Journal of Applied Biomaterials & Biomechanics 2010; Vol. 8 no. 2, pp. 76-81 ORIGINAL ARTICLE

Stress distribution in retentive arms of combination clasps used on premolars

Liliana Sandu[1], Florin Topală[2], Sorin Porojan[2]

[1]Specialization Dental Technology, University School of Dentistry, "Victor Babeş" University of Medicine and Pharmacy, Timişoara - Romania
[2]Department of Prosthodontics, University School of Dentistry, "Victor Babeş" University of Medicine and Pharmacy, Timişoara - Romania

ABSTRACT
Introduction: **Stresses resulting from cast clasp arms during insertion and the removal of removable partial dentures are the main causes of deformations or fractures. Therefore, achieving clasp designs producing less stress is very important.**
Objective: **Retentive clasp arms used for premolars were investigated through the reverse engineering approach. The aim was to determine stress distribution in oval and half-oval clasps cross-sections in order to analyse biomechanical behavior.**
Material and methods: **Purposely designed experimental three-dimensional (3D) models of the clasp arms were constructed on the buccal surface of an upper first premolar, to be used for structural simulations. 3D teeth models obtained after laser scanning were used as a support for retentive clasp arms modeling. Parameters of the clasp arms like length, thickness and cross-section were considered for the simulation of stainless steel wires. A concentrated load of 5 N was applied at the inner tip of the clasp arm.**
Results: **A precise model of the coronal buccal surface of an upper first premolar was generated. This model was a useful tool in designing stainless steel clasp arms of different thickness and cross-section. In all cases, high stress values were located on the inner surface of the clasp arm, in the part located above the height of the contour. A similar bending stiffness was observed between the half-round cross-section design with a diameter of 1 mm and the round cross-section design with a diameter between 0.6 and 0.7 mm.**
Conclusions: **This in vitro study demonstrated that the reverse engineering approach and structural analyses provide a powerful tool for designing clasps and visualizing fracture risk areas and for choosing the adequate cross-section for each case. Within the limitations of this study, it was suggested that, on premolars, the biomechanical performance of half-round cross-sections for the retentive arms may be higher than round sections of clasp arms showing similar mechanical stiffness.**

Key words: Circumferential clasp, Wrought wire retentive dental arm, 3D models, Structural simulation, Stress

Accepted: 10/05/10

INTRODUCTION

In clinical use the clasp arms can be chosen within the limits of the real conditions, but the most important parameter is a design producing less stress (1). Numerical simulations can evaluate this parameter.

Cast circumferential clasps are frequently used in removable partial denture (RPD) technology for their remarkable simplicity, easy construction and excellent retention. An alternative is the assembly known as the combination clasp, which has a wrought wire retentive arm.

Their choice and design depends on several factors: clasp material, clasp form, and the amount of undercut. Among this, only the clasp form is under the control of the dentist or dental technician. The mechanical properties of the clasp material are normally determined by the alloy used, commonly a cobalt-chromium (Co-Cr) alloy or stainless steel wire. The undercut is between 0.25 and 0.5 mm (2).

The combination clasp uses a wrought wire retentive arm. A wrought wire is preferred for retention when the undercut occurs in the mesial third of the buccal surface of an abutment tooth. The adjustability, lack of tissue coverage and reparability are the main advantages of these kinds of clasps. The disadvantages are that they can be poorly adapted by the dental technician, loss of adaptation of the wire after a period of time, which may be due to improper placement of the wire, and the susceptibility to fracture. However, this problem can be controlled and improved by the technique used for construction and the careful selection of the material. Proper material selection is crucial in determining whether wires maintain their adaptation, whether breakage will be a problem, and whether flexibility will be adequate. The gauge of wire used will depend on the abutment periodontal support, degree of reciprocation, clasp arm length, undercut depth and amount of retention desired (3).

A retentive clasp should engage 0.5 mm of the undercut if it is constructed of wrought wire. A wrought wire clasp is more flexible than a comparable design of cast clasp in Co-Cr alloy; and therefore, needs to engage a greater depth of undercut to generate equivalent retention. As a wrought wire clasp has a higher proportional limit than a cast clasp, it can engage this increased undercut without deforming permanently. There can be technical difficulties in the production of accurately fitting wrought wire clasps as the required skill is not universally available. A retentive clasp should be at least 7 mm in length if it is constructed of wrought wire. A wrought clasp of about 7 mm in length can engage 0.5 mm of the undercut without deforming permanently. However, if the wrought clasp is shorter that 7 mm, flexing into this undercut is likely to result in permanent deformation. If an occlusally approaching retentive clasp is used on a premolar or canine, it should be constructed of wrought wire (4).

A premolar or canine tooth is usually wide enough mesiodistally to accept an occlusally approaching clasp of about 7 mm in length but not much longer. A wrought clasp can therefore provide reliable retention in this situation whereas a cast clasp would be too rigid (4).

Because complication and failure rates of RPDs were high for retainers, different studies have tried to clarify the component that had high rates of failure and complications (5). Various retainer designs were compared by measuring the occlusal load (6), the stress distribution in the abutments and the abutment mobility (5, 7), and the masticatory performance of the dentures (8).

Comparative studies were performed for alternative materials for RPD applications for Co-Cr, like titanium and noble alloys (9-12). Using finite element analysis, the clasp should be designed with consideration of the stress distributions within the clasps (13).

The first aim of the study was to achieve 3D models of premolars in order to design and analyze stress distribution in retentive wrought wire dental clasp arms with different cross-sections. The second aim was to investigate the biomechanical behavior of round and half-round cross-sections of clasp arms.

MATERIAL AND METHODS

The computer aided design (CAD) approach was used to design dental clasp arms and to carry out simulations. This approach is widely used to investigate, in vitro, the behavior of tissues and biomaterials involved in oral restorations (14, 15).

The first step in this approach was to achieve 3D teeth models in order to design dental clasp arms. Enlarged plaster teeth (scale 10:1), obtained by substraction from a plaster parallelipiped using literature data (16) were scanned using a LPX-1200 Laser Scanner (RolandDG Corporation, Japan). For most situations, a single scan will not produce a complete model of the object. Multiple scans, from many different directions were required in order to complete the 3D scanning process.

The resulting files were imported into LeiosMesh (Enhanced Geometry Solutions Corporations, Italy), where the point clouds from the tooth surfaces were cleaned and assembled. The collected data were used to construct 3D models using the Rhinoceros (McNeel North America) NURBS (Nonuniform Rational B-Splines) modeling program. Nonuniform rational B-spline (NURBS) is a mathematical model commonly used in CAD, manufacturing and engineering. It was introduced in dentistry through CAD/CAM systems (17, 18). CAD is mainly used for detailed 3D models, but it is also used throughout the manufacturing process, from conceptual design, through strength and dynamic simulation analyses. The models were reduced to the natural size in order to obtain a normal size of the teeth and clasps.

The resulting solid was tilted in order to obtain functionally effective tooth contours. The height of the contour was designed and the 3D models were used as a support for retentive clasp arms modeling (Figs. 1, 2).

Purposely designed experimental 3D models of the clasp arms were constructed on the tooth surface, according to the literature data (7, 19, 20) and exported into Ansys finite element analysis software (Ansys Inc, Philadelphia, USA) for structural simulation purposes.

For the wrought wire clasps simulations, steel wires were modeled considering the diameter values spanning between 0.5 and 1.3 mm. For each diameter, round and half-round cross-sections were developed and compared according to the stiffness value obtained through numerical analysis.

The finite element models were subdivided into solid 7266 elements, connected at 1709 nodes. All nodes at the base of the clasp retentive arm were restrained in all directions and a concentrated load of 5 N was applied at the inner tip of the clasp arm, perpendicular to the inner surface.

RESULTS

The reverse engineering approach was successfully employed to determine an accurate model of the coronal buccal surface of an upper first premolar. This approach represents a useful tool in designing and simulating the biomechanical behavior of stainless steel clasp arms of different thickness and cross-section.

Generated stresses and displacements were calculated numerically and plotted graphically. Results were displayed as colored stress contour plots to identify regions of different stress concentrations. High stress values were present on the inner surface of the clasp arm, in the part located above the height of the contour and for the thicker arms they were more concentrated and closer to the tip (Figs. 3a, 4a). The tip of the clasp arm is located under the height of the contour, in the area with the undercut of 0.5 mm. The deformations are maximal at the tip (Figs.

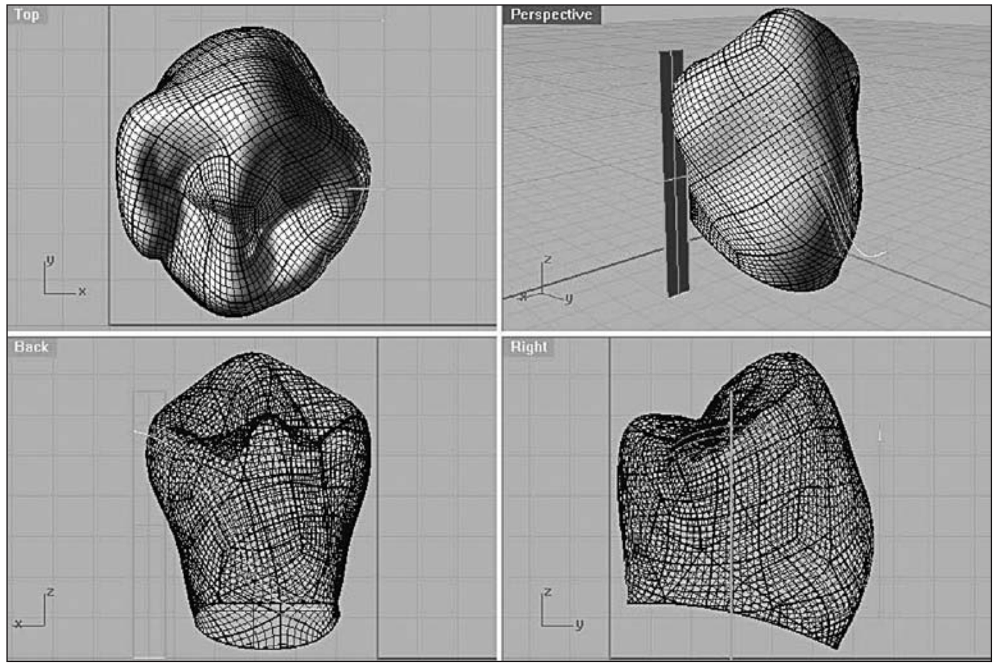

Fig. 1 - *Tooth as support for clasp modeling.*

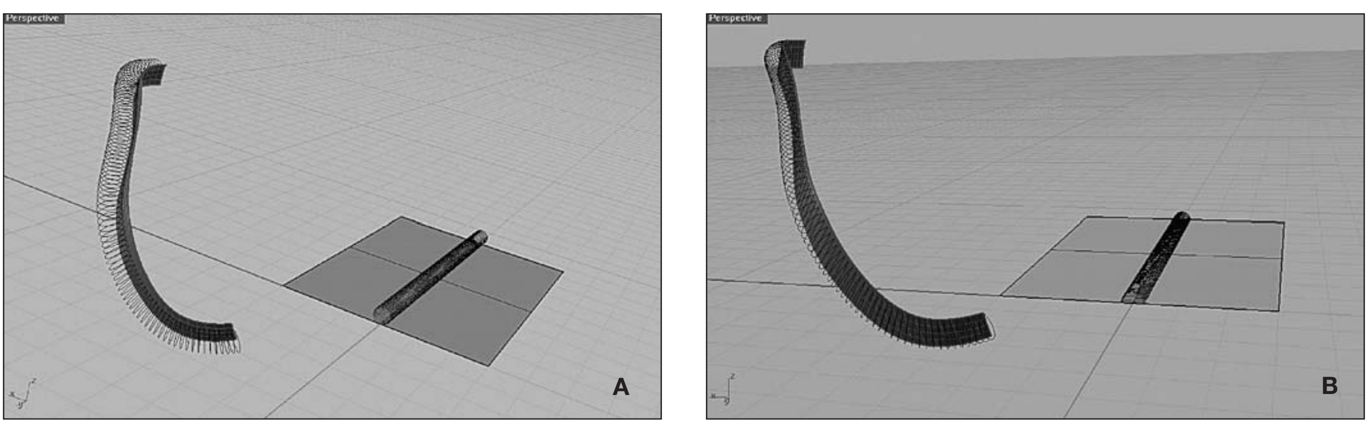

Fig. 2 - *3D clasp modeling: a. round and b. half-round cross-section.*

3b, 4b). Tables I-III present the minimum equivalent stress, maximal equivalent stress and displacement values.

Displacement results of clasp arms (Tab. III and Figs. 3b, 4b) clearly show that the bending stiffness of half-round cross-section designs with a diameter of 1 mm is similar to the bending stiffness of round cross-section designs with a diameter between 0.6 and 0.7 mm. In fact, according to the displacement of the tip of Figure 4b, the round wire that is most similar to half-round wire (Tab. III) will have a diameter slightly lower than 0.7 mm.

This evaluated stiffness value, that is the ratio between the applied load and the resulting displacement simulation, is about 10 N/mm. Therefore, these chosen wire diameters provide similar displacements for a simulated load of 5 N. It is interesting to note that the cross-section areas of these wire is similar (about 0.4 mm^2).

TABLE I - MINIMUM EQUIVALENT (VON-MISES) STRESS

Diameter [mm]	Equivalent stress min. for the round wrought wire clasp [MPa]	Equivalent stress min. the half-round wrought for wire clasp [MPa]
0.5	6.5212	11.6020
0.6	3.7236	7.5826
0.7	3.1629	5.1866
0.8	2.2459	4.3253
0.9	1.6840	2.9583
1	0.9341	1.8118
1.1	0.3537	1.5808
1.2	0.5422	1.1454
1.3	0.5199	0.9084

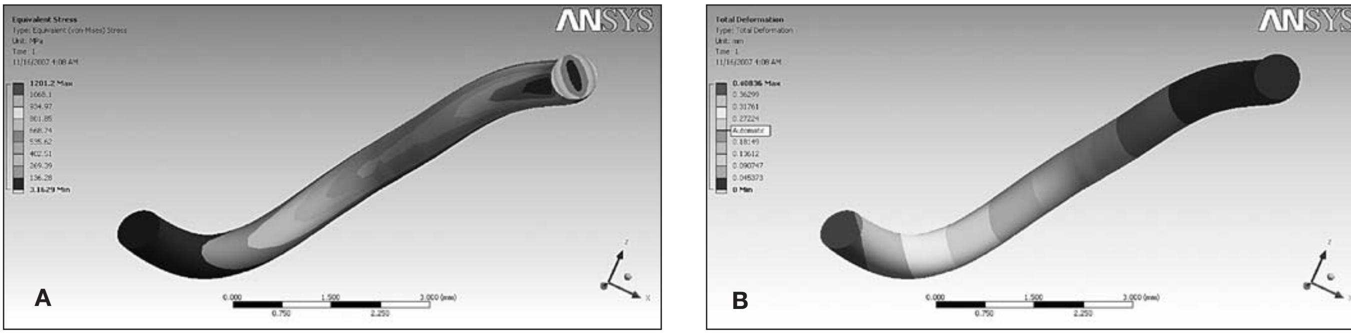

Fig. 3 - *Stress distribution and displacements in the retentive arm of the round wrought wire clasp with a diameter of 0.7 mm: a. stress distribution, b. displacements.*

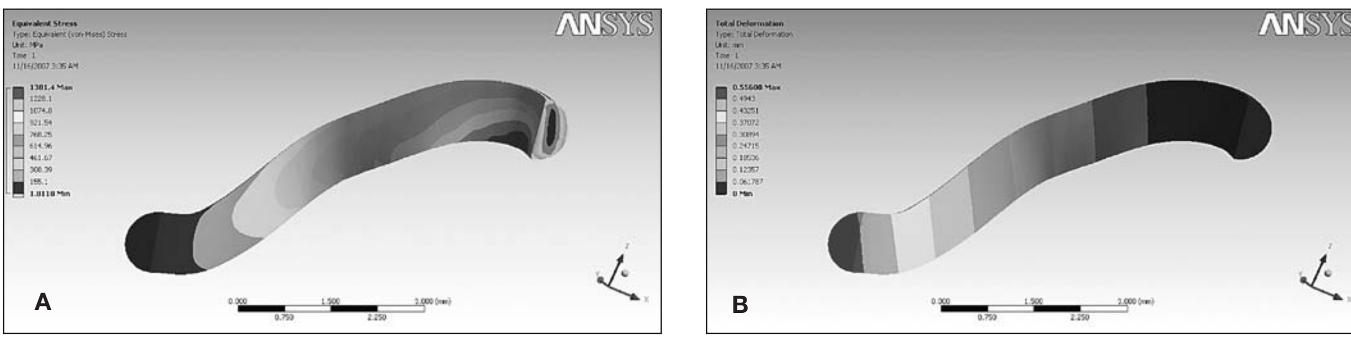

Fig. 4 - *Stress distribution and displacements in the retentive arm of the half-round wrought wire clasp with a diameter of 1 mm: a. stress distribution, b. displacements.*

TABLE II - MAXIMAL EQUIVALENT (VON-MISES) STRESS

Diameter [mm]	Equivalent stress min. for the round wrought wire clasp [MPa]	Equivalent stress min. the half-round wrought for wire clasp [MPa]
0.5	3012.8	9950.8
0.6	1854.8	5907
0.7	1201.2	3778
0.8	844.45	2575.8
0.9	611.55	1846.4
1	452.73	1381.4
1.1	354.89	1060.6
1.2	280.66	835.82
1.3	229.81	672.33

TABLE III - TOTAL DISPLACEMENTS

Diameter [mm]	Equivalent stress min. for the round wrought wire clasp [MPa]	Equivalent stress min. the half-round wrought for wire clasp [MPa]
0.5	1.422	7.8235
0.6	0.72043	3.8633
0.7	0.40836	2.1452
0.8	0.25118	1.2902
0.9	0.16441	0.82631
1	0.113	0.55608
1.1	8.0821e-002	0.38941
1.2	5.971e-002	0.28184
1.3	4.533e-002	0.20972

Because all these variables were the same, only the stress values were taken into consideration for the selection of the adequate cross-section. Figures 3 and 4 show the stresses and displacements.

DISCUSSION

The permanent problem in practice is the choice of clasp geometry and dimensions, so that they satisfy functional needs, alteration of the initial shape or having nocive effects on the remaining teeth. The design of clasp arms may benefit from the tools of the reverse engineering approach, such as imaging and biomechanical simulation.

Modern design and evaluation in order to obtain an adequate framework strength involves numerical simulations. Analyses in this field continuously advance both in 3D modeling, CAD and structural analyses simulation methods.

3D reconstructions after scanning, in order to obtain faithful models, can be used for numerical simulations of the teeth and prosthetic restorations. CAD is mainly used for detailed 3D models, but it is also used throughout the manufacturing process, from conceptual design, through strength and dynamic simulation analyses.

Three types of retainers designed for distal-extension RPDs were assessed and the greatest tooth mobility was observed with the wrought wire clasps. It is important to note that the occlusal load distributed to the free-end saddle is closely related to the connecting rigidity of the retainer (7). Designs of RPDs are suggested to affect the mobility of abutment teeth and RPD during oral functions. This study aimed to examine the effect of direct retainer and major connector designs on RPD dynamics under simulated loading. Rigid direct retainers and rigid major connectors reduce the movements of both abutment teeth and RPD (19).

Different studies have assessed the influence of plastic deformation by bending on stress, flexibility and permanent deformation in wrought wire clasps. Their results suggest that the permanent deformation of wrought wire clasps is likely to initiate at the clasp shoulder, under the bending force, the maximum tensile stress was recorded at the outside surface of the bending corner; while after unloading, the maximum tensile stress appeared at the inside of the bending angle (20).

Stainless steel wrought wires used as clasp arms for RPDs were compared in terms of flexibility, Vickers micro hardness and composition. The results showed that there were significant differences among different wires (21). Various clasp designs of stainless steel wire for clasps were used in different studies to show their effect on the dynamics of RPDs, under simulated loading (22).

The flexibility of the wrought wire clasp is related to a number of factors, including the type and gauge of the alloy. These data indicate that knowledge of the bending properties of an alloy is equally as important as the gauge size when selecting a wire clasp (23).

The objective of other studies was to determine the fatigue resistance of wrought-steel wire clasps used for RPDs. Wrought-steel wires with different cross-sectional diameters were tested using a deflection fatigue test. The results suggest that to avoid fractures of the wrought-steel wire clasps caused by bending fatigue, the stress on the clasp during its deflection should be taken into account (24).

In this investigation, the rationale for using a tooth solid model (scale 10:1) is based on the precision by which 3D LASER imaging can detect the coronal surface of an upper premolar through the scanning of enlarged solid models (Fig. 1). Tools of the reverse engineering approach, such as LASER scanning, CAD 3D reconstruction and numerical simulation, were used to design (Fig. 2) and to compare the biomechanical behavior of stainless steel clasp arms of different cross-section (Figs. 3, 4). We also used the numerical analysis to detect the diameters of round and half-round cross-sections, which could be compared mechanically. Accordingly, for a simulated load of 5 N, half-round wire clasp arms with a diameter of 1 mm (Fig. 4b), showed similar displacements of round wires with the diameter between 0.6 and 0.7 mm (Fig. 3b, Tab. III), closer to 0.7 mm. Therefore, these wires show a similar mechanical stiffness of about 10 N/mm.

Structural analysis allowed the prediction of the sites where higher stresses and deformations will develop, and the sites with high fracture risk during functions. The finite element method allows the calculation of the stresses, through equivalent stress and of the flexibility through calculation of the displacements. For both half-round and round wires, high stress values were observed on the inner surface of the clasp arm, in the part located above the height of the contour (Figs. 3a, 4a). This method of analysis is essential because it is the basis for other complementary analysis methods (at variable solicitations), to explain some complex phenomena that are important in degradations.

The results obtained from this investigation clearly show that clasp arms of different cross-section, but similar stiffness, show similar maximum equivalent stress. It is also interesting to note that the area of half-round wires of 1 mm is very close to the area of round wires of 0.7 mm. Therefore, the same amount of metal is used to realize these clasp arms. Nevertheless, some advantage for using half-round wires can be easily recognised. The first depends on patient comfort: the thickness of the half-round wire in the occlusal plane is 0.5 mm, this value is lower than that of the round wire (diameter of 0.7 mm) with similar stiffness. Therefore, the half-round wire will occupy a lower space between the labial surface of the tooth and the soft labial tissues. Another advantage of the half-round wire can be ascribed to the number of contact areas that this clasp arm can develop with the engaged tooth. In fact, round wires provide a limited number of contact areas on the coronal surface of the tooth due to the round shape of the cross-section, while half-round wires provide higher surface where contact areas can be established (Figs. 1, 2). This point is very important because in clinical practice the stability of a retentive clasp arm also depends on the number of contact points. Moreover, under a similar loading condition, clasp arms which engage the tooth on a limited number of contact areas (i.e. round wires) will also concentrate on the enamel surface higher stress.

Establishing a powerful tool based on 3D imaging and on finite element method for clasps design that is both accurate and practical will be of great benefit in clinical dentistry.

CONCLUSIONS

3D LASER scanning and the finite element method represent a powerful tool to design clasp arms. It has been demonstrated that half-round wires of 0.7 mm show a similar mechanical stiffness of round wires of 1 mm, but the half-round wire provides more comfort and reduces stress concentration on enamel.

This in vitro study demonstrated that LASER imaging in conjunction with structural analyses may offer a powerful tool in order to vizualize fracture risk areas of cast clasps. It ensures optimal performance in selection of an adequate clasp design according to each clinical case.

ACKNOWLEDGEMENTS

The Grant ID_1264/2007 from the Ministry of Education and Research, Romania supported this study.

Conflict of interest: None.

Address for correspondence:
Dr. Liliana Sandu
6 Socrate Str.
300552 Timişoara
Romania
lilianasandu_ls@yahoo.com

REFERENCES

1. Sato Y, Tsuga K, Abe Y, Asahara S, Akagawa Y. Finite element analysis of the effect of vertical curvature on half-oval cast clasps. J Oral Rehabil 1999; 26: 554-8.
2. McGivney GP, Carr AB. McCracken's Removable Partial Prosthodontics. 11th edn. St. Louis: Mosby; 2004; 25-32, 97-143.
3. Aras MA. Extracoronal direct retainers for distal extension removable partial dentures. JIPS 2005; 5: 65-71.
4. Davenport JC, Basker RM, Heath JR, Ralph JP, Glantz PO, Hammond P. Clasp design. Br Dent J 2001; 190: 71-81.
5. Saito M, Notani K, Miura Y, Kawasaki T. Complications and failures in removable partial dentures: a clinical evaluation. J Oral Rehabil 2002; 29: 627-33.
6. Mizuuchi W, Yatabe M, Sato M, Nishiyama A, Ohyama T. The effects of loading locations and direct retainers on the movements of the abutment tooth and denture base of removable partial denture. J Med Dent Sci 2002; 49: 11-8.
7. Igarashi Y, Ogata A, Kuroiwa A, Wang CH. Stress distribution and abutment tooth mobility of distal extension removable partial dentures with different retainers: an in vivo study. J Oral Rehabil 1999; 26: 111-6.
8. Kapur KK, Garrett NR, Dent RJ, Hasse AL. A randomized clinical trial of two basic removable partial denture designs. Part II: Comparisons of masticatory scores. J Prosthet Dent 1997; 78: 15-21.
9. Rodrigues RCS, Ribeiro RF, Chiareloo de Mattos MG, Bezzon OL. Comparative study of circumferential clasp retention force for titanium and cobalt-chromium removable partial dentures. J Prosthet Dent 2002; 88: 290-6.
10. Bridgeman JT, Marker VA, Hummel SK, Benson BW, Pace LL. Comparison of titanium and cobalt-chromium removable partial denture clasps. J Prosthet Dent 1997; 78: 187-93.
11. Gapido CG, Kobayashi H, Miyakawa O, Kohno S. Fatigue resistance of cast occlusal rests using Co-Cr and Ag-Pd-Cu-Au alloys. J Prosthet Dent 2003; 90: 261-9.
12. Vallitu PK, Kokkonen M. Deflection fatigue of cobalt-chromium, titanium, and gold alloy cast denture clasp. J Prosthet Dent 1995; 74: 412-9.
13. Mahmoud A, Wakabayashi N, Takahashi H, Ohyama T. Deflection fatigue of Ti-6Al-7Nb, Co-Cr, and gold alloy cast clasps. J Prosthet Dent 2005; 93: 183-8.
14. Mollica F, De Santis R, Ambrosio L, Nicolais L, Prisco D, Rengo S. Mechanical and leakage behaviour of the dentin-adhesive interface. J Mater Sci Mater Med 2004; 15: 485-92.
15. De Santis R, Mollica F, Zarone F, Ambrosio L, Nicolais L. Biomechanical effects of titanium implants with full arch bridge rehabilitation on a synthetic model of the human jaw. Acta Biomater 2007; 3: 121-6.
16. Scheid RC. Woelfel's Dental Anatomy: Its Relevance to Dentistry. 7th edn. Lippincott Williams & Wilkins, 2007.
17. Luthardt R, Weber A, Rudolph H, Schöne C, Quaas S, Walter M. Design and production of dental prosthetic restorations: basic research on dental CAD/CAM technology. Int J Comput Dent 2002; 5: 165-76.
18. Willer J, Rossbach A, Weber HP. Computer-assisted milling of dental restorations using a new CAD/CAM data acquisition system. J Prosthet Dent 1998; 80: 346-53.
19. Itoh H, Baba K, Aridome K, et al. Effect of direct retainer and major connector designs on RPD and abutment tooth movement dynamics. J Oral Rehabil 2008; 35: 810-5.
20. Shirasu K, Wakabayashi N, Yoneyama T, Igarashi Y. Non-linear finite element stress analysis of plastic deformation in Co-Cr wrought wire clasps. Dent Mater 2008; 24: 1518-24.
21. Benjakul P, Cheunarrom C, Ongthiemsak C. Flexibility and hardness of dental stainless steel wrought wires used in Thailand. J Oral Sci 2001; 43: 15-9.
22. Yewe-Dyer M. A new stainless steel clasp for partial dentures. Br Dent J 1996; 24; 181: 148-9.
23. Waldmeier MD, Grasso JE, Norberg GJ, Nowak MD. Bend testing of wrought wire removable partial denture alloys. J Prosthet Dent 1996; 76: 559-65.
24. Vallittu PK. Fatigue resistance and stress of wrought-steel wire clasps. J Prosthodont 1996; 5: 186-92.