

EFFECT OF DESIGN MODIFICATIONS ON BACK-ACTION CLASPS FLEXIBILITY

Liliana Sandu, Cristina Bortun, Florin Topala, Sorin Porojan

REZUMAT

Objective: În cadrul studiului, analiza tridimensională cu elemente finite s-a utilizat în vederea optimizării design-ului croșetelor circulare cu acțiune posterioară. **Material și metode:** S-au generat modelele experimentale tridimensionale pentru brațele croșetelor cu acțiune posterioară, utilizând elemente solide cu opt noduri pe element. Metoda elementelor finite s-a utilizat pentru simularea deformărilor la inserția și dezinserția croșetelor. Tensiunile generate și deplasările produse sub acțiunea forței de retenție (5 N), aplicată asupra fiecărui croșet, au fost calculate numeric și reprezentate grafic. Corelațiile dintre tensiunile echivalente maxime și deplasările maxime permit determinarea parametrilor optimi pentru brațele croșetelor. Pentru croșetele studiate, au fost selectate formele în care tensiunea echivalentă maximă ce corespunde deplasării specifice croșetelor circulare (0,25 mm) este cea mai redusă. **Rezultate:** Investigațiile au indicat forma pe secțiune și efilarea optimă pentru brațele croșetelor cu acțiune posterioară. Rezultatele acestui studiu in vitro sugerează că brațele croșetelor cu acțiune posterioară cu o efilare de 0,8 prezintă tensiuni mai reduse decât cele cu alte efilări. În ceea ce privește forma lor pe secțiune, raportul determinat grosime/lățime a fost de 0,6. **Concluzii:** Simulările numerice cu metoda elementelor finite permit optimizarea formelor brațelor croșetelor, astfel ca ele să fie suficient de flexibile încât să nu producă efecte nocive asupra dinților stâlpi, dar în același timp să fie eficiente în menținerea protezei.

Cuvinte cheie: analiza cu elemente finite, croșet cu acțiune posterioară, formă pe secțiune, efilare

ABSTRACT

Objective: The current study looked into the use of finite element three-dimensional analysis for optimization of the design of circumferential back-action clasp arms. **Material and methods:** Experimental three-dimensional models of back-action clasp arms were generated using solid eight-node elements. The finite element method was used to simulate the deflection under insertion and removal of the clasp. Generated stresses and deformations produced as a result of retentive force (5 N) applied to each clasp were calculated numerically and plotted graphically. The correlations between the calculated maximal stresses and deformations allow the selection of the optimal parameters of clasp arms. For all clasps studied, the shapes where the lowest maximal equivalent stress corresponds to the typical displacement of circumferential clasps (0.25 mm) were selected. **Results:** The investigations indicated the preferable cross-section shape and taper of back-action clasp arms. The results of this in vitro study suggested that back-action clasp arms with a taper of 0.8 showed less stress than those with other tapers. Regarding their cross-section shape, the determined thickness/width ratio was 0.6. **Conclusions:** Numerical simulations using the finite element method allow the shape optimization of retentive clasp arms, so that they can be sufficiently flexible to prevent damaging effects on the abutment teeth, and at the same time be efficient in maintaining the denture.

Key Words: finite element analysis, back-action clasp, cross-section shape, taper

INTRODUCTION

Removable partial dentures are designed so that they can be voluntarily removed from the oral cavity. The insertion and removal of removable partial dentures can be accomplished either by the patient or the dentist, in case that all support, retention and

stabilization components are efficient, but do not make this displacement impossible. Voluntary removal is absolutely necessary for denture cleaning and is based on overcoming the clasps elastic retentive forces. This is considered a necessary move, which is not damaging if the clasp force is correctly calculated.¹⁻⁴

These movements are accompanied by clasp stresses and displacements. The subject is widely debated in the specialized literature. Several studies evaluated the clasp arm morphology, so that clasps become sufficiently flexible and efficient at the same time.^{5,6}

Other studies investigated different aspects of the clasp design in relation to their retention and usage. Saito et al. clarified the complications and failures of the clasps, direct retainers of removable partial dentures.⁷

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Regarding the circumferential clasp arm forms (cross-sectional form and taper), Sato et al. stated that clasp arms with thinner and wider dimensions and with the taper of 0.8 showed less stress.⁵ Other findings showed the effect of the vertical curvature on the stress and flexibility of the clasp arms.⁶

The studies of Bridgeman et al., and Rodrigues et al. investigated clasps made from different alloys and suggested that titanium and titanium alloys are suitable materials for cast clasps, but these have lower retention than those made by cobalt-chromium alloys.^{8,9} Vallittu suggested that significant differences exist in the fatigue resistance of removable denture clasps made from different alloys, which may cause loss of retention of the removable partial denture and clasp failure.¹⁰

It has been recognized that three factors affect the design of the clasp arms. These are: clasp material, clasp form and amount of undercut. Among this, only the clasp form is under control of the dentist or dental technician. The mechanical properties of the clasp material are normally determined by the alloy to be used, commonly a cobalt-chromium alloy. Regarding the size of dental undercuts, it is selected according to the clasp type: 0.25 mm for circumferential clasps; 0.50 mm for Roach clasps and 0.75 mm for mixed clasps.¹⁻⁴

Consequently, the shape of the clasp arm is the defining feature. Regarding their length and curvature, these features depend on the abutment tooth morphology. However, the dentist and dental technician can control the cross-section profile. They have to know that the choice of the retention elements and their individual designs require biomechanical considerations.^{6,11}

The retentive force and the stress distribution in the clasp arms represent the key of a long lasting success of removable partial dentures, without distortions or fractures. When stress conditions occur, arm flexibility plays an essential role, and it mainly depends on the shape.⁶ This study analyzes back-action clasps, which are less studied in the specialized literature, where researches focus on circumferential Akers and I-bar clasps.^{5,6,12-20}

MATERIAL AND METHODS

In order to study the stresses and displacements that occur in back-action clasp arms, experimental three-dimensional models of various shapes and sizes were made. The starting point was the measurement of circumferential cast clasps in some removable partial denture frameworks and of some preformed wax

profiles (Clasp Wax, Fino, Bad Bocklet, Deutschland).

The parameters necessary for geometrical modeling were represented by: length, width and thickness at base and tip. The arm length (x) was considered to be of 20 mm. The parameters considered for study were: $L_2/L_1 = 0.4; 0.6$ and 0.8 ; $T/L = 0.4; 0.5$ and 0.6 ; $L_1 = 2$ mm, 2.2 mm and 2.4 mm. By making all possible combinations with the parameters above, 27 geometrical models were obtained. (Table 1)

Table 1. Parameters used in the geometrical modeling of clasp arms.

Case	L_1 (mm)	L_2/L_1	T/L
1	2	0.4	0.4
2	2	0.4	0.5
3	2	0.4	0.6
4	2	0.6	0.4
5	2	0.6	0.5
6	2	0.6	0.6
7	2	0.8	0.4
8	2	0.8	0.5
9	2	0.8	0.6
10	2.2	0.4	0.4
11	2.2	0.4	0.5
12	2.2	0.4	0.6
13	2.2	0.6	0.4
14	2.2	0.6	0.5
15	2.2	0.6	0.6
16	2.2	0.8	0.4
17	2.2	0.8	0.5
18	2.2	0.8	0.6
19	2.4	0.4	0.4
20	2.4	0.4	0.5
21	2.4	0.4	0.6
22	2.4	0.6	0.4
23	2.4	0.6	0.5
24	2.4	0.6	0.6
25	2.4	0.8	0.4
26	2.4	0.8	0.5
27	2.4	0.8	0.6

A three-dimensional finite element analysis software (Cosmos/M, version 2.5; Structural Research and Analysis, Santa Monica, California) was used for the study. The finite element method was selected because it is an established theoretical technique for biomechanical problems.¹⁶

The constructed finite element models were subdivided into 2500 solid eight-node elements, connected at 3056 nodes. When creating the finite

element models, the mechanical, elastic and thermal characteristics of the Co-Cr alloy (WironiumLA; Bego, Bremen, Germany) used for the framework were entered into the computer program: tensile strength $R_m = 1000$ MPa; ductile yield $R_p 0.2 = 700$ MPa; modulus of elasticity $E = 2.2 \times 10^5$ MPa; Poisson's ratio $\nu = 0.3$; Vickers hardness (HV 10) = 340.¹⁵ The base surface was blocked in all directions, and the load was applied with a 5 N force at the tip, uniformly distributed on width L2. The direction of the force was perpendicular on the clasps length, towards the convex surface.

RESULTS

Following the static analyses, the computer program allowed the calculation of stresses and displacements, as well as colored-spectrum-type graphic representation. Each representation had its own explanatory legend. Tension was measured in MPa, and displacements in mm. The distortion representation scale was automatically increased by the computer, depending on the results, so that the slightest displacements would also be visible. In all cases, the stresses, represented by the equivalent Von Mises stress, were presented on the undistorted model, while the displacements were visible in the cases of distortion highlighting, and the initial condition was also given.

Further on, Figures 1 and 2 are going to represent the analysis results for stresses and displacements one case of loading.

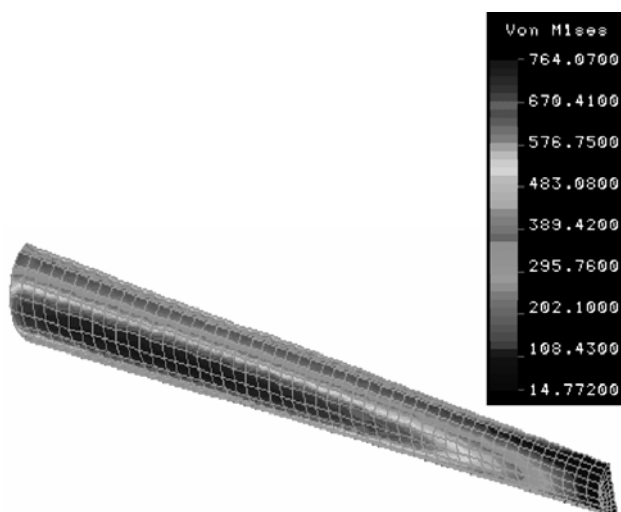


Figure 1. Representation of the Von Mises equivalent stress distribution in case 7.

The highest stresses were distributed on the external sides of the clasp arms, at the level of maximal convexity. On the internal side of the clasps there were

still areas of stresses, but these had much lower values and were situated at the same level with the ones on the external side. The greatest displacements were situated at the tip level of the clasp, and then gradually decreased towards the base. The terminal quarter of the arms length suffered no displacement.

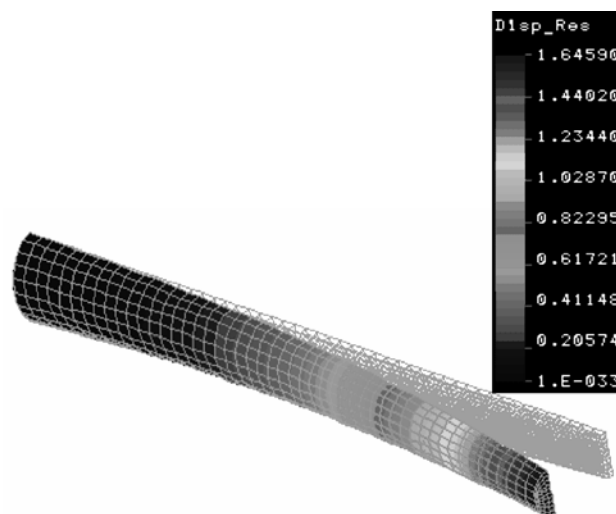


Figure 2. Representation of displacements in case 7.

Because these analyses used solid-type finite elements with eight nodes per element, which are spatial elements, the stresses in the volume of clasp arms could be visualized. (Fig. 3)

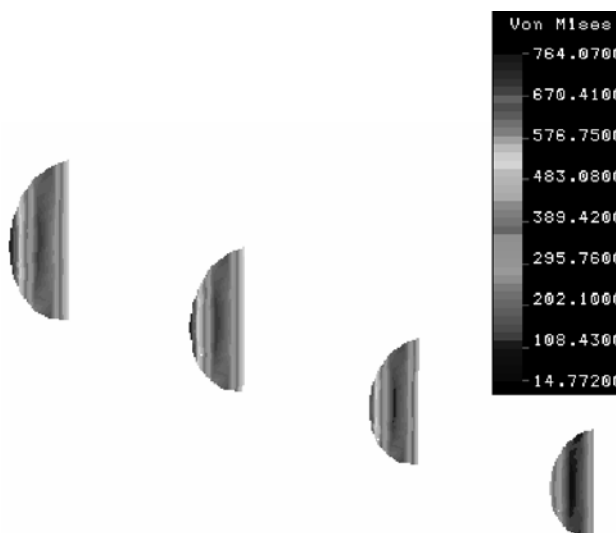


Figure 3. Representation of the Von Mises equivalent stress distribution arm thickness-wise, in case 7.

By analyzing the images in which stresses were represented by sections, it was noticeable that maximal stresses, present at the level of the convex surface, extended very little depth-wise. It was noticeable that only the mid-third of the arm, longitude-wise, presents relatively low stresses. The thicker the arm, the lower

the tensions were.

All cases were analyzed in turn. The analysis began with the first nine, which had the same 2 mm base width, varying L_2/L_1 and T/L ratios and there were combinations made between them.

As a result of the two ratios' variations, L_2/L_1 and T/L , there were certain features emerging. Concurrently with the increase of the T/L ratio to highlight the influence of thickness on stress distribution, it was noticeable that as the arm thickness increased, i.e. as the clasp became more rigid, the stress area moved towards the tip of the clasp and reduced its surface, meaning that a stress concentration was taking place. Concurrently with the L_2/L_1 ratio increase, i.e. taper decrease, displacement was produced towards the base of the arm, with concentration increase in both cases.

Because not all case results have been presented, Table 2 shows the values of maximum equivalent tensions and maximum displacements, for cases 1-9.

Table 2. Maximal equivalent stress and maximal displacement values for cases 1-9.

Analyzed case	Maximal equivalent stress (MPa)	Maximal total displacement (mm)
1	1050.30	2.249
2	721.29	1.231
3	521.41	0.741
4	823.33	1.855
5	558.73	1.006
6	400.94	0.602
7	764.07	1.645
8	513.56	0.887
9	366.68	0.528

Figures 4 and 5 are the graphic representation of maximal stresses according to maximal displacements, for ratios $L_2/L_1 = \text{constant}$ and $T/L = \text{constant}$.

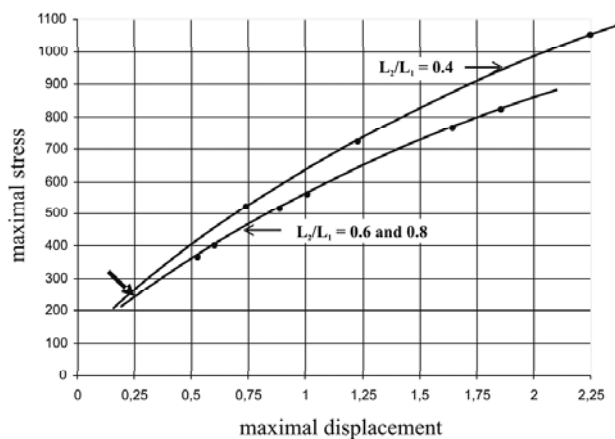


Figure 4. Representation of the connection between maximal displacements and maximal equivalent stresses in cases 1-9, for $L_2/L_1 = \text{constant}$.

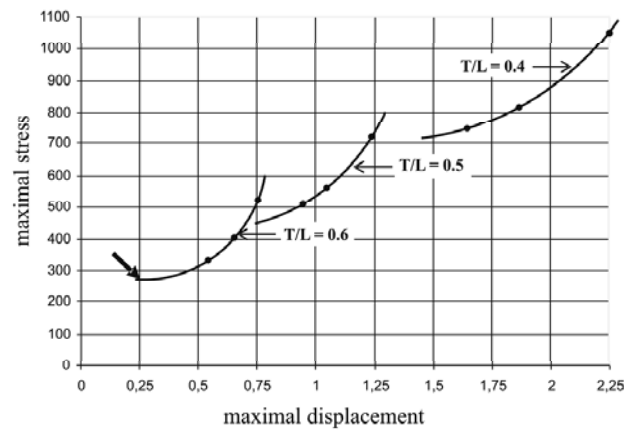


Figure 5. Representation of the connection between maximal displacements and maximal equivalent stresses in cases 1-9, for $T/L = \text{constant}$.

Graphic representations were necessary to determine the adequate profile to fulfill the requirements: obtaining the desired flexibility, so that stresses are as low as possible. For the back-action clasp arm, which is a circumferential clasp, the attention was focused on the 0.25 mm displacement.

Regarding the L_2/L_1 ratio, it was found that the connection of maximal equivalent stresses with the maximal displacements for values 0.6 and 0.8 was the same. However, regarding stress distribution, we noticed that for the 0.8 ratio high stresses accumulated towards the arms base, where thickness was greater, which had a favorable effect. This was the reason this ratio was preferred.

When the clasp base width was of 2 mm, the most adequate cross-section profile was the half-oval, with ratio $T/L = 0.6$.

Subsequently the same analyses were run for the situation in which the arm base width was of 2.2 mm, present in cases 10-18. Regarding stress distribution, the features of the previous cases were maintained. As taper decreased, the maximal equivalent stresses and maximal displacements also decreased, but it was necessary to determine the most convenient ratio for the targeted purpose. The clasp has to fulfill its functions, without affecting the strength.

Table 3 shows the maximal equivalent stress and displacement values for cases 10-18.

To analyze the connection between maximal stress values and displacements, graphic representations were also necessary for $L_2/L_1 = \text{constant}$ and $T/L = \text{constant}$. (Figs. 6, 7)

Just like in the previous situation, the lowest equivalent stress corresponding to the maximum 0.25 mm displacement was noticed in the two situations when $L_2/L_1 = 0.6$ and 0.8. Again, the difference was made based on stress distribution. Stresses were

Table 3. Maximal equivalent stress and maximal displacement values for cases 10-18.

Analyzed case	Maximal equivalent stress (MPa)	Maximal total displacement (mm)
10	820.74	1.584
11	556.92	0.859
12	399.63	0.514
13	639.83	1.301
14	429.64	0.699
15	306.36	0.416
16	571.68	1.101
17	380.51	0.589
18	270.10	0.349

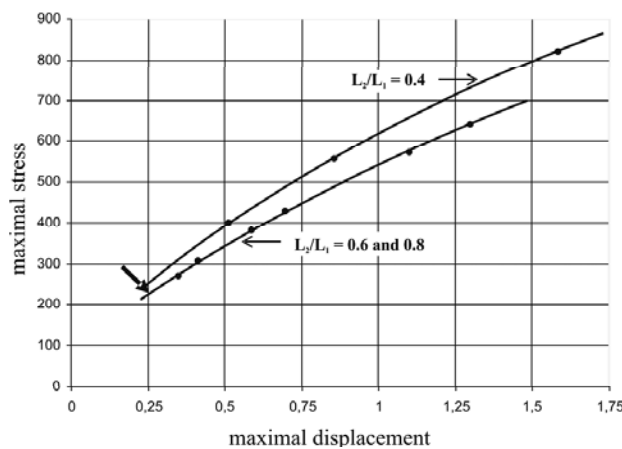


Figure 6. Representation of the connection between maximal displacements and maximal equivalent stresses in cases 10-18, for $L_2/L_1 = \text{constant}$.

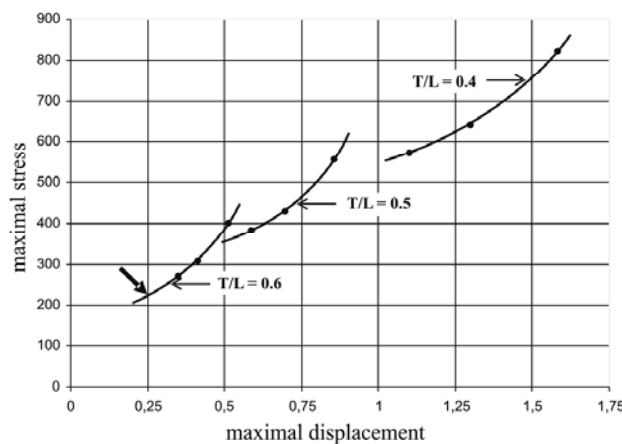


Figure 7. Representation of the connection between maximal displacements and maximal equivalent stresses in cases 10-18, for $T/L = \text{constant}$.

located rather towards the clasp arm base, where it was thicker, in case $L_2/L_1 = 0.8$. As a result, this was the preferred option.

Regarding the T/L ratio, the lowest equivalent stress corresponding to the maximal 0.25 mm displacement was found for the 0.6 value. As a result, the clasp arms cross-section shape will be half-oval.

Finally, the greatest back-action clasp arm width was of 2.4 mm, being analyzed in nine cases; the maximal stress and displacement values are showed in Table 4.

Table 4. Maximal equivalent stress and maximal displacement values for cases 19-27.

Analyzed case	Maximal equivalent stress (MPa)	Maximal total displacement (mm)
19	652.09	1.146
20	438.22	0.617
21	312.62	0.367
22	506.08	0.937
23	336.97	0.501
24	239.08	0.297
25	447.26	0.792
26	296.21	0.421
27	209.65	0.249

These values were useful for the graphic representations of the maximal stress depending on the maximal displacement, in order to determine the optimum clasp arm shape.

Graphs were drawn, representing the connection between maximal stresses and displacements, in the cases when $L_2/L_1 = \text{constant}$ and $T/L = \text{constant}$. (Figs. 8, 9)

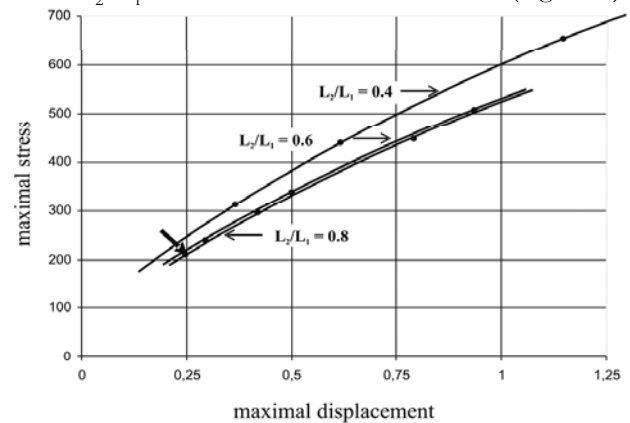


Figure 8. Representation of the connection between maximal displacements and maximal equivalent stresses in cases 19-27, for $L_2/L_1 = \text{constant}$.

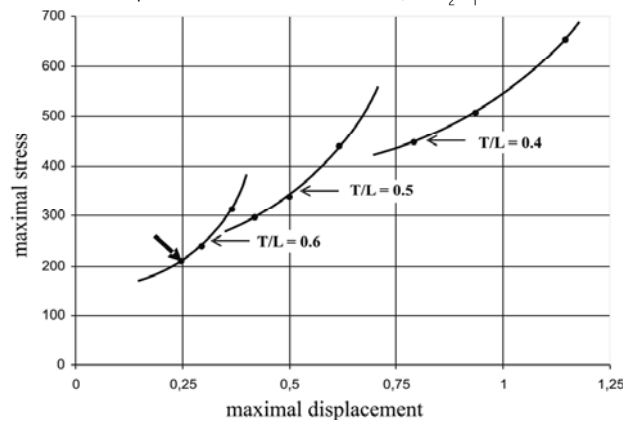


Figure 9. Representation of the connection between maximal displacements and maximal equivalent stresses in cases 19-27, for $T/L = \text{constant}$.

In this case, the difference between the curves of L_2/L_1 for values 0.6 and 0.8, even when they are close, could be demonstrated. It was obvious here that the situation when $L_2/L_1 = 0.8$ was the most favorable.

The graph analysis showed that the most favorable T/L ratio, i.e. when the maximal equivalent stress is lowest for a maximum displacement of 0.25, was of 0.6. As a result, the clasp arms cross-section will be a half-oval.

Likewise, starting from any clasp arm size, one can determine the ideal shape for a certain size. Up to this point a few cases which correspond to the most frequently used sizes in practice were analyzed.

DISCUSSIONS

Because of the various kinds of clasp patterns commercially available, their selection in practice is very difficult. In clinical use the clasp arms may be chosen within the limits of the real conditions, but a design producing less stress is the most important parameter.

The finite element method allows both the determination of stresses, by calculating equivalent stresses, as well as the determination of arm flexibility, by calculating the displacements resulting from distortions.^{21,22}

The topic of determining the optimum shape of circumferential clasps is debated in the specialized literature, while the numeric simulation methods represent a useful means for these analyses. Sato, quoting Moris, shows that the most favorable G/L ratio is 0.4.⁵ His studies carried out through numeric simulations using the finite element method, confirm these results. Thus, the optimum clasp arm shape is thin and wide. The indicated taper is 0.8.^{5,6}

The results of the study made on Akers clasp retentive arms indicate a 0.6 taper, regardless of the clasps thickness or width. Regarding the thickness of these clasp arms, the T/L ratio varies between 0.5 and 0.6 as follows: 0.5 for Akers clasp arms of 2 and 1.8 mm base width; 0.6 for Akers clasp arms of 1.6 mm base width.²³

In this study, the numeric simulation was used for the analysis of back-action clasp arms, with the purpose of optimizing them. The analyses were run based on a set algorithm, so that results would allow the orientation towards the optimum shape of the clasp arms. Due to the difficulties of obtaining geometrical models, all analyses were run on straight models.

By synthesizing the results of all cases, it can be noticed that, as the arm thickness decreases, while all other parameters are maintained constant, maximal

stresses move towards the clasp tip. By decreasing taper, also maintaining all other parameters constant, high stresses move towards the base.

The results obtained using a finite element method depend on parameters that would be introduced into a computer program, such as the coordinates of the points, the constitution of the geometric model, choice of finite element type, material properties, element properties, and conditions of restraining and loading.^{8,9} The skill, accuracy, and expertise of those who make the analyses also play an important role on the outcome.

Materials used for the manufacturing of dentures were considered homogeneous, isotropic, and elastic, with known mechanical and elastic properties. The physical phenomenon have to be correctly represented. The results depend on the size, placement, and type of external loads.²⁴

It is important to mention the fact that determinations were limited to a number of clasp arm sizes, which coincide with the ones most frequently used in practice.

CONCLUSIONS

Regarding the use of the finite element method to optimize the shape of back-action clasp arms, the following conclusions can be drawn:

1. The finite element method allows the simulation of the effect of retentive forces on clasp arms with different cross-section shapes and tapers.

2. Decreasing the thickness of the arms, without the variation of the other parameters, the maximal stresses move closer to the tip. Also, decreasing the taper, without variation of the other parameters, the maximal stresses move closer to the base of the clasp arm.

3. By representing the connection between maximal equivalent stresses and maximal displacements, the cases in which the displacement typical of each clasp type has the lowest corresponding maximal equivalent stress can be selected.

4. Numeric simulations using the finite element method allow the shape optimization of circumferential cast clasps retentive arms, so that they can be sufficiently flexible to not have damaging effects on the abutment teeth, but at the same time be efficient for the denture retention.

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