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Finite Element Method Analysis of the Stress Distribution to Supporting Tissues in a Class IV Aramany Removable Partial Denture (Part I: The Teeth and Periodontal Ligament)

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Abstract

Aim: Special care is required in the fabrication of a Class IV Aramany removable partial denture (RPD) in order to minimize the stress distribution to supporting tissues. Using the finite element method, the aim of this study was to analyze the distribution stress to supporting tissues when a Class IV Aramany RPD is worn.

Methods and Materials: Three RPD designs with circumferential cast retainers were examined in this study. These varied in retainer configuration which included: buccal retention and palatal reciprocation (P1); palatal retention and buccal reciprocation (P2); and buccal and palatal retention (P3).

The stress distribution in models using the Von Mises criteria was analyzed for each RPD design when placed under a 53N load from three different directions that included: vertical to the posterior teeth of the RPD (F1); at a 33º angle to the posterior teeth of the RPD (F2); and vertically on the anterior teeth of the RPD (F3).

Results: The maximum stress in teeth (91.3 Mpa) was generated when a 53N force was applied vertically from anterior teeth of RPD (F3) using buccal and palatal retention (P3). The maximum stress (0.494 Mpa) in the periodontal ligament (PDL) was also generated under the same conditions using the F3 load on the P3 design.

Conclusion: In all three directions of force application RPDs with buccal and palatal retention induced more stress in the tooth and the PDL with the maximum stress generated when the force was applied vertically to the anterior teeth. The axis of rotation can be changed by altering the RPD design as well as the direction and amount of force applied to the teeth.

Keywords: Finite element analysis, Aramany CL IV, supporting tissues

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Introduction

Patients who undergo surgical resection of the maxilla need prosthetic treatment to obturate the cavity made between the nares, sinuses, and oral cavity in order to restore mastication and speech. Supporting tissues and the number of teeth are often less than optimal in these patients, therefore, not only designing the partial metal framework and retentive clasps in such patients is vital and necessary but also fabricating the appropriate design of a RPD metal framework and its retentive clasps is even more critical.

Maintenance of the few remaining teeth in these patients is of great importance for support and retention of such prostheses.[1]

In this study the finite element method of analysis of stress distribution to supporting tissues was used to determine which Class IV Aramany RPD is more helpful in minimizing stress on supporting tissues.

Beumer & Caputo[2] studied the transfer of occlusal forces and stress in maxillectomy partial dentures (Class I Aramany). In their study a 12 pound force was applied to two points on the artificial teeth of the RPD, and the resulting stress was evaluated using three dimensional photoelastic analysis and their results were as follows:

1. There was a significant decrease of stress on supporting tissues after physiologic adjustment of the metal RPD frames.
2. A greater degree of stress was seen in the premolar area.
3. Use of an I-bar and cingulum rests in the anterior region (on central incisors) resulted in the best transference of force to the longitudinal axis of teeth.
4. In terms of stress distribution the Swing-lock design was the least favorable.

Beumer and Schwartzman[3] studied the weight of six obturator designs in maxillectomy partial dentures (CL I Aramany) using three dimensional photoelastic analysis. The results were as follows:

1. The best designs were the I-bar buccal retentive partial denture with a palatal stabilizer and another with a retentive circumferential buccal clasp and a palatal circumferential stabilizer.
2. Designs with palatal retentive areas demonstrated more stress on the supporting tissues.
3. The Swing-lock denture design and the light wire circumferential clasp design were intermediate in terms of stress generation.

Myers & Donald[4] studied the stress distribution of Class I Aramany RPDs with four different designs according to the type of retention used. Their results were as follows:

1. All frameworks applied stress on the palate.
2. Both the designs using either a buccal circumferential retentive clasp with a palatal plate or the type with a buccal circumferential retentive clasp with a palatal stabilizer in the anterior area (incisor to premolar) had the least stress.
3. Swing lock partial dentures and the palatal

I-bar with a buccal circumferential stabilizer design had the most stress on all of the teeth.

Methods and Materials

The Computer Model

With the help of Auto-CAD® (Autodesk Development Sarl, Neuchâtel, Switzerland) and Adobe Photoshop® (Adobe Systems Inc., San Jose, CA, USA) software a computerized anatomical model of the teeth and supporting tissues was created. The normal dimensions and morphological features of first and second premolars as well as first and second molars were designed using a reference book on dental anatomy.[5] Bone and supporting tissue characteristics were derived from reference books on periodontology[6,7] and orthodontics.[8] These characteristics were used in the model for the maxillectomy. With respect to anatomy references, alignment of the teeth in the jaw and the position of teeth in relation to a longitudinal axis were considered and the data was processed in the computer.

As the model was prepared for a RPD metal framework, a specific path of insertion and similar undercuts at the end of retentive arms were incorporated into the model design. After modeling the teeth and their alignment, a periodontal ligament (PDL) with a width of 0.25 mm was incorporated around the roots. The palatal vault was considered normal and 1.5 mm thickness of mucous membrane was considered on palate. The characteristics associated with the cortical and inner layers of cancellous bone of the buccal aspect of the maxillary alveolar bony walls were included in the model design and the data was transferred to the computer. The characteristics of a Class IV Aramany RPD (palatal plate, minor connector, guiding plate, rests, retentive and stabilizing arms) were replicated in the computer model.[9,10]

Partial Denture Designs

Three partial denture designs were used in the study as follows:

P1: The maxillary major connector was a palatal plate with embrasure clasps placed on the first and second premolar and on the first and second molars. Retentive arms of the embrasure clasps were created on the buccal sides and the stabilizer arms on palatal surfaces.

P2: Similar to the P1 design with the difference being placement of the retentive arms of the embrasure clasps on the palatal surface and the stabilizer arm on the buccal side.

P3: Similar to the P1 design with the difference being two embrasure clasps used as retentive arms.

The modulus of elasticity and Poisson index for cancellous and cortical bone, dentin, enamel, PDL, pulp, mucous and chrome cobalt alloy were used in accordance with standard references.[5,6,7,8]

Analytical Software

The prepared models were assembled exactly as the RPDs and the teeth were designed on the computer to replicate the same as they are in the mouth, then analyzed with ANSYS version 5.4 software (ANSYS Europe Ltd., Abingdon, UK) for stress distribution. In this study the Von Mises criteria were used for comparing stress distribution patterns on denture supporting tissues.[13]

Force Application

The stress distribution in computer models using the Von Mises criteria was analyzed for each RPD design when placed under a 53N load applied by the software using the finite element method, the same as it is in the mouth from three different directions that included the following:

- F1 = vertical to the posterior teeth of the RPD
- F2 = at a 33° angle to the posterior teeth of the RPD
- F3 = vertically on the anterior teeth of the RPD

Results

In this study Von Mises tension pattern images were used to evaluate the results. (Figures 1 A and B)

Using tension patterns the results were obtained from nine different scenarios shown in Table 1.

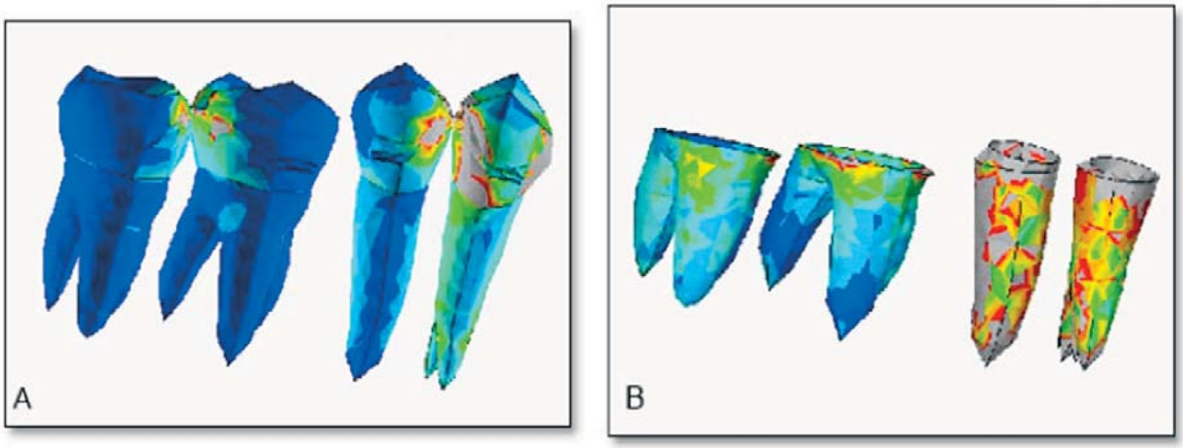

Figure 1. Stress distribution pattern in the P3 design. **A.** The teeth. **B.** The PDL.

Table 1. Maximum tension on teeth and PDL (Mpa).

First Premolar	F1	F2	F3
P1	5.76	5.86	88.40
P2	5.12	5.54	85.12
P3	6.57	7.14	91.31
Second Premolar	**F1**	**F2**	**F3**
P1	1.34	1.53	29.40
P2	1.28	1.33	18.90
P3	2.37	2.51	32.41
First Molar	**F1**	**F2**	**F3**
P1	2.42	2.61	15.14
P2	2.14	2.37	14.21
P3	3.56	2.04	16.31
Second Molar	**F1**	**F2**	**F3**
P1	1.55	1.61	18.31
P2	1.36	1.39	15.27
P3	2.17	3.25	19.08
PDL	**F1**	**F2**	**F3**
P1	0.256	0.267	0.423
P2	0.252	0.261	0.387
P3	0.297	0.341	0.494

Discussion

The finite element method of analysis in maxillofacial prosthodontics has been rarely used because of the difficulty and time consumption associated with analytical modeling. There has been limited research on the tension distribution of maxillofacial prostheses, most of which has been carried out using the photoelastic method. As there has not been a general analysis on the pattern and amount of tension distribution in Class IV Aramany RPDs, this study used finite element analysis to study the tension on the supporting tissues of this type of prosthesis.

In this study three treatment options for these patients were studied using three different applications of 53N of force.

F1: Vertical Force on Posterior Teeth

Teeth: The area of maximum tension in this case was wider in the P3 design and was more than the other two designs. Because of the presence of two retentive clasps on both the buccal and palatal aspects of the retention tooth, it is predictable a vertical force would activate both clasps and create a wider area of tension on the tooth. In this case tension area on teeth was more than either P1 or P2. With similar forces applied to the P1 denture, the tension distribution pattern was the same as with the P3 denture. The range of maximum tension on the P1 denture was similar to P3 but just as the maximum tension created in the P1 denture was less than the P3 denture, the results showed the P1 denture creates less tension on teeth than does the P3 denture.

The area of maximum tension in P2 was a little wider than P1 but as the maximum tension around P2 was less than P1, it is assumed the P2 denture creates less tension on teeth. With the F1 load scenario the P3 denture design created more tension on teeth followed by the P1 denture and then the P2 dentures. In all three denture designs tension distribution was more around the first premolar compared to the other teeth. Maximum tension in this area is predictable because the first premolar is near the surgical defect and the axis of rotation.

Caputo and Beumer[2] also suggested the maximum tension in maxillectomy patients is in the premolar area. Their study confirmed it is better not to use clasp on teeth. However, it is well known retention in these special denture cases is very critical.

PDL: Maximum tension and area of tension in the PDL around retention teeth was greater in the P3 denture design and wider than the other two designs. In this study the maximum tension was distributed over a wide area of the PDL around the palatal aspect of the first premolar. In the P1 and P2 dentures the area of maximum tension was nearly similar but in the P1 denture the maximum tension was greater than the P2 design.

F2: Force at a 33º Angle to the Posterior Teeth

Teeth: The maximum tension as well as the tension area in the P3 denture design were wider than with the other two designs. The P1 and P2 denture designs had similar maximum tension areas, but the maximum tension on the teeth was greater in the P1 denture compared to the P2 denture. In a study by Caputo and Beumer[2] it was suggested when force is applied obliquely on dentures the area of tension is wider compared to vertical forces. In the present study the pattern of tension distribution was similar when force was applied vertically or at a 33º angle, but the area and amount of maximum tension was greater in the cases with force applied vertically. The horizontal axis of applied force makes the area of maximum tension wider compared to cases with force applied at a 33º angle. When the 53N force was applied at a 33º angle in the P3 denture design, maximum tension is created around the retention teeth followed by the P1 denture and then the P2 denture, which had the least tension, utilzing a palatal retentive clasp and buccal stabilizer.

PDL: When a 53N force was applied at a 33º angle to the posterior teeth, the area and amount of maximum tension were the greatest in the P3 design. The area of maximum tension was wider around the PDLs on the palatal aspect of the premolars and the molar teeth in the P3 denture design. The P1 and P2 designs had nearly similar areas and amounts of maximum tension around the PDL.

F3: Vertical Force Applied to Anterior Teeth

Teeth: The pattern of tension distribution when a vertical force is applied to anterior teeth is completely different from the other two force applications (F1 and F2). In this case the maximum tension was seen in the premolar area and residual palatal tissues around the anterior wall of the surgical defect. Because of the movement expected with this type of denture, there is great tension on the anterior teeth around the defect (premolars). Myers and Ronald4 suggested the greatest focus of tension is generated in the anterior residual maxilla when force is applied from anterior aspect of the defect in Class I Aramany patients. The present study verified their findings using an anterior force. The results showed the first and second premolars demonstrated more tension in the crown and root compared to first and second molars. The amount and area of maximum tension on teeth in P3 denture design is greater than the other two denture designs (P1, P2). Like the other cases, the maximum tension on teeth is greatest in the P3 design but the pattern of tension distribution was found to be completely different. The greatest amount of tension in the P3 denture design is due to the presence of two retentive clasps around the retention tooth. The general pattern of the amount and area of maximum tension in the P1 and P2 designs were nearly similar. The maximum amount of tension was seen in the premolar teeth, but the area of maximum tension was wider in the P1 design compared to the P2 denture design. Because the maximum tension generated in the P1 denture was greater than the P2 denture the P1 denture resulted in more tension around the retention teeth. When a 53N vertical force was applied on anterior part of the denture, maximum tension was generated in the P3 design.

PDL: Like the teeth, the pattern of tension distribution is completely different in the PDL when a vertical force is applied to anterior teeth compared with the other two force applications (F1 and F2). In this case the maximum tension was in the PDL around the buccal and palatal aspects of the premolar roots and palatal roots of molars (less). The area of maximum tension in this case occupied a wider region compared to the other two force application scenarios. A greater amount and a wider area of maximum tension was found with the P3 denture design compared to the other two designs suggesting the use of two cast retentive clasps on both sides of a retention tooth results in more tension produced around the PDL. The area of maximum tension in P1 and P2 dentures is similar, although maximum tension is slightly greater in the P1 design compared to P2.

Conclusion

Within the limits of this study, the following conclusions can be made from the findings:

1. When 53N of force is applied to anterior teeth (F3), more tension is generated compared to the situations when force is applied on posterior teeth (F1, F2).
2. Applying 53N force at a 33º angle on posterior teeth in the type of denture with retentive clasps on both sides (P3), maximum tension is generated on the retention teeth and the PDL.
3. The denture with palatal retentive clasp and buccal stabilizer (P2) had the least tension around the retention teeth and PDL.

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