theoretically, there should be a balance between the occlusal forces and the resistance forces for dento-maxillary homeostasis.

It is found that the value of these jaw and teeth increases as dental wear increases. This phenomenon is more visible in the teeth where the value almost doubles. Two explanations could be made for this situation:
- mechanically, these stresses are inversely proportional to the volume of the dental structures and, as they reduce, through dental wear, tensions increase;
- sharp edges resulting from dental wear are mechanical stress concentrators.

This study is innovative because it highlights the presence of stress, displacements and deformations generated by the resistance forces in the structures of the jaw bone and the teeth. We have not found any other study on this topic in the literature. As can be seen from the results of the study and the conclusions, the greatest effects of the resistance forces were recorded in lifting and lateral movements, in the case of teeth with 1 mm wear.

FINAL CONCLUSIONS

Dental wear is a loss of dental hard tissue under the influence of extrinsic or intrinsic factors, other than dental caries and bruising of the teeth.

This doctoral thesis was structured on four research directions:
- Clinical-statistical study of dental wear;
-the applications of Optical Tomography in Coherence (OCT) in the diagnosis of dental wear;
-determination of the resistance forces from the mandibular movements through dynamic simulation using the kinematic and finite elements methods;
-Depending and evaluating resistance forces in dental structures using finite element method.

Regarding the clinical-statistical study of dental wear, it was performed on a group of 485 patients who presented themselves in the Clinic of Dental Prosthetics and Oral Rehabilitation during 2014-2017. Based on the exclusion criteria, 57 patients were excluded and 428 patients remained in the study.

With respect to the applications of Optical Tomography in Coherence (OCT) in the diagnosis of dental wear, the study highlighted every clinical form of dental wear through the characteristics of the OCT signal and, in conjunction with the clinical aspects, highlighted the mechanism by which the main etiological factor acting in the production of the lesion.

This study presents a high degree of originality in that the OCT aspects of clinical wear patterns have not been described so far, and has also made it possible to identify the etiological factors involved in each lesion.

The following study aimed to determine the strength forces of mandibular movements through dynamic simulation using the kinematic analysis and finite elements. The study provided a three-dimensional model of dento-maxilla scanning from a body skull scan and 1256 CT and MRI images from 8 patients. Many softwares were used in 3D dentomaxial reconstruction: SolidWorks, Geomatic for Solidworks, AutoCAD, "smoothing" software, Assembly module, Multi-Body module. This study allowed the simulation and determination of the amplitude of the resistance forces occurring in the dental structures (dento-maxillary components) in the functional movements of the mandible with occlusal contacts. The value of these resistance forces was comparable to the value of the occlusal forces determined in other studies.

The study on the evaluation and evaluation of resistance forces in dental structures using the finite element method of the virtual skull model obtained in the previous study (CHAPTER 8). The virtual models of the two upper premolars on the left hemiarcade were generated, they were positioned on the virtual arcade, then the finite element method evaluated the stresses, displacements and deformations generated by the resistance forces from the dental tissues of the two premolars during mandibular movements with occlusal contact.

It has been found that the value of these jaw and teeth tensions generated by resistance forces increases as the dental wear increases. This phenomenon is more visible in the teeth, where the value almost doubles. Unlike these reaction forces, occlusal forces are thought to decrease with dental wear.

This situation can be interpreted by breaking the balance between the occlusal forces and the resistance forces in the case of dental wear.

Regarding the distribution of these tensions, displacements and deformations for all types of dental tissues (enamel, dentin, pulp) these were located at the occlusal surface and at the level of the vestibular cervical area. This situation was more evident at the level of the first premolar superior.

We can give the following interpretation for this distribution of stresses, displacements and deformations generated by the resistance forces: **Strength forces can cause the enamel layer to be dislocated in the occlusal area and vestibular cervical area, so they can cause dental wear.**

This study is innovative, because:
- Provides a description of the OCT aspect that allows the identification of etiological factors for each clinical form of dental wear;
- highlights the presence and amplitude of the resistance forces in the structures of the dento-maxillary apparatus;
- highlights the presence of stresses, displacements and deformations generated by the forces of resistance in the structures of the jaw bone and the teeth;
- the distribution of stresses, displacements, deformations generated by resistance forces may be evidence of their involvement in dental wear.

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