

# INFORMATICS SYSTEMS FOR THE ANALYSIS OF REMOVABLE PARTIAL DENTURES

Cristina Bortun, Liliana Sandu, Florin Topala, Sorin Porojan

## REZUMAT

**Objective:** Obiectivul principal al studiului a fost predictibilitatea duratei de utilizare a unor componente ale protezelor parțiale mobilizabile scheletate, printr-o metodă neinvazivă - metoda elementelor finite, cu scopul de a realiza un design optim biomecanic al protezelor. **Material și metodă:** Au fost luate în studiu componente a 30 de proteze parțiale mobilizabile scheletate (croșete și bare linguale), cu design diferit, care au fost evaluate prin metoda elementelor finite, utilizând programul de analiză automată COSMOS/M, versiunea 2.5. (Structural Research and Analysis Corporation, USA). Studiul a vizat analize statice, de deformare, de transfer termic și de evaluare a degradărilor la oboseală în unele componente ale protezei scheletate. **Rezultate și discuții:** Utilizarea metodei elementelor finite a permis evidențierea zonelor de potențiale tensiuni și de minimă rezistență din componentele protezei parțiale mobilizabile. La croșetele dentare turnate din aliaje de Co-Cr-Mo, supuse unor sarcini variabile rezultate în urma masticăției, durata de viață a fost estimată la 5,5 ani. Barele linguale nu s-au rupt la timpii testați. Zonele de minimă rezistență la nivelul croșetelor se distribuie la nivelul brațelor, aproape de zona de îmbinare cu corpul croșetului, iar la barele linguale la mijlocul acestora. **Concluzii:** Evaluarea experimentală a protezelor prin metode neinvazive, permite aprecierea rezistenței piesei protetice, fără a le deteriora efectiv. Prin aplicarea metodei elementelor finite se permite prognozarea duratei optime de utilizare a protezelor scheletate.

**Cuvinte cheie:** proteză parțială mobilizabilă scheletată, metoda elementelor finite, durata optimă de utilizare

## ABSTRACT

**Objectives:** The present study's main objective was to determine the predictability of the period of operation of certain removable partial denture components, using a noninvasive method - the finite element method, with the purpose of achieving an optimal biomechanical denture design. **Materials and method:** Components of 30 removable partial dentures (clasps and lingual bars), having different designs were studied and evaluated through the finite element method, using the COSMOS/M automatic analysis computer program, version 2.5 (Structural Research and Analysis Corporation, USA). Our study focused on static, distortion, heat transfer and fatigue-caused degradation evaluation analyses in certain removable partial denture components. **Results and discussions:** By using the finite element method, we managed to highlight the potential stress and minimum strength areas in removable partial denture components. In the case of dental clasps cast in Co-Cr-Mo alloys, subject to variable loads resulting from mastication, life expectancy was estimated to be of 5.5 years. Lingual bars did not break within the tested periods. The minimum strength areas in clasps are distributed in the arms, near the clasp body joint, while in lingual bars these areas are distributed in their middle. **Conclusions:** The noninvasive experimental evaluation allows estimation of the strength of the prosthetic parts without actually damaging them. By applying the finite element method, the optimal period of using for removable partial dentures can be estimated.

**Key Words:** removable partial denture, finite element method, optimal period of using

## INTRODUCTION

The removable partial denture concept has undergone several stages along the decades. These stages can be systematized according to Becker:<sup>1</sup>

- The early concept (before 1950);
- The period of investigation (1950-1970);

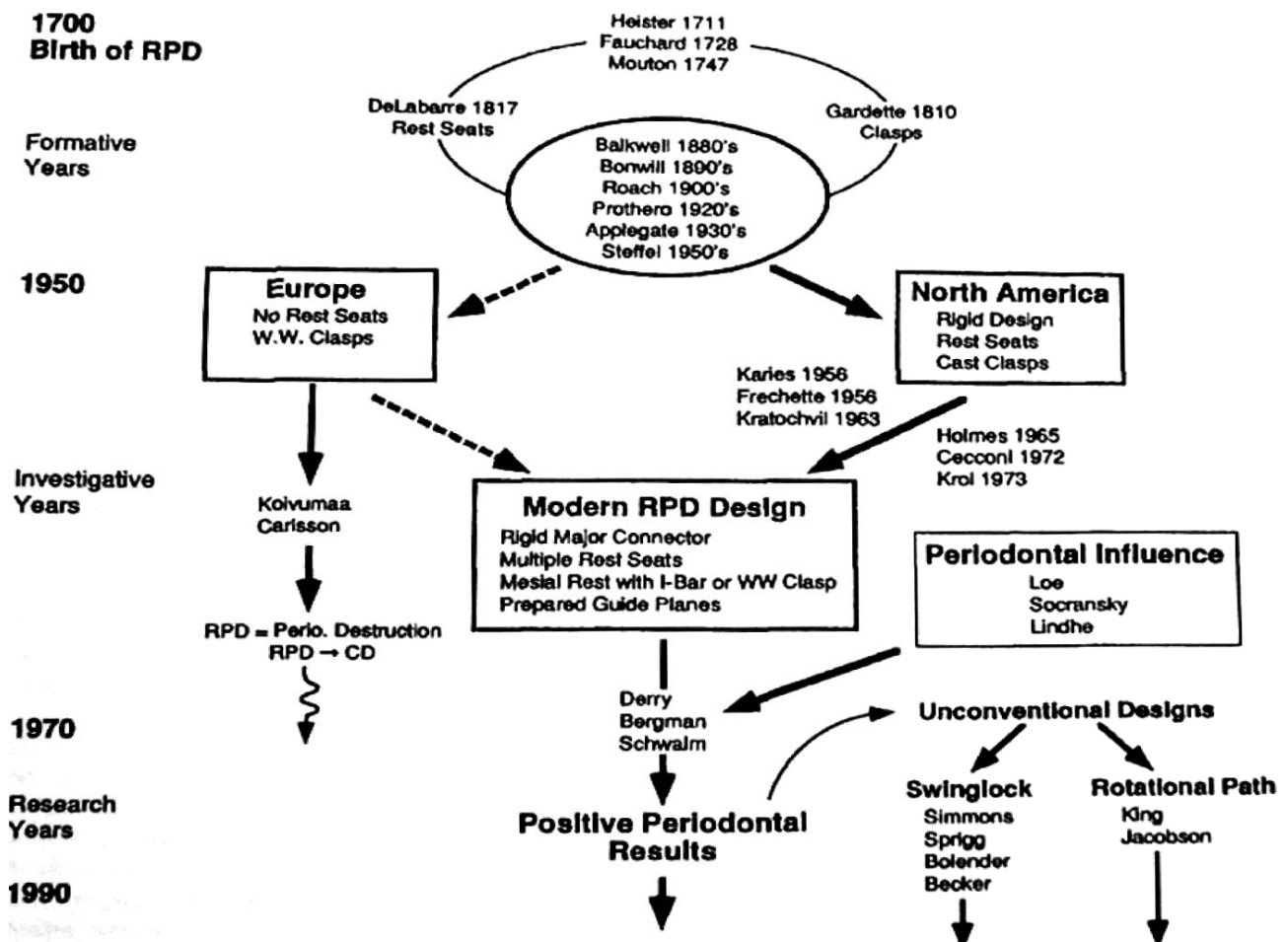
- The period of serious research starting 1970 up to present. (Fig. 1)

The errors that occur in the manufacturing of complex prostheses, such as removable partial dentures, are due to the biomechanically faulty projects and the laborious, energy- and time-consuming manufacturing technologies. For this reason, new, computer-assisted means of evaluation and even design have emerged. Computer-created projects, achieved according to real removable partial dentures, stay at the basis of running complex tests for prosthetic pieces, without actually damaging them, thus having favorable effects on their design. The studies carried out until now, using the finite element method, focused only on fragments of removable partial dentures, thus revealing the areas of stress, distortion and fatigue in metallic frameworks, which have a direct effect on the denture's period of using.

Department of Removable Partial Dentures Technology, Faculty of Dental Medicine, Victor Babes University of Medicine and Pharmacy Timisoara

Correspondence to:  
Prof. Cristina Bortun, Department of Removable Partial Dentures Technology,  
9 Revolutiei 1989 Blvd., 300070 Timisoara  
Email: cristinabortun@gmail.com

Received for publication: Sep. 5, 2006. Revised: Dec. 23, 2006.



**Figure 1.** Presentation of the evolution of removable partial dentures - Becker's diagram. (Adapted with permission from Becker et al, 2004)<sup>1</sup>

Design optimization for certain complex prostheses implies training both in the field of biomechanics and computer-assisted numerical methods.

The finite element method was developed in the 60's and entered the field of dentistry three decades ago. Due to their efficiency, numerical simulations tend nowadays to replace experiments, and allow the performing of applications that would otherwise be difficult or even impossible to achieve using other methods.<sup>2-16</sup>

Removable partial dentures have been less studied, probably because of their complexity and the numerous parameters involved in the analysis. Current studies have been carried out only on certain partial denture components: major connectors, maintaining, and support and stabilization elements.

Thus, Eto M et al, using finite element analysis, studied the stresses occurring in various types of major maxillary connectors.<sup>17</sup> Three-dimensional schematized models were created, for various major connectors, which were subject to occlusal load simulation. More rigid connectors proved to be most efficient in transmitting the forces to the opposite half-arch.

The analysis of cast dental clasps by using the finite element method is also reflected in the literature.<sup>10-15,18</sup>

The maintaining, support and stabilization elements are the critical components of partial dentures, as they are most easily damageable. Their iatrogenic effect on the abutment teeth has been confirmed, and many attempts to fight it have followed. Their retention and strength represent the success of a long-lasting and quality prosthesis. Subsequently, a tendency to modify the typical semicircular profile of dental clasps to half-pear shape has emerged, the latter being considered to be more resistant and efficient.<sup>19</sup>

Y. Sato et al have built computer-assisted cast clasp simplified models, which were first created two-dimensionally and then three-dimensionally.<sup>12-15</sup> M. Saito also studied the stress distribution in abutment teeth and in partial dentures with precision attachments or clasps.<sup>8</sup> Güngör et al analyzed the abutment teeth and surrounding tissues when using telescopic crowns.<sup>6</sup> Study results show that stresses on abutment teeth are maximal in case of using special systems, followed by telescopic crowns and clasps. The analysis of various loads exerted on dentures shows that here the

situation is just the opposite: clasps are subject to the highest loads, followed by attachments or telescopic crowns, without any significant difference between the last two.

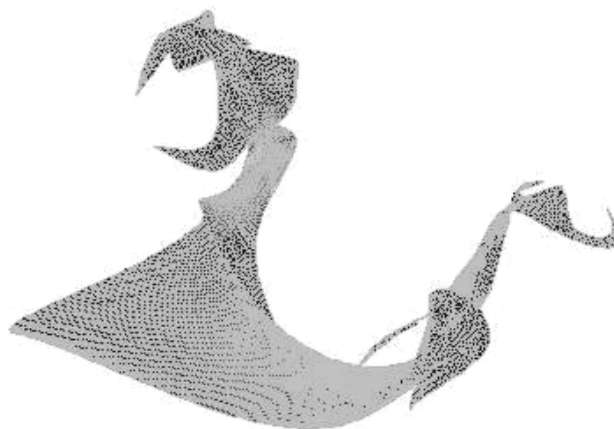
In Iasi, a team formed of Norina Forna, Cornelia Brezulianu and Gabriela Ifteni have carried out various biomechanical analyses using numeric simulation methods.<sup>5,10,11</sup> Also, they have proved the importance of computers in creating partial dentures.

In Timisoara, Liliana Sandu and Cristina Bortun have applied the finite element analysis in the field of removable partial prosthodontics.

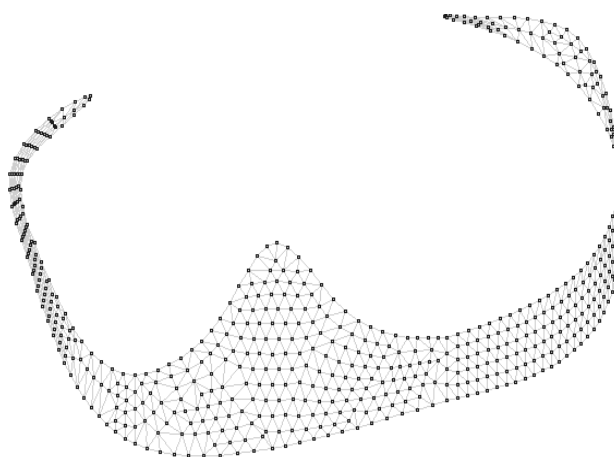
## MATERIALS AND METHODS

Elements of the metallic framework of 30 removable partial dentures were studied: 25 cast dental clasps and 15 lingual bars.

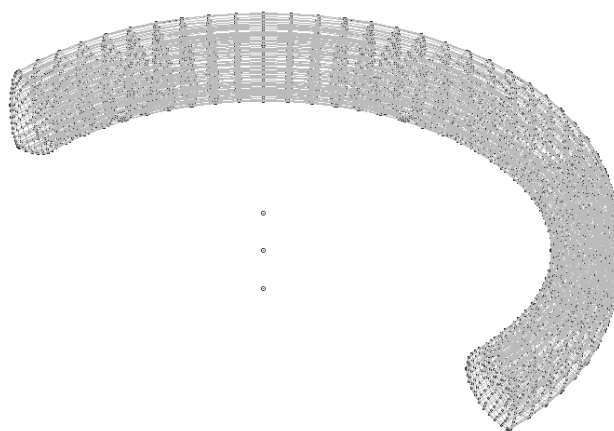
The finite element method is a numerical analysis technique used by various automatic computer programs. Because the fields of application for the finite element method vary widely and the offer is rich, the method of analysis under static loads, heat transfer and fatigue-caused degradation was used. Based on the geometrical model of the denture, lingual bars and clasps (which resulted from the measurement of certain point coordinates), a model containing the real system's essential characteristics was built. The finite element method implies dividing the structure into individual elements of determined sizes, connected to each other through a finite number of points, called nodes. A metal framework was meshed into 9865 finite elements, to which various framework thickness values were associated as real constants. (Fig. 2) The clasp's supporting structure was meshed into 1017 finite elements, connected through a number of 607 nodes, while the lingual bar was meshed into 4000 finite elements, connected through 5324 nodes. (Figs. 3, 4) Shell-type finite elements with 3 nodes/element were used, as well as solid type finite elements, with 8 nodes/element. The finite element analysis computer program allowed determining the analyzed metallic component's conditions of stress and distortion, resulted from applying an occlusal force. An average intrusion force of 30 N was applied evenly on the occlusal surfaces of all artificial teeth, and its results on the clasps and connectors were studied. (Fig. 5) The automatic analysis software program (COSMOS/M, Version 2.5) allowed to highlight the displacement tendencies that occur within the denture's metal framework, as well as the distribution of the equivalent von Mises stress in the analyzed structures.



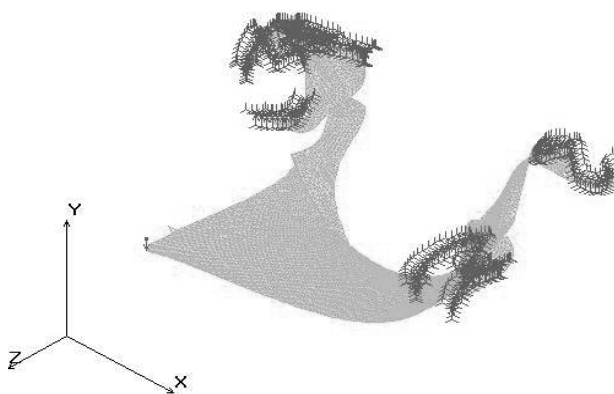
**Figure 2.** RPD framework meshing.



**Figure 3.** Clasp meshing.



**Figure 4.** Lingual bar meshing.



**Figure 5.** Framework blocking and loading.

The parameters fed into the computer program refer to the mechanical and elastic characteristics of the framework's material, a Co-Cr alloy: ductile yield  $R_{0.2} = 700$  MPa; tensile strength  $R_m = 1000$  MPa; modulus of elasticity  $E = 2.2 \times 10^5$  MPa; Poisson's ratio  $\nu = 0.3$ ; Vickers hardness (HV 10) = 340.

When simulating the movement of the partial denture towards the ridge, the parameters of variable loads in the load cycle of a masticatory cycle were:

- Duration: 0.7 – 0.8 s;
- Frequency: 40 – 120 cycles/minute;
- Number of mastication cycles: 4500 cycles/24 hours;
- Applied force: maximum 20 N.

## RESULTS

The computer-generated results are represented in the form of stress spectrums and are evaluated according to chromatic values (red – high stress areas, and blue – no-stress areas). Under normal static load conditions, the value and distribution of stresses are within the normal limits and consequently do not affect the strength of the denture components. The computer-represented distortions are suggestive because they highlight the displacement tendencies of the denture components.

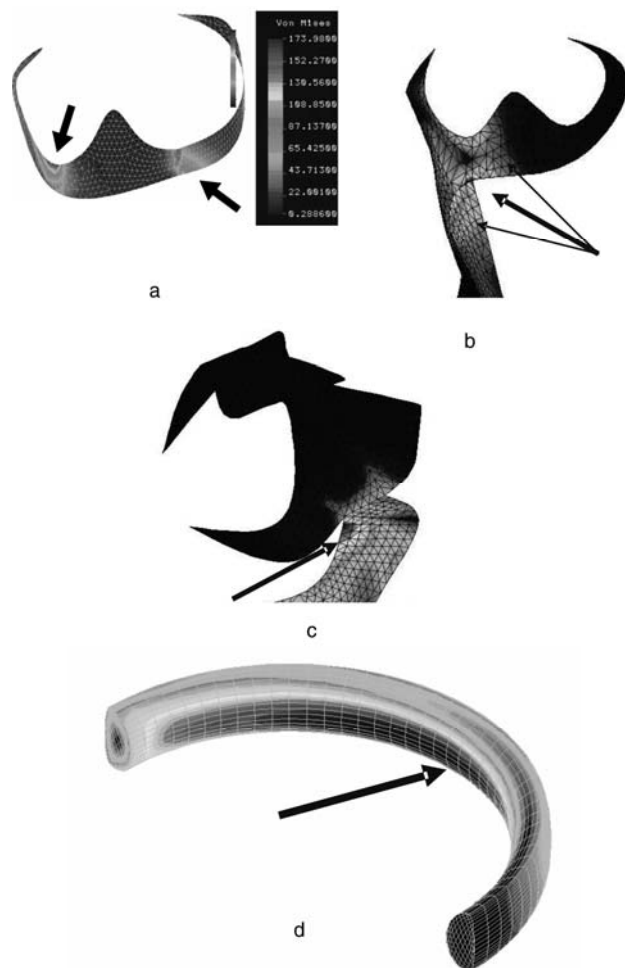
Static analysis allows estimating the place of occurrence for stresses and distortions, as well as the fracture-risk areas, as a result of increased forces occurring during functions. (Fig. 6)

The cast clasps of partial dentures, subjected to variable loads resulting mainly from mastication, break due to fatigue-caused degradation. (Fig. 7) The conventional fatigue strength is of 330 MPa and is evaluated on the fatigue durability Wöhler curve.

The time-dependant degradation factor for a high-risk node was computed according to the Palmgreen-Miner damage accumulation criterion (for 6 months, 1 year, 5 years).<sup>10,11</sup>

The numerical simulation software program allows the automatic calculation of degradation in various components of the denture, at given time intervals, as well as the denture's life expectancy. The computed result for the fatigue-caused degradation factor in a circumferential clasp shows that this can experimentally function for 5.5 years.

Arm flexibility, which mainly depends on their shape, plays an essential role in the occurrence of stress conditions. The finite element method allows both the determination of stress conditions, by calculating the equivalent stresses, as well as the determination of arm



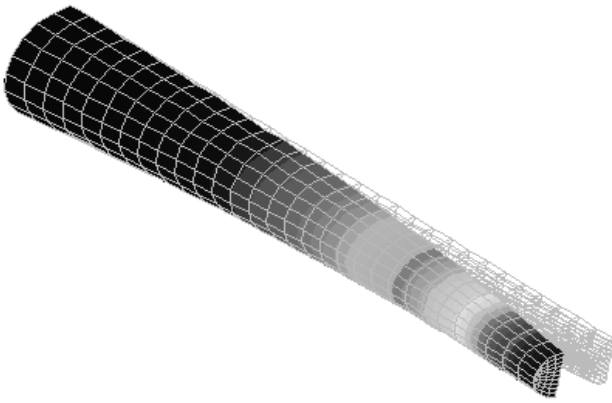
**Figure 6.** Static analysis of stresses and distortions in circumferential clasps and lingual bar. The high-risk areas are marked by arrows: a. Akers clasp, b. back-action clasp, c. Bonwill clasp, d. lingual bar.

Fatigue Calculation					
(location 1 node 472)					
Loading (Evn)	Loading (Evn)	Cycles Used/Allowed	Alter. Stress	Partial Factor	
1	1	5 4	912500 2E+006	87.959	0.45625
2	2	3 3	912500 2E+006	23.773	0.45625
Cumulative Fatigue Usage Factor =		0.9125			

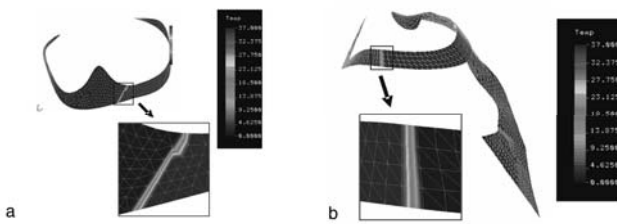
**Figure 7.** Calculus of the fatigue-caused degradation factor in dental clasps.

flexibility, by calculating the displacements resulted from distortions. Numerical simulations using the finite element method allow the optimization of the shape for cast clasp retentive arms (depending on the size, place and method of external force application, clasp type), so that they can be sufficiently flexible and that they do not produce damaging effects on the abutment teeth. (Fig. 8)

By associating the thermal gradient to the functional loads, both the stress spectrum and the maximum equivalent stress values are modified. For the thermal analysis (at extreme temperatures of 0°C and 60°C, respectively), besides the material's properties, data on the thermal characteristics are also necessary: thermal conductivity and thermal expansion coefficient. (Fig. 9)



**Figure 8.** Shape optimization for clasp retentive arms.



**Figure 9.** Thermal analysis - at 0°C temperature - in 2 types of clasps: a. Akers clasp, b. back-action clasp.

When masticating cold food, the value of the maximum equivalent stress is not influenced significantly by the accumulation of loads (178.20 MPa as compared to 173.98 MPa and 168.90 MPa). However when masticating warm food, the exertion of the occlusal force has a favorable effect by diminishing the stresses which occur due to thermal stimulation (from 451.16 MPa to 396.89 MPa).

Results indicate that by the accumulation of mechanical and thermal loads, the stresses do not add up, but they are redistributed.

## DISCUSSIONS

The errors that occur in the design and manufacture of classical removable partial dentures are due to the laborious manufacturing technologies, confirmed especially by clinical practice observations.<sup>22-24</sup>

Initially, the digital transfer of removable partial denture components to the computer was carried out for two-dimensional models, and then for three-dimensional models.<sup>25,26</sup>

Naturally, the errors of the first interpretations were related to simple data introduced into the computer, which were not always real.

With the new means of three-dimensional scanning, mathematical models closer to real-life situations were created. Errors can occur in any system, especially related to the introduction of data into the computer. For removable partial dentures, the equation

with “n” unknowns can hardly cover the whole range of possible moves. This is why most authors focused on various components of this denture type, without managing to study it as a whole. The studies carried out until now have revealed stress and distortion areas with implications for the denture’s period of using. Studying the behavior of removable partial dentures as a whole is a necessity, in order to obtain an optimal and functional design.

The change of views in this field will result in a coherent thinking on denture profile design, and will make possible the modification of certain components based on mechanical strength and fatigue-caused degradation tests.

The issue of fatigue-caused degradation in partial dentures was first mentioned by Morris H. (1970) quoted by Valittu.<sup>27</sup>

Theoretically, the experimental research conducted by Valittu P.K. on clasps shows that the average period of time before the final break is of 7 years.

According to Saito, Vandenbrink, Yeung, the period of time after which cast clasp degradation occurs is of 5-7 years.<sup>8,28,29</sup>

It seems that mastication contributes most to the fatigue-caused degradation in clasps, showed by finite element analyses.<sup>12-15</sup>

An interdisciplinary research network, which can create computerized projects of removable partial dentures is the starting point of designing simple and resistant prosthetic parts, that can fulfill all conditions for long-term use.

## CONCLUSIONS

1. Finite element analysis is a method with multiple options. It allows the estimation of an optimal period of using for some removable partial denture components.

2. The experimental evaluation of dentures through non-invasive methods allows the estimation of the prosthetic parts’ strength without actually damaging them, as it is the case in classical experiments.

## ACKNOWLEDGEMENTS

The authors want to thank to the Department for Strength of Materials of the Timisoara Polytechnic University for their cooperation.

## REFERENCES

1. Becker CM, Kaiser DA, Goldfogel MH. Evolution of removable partial denture design. *J Prosthodont* 1994;3:158-66.

2. Blumenfeld, M. Introducere in metoda elementelor finite. Bucuresti, Ed. Tehnica, 1995.
3. Bortun C, Leretter M, Sandu L. Tehnologia protezelor partiale, Vol I, II. Ed. Eurobit, Timisoara, 2002.
4. Faur N. Elemente finite - fundamente, Ed. Politehnica, Timisoara, 2002.
5. Forna N, Stadolean C, Budaie D, et al. Evaluarea solicitariilor biomecanice in protezarea partiala amovibila. *Medicina Stomatologica* 2001;5(2):448-54.
6. Güngör MA, Artunç C, Sonugelen M et al. The evaluation of the removable forces on the conus crowned telescopic prostheses with the finite element analysis (FEA). *J Oral Rehabil* 2002;29:1069-75.
7. Manac C, Bucur C. Noi metode de investigatie in stomatologie. Ed. Didactica si Pedagogica, Bucuresti, 1999.
8. Saito M, Notani K, Miura Y, et al. Stress distribution of abutments and base displacement with precision attachment- and telescopic crown - retained removable partial dentures. *J Oral Rehabil*, 2003;30:482-7.
9. Sandu L, Faur N, Bortun C. The finite element analysis – A method for the study of the states of tension and deformation of a removable partial denture. *Trends in Romanian health. Proceedings of MEDINF 2002*. Ed Eurobit, Timisoara, 2003, p. 25-8.
10. Sandu L. Simularile numerice in alegerea, dispunerea si actiunea crosetelor dentare. PhD Thesis, Victor Babes University of Medicine and Pharmacy, Timisoara, 2004.
11. Sandu L, Bortun C, Faur N, et al. Crosetele dentare turnare - alegere, proiectare si analiza numerica, Ed. Eurobit, Timisoara, 2004.
12. Sato Y, Yuasa Y, Akagawa Y, et al. An investigation of preferable taper and thickness ratios for cast circumferential clasp arms using finite element analysis. *Int J Prosthodont* 1995;8:392-7.
13. Sato Y, Tsuga K, Abe Y, et al. Finite element analysis of the effect of vertical curvature on half - oval cast clasps. *J Oral Rehabil* 1999;26:554-8.
14. Sato Y, Tsuga K, Abe Y, et al. Dimensional measurement and finite element analysis of I - bar clasps in clinical use. *J Oral Rehabil* 2000;27:935-9.
15. Sato Y, Tsuga K, Abe Y, et al. Y Finite element analysis on preferable I-bar clasp shape. *J Oral Rehabil* 2001;28:413-7.
16. Tripa P, Faur N. Metode teoretice si experimentale pentru determinarea starii de tensiune si deformatie. Timisoara, UTT Litography, 1994.
17. Eto M, Wakabayashi N, Ohyama T. Finite element analysis of deflections in major connectors for maxillary RPDs. *Int J Prosthodont* 2002;15:433-8.
18. Sandu L, Faur N, Bortun C. Spannungsanalyse der Klammern von Modellgussprothesen durch die Methode der finiten Elemente. *Quintessenz Zahntech* 2006;32(4):372-81.
19. Palanuwech M. The fatigue resistance of commercially pure titanium (grade II), titanium alloy (Ti6 Al7Nb) and conventional cobalt-chromium cast clasps; Dissertation, Eberhard-Karls-Universität, Tübingen, 2003.
20. Sandu L, Bortun C, Faur N. Three-dimensional finite element analysis on preferable cast circumferential clasps arms design. *Saudi Dent J* 2006;18(2):100-4.
21. Sandu L, Bortun C, Ardelean L, et al. Finite element analysis of stress distribution induced by thermal variations on cast clasps. *Eur Cells Mat* 2002;9(Suppl. 1):3-4.
22. Bortun C, Sandu L, Leretter M, et al. Modalitati practice de optimizare a retenției crosetelor turnate. *Rev Nat Stom Chir Max Fac Chir Or* 2003;I(4):50-6.
23. Bortun C, Rominu M, Leretter M, et al. Elastic couples – model analysis in the biodynamics of the removable partial dentures. *TMJ* 2003;53(1):73-5.
24. Bortun C, Sandu L. Design-ul protezei partiale mobilizabile. Victor Babes University of Medicine and Pharmacy Lithography, Timisoara, 2005.
25. Farah, JW, Craig RG. Finite element stress analysis of a restored axisymmetric first molar. *J Dent Res* 1974;53(4):859-66.
26. Tresher RW; Saito GE. The stress analysis of human teeth. *J Biomech* 1973;6(5):443-9.
27. Vallittu PK, Kokkonen M. Deflection fatigue of cobalt chromium, titanium and gold alloy cast denture clasp. *J Prosthet Dent* 1995;74(5):412-9.
28. VandenBrink JP, Wolfaardt JF, Faulkner MG. A comparison of various removable partial denture clasp materials and fabrication procedure for placing clasps on canine and premolar teeth. *J Prosthet Dent* 1993;70(2):180.
29. Yeung ALP, Lo ECM, Clark RKF. Et al: Usage and status of cobalt-chromium removable partial dentures 5-6 years after placement. *J Oral Rehab* 2002;29(2):127-32.