J Indian Prosthodont Soc (Oct-Dec 2013) 13(4):560–570
DOI 10.1007/s13191-012-0191-0

ORIGINAL ARTICLE

Deflections in Mandibular Major Connectors: A FEM Study

K. S. Satheesh Kumar · S. K. Preeti · R. Savadi · R. Patel · V. Vinod · J. John

Received: 28 September 2012 / Accepted: 8 October 2012 / Published online: 30 October 2012

Abstract The major connector is the most vital component critically subjected to maximal stress concentration due to various forces acting on it. The main requirement of a major connector is its resistance to deformation by occlusal stresses. This resistance to deformation is a direct consequence of the rigidity of the major connector. Thus rigidity of the major connector is paramount to resist flexing and torquing forces that could be transmitted to the abutment teeth and other structures as destructive forces. The commonly used major connectors for the mandibular arch are lingual bar and lingual plate. In the present study, the deflection of various major connector designs due to occlusal load is assessed by finite element method. They have been analyzed through finite element models. The differences in the deflection behaviour of mandibular major connector used in Kennedy's Class I, Class II, Class III, and Class IV edentulous situations have been compared. A CT scan of human edentulous mandible was taken and each section from symphysis to condylar region was projected on a graph paper and three-dimensional volumes were created from connected successive profiles to define the final solid geometry of cortical bone. Six framework models with different mandibular major connectors, lingual bar and lingual plate for Kennedy's Class I, Class II, Class III, and Class IV situations were created. The three dimensional finite element models corresponding to the geometric model were generated using Ansys's pre-processor. The model was assigned material properties. A vertical biting force of 20 N was applied. The results showed that the maximum deflection was seen in the saddle area when compared to other areas, i.e., major connector and the occlusal rest regions. The lingual bar in Kennedy's Class III situation and lingual plate in Kennedy's Class IV situation showed the least deflection when compared to Class I and Class II (distal extensions) situations. Lingual plate is more rigid major connector than lingual bar.

Keywords Major connector · Finite element modeling · Lingual bar · Lingual plate

Introduction

Removable partial denture is a useful treatment modality in treating partial edentulism. Each type of prosthesis requires use of various remaining teeth and/or tissues and consequently demands appropriate application of knowledge and critical thinking to ensure the best possible outcome of patient needs and desires [1].

A major connector is a component of the partial denture that connects the parts of the prosthesis located on one side of the arch with those on the opposite side. It is through the major connector that other components of the partial denture become unified and effective [1]. Rigidity of the major connector is paramount to resist deflection, deformation, flexing and torquing forces that could be transmitted to the abutment teeth and other structures as destructive forces. The major connector is thus the most vital component critically subjected to

Electronic supplementary material The online version of this article (doi:10.1007/s13191-012-0191-0) contains supplementary material, which is available to authorized users.

K. S. Satheesh Kumar (✉) · S. K. Preeti · R. Savadi · V. Vinod · J. John
Department of Prosthodontics, The Oxford Dental College, Hospital & Research Institute, Bommanahalli, Hosur Road, Bangalore 560068, India
e-mail: drkssk@gmail.com

R. Patel
Ahmedabad Dental College, Ahmedabad 380025, Gujarat, India

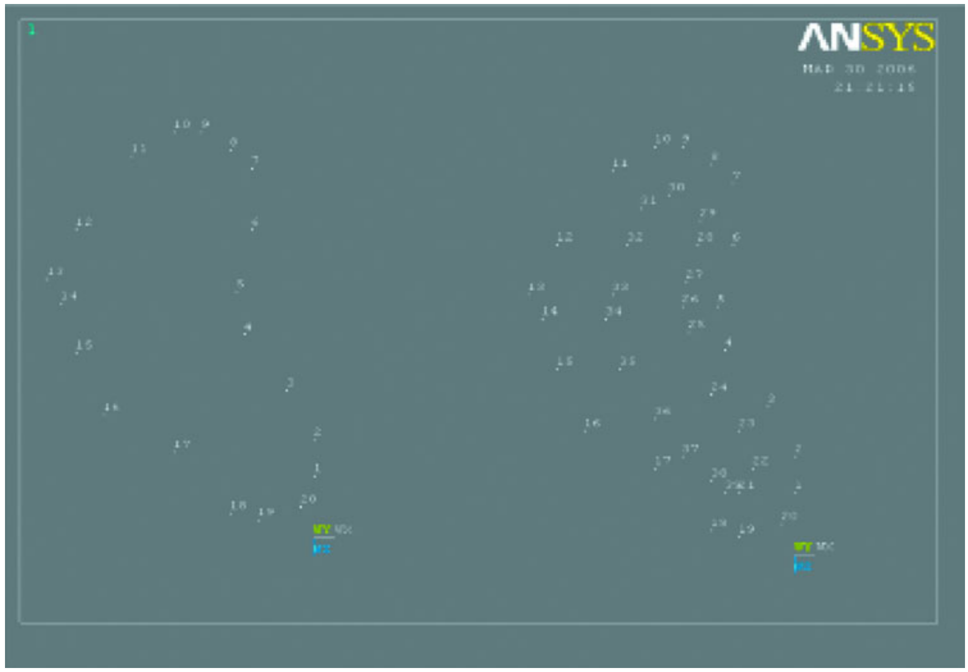

Fig. 1 Transformation of profiles into *X*, *Y*, *Z*

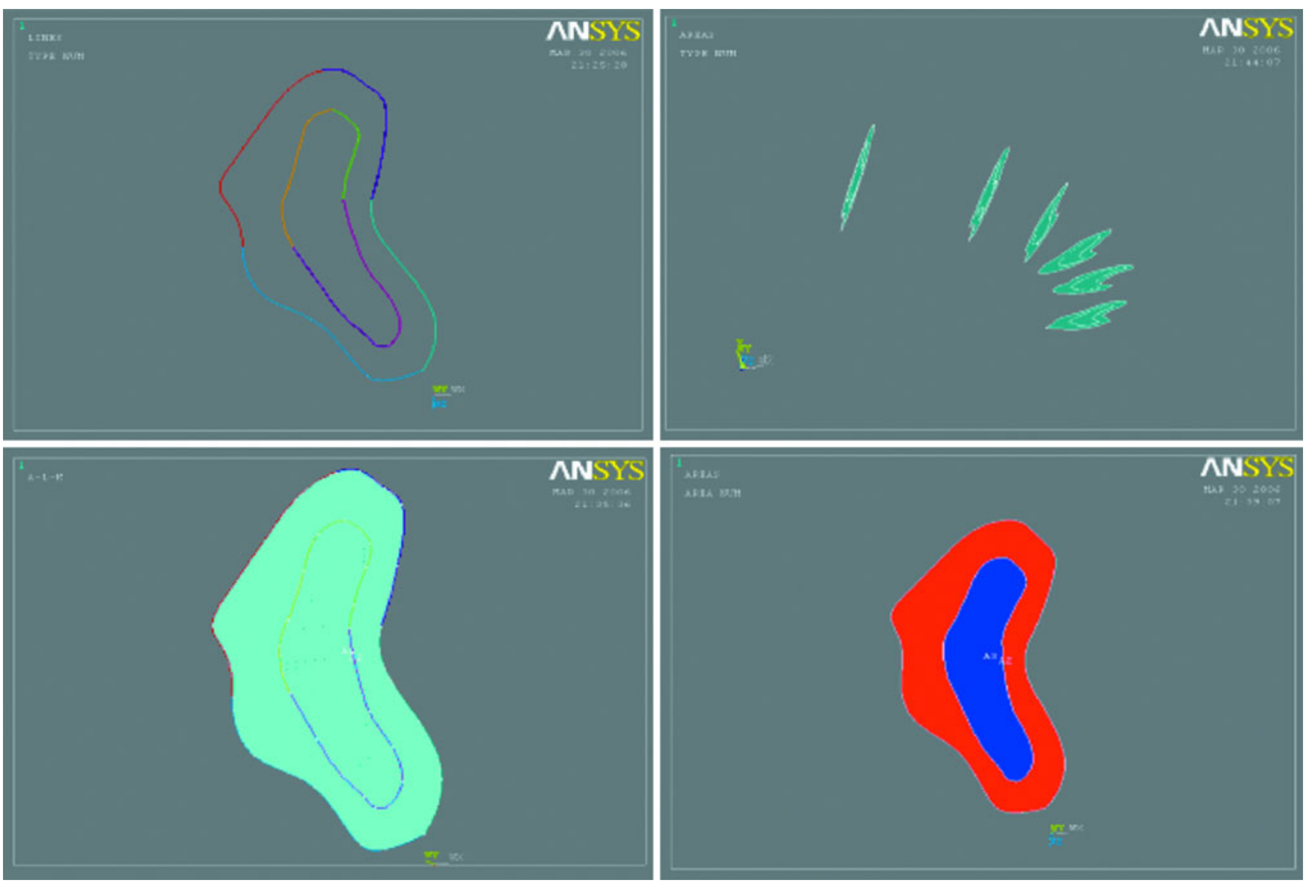

Fig. 2 Line geometry, surface geometry and solid geometry of cortical bone

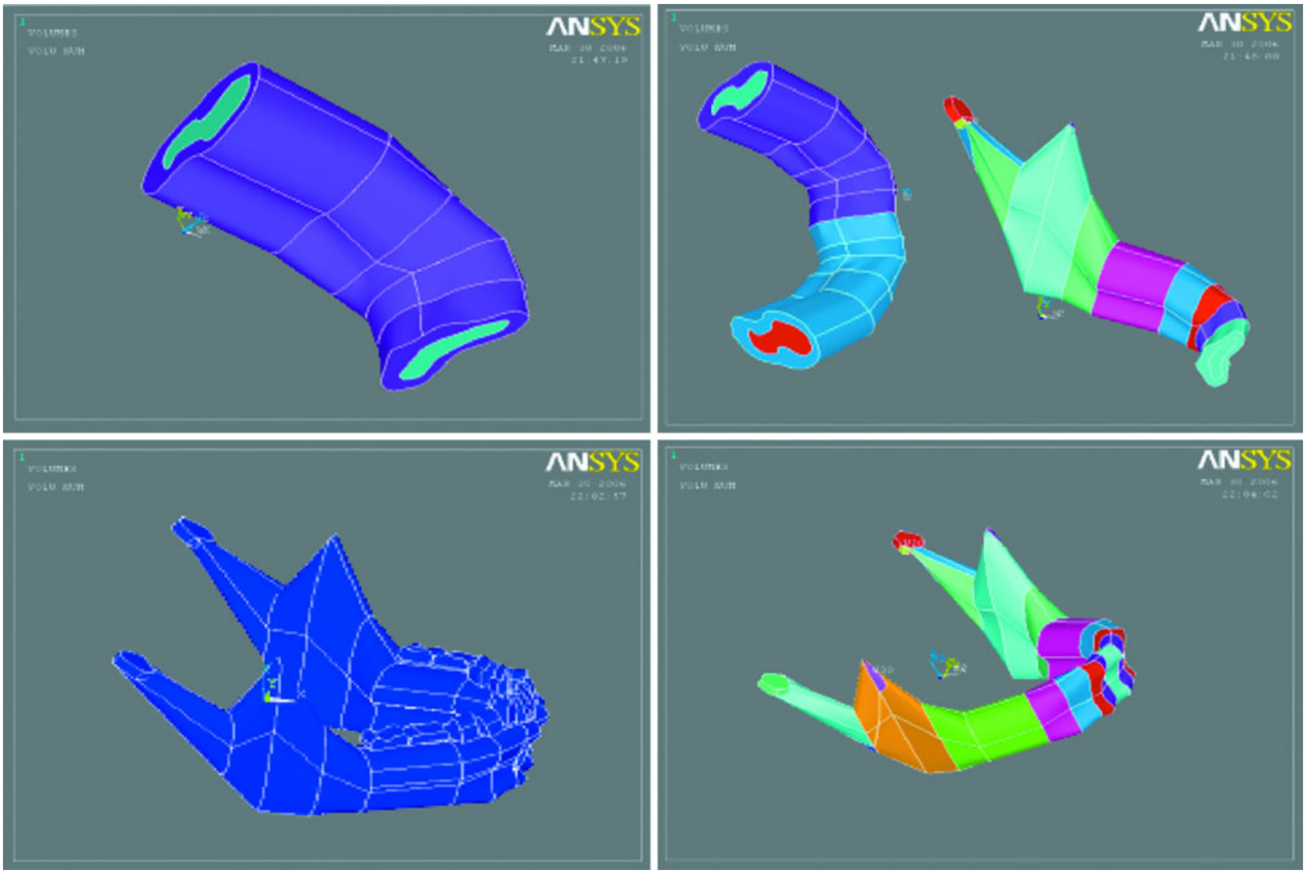

Fig. 3 Anatomical model of the mandible after superimposition

maximal stress concentration and deflection due to various forces acting on it [2].

Methods for the evaluation of deflection include mechanical stress analysis, photo elasticity and stereo-photogrammetry. In the past two decades, finite element analysis has become an increasingly useful tool for predicting the effects of occlusal forces.

Finite element analyses multifactorial field variables i.e. stress, dynamics, hydraulics and deflection. Numerical finite element analysis simulates a real time situation at points connected by strings that act like a spider web, so that a change in a local region is transmitted throughout the structure. It is a high experimental dispersion that suggests a numerical approach for mechanical analysis of the biological system, which can be applied with a suitable degree of reliability and accuracy [3].

A three dimensional finite element models of the major connectors was designed for evaluating the deflection pattern [4]. A three dimensional model gives a close representation of the actual anatomic and physiologic structures of the mandible, and acts as a theoretically superior tool when compared to the two dimensional model.

The current study is modeled to determine and compare the deflection seen in removable partial denture frameworks by using two commonly used mandibular major connectors lingual bar and lingual plate [5] in Kennedy's Class I, Class II, Class III, and Class IV situations.

Procedure Used in the Present Study

The Study was divided under following steps

(1) Construction of geometric model.
(2) Preparing of finite element mesh.
(3) Material properties.
(4) Application of boundary conditions.
(5) Application of different loads.
(6) Analysis of deflection pattern.

Construction of Geometric Model

It has been divided into three parts which included modeling of the edentulous mandible, modeling of the teeth and modeling of the cast partial dentures.

a. Modeling of the Edentulous Mandible

Algorithm in this study is to generate finite element models from a CT scan data, wherein a CT scan of human

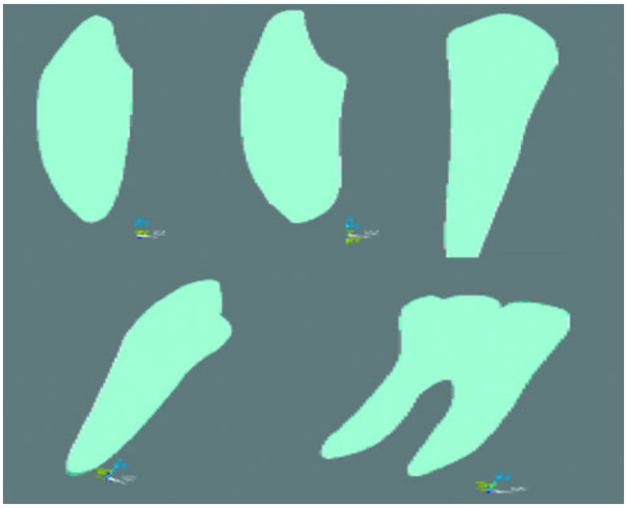

Fig. 4 Finite element of teeth modeled

edentulous mandible was taken and each section from symphysis to condylar region was projected on a graph paper [6, 7]. The entire outline of the mandible from the symphysis to the angle was traced, followed into the contour of the posterior border of the ramus and extended to the condylar neck and head. The contour data of the profiles of the teeth were transformed into the *x*, *y* and *z* co-ordinate points and read by finite element program (Fig. 1). Connecting these coordinate points give a line geometry also called as wire frame modeling. Connecting the lines of each section gave surface geometry or called as surface modeling.

Three-dimensional volumes were created from connected successive profiles to define the final solid geometry of cortical bone. The modeling of the bone was done separately in the same way to get the solid geometry (Fig. 2). The final anatomical model was obtained by superimposing both the models over each other. This sequence done on one side was repeated to obtain the opposite side. Through this process the CT scan data was converted into three-dimensional solid model of the entire edentulous mandible (Fig. 3).

b. Modeling of the Teeth

Teeth were added to the finite element model of the edentulous mandible after the final model of the mandible was completed. The specifications for the dimensions of the teeth, incisors, canines, premolars and molars [8] were obtained and modeled using this software. The central incisors were modeled by line modeling. Then the outline was solidified with the elements and nodes resulting in the element plot. This gave the solid geometry of the central incisors. The same was followed for the laterals, canines, premolars and the molars (Fig. 4).

c. Modeling of the Cast Partial Dentures

Six framework models with different mandibular major connectors were created. The models created were:

(1) Model No. 1: Lingual bar for Kennedy's Class I situation.
(2) Model No. 2: Lingual plate for Kennedy's Class I situation.
(3) Model No. 3: Lingual bar for Kennedy's Class II situation.
(4) Model No. 4: Lingual plate for Kennedy's Class II situation.
(5) Model No. 5: Lingual plate for Kennedy's Class III situation.
(6) Model No. 6: Lingual plate for Kennedy's Class IV situation.

The basic form of the lingual bar is that of half pear shaped with the broadest portion at the inferior end of the bar. The height and width of the lingual bar is 5 mm and the distance between the gingival margin and superior border of the bar is 3 mm.

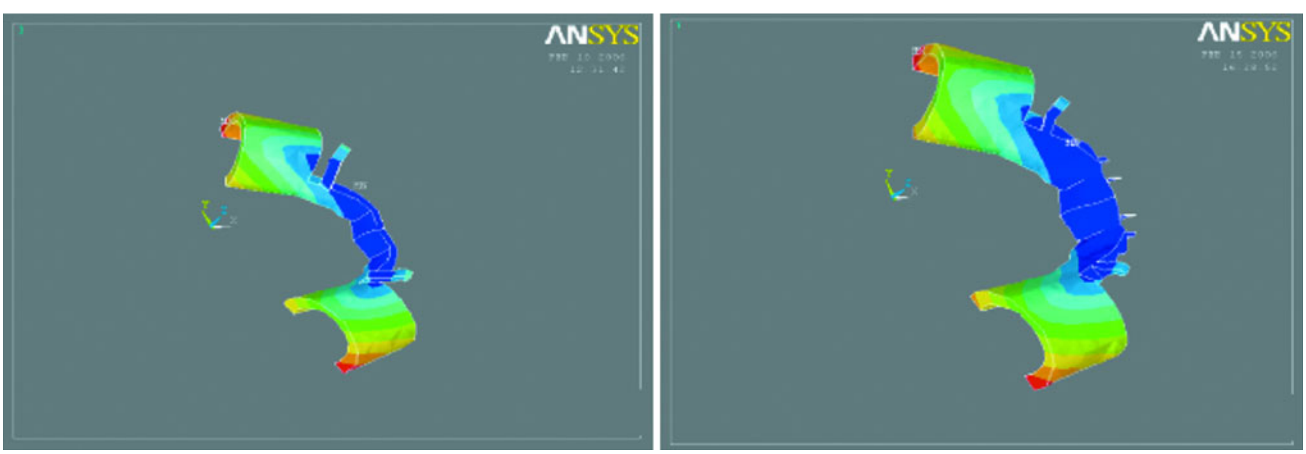

Fig. 5 Lingual bar and lingual plate for Kennedy's Class I situation

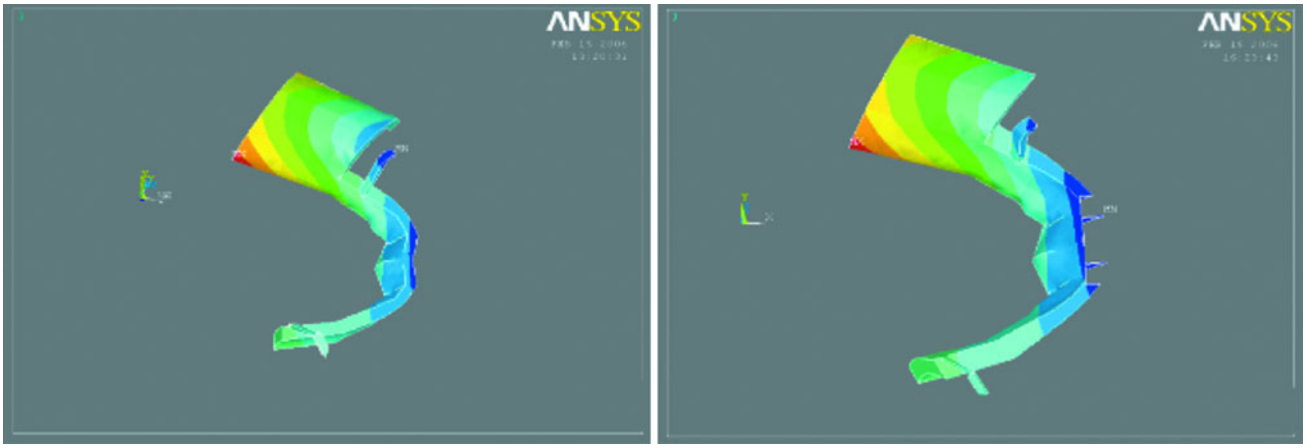

Fig. 6 Lingual bar and lingual plate for Kennedy's Class II situation

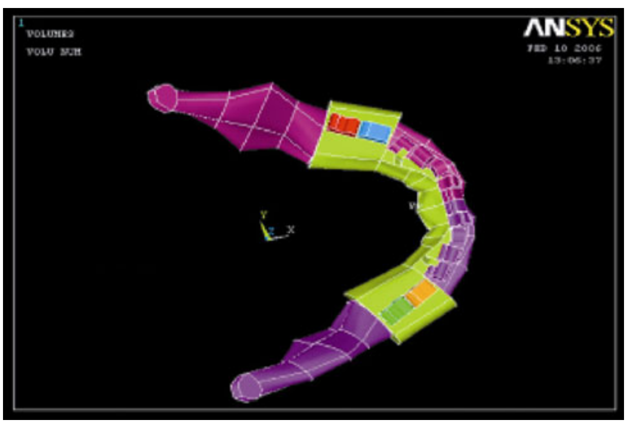

Fig. 7 Solid volume finite element of the entire dentulous mandible and cast partial denture framework

Table 1 Distance vector components used for the finite element modelling

X direction	*Y* direction	*Z* direction
0	28.07	33.01
0	30.61	5.27
0	9.56	6.31
0	27.67	38.97
0	80.63	23.89

Table 2 Mesh data—number of elements, nodes and degrees of freedom

Region	Elements	Nodes	Degrees of freedom
Dentulous mandible	51,579	26,708	154,737
Lingual bar/plate	201,360	92,320	604,080
Complete model	252,939	119,028	758,817

Table 3 Material properties assigned to the model

Material	Modulus of elasticity (MPa)	Poisson's ratio
Cancellous	2,200	0.3
Cortical	19,700	0.35
Chrome cobalt	2.18×10^5	0.33

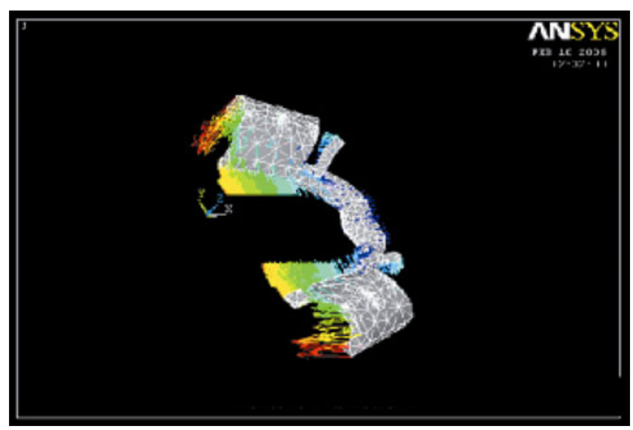

Fig. 8 Application of load to the cast partial denture framework

The basic form of the lingual plate is that of half pear shaped lingual bar with a solid piece of metal extending upward. The upper border of the plate should be placed onto the middle third of the lingual surfaces of mandibular anterior teeth [9]. Cobalt chrome metal has been used in this study [1, 2, 9].

The lingual bar/plate featured two posterior saddle areas in the Class I situations and only one in Class II and III situations. There was a single anterior saddle area in the Class IV situations. In Class I both the lingual bar and plate had a premolar occlusal rest on both sides of the arch. The occlusal rest on the right side in class II and class III was fixed in all directions (vertical, buccal and distal directions),

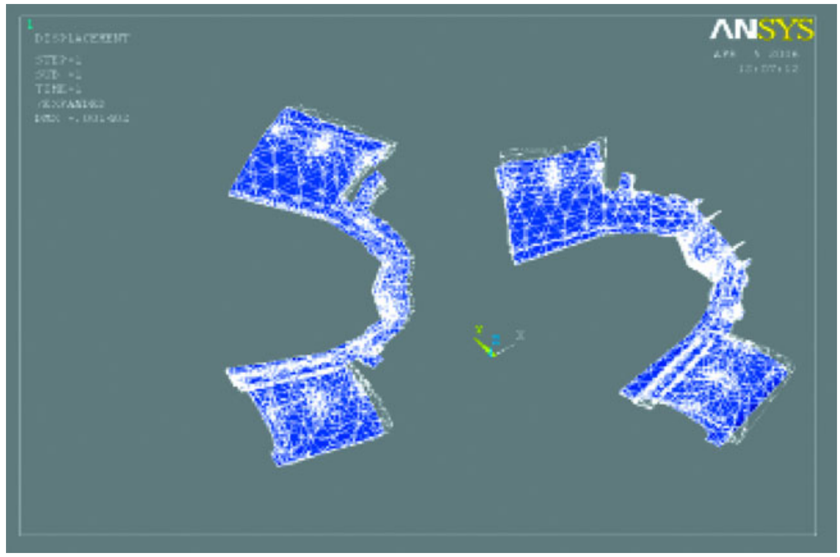

Fig. 9 Maximum displacement among Class I lingual bar and lingual plate Kennedy's situation under applied load

Table 4 Maximum deflection among the different Kennedy's situations under the applied load

Model	Maximum deflection of the partial denture framework
Class I lingual bar	0.002522
Class I lingual plate	0.001402
Class II lingual bar	0.001759
Class II lingual plate	0.001353
Class III lingual bar	0.000924
Class IV lingual plate	0.001335

based on the assumption that the indirect retainer (clasps and rests) engaged on two healthy posterior teeth on the contralateral side of the edentulous area was rigid enough to render this part of the framework immobile. On the other hand, the left occlusal rest on the abutment adjacent to the edentulous ridge was fixed only in the vertical direction [4]. The location of the occlusal rests and the manner of indirect retention in the different models were as follows:

(A) Model No 1 and 2: Two mesial occlusal rest on the first premolar.
(B) Model No 3 and 4: A single mesial occlusal rest on the first premolar of the same side and an indirect retainer between the first and second molar on the contralateral side.
(C) Model no 5 and 6: A mesial occlusal rest on the second molar and a distal occlusal rest on the first premolar on both the sides, making a total of four rests.

In addition to simulate the differences in the resilience between oral mucosa and the abutment teeth, or the negligible resistance of the oral mucosa to denture base intrusion, oral mucosa was excluded from the model [4]. Clasps, artificial teeth and the resin denture base were excluded from the model [4]. The finite element meshworks of the individual teeth were integrated three dimensionally with the previously created full-scale model of the mandible (Figs. 5, 6).

After the preparation of the model the next step was the meshing of each model.

Preparing of Finite Element Mesh

Preprocessed model was subjected to processing by conversion of geometric data into a graphical data by the Ansys finite element software (Fig. 7). Default element size with SOLID 187 element was selected. It was a higher order three-dimensional 10-node element with quadratic displacement behaviour and was well suited for modeling irregular meshes. The element was defined as 10 nodes having three degrees of freedom at each node in hexahedral bodies: translations in the nodal x, y and z directions (Table 1). [4].

The completed anatomical model consisted of total a number of 119,028 nodes and 252,939 elements with 758,817 degree of freedom (Table 2).

Material Properties

All the vital tissues (mandibular bone and teeth), cast partial denture frameworks with the saddle were presumed to be linearly elastic, homogenous and isotropic. The corresponding elastic properties such as Young's modulus (E) and Poisson's ratio (δ) of the mandible, cast partial denture framework and saddle were determined according to literature survey. The model was assigned material properties shown in (Table 3) [4].

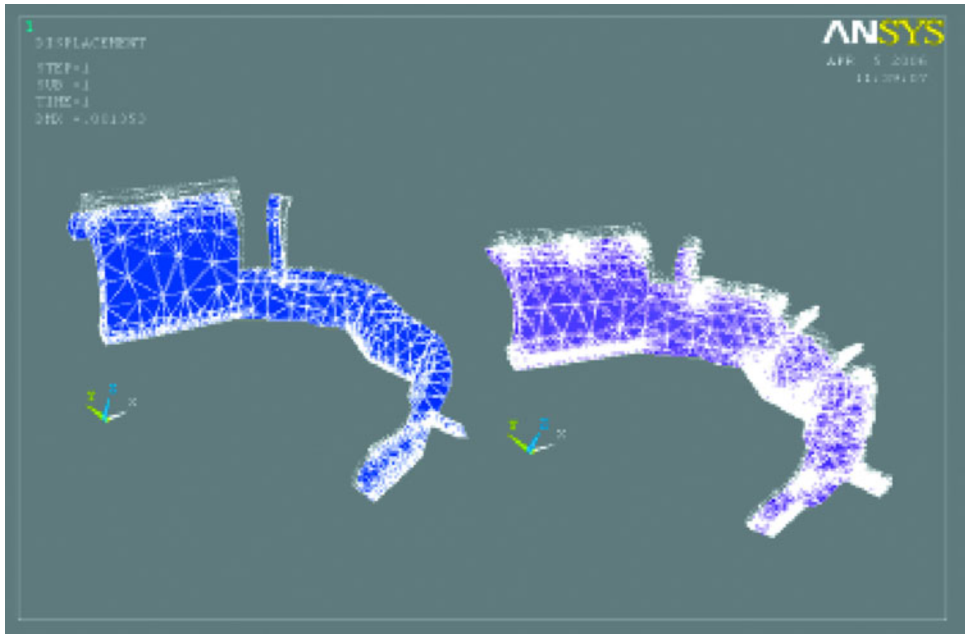

Fig. 10 Maximum displacement among Class II lingual bar and lingual plate Kennedy's situation under applied load

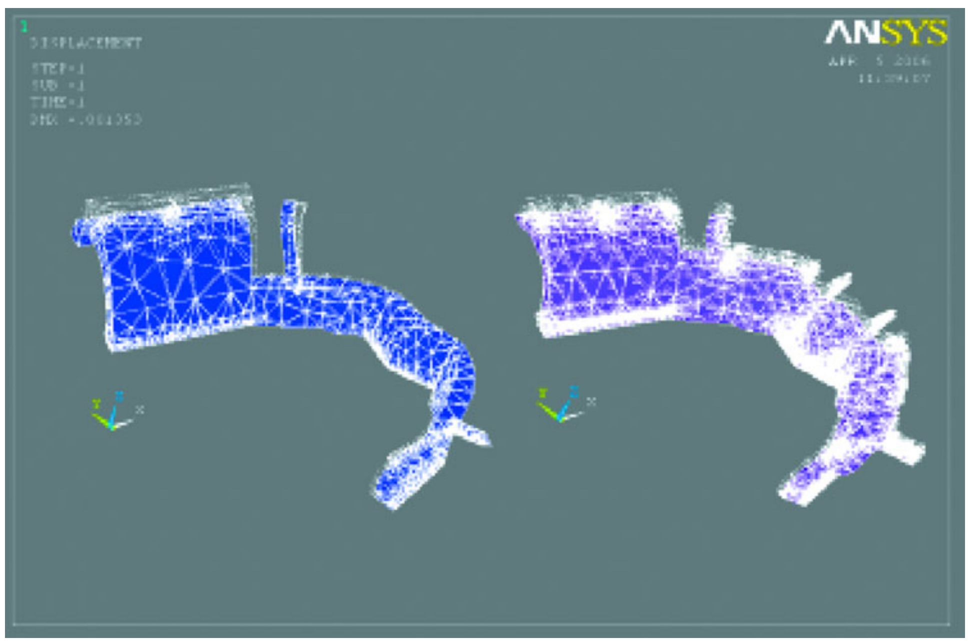

Fig. 11 Maximum displacement among Class III lingual bar and lingual plate Kennedy's situation under applied load

Application of Boundary Conditions

Symmetrical boundary conditions were imposed at the mid symphyseal region. On the distal side all the three translations were fixed [4, 10].

Application of Load

A vertical biting force of 20 N was directed simultaneously towards an imaginary centre point on each of the two missing teeth locations (Figs. 8, 9) [4].

Analysis of Deflection Pattern

Six models were made and forces of the said magnitude and direction applied. These different models were analyzed by the processor and displayed by post processor of the Finite Element Software (Ansys, Version 10) using vector deflection analysis.

Results

This study consisted of a finite element analysis of the deflection of various designs of chrome cobalt cast partial

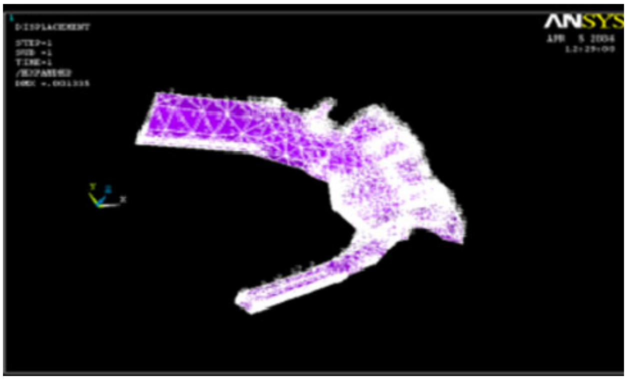

Fig. 12 Maximum displacement among Class IV lingual bar and lingual plate Kennedy's situation under applied load

Table 5 Deflection of the various areas of the major connectors under the applied load

Model	Major connector	Occlusal rest	Saddle area
1	0.000462	0.001377	0.002522
2	0.000034	0.0001864	0.001402
3	0.000186	0.000361	0.001759
4	0.000128	0.0004	0.001353
5	0.000206	0.000341	0.000924
6	0.000407	0.000407	0.001335

denture frameworks in different Kennedy's situations (Table 4). The results showed:

Under a single vertical load, the maximum deflection was seen in the saddle area of Class I lingual bar, 0.002522 mm, followed by Class II lingual bar (0.001759 mm), Class I lingual plate (0.001402 mm), Class II lingual plate (0.001353 mm) and Class IV lingual plate (0.001335 mm) in descending order. This indicates that the maximum deflection is seen in the distal extension situations when compared to tooth borne situation. The maximum deflection is seen in the Class I lingual bar (Model 1) 0.002522 mm and the least in Class III lingual bar (Model 5) 0.000924 mm (Figs. 10, 11, 12) (Table 5).

On comparison of the different areas of the partial denture frameworks, the major connector, the occlusal rest and the saddle area, the maximum deflection was seen in the saddle areas in almost all the models. Among the saddle areas the maximum deflection was seen in that of Class I lingual bar. Among the saddle areas the minimum deflection was seen in that of Class III lingual bar. Among the saddle areas the maximum deflection was seen in that of Class I lingual bar (0.002522 mm) and the least in that of Class III lingual bar (0.000924 mm) (Figs. 13, 14, 15, 16) (Graphs 1 and 2 in Supplementary Material).

Discussion

Rigidity of a major connector, allows stresses that are applied to any component of the partial denture to be effectively distributed over the entire supporting area, including abutment teeth, underlying bone and soft tissues. The greatest damage a partial denture can produce is that which results from a flexible major connector. Flexibility concentrates forces on individual teeth or the edentulous ridge, causing damage to the abutment teeth, impingement and injury to the soft tissues thus gradually leading to the resorption of the residual ridge.

The commonly used major connectors for the mandibular arch are lingual bar and lingual plate. Literature claims that a rigid lingual bar is more desirable for withstanding horizontal stress and restraining excess movements of abutments [11]. Vibratory studies have demonstrated that

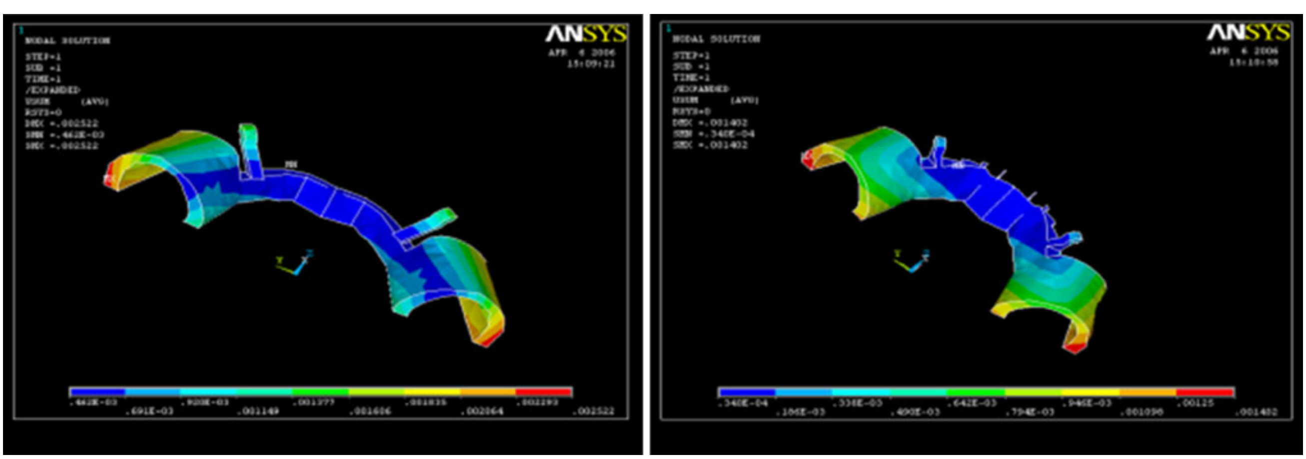

Fig. 13 Displacement among different parts of lingual bar and lingual plate in Kennedy's Class I situation under applied load

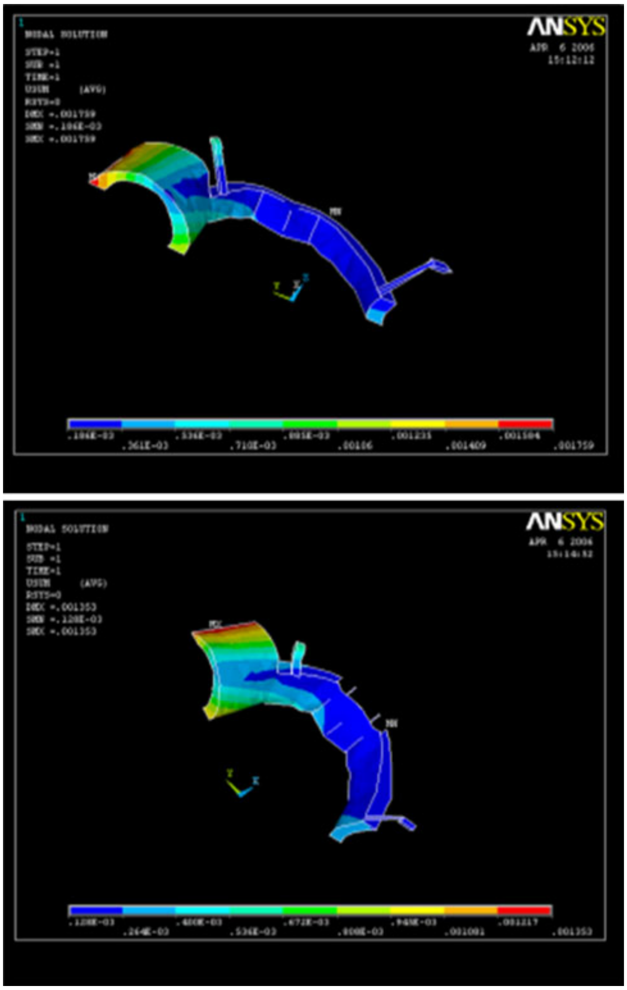

Fig. 14 Displacement among different parts of lingual bar and lingual plate in Kennedy's Class II situation under applied load

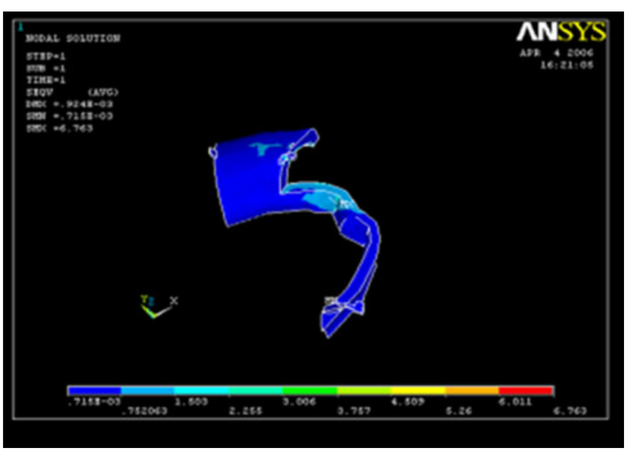

Fig. 15 Displacement among different parts of lingual bar and lingual plate in Kennedy's Class III situation under applied load

the lingual bar exhibits the maximum decay rate and the minimum amplitude of the direct and indirect retainers, among lingual bar, lingual plate and Kennedy's bar [12].

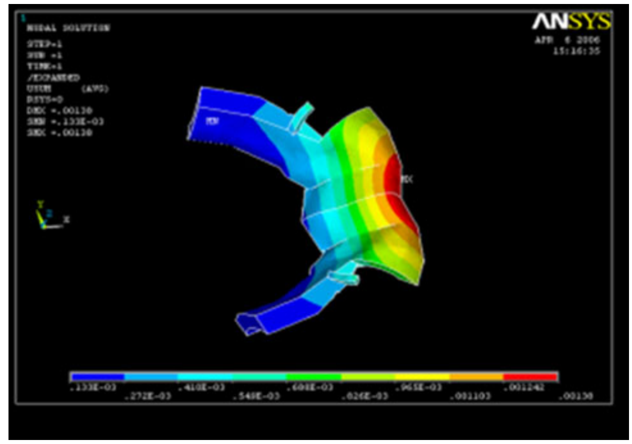

Fig. 16 Displacement among different parts of lingual bar and lingual plate in Kennedy's Class IV situation under applied load

The rigid connectors proved to be the most effective in transmitting applied occlusal forces to the contralateral side of the framework [13].

The amount of deflection of the partial denture framework is an important consideration in its selection for a particular situation for replacement of missing teeth. One of the major factors that control the amount of deflection is the design of the major connector. The design of the major connector influences the degree of deflection of the whole framework. The other major factor is whether; the edentulous area is tooth borne, tissue borne or a combination.

Traditionally literature reports that the maximum deflection of the saddle area is seen in distal extension situation. The least is reported to be in Class III situation where both the ends of the edentulous area are supported by teeth as abutments. In this study, the deflection of various major connector designs due to occlusal load is assessed using finite element methodology. The commonly used lingual bar and plate have been analyzed through finite element models. The differences in the deflection in different edentulous situations have been compared.

In a study conducted by Eto et al. [4], oral mucosa covering the edentulous ridge vertically distorts by approximately 0.5 mm under 4 N of vertical force. This is considerably greater than the intrusion exhibited by abutment teeth, at approximately 0.02 mm [1].

The resistance of periodontal tissue is expected to be greater against vertical occlusal force than horizontally applied force, it was assumed that the occlusal rest on the edentulous side was fixed only in the vertical direction. But the displacement of the removable partial denture framework was observed in all three dimensions of space, the anteroposterior, supero-inferior and bucco-lingual.

This current study determines the deflection of various designs of chrome cobalt cast partial denture frameworks in different Kennedy's situations using finite element analysis.

A vertical load of 20 N was applied simultaneously towards an imaginary centre point on each of the two missing teeth locations and different finite element models were analysed for the deflection of the various denture framework parts in the three dimensions of space. Under a single vertical load, the maximum deflection was seen in the saddle area of Class I lingual bar, 0.002522 mm. The next highest deflection were seen in Class II lingual bar, Class I lingual plate, Class II lingual plate and Class IV lingual plate, the values being 0.001759, 0.001402, 0.001353 and 0.001335 mm, respectively, in descending order. This indicates that the maximum deflection is seen in the distal extension situations when compared to tooth borne situation. The maximum deflection is seen in the Class I lingual bar (Model 1) and the least in Class III lingual bar (Model 5) 0.000924 mm.

This indicates that the lingual bar in Kennedy's Class III situation showed the least deflection when compared to Class I and Class II (distal extensions) situations and also that lingual bar major connector in Kennedy's Class I situation showed the most deflection when compared to similar situation with lingual plate major connector. This is in accordance with the findings of Vollmer et al. [6] who demonstrated that the maximum displacement occurs in using a distal end saddle situations and by reduction of the occlusal area in bucco-lingual dimension, the denture saddle can be better stabilized and the lateral stress on the abutment tooth reduced effectively.

The findings are in harmony with that of Eto et al. [4] who concluded that major connectors with decreased thickness or width showed more displacement. They also found that the use of an additional occlusal rest decreased the amount of displacement. They also agree with the findings of Ben-Ur et al. [14] who found that in the mandibular arch, the most important factor in achieving rigidity was the cross-sectional shape of the major connector. The half pear-shaped cross section proved to be the most rigid.

On comparison of the different areas of the partial denture frameworks, the major connector, the occlusal rest and the saddle area, the maximum deflection was seen in the saddle areas in almost all the models. This is in accordance with the findings of Sato et al. [15] determined that yield strength increased with increased width and thickness.

The findings of the present study also agree with that of Green and Hondrum [13] who concluded that doubling the thickness of the anterior strap of a U-shaped maxillary major connector improved the rigidity of the framework to torsional loads. The thickness of the major connector has an important role in decreasing the overall displacement of the framework.

The findings of the present study are in harmony with that of Cohen and Faigenblum [16] who found that the lingual bars and plates did not distribute lateral stresses effectively to the contralateral side of the arch and were found to be less rigid than the modified sublingual bars.

Limitations of Finite Element Modeling

The present study has certain limitations firstly the vital anisotropic tissues were considered isotropic. Next the loads applied were static loads that were different from dynamic loading seen during function. Living structures are more than mere objects, which are beyond the confines of set parameters and values. Since biology is not a compatible entity, hence even though finite element analysis provides a sound theoretical basis of understanding the behaviour of a structure in a given environment, it should not be considered alone. Actual experimental techniques and clinical trials should follow finite element analysis to establish the true nature of the biologic system.

Conclusion

The conclusions drawn from this study were:

(1) The lingual bar in Kennedy's Class III situation and lingual plate in Kennedy's Class IV situation showed the least deflection when compared to Class I and Class II (distal extensions) situations.

(2) Lingual bar major connector in Kennedy's Class I situation showed the most deflection when compared to similar situation with lingual plate major connector.

(3) The maximum deflection was seen in the saddle area when compared to other areas, i.e., major connector and the occlusal rest regions.

References

1. Alan B et al (2005) Mc Cracken removable partial prosthodontics, 11th edn. C.V. Mosby, St. Louis
2. Stewart KL, Rudd KD, Kuebker WA (2000) Clinical removable partial prosthodontics, 2nd edn. C.V. Mosby, St. Louis
3. Cook RD, Plesha ME (2002) Concepts and application of finite element analysis, 4th edn. Wiley, New York
4. Eto M, Wakabayashi N, Ohyama T (2002) Finite element analysis of deflections in major connectors for maxillary RPDs. Int J Prosthodont 15(5):433–438
5. LaVere AM, Krol AJ (1973) Selection of a major connector for extension–base removable partial denture. J Prosthet Dent 30(1):102–105
6. Vollmer D, Meyer U, Joos U, Vegh A, Piffko J (2000) Experimental and finite element study of a human mandible. Eur Assoc Craniomaxillofac Surg 28:91–96
7. Cruz M, Wssall T, Toledo EM, Barra LP, Lemonge AC (2003) Three-dimensional finite element stress analysis of a cuneiform-geometry implant. Int J Oral Maxillofac Implants 18(5):675–684

8. Ash MM, Nelson SJ (2003) Wheeler's dental anatomy, physiology and occlusion, 8th edn. Elsevier, St. Louis
9. Grasso JE, Miller E (1991) Removable partial prosthodontics, 3rd edn. Mosby, St. Louis
10. Meijer HJ, Starmans FJ, Steen WH, Bosman F (1996) Loading conditions of endosseous implants in an edentulous human mandible: a three-dimensional, finite-element study. J Oral Rehabil 23(11):757–763
11. Henderson D (1973) Major connectors for mandibular removable partial dentures: design and function. J Prosthet Dent 30(4): 532–548
12. Arksornnukit M, Taniguchi H, Ohyama T (2001) Rigidity of three different types of mandibular major connector through vibratory observations. Int J Prosthodont 14(6):510–516
13. Green LK, Hondrum SO (2003) The effect of design modifications on the torsional and compressive rigidity of U-shaped palatal major connectors. J Prosthet Dent 89(4):400–407
14. Ben-Ur Z, Mijiritsky E, Gorfil C, Brosh T (1999) Stiffness of different designs and cross-sections of maxillary and mandibular major connectors of removable partial dentures. J Prosthet Dent 81(5):526–532
15. Sato Y, Shindoi N, Koretake K, Hosokawa R (2003) The effect of occlusal rest size and shape on yield strength. J Prosthet Dent 89(5):503–507
16. Cohen KD, Faigenblum MJ (1990) An examination of the rigidity of major connectors for removable partial dentures: an in vitro study investigating horizontal loading of mandibular connectors. Clin Mater 6(2):163–179