Dental Materials Journal 2014; : –

Three-dimensional finite element analysis of Aramany Class IV obturator prosthesis with different clasp designs

Hideaki HASE[1], Akikazu SHINYA[2,3], Daiichiro YOKOYAMA[2], Akiyoshi SHINYA[2] and Yutaka TAKAHASHI[1]

[1] *Division of Removable Prosthodontics, Department of Oral Rehabilitation, Fukuoka Dental College, 2-15-1 Tamura, Sawara-ku, Fukuoka 814-0193, Japan*

[2] *Department of Crown and Bridge, The Nippon Dental University, School of Life Dentistry at Tokyo, 1-9-20 Fujimi, Chiyoda-ku, Tokyo 102-8159, Japan*

[3] *Department of Biomaterials Science, Institute of Dentistry, University of Turku and BioCity Turku Biomaterials Research Program, Lemminkäisenkatu 2 20520 Turku, Finland*

Corresponding author, Yutaka TAKAHASHI; E-mail: ytakaha@college.fdcnet.ac.jp

The purpose of this study was to evaluate the stress distribution on the alveolar bone surrounding abutment teeth and the displacement of the Aramany Class IV obturator prosthesis with two different clasp designs. Three-dimensional finite element models of an Aramany Class IV maxillary defect were constructed. Two different clasp designs on an obturator prosthesis (double Akers clasps and multiple Roach clasps) and two different load conditions (vertical and horizontal) were compared. Finite element analysis was used to calculate the equivalent stress. The difference in the clasp design of the Aramany Class IV obturator prosthesis affected the stress distribution of the alveolar bone surrounding the abutment teeth and the displacement of the obturator prosthesis. Multiple Roach clasps reduced the stress distribution on the alveolar bone surrounding the abutment teeth and the displacement of the Aramany Class IV obturator prosthesis compared to double Akers clasps.

Keywords: Three-dimensional finite element analysis, Aramany Class IV obturator prosthesis, Clasp design, Double Akers clasps, Multiple Roach clasps

INTRODUCTION

The defining characteristic of an obturator prosthesis is that it serves to restore separation of the oral and adjacent cavities following surgical resection of tumors of the nasal and paranasal regions[1]. An obturator prosthesis facilitates speech and deglutition by replacing those tissues lost due to the disease process and, as a result, can reduce nasal regurgitation and hypernasal speech, improve articulation, deglutition and mastication. Partially edentulous maxillectomy dental arches are quite different from normal partially edentulous arch anatomical features; obturator prosthesis support and stabilization are largely dependent on the ability to aggressively engage the remaining teeth and residual ridge structures. Compared to partially edentulous arches, the movement potential for the prosthesis extension into the defect can be significant. The movement potential for the obturator prosthesis increases as the remaining tooth number decreases; therefore, the maintaining teeth are very important for obturator prosthesis stabilization. Forces are transmitted to the abutment teeth of the prosthesis through the rests, guide planes, and retainers. Therefore, optimum framework designs should be based on sound research data and clinical experience aimed at preserving the health of the abutment teeth and their supporting structures[2]. The forces placed on the abutment teeth and the remaining bone of a maxillary resection patient must be completely understood because this clinical situation occurs frequently[3]. Various clasp designs for obturator prostheses have been advocated. In a large surgical resection case of the maxilla, the Aramany Class IV[4] maxillary defect case, double Akers clasps were used for an obturator prosthesis[2,5-7]. A clinical evaluation of the case report[8] suggested that multiple Roach clasps for obturator prostheses were an effective means of preserving the abutment teeth. However, few studies have been performed to evaluate the stresses of various clasp designs.

The finite element (FE) analysis is useful in the field of dentistry. Three-dimensional (3D) FE analysis can be used to verify displacement and deformation and to determine the location of stress concentration. In addition, 3D FE analysis is able to repeat an experiment many times; it can be performed on a computer without putting any stress on the human body from technical materials; the results can be displayed visually very simply. Because of improved simplicity and reproducibility, 3D FE analysis has become increasingly popular for stress analysis[9] and has been used in prosthodontics studies. However, there has been little study done concerning obturator prostheses.

It was hypothesized in this study that the different clasp design of the Aramany Class IV obturator prosthesis affects the stress distribution of the alveolar bone surrounding the abutment teeth and the displacement of the obturator prosthesis. The purpose

Color figures can be viewed in the online issue, which is available at J-STAGE.

Received Jan 16, 2014: Accepted Feb 17, 2014
doi:10.4012/dmj.2014-015 JOI JST.JSTAGE/dmj/2014-015

of this study was to use 3D FE analysis to evaluate the stress distribution of the alveolar bone surrounding the abutment teeth as well as the displacement of the Aramany Class IV obturator prosthesis with the double Akers clasps or the multiple Roach clasps.

MATERIALS AND METHODS

3D FE modeling

A three-dimensional (3D) FE model of the Aramany Class IV maxillary defect was used in this study (Fig. 1). It was based on the Aramany Class IV maxillary replica model (NISSIN D50-555, Nissin, Kyoto, Japan) and simulated the Aramany Class IV maxillary defect that included mucosa, alveolar bone, maxillary left first and second molars, and maxillary left first and second premolars. The geometry of the restored dentition followed Wheeler's description[10]. Three-dimensional FE models of obturator prostheses were used (Fig. 2), which were based on the Aramany Class IV obturator prosthesis and were made so that the obturator, denture base and metal clasps were constructed[5] were conformable to the Aramany Class IV maxillary replica model. Two different clasp configurations —the double Akers clasps (Fig. 2-a) and multiple Roach clasps (Fig. 2-b)— were compared in this study. The coordinates of each point of the shape were then entered into the preprocessor of an FE analysis program (ANSYS 10 Sp, ANSYS, Inc., Houston, TX, USA) to build solid models for the Aramany class IV maxillary defect and obturator prosthesis.

Boundary condition and date processing

Figure 3 shows the boundary conditions of this study. Two loading directions were employed. A vertical force of 30 N was applied to the imaginary center on the maxillary right premolar and molar teeth parts (120 N total; Fig. 3-a). A horizontal 45-degree oblique

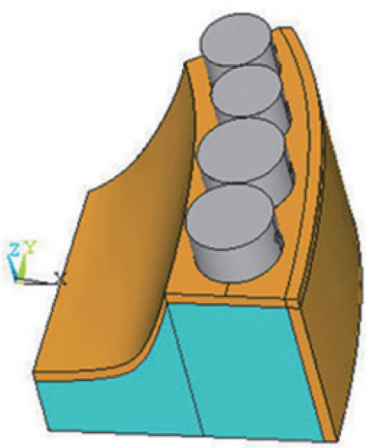

Fig. 1 Three-dimensional finite element model of the Aramany class IV maxillary defect situation.

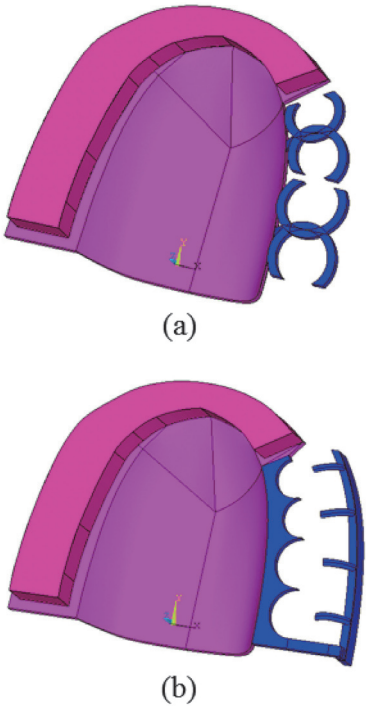

Fig. 2 Designs of obturator prostheses.
(a): Double Akers clasps model, (b): Multiple Roach clasps model.

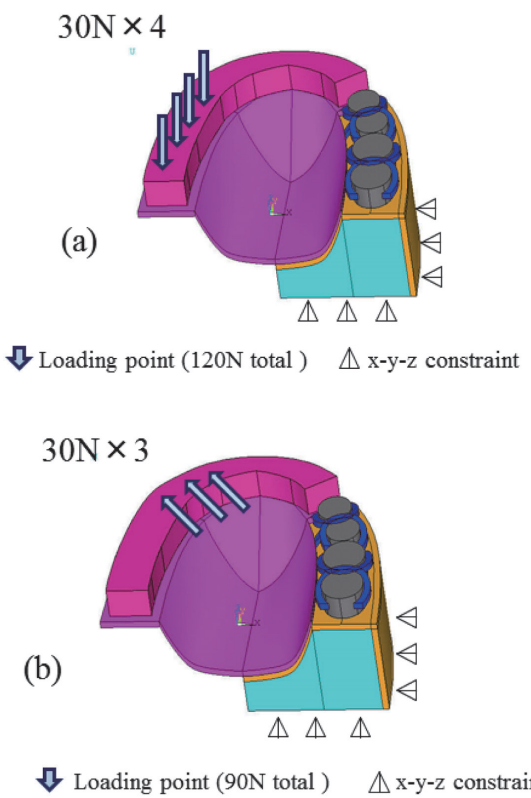

Fig. 3 Boundary conditions used in this study.
(a): Vertical loading, (b) Horizontal loading.

angle distal force of 30 N was applied to the imaginary center on the maxillary right canine and premolar teeth parts (90 N total; Fig. 3-b). The alveolar bone base was fixed in all directions. The Young's modulus and Poisson's ratio presented in Table 1 were determined from a literature review[11,12]. The double Akers clasps model generated 45,279 elements and 9,662 nodes. The multiple Roach clasps model generated 62,992 elements and 10,224 nodes. To avoid quantitative differences in the stress values of the models, all the solid models were derived from a single mapping mesh pattern. FE model construction and analysis were performed on a personal computer (Precision Work Station 670, Dell, Round Rock, TX, USA) using a FE program. A FE analysis was used to calculate the displacement of the obturator prosthesis and the equivalent stress on the alveolar bone.

Table 1 Properties of the oral structures and materials used in this study

	Young's modulus (MPa)	Poisson ratio
Acrylic resin	2,650	0.3
Co-Cr alloy	200,000	0.3
Mucosa	3.5	0.4
Bone	20,000	0.3
Dentin	18,000	0.31
Enamel	47,600	0.27

RESULTS

Displacement of obturator prosthesis

Figure 4 shows the displacement vector of the models during vertical loading. In the double Akers clasps model, the pivot of the obturator prosthesis was the palatal side of the proximal surface between the first and second premolars. In the multiple Roach clasps model, the pivot of the obturator prosthesis was the distal side of the second molar.

Figure 5 shows the displacement vector of the models during horizontal loading. In the double Akers clasps model, the pivot of the obturator prosthesis was the buccal side of the proximal surface between the first and second premolars, and in the multiple Roach clasps model, the pivot of the obturator prosthesis was the buccal side of the second molar.

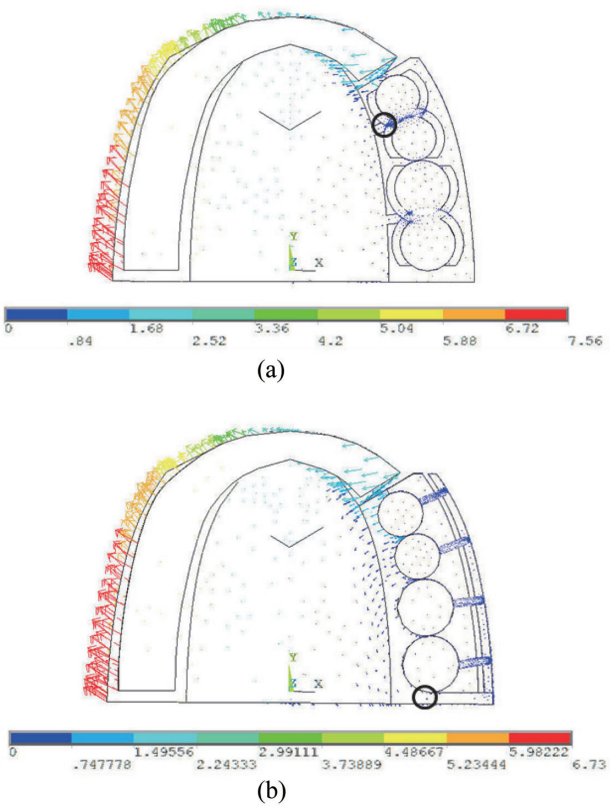

Fig. 4 Displacement vector of the models at vertical loading.
(a): Double Akers clasps model, (b): Multiple Roach clasps model. ○: Pivot of the obturator prosthesis.

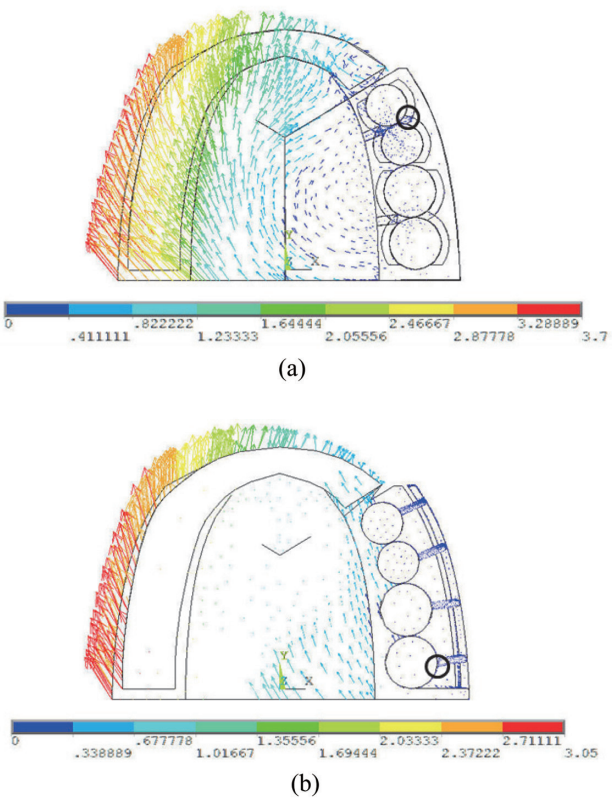

Fig. 5 Displacement vector of the models at horizontal loading.
(a): Double Akers clasps model, (b): Multiple Roach clasps model. ○: Pivot of the obturator prosthesis.

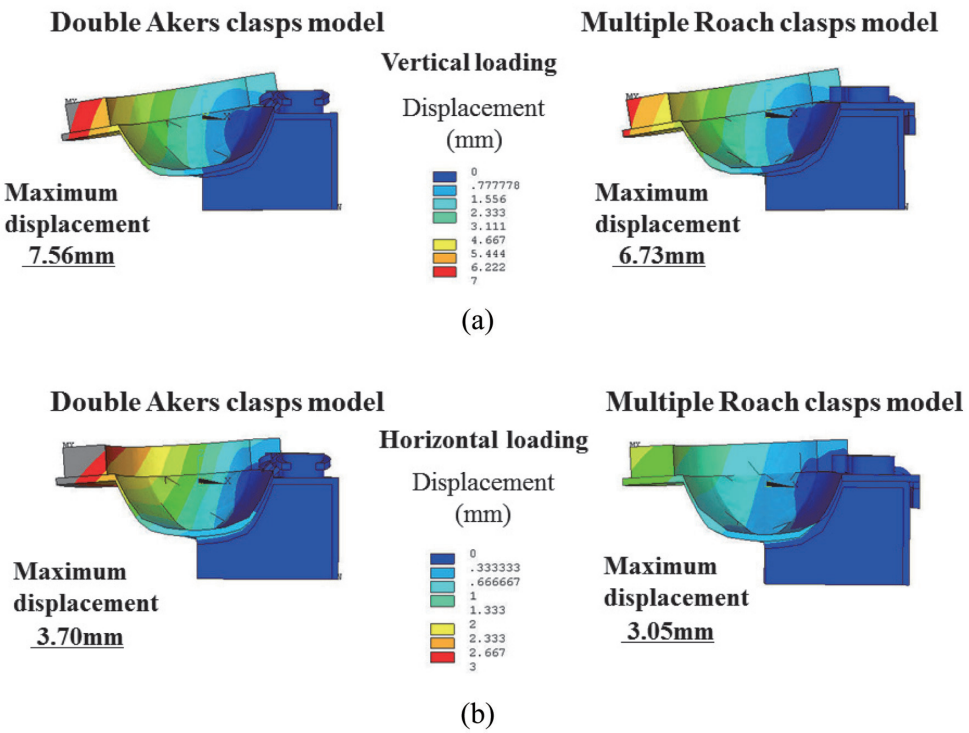

Fig. 6 Posterior view of the displacement of the models.
(a): Vertical loading, (b) Horizontal loading.

Figure 6 shows the posterior view of the displacement of the models. During vertical loading, the maximum vertical displacements were observed at the posterior edge of the denture base for both clasp designs, and both of the 3D FE obturator prosthesis models were displaced to the -XZ direction. The maximum 3D displacement of the double Akers clasps model and the multiple Roach clasps model at vertical loading were 7.56 mm and 6.73 mm, respectively. Both the 3D FE obturator prosthesis models at horizontal loading were displaced to the -XZ direction, and the maximum 3D displacement of the double Akers clasps model and the multiple Roach clasps model at horizontal loading were 3.70 mm and 3.05 mm, respectively.

Stress distribution and stress concentration on alveolar bone

Figure 7 shows the occlusal surface view of the stress distribution and stress concentration on the alveolar bone.

In the double Akers clasps model at vertical loading, the stress concentrations of the alveolar bone were noted at the proximal surface between the first and second premolars. The maximum equivalent stress value of the double Akers clasps model was 8.81 MPa.

In the multiple Roach clasps model at vertical loading, the stress concentrations of the alveolar bone were located around the second molar and palatal side of the proximal surface between the first and the second premolars. The maximum equivalent stress value of the multiple Roach clasps model was 1.97 MPa.

In the double Akers clasps model at horizontal loading, the stress concentration of the alveolar bone was noted at the palatal side of the first premolar and the proximal surface between the second premolar and first molar. The maximum equivalent stress value of the double Akers clasps model was 10.69 MPa.

In the multiple Roach clasps model at horizontal loading, the stress concentration of the alveolar bone was the proximal surface between the first and the second molars. The maximum equivalent stress value of the multiple Roach clasps model was 6.39 MPa.

DISCUSSION

FE analysis has been widely used in removable prosthodontics studies[13-17]. However, there are few studies about obturator prostheses[18,19]. Some studies have reported on obturator prosthesis clasp designs using photoelastic analysis[2,3,20]. The photoelastic analysis can display stress distribution and evaluate the forces exerted on the supporting structures[21]. However, photoelastic studies were not able to separate the material property of the supporting structures and could not reproduce the analysis of the same photoelastic model. FE analysis makes separating the material property of support structures and establishing boundary conditions and load conditions easier. In

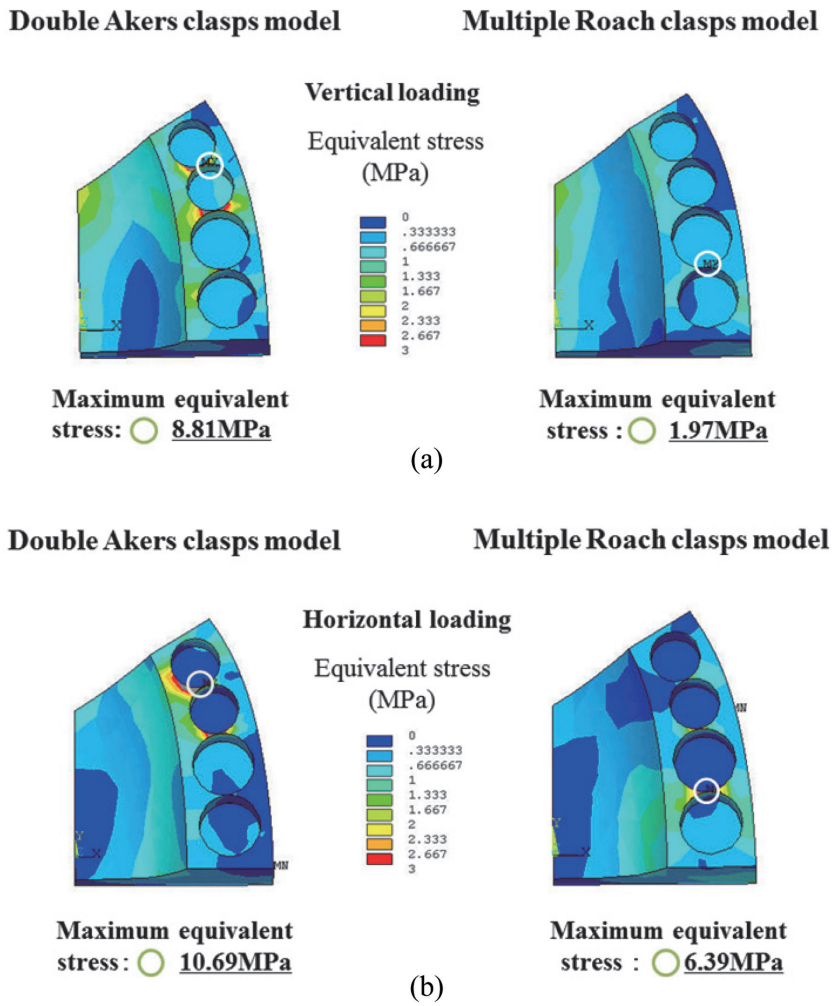

Fig. 7 Occlusal surface view of the stress distribution and stress concentration on the alveolar bone. (a): Vertical loading, (b) Horizontal loading. ○: Point of maximum equivalent stress.

addition, FE analysis allows the numerical measurement of the internal stress in obturator prosthesis FE models to be visualized. Therefore, the FE is useful for analyzing the stress on obturator prostheses; this stress originates in various components such as the teeth, alveolar bone, denture base, and clasps.

This study used the simplified tooth model with no counter, no friction coefficient, and no periodontal ligament in order to simplify the analysis of the results. Thus, the simplified FE models could clearly show significant stress distribution on the supporting bone in this study. Although the masticatory force is different for each individual and each food, the load condition of this study was set up using 30 N as a constant value to simplify the analysis. Movement of a prosthesis from chewing affects the behavior of the prosthesis; therefore, in this study the movement was simulated as a vertical and a horizontal load.

In this study, both obturator prosthesis FE models at vertical loading were displaced in the-XZ direction and to the right canine buccal side direction. These results showed that the movement of the obturator prosthesis was affected by the location of the maxillary bone defect. At horizontal loading, both obturator prosthesis FE models were also displaced in the-XZ direction. The results showed that the horizontal loading force was converted to turning force, owing to the position of the center of rotation.

In both load conditions, the double Akers clasps model showed that high equivalent stresses were distributed over a wide area compared to the multiple Roach clasps model. At vertical loading, the occlusal rest of the double Akers clasps model added power to the tooth axis direction. The occlusal rest acted as the fulcrum, and then the obturator prosthesis moved in a rotary motion. As a result, a pulling movement of the maxillary left first and second premolar occurred, which caused a greater displacement of the obturator

prosthesis, and then the high equivalent stress was distributed widely on the alveolar bone surrounding the abutment teeth. At horizontal loading, the displacement of the double Akers clasps model was greater than that of the multiple Roach clasps model. It seems that the pivot point of the obturator prosthesis was adjacent to the maxillary defect. As a result, high equivalent stresses on the alveolar bone were recorded in the case of the double Akers clasps model.

When the multiple Roach clasps model was under loading, the obturator prosthesis was rotated. At that time, the clasps were most likely to extend in the-X direction around the second molar. As a result, the stress concentration of the alveolar bone around the abutment teeth was dispersed to the surrounding palatal area and the stress was distributed equally on the alveolar bone. Consequently, the stress concentration of the alveolar bone around the abutment teeth may be reduced by the multiple Roach clasps of the obturator prosthesis.

Under the vertical loading, the maximum equivalent stress value of the multiple Roach clasps model (1.97 MPa) was 22% of that of the double Akers clasps model (8.81 MPa). Under the horizontal loading, the maximum equivalent stress value of the multiple Roach clasps model (6.39 MPa) was 60% of that of the double Akers clasps model (10.69 MPa). The results indicated that the obturator prosthesis with the multiple Roach clasps produced less stress on the alveolar bone surrounding the abutment teeth compared to the obturator prosthesis with the double Akers clasps.

From these results, the research hypothesis of this study was confirmed. As mentioned earlier, this study used the simplified tooth model with no counter, no friction coefficient, and no periodontal ligament; therefore, further study is needed using an anatomical tooth shape model.

CONCLUSIONS

Using three-dimensional finite element analysis, this study evaluated the stress distribution on the alveolar bone surrounding the abutment teeth and the replacement of the Aramany Class IV obturator prosthesis with the double Akers clasps or the multiple Roach clasps. Based on the experimental conditions, the following conclusions can be drawn:

1. The difference of clasp design of the Aramany Class IV obturator prosthesis affected the stress distribution of the alveolar bone surrounding the abutment teeth and the displacement of the obturator prosthesis.
2. The multiple Roach clasps reduced the stress distribution of the alveolar bone surrounding the abutment teeth and the displacement of the Aramany Class IV obturator prosthesis compared to the double Akers clasps.

REFERENCES

1) Carr AB, Brown DT. McCracken's removable partial prosthodontics. 12th ed. St.Louis: Elsevier; 2011. p. 316-337.
2) Schwartzman B, Caputo AA, Beumer J. Occlusal force transfer by removable partial denture designs for a radical maxillectomy. J Prosthet Dent 1985; 54: 397-403.
3) Myers RE, Mitchell DL. A photoelastic study of stress induced by framework design in a maxillary resection. J Prosthet Dent 1989; 61: 590-594.
4) Aramany MA. Basic principles of obturator design for partially edentulous patients. Part I: Classification. J Prosthet Dent 1978; 40: 554-557.
5) Aramany MA. Basic principles of obturator design for partially edentulous patients. Part II: Design principles. J Prosthet Dent 1978; 40: 656-662.
6) Kobayashi M, Oki M, Ozawa S, Inoue T, Mukohyama H, Takato T, Ohyama T, Taniguchi H. Vibration analysis of obturator prostheses with different bulb height designs. J Med Dent Sci 2002; 49: 121-128.
7) Parr GR, Tharp GE, Rahn AO. Prosthodontic principles in the framework design of maxillary obturator prostheses. J Prosthet Dent 2005; 93: 405-411.
8) Nomura T, Kawaguchi K, Sato J, Yagi M, Sonoyama T, Ishii H, Matsuura M, Seto K. Clinical evaluation of the retainer design in the long-term course of two patients with maxillary prosthesis. Maxillofacial Prosthetics 2005; 28: 69-77.
9) Cheng YY, Cheung WL, Chow TW. Strain analysis of maxillary complete denture with three-dimensional finite element method. J Prosthet Dent 2010; 103: 309-318.
10) Wheeler RC. An atlas of tooth form. 4th ed. Philadelphia: WB Saunders; 1969. p. 40-54.
11) Craig RG, Peyton FA, Johnson DW. Compressive properties of enamel, dental, cements, and gold. J Dent Res 1961; 40: 936-945.
12) Kydd WL, Mandley J. The stiffness of palatal mucoperiosteum. J Prosthet Dent 1967; 18: 116-121.
13) Sato Y, Abe Y, Okane H, Tsuga K. Finite element analysis of the stress relaxation in soft denture liner. J Oral Rehabil 2000; 27: 660-663.
14) Eto M, Wakabayashi N, Ohyama T. Finite element analysis of deflections in major connectors for maxillary RPDs. Int J Prosthodont 2002; 15: 433-438.
15) Takanashi T, Shimamura I, Sakurai K. Influence of width and depth of palatal vault on rigidity of palatal strap: a finite element study. J Prosthodont Res 2009; 53: 95-100.
16) Kondo T, Wakabayashi N. Influence of molar support loss on stress and strain in premolar periodontium: A Patient-specific FEM study. J Dent 2009; 37: 541-548.
17) Aoda K, Shimamura I, Tahara Y, Sakurai K. Retainer design for unilateral extension base partial removable dental prosthesis by three-dimensional finite element analysis. J Prosthodont Res 2010; 54: 84-91.
18) Miyashita ER, Mattos BC, Noritomi PY, Navarro H. Finite element analysis of maxillary bone stress caused by Aramany class IV obturator prosthesis. J Prosthet Dent 2012; 107: 336-342.
19) Sun J, Jiao T, Tie Y, Wang DM. Three-dimensional finite element analysis of the application of attachment for obturator framework in unilateral maxillary defect. J Oral Rehabil 2008; 35: 695-699.
20) Schwartzman B, Caputo AA, Beumer J. Gravity-induced stresses by an obturator prosthesis. J Prosthet Dent 1990; 64: 466-468.
21) Lyons KM, Beumer J, Caputo AA. Abutment load transfer by removable partial denture obturator frameworks in different acquired maxillary defects. J Prosthet Dent 2005; 94: 281-288.