FINITE ELEMENT ANALYSIS OF STRESS DISTRIBUTION IN THE CAST CLASPS, DIRECT RETAINERS OF A REMOVABLE PARTIAL DENTURE

Liliana Sandu[1], Nicolae Faur[2], Cristina Bortun[3]

ABSTRACT

Objectives: The purpose of this study was to evaluate the stress distribution in the critical components of the removable partial denture - the cast clasps.
Materials and method: The three-dimensional models of the clasps were generated using three-dimensional measurements and investigated during loading, using the finite element stress analysis.
Results: Although the loading influences the stress distribution and stress levels, considerable values were always observed in the clasp arms, close to the junction with the body of the clasp. The maximum stress recorded in all cases was between 310.27 MPa and 404.74 MPa, below the ductile Yield of the Co-Cr alloy (700 MPa).
Conclusion: With the use of a properly designed removable partial denture, the magnitude and distribution of the stress in the cast clasps are within the normal limits.

Key Words: finite element analysis; stress distribution; removable partial denture; cast clasps.

INTRODUCTION

Removable partial dentures are not rigidly connected to teeth or tissues, therefore they are subject to movements in response to functional loads. Consequently, their design requires biomechanical considerations.

Every component is designed and used to control the possible movements such as vertical displacements and rotations toward, away or horizontally across the underlying tissue. These possible movements do not occur singularly or independently, but tend to be dynamic and all occur in the same time.[1-4]

The complex geometry of the removable partial dentures makes stress distribution analysis very complicated. Among the different methods of stress analysis, we selected the finite element method, a powerful and popular numerical model. The finite element method was initially developed on a physical basis for the analysis of problems in structural mechanics. However, it was soon recognized that the method could be applied equally for solving many other classes of problems, like biomechanics, where it is used for nearly three decades.[5] This method is based on the idea of building a complicated object with simple blocks, or dividing a complicated object into small and manageable pieces (finite elements). By analyzing what happens with each finite element, as part of the whole system, we can establish the response of the system to external stimuli.[6-8]

The clasp-retained partial denture, for reasons of cost and time devoted to fabrication, will continue to be widely used for most pacients needing removable partial dentures.[1,2,4] We used this method for the structural analysis of the critical components of these removable partial dentures, under different loading conditions.

The purpose of this study was to evaluate the stress distribution in the critical components of the removable partial denture, the cast clasps.

MATERIALS AND METHODS

The models were created for the cast clasps, as

[1] Department of Prostheses Technology and Dental Materials, University School of Dentistry, Victor Babes University of Medicine and Pharmacy Timisoara, Romania
[2] Department of Material Strength, University School of Mechanics, Technical University Timisoara, Romania
[3] Department of Prostheses Technology, Dental College
Victor Babes University of Medicine and Pharmacy Timisoara, Romania

Correspondence to:
Liliana Sandu
Str. Socrate nr. 6, Timisoara, Romania
Phone: 0722 310299; E-mail: sliliana@medinfo.umft.ro

components of a maxillary removable partial denture (Fig. 1) conceived for a Kennedy class II edentation with one modification space. A denture with different types of cast clasps (circumferential Ackers clasps and back-action clasp) was selected for a comparative analysis. The Ackers clasp is a rigid circumferential clasp, with a rigid minor connector, and the back-action clasp is a clasp with high elasticity and with a long and elastic minor connector.

Figure 1. The removable partial denture clasp retained used as a model for the study

The geometric models for the direct retainers (Fig. 2) were generated using three dimensional measurements.

Figure 2. The direct retainers of the denture used for the geometrical model: a. back-action clasp from 1.4, b. Ackers clasp from 2.4

A three-dimensional finite element analysis software (COSMOS/FFE Static) was used for the study of structural simulations. It is a fast, robust, and accurate finite element software for the analysis of linear static structural problems. The program exploits a new technology developed at Structural Research for solving large systems of simultaneous equations using sparse matrix technology along with iterative methods combined with novel database management techniques to substantially reduce solving time, disk space, and memory requirements.

The procedures in structural analysis are:

- divide structure into pieces (elements with nodes);
- describe the behavior of the quantities of each element;
- connect the elements at the nodes to form an approximate system of equations for the whole structure;
- solve the system of equations involving unknown quantities at the nodes (displacements);
- calculate desired stresses at selected elements.

The finite element analysis requires the creation of a computer-simulated model. The basic process consists in considering the complete structure is considered as an assembling of individual structural elements. Therefore each part of the model was divided into individual elements – finite elements. Adjacent elements were connected at specific points – nodes on their common boundaries.

The mathematical model was completed and the finite element model was developed by dividing the model of the Ackers clasp into 1017 elements connected at 607 points and for the back-action clasp into 1772 elements, connected at 1263 nodes, using shell 3 elements (Triangular Thin Shell).

In making the finite element model, the characteristics of the Co-Cr alloy used for the framework were entered into the computer program:

- tensile strength (R_m): 1000 MPa;
- ductile Yield (R_p0,2): 700 MPa;
- modulus of elasticity (E): 2.2×10^5 MPa;
- Vickers hardness (HV10): 340;
- Poisson's ratio (õ): 0.3.

An occlusal load of 140 N was applied to the occlusal surface of the teeth.[9] This is the masticatory force on a distal-extension removable partial denture and it is of sufficient magnitude to provide response in the model. Other loads did not provide significant information because of the proportionate stress response.[10-12] This was selected to simulate possible movements like vertical dispacements and rotations towards the underlying tissue.

RESULTS AND DISCUSSIONS

Generated stresses were calculated numerically as Von Mises equivalent stress and plotted graphically. Results were displayed as coloured stress contour plots to identify regions of different stress concentrations.

Figures 3 and 4 illustrate the Von Mises equivalent stress which was evaluated for the two models under different loading conditions, for the simulation of the vertical displacement and rotation of the prosthesis.

In Figure 3 shows that the greatest value of stress was recorded inside the clasp arms. The maximum values are 310.27 MPa for the Ackers clasp and 407.74 MPa for the back-action clasp, greater in the more elastic clasp.

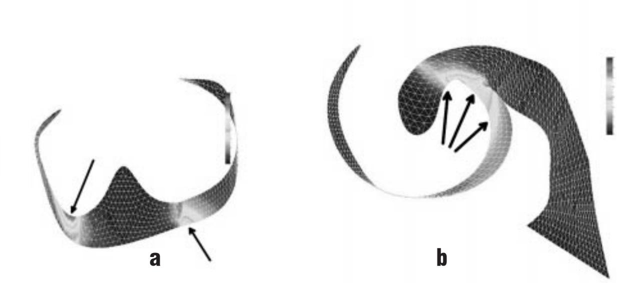

Figure 3. Von Mises stress distribution in the clasps during the vertical displacement simulation: a. in the Ackers clasp, b. in the back-action clasp

At the simulation of the denture rotation, high stress values are localized also in the minor connector of the elastic clasp, the back-action clasp (Fig. 4). The maximum values recorded in this case are also smaller for the Ackers clasp (310.31 MPa) and greater for the back-action clasp (382.01 MPa).

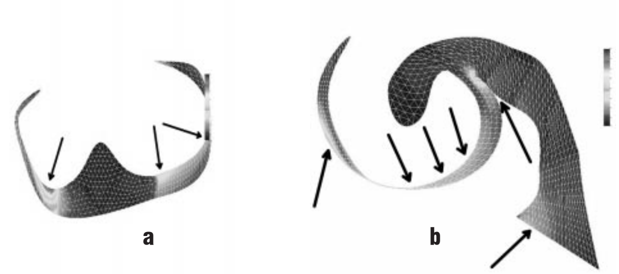

Figure 4. Von Mises stress distribution in the back-action clasp during the rotation simulation: a. in the Ackers clasp, b. in the back-action clasp.

Table 1 lists the maximal values of the von Mises stress recorded in the cast clasps in the two investigated cases: by vertical displacement and rotation simulation of the removable partial denture.

Table 1. The maximal values of the von Mises stress recorded in the cast clasps during the vertical displacement (case 1) and rotation simulation (case 2).

cast clasp	maximum von Mises stress in case 1 (MPa)	maximum von Mises stress in case 2 (MPa)
Ackers clasp	310.27	310.31
back-action clasp	407.74	382.01

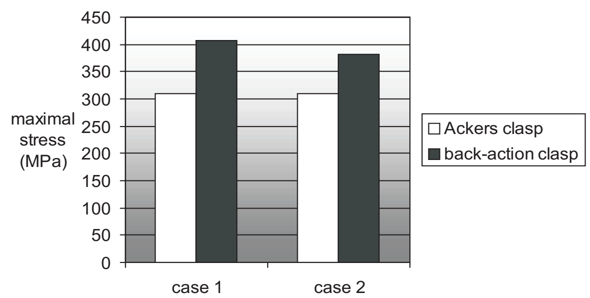

Figure 5. Comparative representation of the maximal stresses in the cast clasps during the vertical displacement (case 1) and rotation simulation (case 2)

Figure 5 illustrates a comparative representation of the maximal stresses in the cast clasps during the vertical displacement (case 1) and rotation simulation (case 2).

In all cases the magnitude and distribution of the stress in the cast clasps are within the normal limits, less than the ductile Yield of the Co-Cr alloy (700 MPa).

The finite element method is an established theoretical technique used in the solution of engineering problems and the role of bioingineering in prosthodontics cannot be underestimated.

Using the finite element method on a digital computer, it is possible to establish and solve the governing equations for complex systems, such as removable partial dentures, in a very effective way.[13]

This numerical analysis can be a good way to study the biomechanics of the removable partial dentures because it is preferable modelling than experimenting on the pacient.

CONCLUSIONS

As a result of this study, the following observations were made:

1. Considerable stresses are concentrated in the clasp arms, close to the junction with the body of the clasp;
2. The stress levels and distribution depend from the load case and the clasp type (the values of the equivalent stress are greater for the more elastic clasp – the back-action clasp);
3. With the use of a properly designed removable partial denture, the magnitude and distribution of the stress in the cast clasps are within normal limits.

REFERENCES

1. Bortun C, Leretter M, Sandu L. Tehnologia protezelor partiale, vol I si II. Timisoara: Ed. Eurobit, 2002.
2. Caesar H, Lehman K. Die Teilprothese. München: Verlag Neuer Merkur, 2002.
3. Davenport JC, Basker RM, Heath JR, et al. Retention. British Dental Journal 2000;189(12):646-57.
4. Ionescu A. Tratamentul edentatiei partiale cu proteze mobile. Clinica si tehnica de laborator. Ed. National, 1999.
5. Ching-Chang K, Chung - Sheng C, Kwok - Hung C, et al. Effects of posts on dentin stress distribution in pulpless teeth. J Prosthet Dent 1992;68(3):421-7.
6. Faur N. Elemente finite - fundamente. Timisoara: Ed. Politehnica, 2002.
7. Manac C, Bucur C. Noi metode de investigatie în stomatologie. Bucuresti: Ed. Didactica si Pedagogica, 1999.
8. Dumitru I, Faur N. Elemente de calcul si aplicatii în rezistenþa materialelor. Timisoara: Ed. Politehnica, 1999.
9. Berg T, Caputo AA. Comparison of load transfer by maxillary distal extension removable partial dentures with a spring - loaded plunger attachment and I - bar retainer. J Prosthet Dent 1992; 68(3):492-99.
10. Sandu L, Bortun C, Faur N, Leretter M. Studiul starilor de tensiune si deformatie ale elementelor componente ale protezelor scheletate printr-o analiza cu elemente finite. Revista Nationala de Stomatologie 2002:V(1):17-21.
11. Sandu L, Faur N, Bortun C. Investigation of stress distribution in circumferential cast clasps using the finite element analysis. Proceedings of the 6th International Conference on Boundary and Finite Element Timisoara: Ed. Politehnica, Timisoara, 2003, pg. 183 - 188.
12. Sandu L, Bortun C, Faur. Stress-ul dintilor stalpi implicati în protezarea mobilizabila - analiza cu ajutorul elementelor finite. Medicina in evolutie 2002;3:27-9.
13. Blumenfeld M. Introducere în metoda elementelor finite. Bucuresti: Ed. Tehnica, 1995.