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TRIBOLOGICAL BEHAVIOR SIMULATION OF HARD DENTAL STRUCTURES USING THE FINITE ELEMENT ANALYSIS

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ABSTRACT

Simulating the biomechanical behavior of a reconstruction using the finite element analysis method is a modern method necessary before the practical stage of a research, thus enabling the precise shaping of certain trajectories in the approach of certain directions of practical applicability, as well as obtaining final results with relevant data (results coupled with experimental models that reiterate the clinical situation that will be later analyzed).

Key words: tribological behavior, simulation, dental structures, restorative materials

INTRODUCTION

Our study aimed to analyze, using the finite element method, the state of stress and strain recorded at the point of direct contact between two structures (two hard dental structures in tripod relation), and determine the points of their maximum wear.

MATERIAL AND METHODS

In order to determine the state of tension and estimate the areas of maximum wear between the two structures in direct contact, we used a group of 10 patients that needed dental prosthetics.

A tridimensional analysis of the clinical situation was carried out, where the lower molar establishes a tripod contact with its natural antagonist tooth.

The accuracy of the reconstruction is presented in figure 1 by the precision of the structures represented and analyzed using a CT scan (Fig. 2, Fig. 3) in one of our patients that needed a ceramic prosthetic. A simple radiography would not have revealed an image as accurate of the aimed structures.

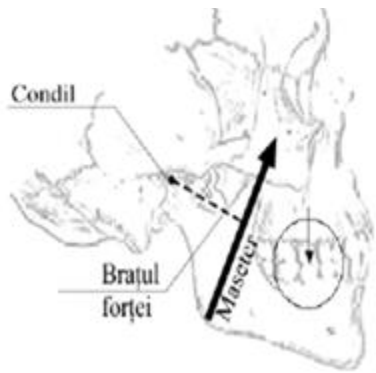

Figure 1. Anatomical reference points used in the 3D reconstruction

The CT-scan is a diagnosis method that uses special X-ray equipment (the CT scanner) to obtain transverse sections of the scanned object, by means of X-ray detectors. For the 3D reconstruction we used the ABAQUS STANDARD 6.5-1 software.

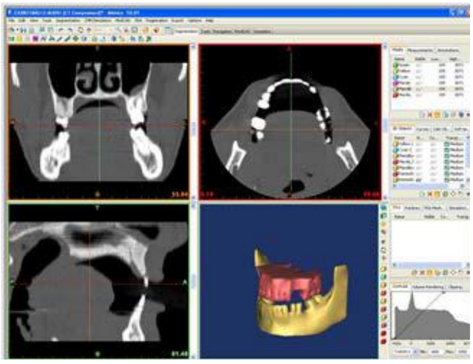

Figure 2. The 3D reconstruction using the CT scan

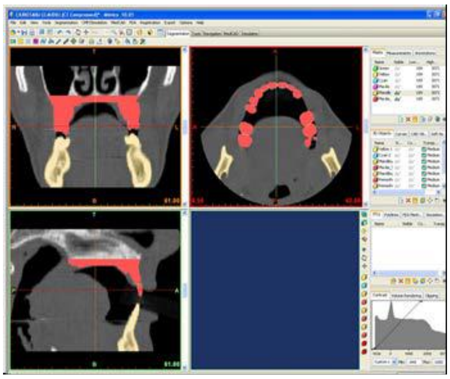

Figure 3. 3D reconstruction of the anatomical reference point in the analyzed CT scan

We considered the muscle forces acting on the mandible in complete occlusion (ie forces developed by the masseter, temporal, pterygoid muscles, etc.), whose direction, orientation and size is calculated from the equilibrium condition of temporo-mandibular joint lever.

The measurements were carried out applying relatively large forces, but considered normal for the oral cavity, of 300N (30KgF) and 500N (50 Kgf) and a force of 800N considered an overload (80 Kgf); testing began with a 300N force applied on the crown of the tooth to avoid convergence issues (possible mathematical errors), then the intensity of the force was increased to values high enough to simulate a parafunctional activity. 500N is regarded as the average force between the upper physiological limit for which changes are physiological and reversible.

The force that was applied to the mandible bone had an anterior-posterior direction and was oriented at 15° to the vertical plane. Also, we used embeddings into the upper jaw bone to determine the propping of the structure. Due to the fact that during mastication only the lower jaw is mobile, the upper jaw is considered a fixed reference point, so bearings (ie motion constraints) will only apply to the upper jaw bone and pressure (ie, an evenly distributed force that replaces the mastication muscles' action) will apply on the mandible.

For measurements, the following factors weretaken into account: material properties, namely, modulus of elasticity E and Poisson coefficient corresponding to dental structures, bone, muscle and ceramic material to be used in restoration (Table I).

COMPONENT	ELASTICITY MODULE [GPa]	POISSON COEFICIENT
Bone	138	0,33
Tooth	186	0,31
Muscle	0,02	0,40

RESULTS AND DISCUSSIONS

Figure 4 reveals that, when using a 300 N load, the value of the maximum contact pressure in molars is 180 MPa (180 N/mm2), with the pressure tensor concentrated on the tip of the disto-palatal cusp. Little pressure concentration is observed at this level.

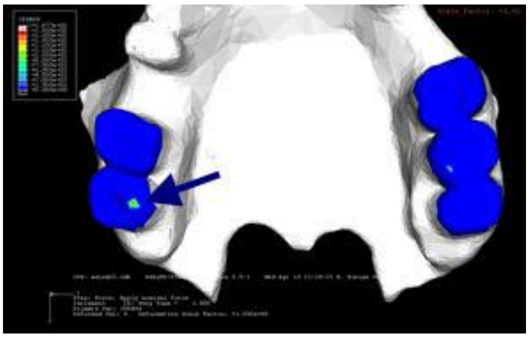

Figure 4. Molar contact pressure for a 300 N load

The Von Misses stresses are shown in a color code, ranging from blue (for the value 0) to red / white (Fig. 5, Fig. 6).

Thus, the maximum equivalent tension on molars is just 29 MPa, with an even distribution along the edentulous area, where the maximum equivalent tension reaches values of 5 MPa.

Figure 5. Molar Von Misses tension for a 300 N load (30 kgF): posterior-anterior view

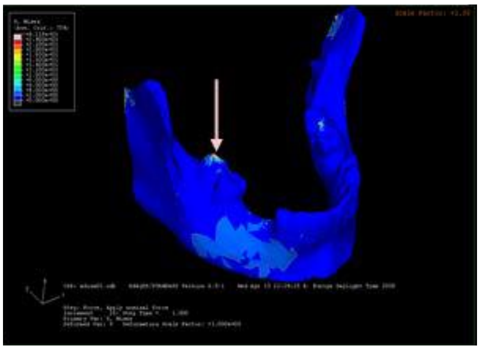

Figure 6. Molar Von Misses tension for a 300 N load (30 kgF): frontal-lateral view

The minimum tensions are registered at the marginal ridge level and on the external slopes of the disto-vestibular and disto-lingual cusps, and the maximum are located on the top and internal slopes of the same cusps. Moreover, overburdened areas, where the Von Misses stress reaches up to 92.18 MPa will become starting points for the wear process.

Along with the value increase of the force applied to 500 N, contact pressure will vary between 180 MPa - 256 MPa (180 to 256 N/mm2), the stress concentration area extending to the mesial, as outlined in Figure 7.

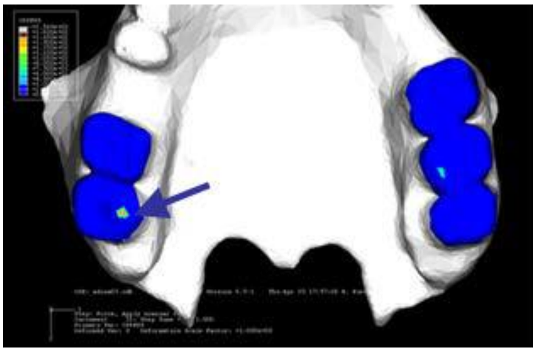

Figure 7. Molar contact pressure for a 500 N load

Maximum equivalent stress reaches about 240 MPa-290 MPa consequently with the broadening of the stress concentration area (the whole disto-lingual cusp of the mandibular molar, the distal pit, distal marginal ridge and distal side of the mesio-lingual cusp), with an even distribution along the edentulous area, where the maximum equivalent stress reaches about 6 MPa. (Fig. 8, Fig. 9).

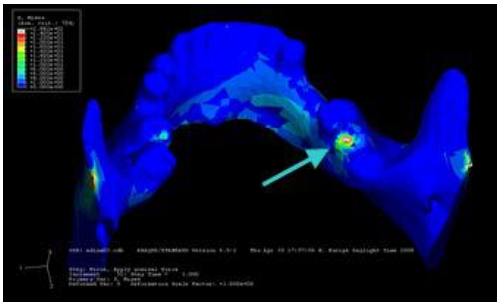

Figure 8. Molar Von Misses tension for a 500 N load (50 kgF): posterior-anterior view

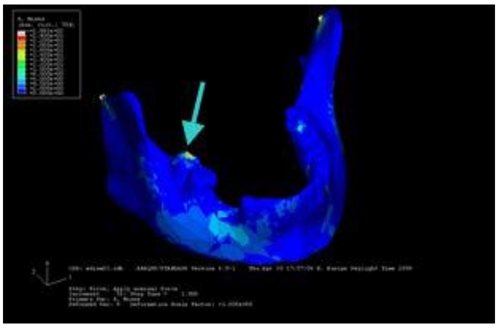

Figure 9. Molar Von Misses tension for a 500 N load (50 kgF): frontal-lateral view

Seen in antero-posterior perspective, the maximum tension area is visible in the disto-lingual cusp and on the adjacent anatomical elements, as an intense red area. This will be the starting point of the abrasion wear.

Should the patient undergoing CT examination present a parafunctional activity (grinding of the teeth, for example), the force acted in the jaw would have a value of about 800 N (80KgF). The result of the finite element analysis for a 800 N load is represented in Figure 10. It is noted that the molar bears high pressure, which can reach up to 350 MPa (350 N/mm^2).

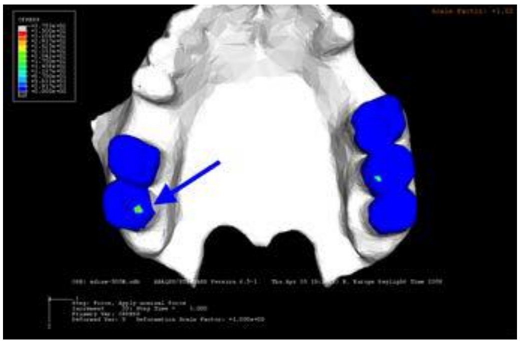

Figure 10. Molar contact pressure for a 800 N load

Figure 11 shows the appearance of high tensions in the mandible, tensions that are also present in the bone, leading to occurrence of shear phenomena in time.

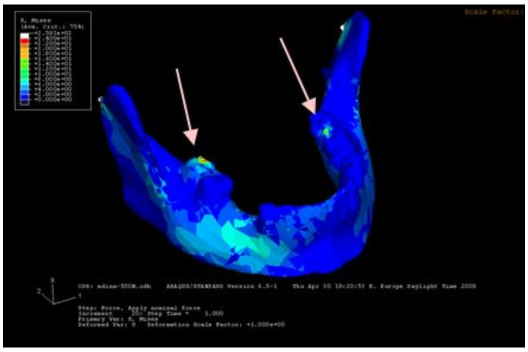

Figure 11. Molar Von Misses tension for a 800 N load (80 kgF): frontal-lateral view

The fact that there is a 240 MPa - 250 MPa tension on the contact area, but extended throughout the lingual half of the molar, causes rapid occurrence of the wear process. (Fig. 12).

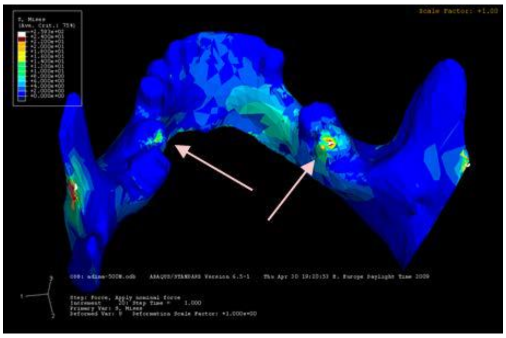

Figure 12. Molar Von Misses tension for a 800 N load (80 kgF): posterior-anterior view

In the cervical area, the maximum tension reaches 220-240 MPa playing, along with the structural features of this area, an important role in the initiation of fatigue wear at this level (5).

The increasing impact load is transmitted from the molar in the mandible bone, where the maximum equivalent tension reaches about 120 MPa on the lingual side of the ridge and 100 MPa on the vestibular. Also, there is a concentration of tension in the edentulous area that reaches values of 8 MPa.

In all three cases, it was found that minimum tensions are localized in the edentulous area (up to 8 MPa for a maximum of 800N load, minimum 5MPa for a 300 N load), while the maximum tensions, probably due to small contact areas associated with the occurrence of the end effect are present in the interdental contact area (2,3, 4).

A different thing happens when the patient closes the mouth and the two arches come in direct contact. The occlusal contact areas, the coronary, cervical and periodontal structures are affected differently depending on the load applied (5, 6, 7). Thus, Figure 13, Figure 14 and Figure 15 present the overloading areas that underlie the occurrence of abrasion wear, under the action of 300 N, 500 N and 800 N forces, various situations associated with fatigue wear in the cervical level.

For a 300 N load developed during the performance of stomatognathic system functions, it is found that the most affected areas are located in the occlusal contact area in the vestibular half (top of vestibular cusps), with a 180 MPa tension recorded, gradually decreasing to 160 MPa for root and bone portion.

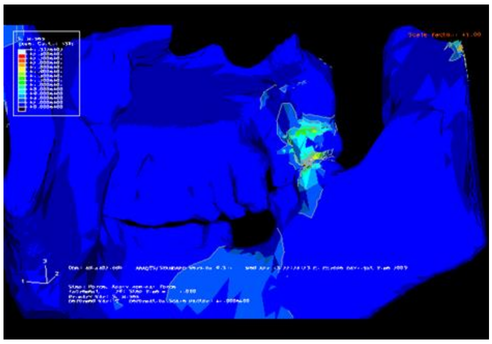

Figure13. Dental-periodontal alterations for a 300 N load

When the load reaches about 500 N, the occurrence of overload stress is obvious in mesio-buccal cusps and medial-vestibular (220 MPa), associated with involvement of the cervical area (200 MPa) and transmission of the pressure along the crown to the root and bone, also involving the antagonist tooth (8, 9, 10).

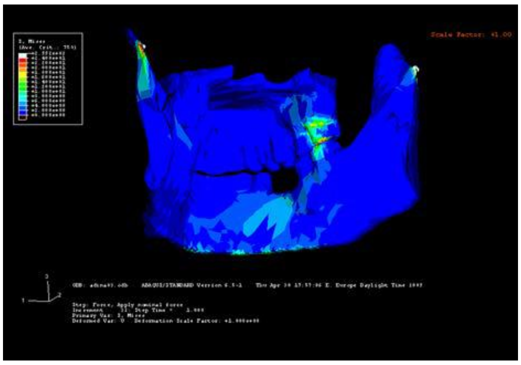

Figure 14. Dental-periodontal alterations for a 500 N load

When a 800 N overload occurs all structures are affected: the whole area of occlusal contact, cervical regions, opposing teeth, with the transmission of the load to the bone of the edentulous region (11, 12). Tensions reach values of 310 MPa in the maximum strain area.

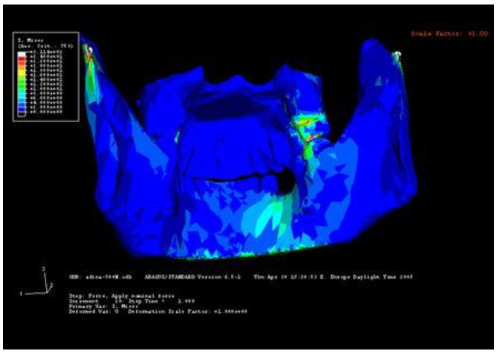

Figure 15. Dental-periodontal alterations for a 800 N load

This three-dimensional model indicates values of the equivalent tension as normal as possible given the clinical situation (13). Not the same can be said about the contact stresses, whose values can reach up to 314 MPa. This is because, these tensions were determined at the contact point areas, knowing that a contact point is accompanied by high, but still less relevant tension values. (14)

Burdened unphysiological forces applied to the tooth cause occurrence of tension concentrators in the intercuspidian fissure and in the dentin – enamel interface, with consequent dentin or enamel cracks and periodontal ligament strain (4, 11).

These high and deep strain zones will have a faster destructive effect than an unphysiological vertical axial force, causing cracks, peeling or pulling of the the material in time, especially in the cervical region, area which favors the emergence and spread of these phenomena dut to its particular anatomical features. Thus, fatigue occurs (1,9).

During occlusal solicitation, the top of the cusp undergoes a compressive axial load, which induces cervical tension associated with the development of a shear effort that occurs at a right angle to the load.

The tension and shear are accompanied by brakeage of the links between hydroxyapatite crystals, thus initiating cracks that in time lead to "fatigue" areas, with exfoliation and even loss of material (6, 8).

A rapid increase in tension concentrator values can be explained by the fact that without lubrication, wear particles are formed, making the two-body wear (seen frequently in cases of teeth grinding) in three body abrasion wear. As the labor intensity progresses the adjacent bone undertakes the increasingly higher load, with the overload gradually extending towards the maximum resistance area of the bone (5, 6, 11, 13).

CONCLUSIONS

As a result of our analysis, the following conclusions can be drawn:

• Understanding the properties of the dental material allows foreshadowing of the strain zones and thus the appearance of the first wear areas located either on dental support or on the restorative material

• The most burdened areas are represented by cusps that come in contact

• These areas are oriented along the direction of the masticating muscles

• The geometry of this burdened area is adapted to the effort that it must endure, being the most developed one of the studied area.

In all cases a sum of tensions act, as an expression of combined normal tensions (tensile, compressive, crushing, bending) and tangential (shear or torsion), which will result in the initiation and / or evolution of combined patterns of wear, abrasive wear braiding with fatigue as the intensity of the applied force increases.

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