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Biomechanical application - Parametric modeling and transfer for FEM analysis

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Abstract

This paper presents a biomechanical application, namely the analysis of an orthodontic structure, of parametric modeling using Autodesk Inventor design program and then transfer for FEM analysis using ALGOR analysis program.

1. Theoretical aspects

The study performed is aimed at analysing through FEM the biomechanical reactions due to the dental drifting produced by the action of the orthodontic forces, with a view to anticipating the tissular phenomena affecting the dento-periodontal structures.

The upper *central incisor (CI)* without dento-maxillary disharmony and osseous radicular resorption has been considered as being representative for the study, as it shows the most significant dental drifting as well as a high risk of radicular resorption when compared to the rest of the teeth.

The orthodontic forces that may act on the dental corona may have different directions. Generally, the most stressed in the case of a periodontal structure are the horizontal orthodontic forces (tilting forces). They can cause structural modifications, parallel with the changing of the teeth position. For this reason, force intensity and dosing are very important, depending on the individual reactivity of the periodontal tissues.

Their values, hard to measure, are in line with those indicated by the studied specialized literature. They range between the values: $F = 1 \div 3$ N. In order to realize a complex study and to be able to extend the obtained conclusion, given the case of a stressed periodontal structure, a simulation on the model created through FEM has also been performed with an excessive value of the orthodontic force (supraliminal) which practically exceeds the usual values, namely of $F = 5$ N.

The sequence of operations with a view to FEM modeling and analyzing can be expressed by the algorithm in figure 1.

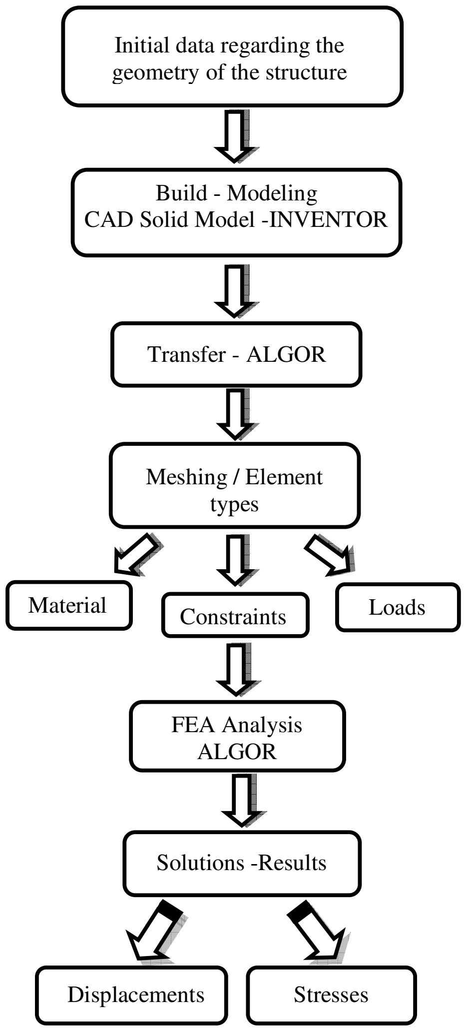

Fig.1. The algorithm of the modeling – FEM analysis

Keywords: *biomechanical application, fem analysis, algorithm*

2. Modeling

By respecting the geometry, the dimensions and the morphologic information from the specialized manuals relating to the upper central incisor, (CI), a three-dimensional general model of the proper tooth has been created using Autodesk Inventor parametric modeling program (Figure 2).

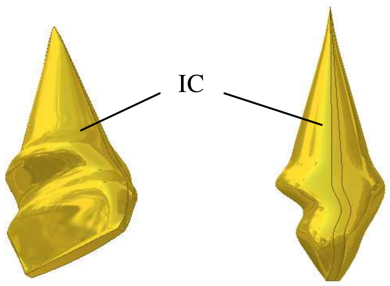

Fig. 2. Parametric modeling – Autodesk Inventor

Using Autodesk Inventor design program for modeling, an accuracy image of the real geometry of the tooth cold be obtained.

3. Meshing. Materials

By maintaining the geometric equivalence to the shape of the upper central incisor for the generated three-dimensional model of the tooth, 3D type finite elements - tetrahedron or hexahedron – have been used (Figure 3).

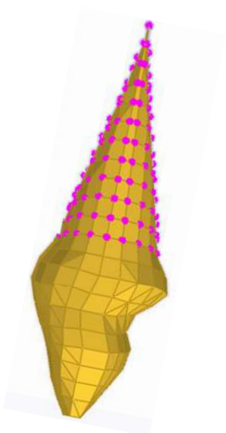

Fig. 3. Meshing model

The extreme conditions imposed for all the peripheral nodes at the level of the alveolar bone are null drifting conditions.

The loading of the model has been performed using a nodal forces which corresponds to the horizontal orthodontic forces and which produces a titling-type drifts, having as application point the node located in the centre of the vestibular side of the upper CI, at 4.5mm of the incisal surface, with intensities of: $F = 1 \div 5$ N ($F = 5$ N as supraliminal value).

The material characteristics of the tooth (Poisson's ration, ν, and Young's module, E), have been considered given the case of a tooth without dento-maxillary disharmony and osseous radicular resorption. Furthermore, the tooth is considered homogenous and isotropic, with a static linear behavior, taking a linear relation between the tensions (stress) and deformations.

The situation is different in the case of periodontal structures at patients of old age, when the osseous resorption phenomenon appears and the tissues of the structure change, thus modifying the material characteristics too. For the case studied: $E=1.96 \cdot 10 N/mm^2$ and $\nu = 0.3$.

4. Results

The results which are considered significant for the interpretation of the biomechanical reactions in case of orthodontic displacements and which give relevance to the phenomena studied are expressed by the following values:

a. *Drifting depending on the acting direction of the force;*

b. *Stress depending on the direction of the applied orthodontic force:* on Y axis, when the force is horizontal (corresponding to the direction of action of the force); the orthodontic tilting movement has been simulated by applying a horizontal orthodontic force in the middle of the vestibular side (V) of the upper CI, at 4. 5mm of the incisal surface; $F = 1 \div 5$ N (the application of a horizontal force having an intensity 5 times bigger $F = 5$ N shows the consequences of the orthodontic supraliminal forces);

c. *Stress according to Von Mises' theory*, namely the resulting or the equivalent stress in the three-dimensional space X, Y, Z;

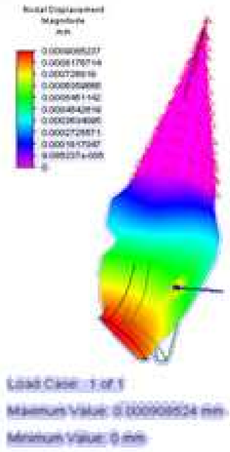

Fig.4. Distribution of displacements – equal areas deformations, when F = 5 N [mm]

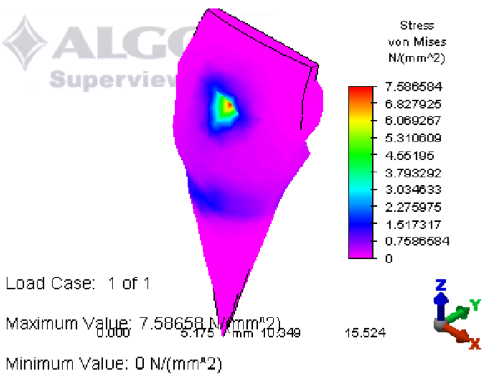

Fig.5. Distribution of equivalent stress Von Mises, when F = 5 N [N/mm²]

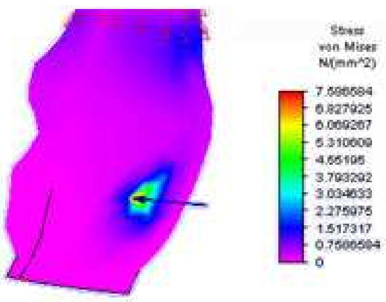

Fig.6. Detail – Distribution of equivalent stress according to Von Mises, when F = 5 N [N/mm²]

5. Conclusion

The application of tilting horizontal forces having the same orientation and on the same nodal point on the side V of the upper CI, but of different intensities, allows a comparison of the values related to the tooth deformation as well as the visualization of the distribution of displacement/stress, and the areas with equal deformations/stress:

One can notice high values of the displacements at the level of the dental corona, reaching maximum values at the level of the incisal surface according to plan +10.5, decreasing, with minimal values at the level of the dental neck (fig.4);

As a result of the simulation performed by applying horizontal orthodontic forces in the middle of the vestibular side (V) of the upper CI, its tilting process has been confirmed ; the stronger the tilting phenomenon, the higher the value of the horizontal orthodontic force;

The application of a horizontal force in the same nodal point on the side V of the upper CI, on the same direction but having an intensity 5 times bigger, shows the dangerous consequences of the supraliminal orthodontic forces;

The evaluation of the results related to the stress depending on the direction of the force (Y axis) indicates that from a qualitative viewpoint, the phenomenon manifests identically in all cases (F = 1 N ÷ 5 N). By displaying in detail the tensions from the radicular transversal sections corresponding to the surfaces located between the incisal surface [+10,5mm] and the dental neck [0] one can notice:

Maximum stress at the level of the dental corona, in the area where the forces have been applied;

When the horizontal force is excessive, there are areas of pressure and tension between the edge and the apical areas of the periodontium;

It is important to emphasize that high values of the orthodontic supraliminal forces induce dangerous values of the compression-type stress, in the area where these have been applied, in the middle of the vestibular side of the upper CI (Fig. 6);

In all cases of strain with values of the orthodontic forces having different intensities, the area of maximum strain for the tooth is located near the point where the force has been applied;

The strain is a stress reduction-type and it grows as the intensity of the orthodontic forces grows;

The distribution of the equivalent tensions according to Von Mises indicates, in the case of a force with 5N intensity, the same significant stress areas as for a force having an intensity of 1N, but at much higher values (Fig. 5).

6. References

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[4] *** Scientific Research Project financed by the Romanian National University Research Council