Received: 01st May 2015 Accepted: 12th August 2015 Conflicts of Interest: None

Source of Support Nil

Original Research

Evaluation of Deflection in Single Palatal Strap Major Connector as Influenced by Different Shapes of Palatal Vault: A Three-Dimensional Finite Element Study

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How to cite the article:
Hallikerimath RB, Mallikarjun HD, Patil V, Kumar VS. Evaluation of deflection in single palatal strap major connector as influenced by different shapes of palatal vault: A three-dimensional finite element study. J Int Oral Heath 2015;7(10):53-57.

Abstract:

Background: The main function of a major connector is to unify all other components of a cast partial framework and even distribution of forces applied on it throughout the arch, and also minimizing the torque on the teeth. A well designed rigid major connector can distribute the forces applied on it effectively throughout the arch, while controlling the movement of prosthesis effectively. Since very few studies have reported regarding stresses in single palatal strap major connector as influenced by different shapes of the palatal vault. The main objective of the study was to determine the deflections following simulated occlusal loading as influenced by different shapes of the palatal vault in single palatal strap and to propose the best design modification which is efficient in function.

Methods: Measurements of palatal vaults in 60 dentulous stone casts of the maxillary arch were made using a digital vernier caliper instrument. Depending on the average of 60 palatal shapes, five three-dimensional finite element models were constructed: An average model, a wide model, a narrow model, a deep model and a shallow model. These finite element models resembled Kennedy's Class II situation with the following missing teeth, i.e., second premolar and first and second molar on the left side of the maxillary arch. This framework design includes a single palatal strap, two rests and denture base.The mechanical property of the Co-Cr alloy was given to the framework. The vertical biting force of 60 N was loaded on the saddle area and a force of 5 N on the occlusal aspects of rests on both the sides.

Results: All the frameworks evidenced distal displacement values greater than buccal and vertical displacements. Maximum buccal displacement values were seen in a deep model (110 μm), maximum distal displacement was seen in wide palatal strap model (138 μm) and in the vertical direction maximum deflection of 99 μm was recorded in average model.

Conclusion: Analysis of each of the model showed that the maximum displacement is seen in the wide model and the shallow model. This suggests increasing the anteroposterior width of the palatal strap and reinforcing it. However, a narrow model deflection was smaller comparatively with other models. This suggests decreasing the anteroposterior width of the palatal strap.

Key Words: Displacement/deflection, finite element analysis, rigidity, single palatal strap, stress

Introduction

A number of factors affect the rigidity of a major connector, including width, thickness, length, configuration cross-sectional shape, modulus of elasticity, and shape of the dental arch and palate. The rigidity of major connectors has been investigated using various methods, including modeling,[1-3] finite element analysis (FEA),[4] stereophotogrammetric analysis,[5] photoelastic study[6] and vibration analysis.[7] However, most of these studies have been concerned with the configuration of the major connector itself, and only a few have investigated the relationship between the maxillary major connector and palatal shape and width.

Reports regarding the relationship between the rigidity of a major connector and palatal shape are limited to studies on bending tests with the sample of a simple strap configuration or theoretical analysis of deformation of the circular cantilever.[8,9]

FEA makes use of a complex system of points called nodes. These nodes together make a grid called mesh. This mesh is programmed so that it has the structural and materialistic properties to simulate the reactions of the structure under various loading conditions. Depending on the anticipated levels of stress in that particular area, a certain density was assigned to the nodes throughout the material. A higher density of nodes is usually seen in those areas which receive the maximum amount of stress than those areas with minimum or no stress. This mesh acts like a spider web with the extensions of mesh elements between the adjacent nodes. This resultant web of vectors acts as a fundamental unit to carry the materialistic properties to the object.[10]

This study is intended to evaluate the palatal shape that might affect the rigidity of the maxillary major connector, and therefore, the design must be changed accordingly. This study was intended to develop a design criterion for palatal straps, by determining the influence of strap configuration based on the differences in palatal shape on the vertical displacement of dentures under loading.

Methods

The finite element models consisting of the palatal strap major connector with various palatal width and depth dimensions were made after analyzing 60 maxillary dentulous casts (age 20-40 years). The palatal vault was measured with digital vernier caliper and averages were calculated for depth and width. Denture models were constructed with six different palatal strap configurations. The FEA models were made by a professional computer programmer, and same models were used for the study.

The distance in the straight line between the mesiodistal center of the palatal gingival margin of the left and right first molars was measured as an indicator of palatal width. Moreover, the vertical distance from the occlusal plane to the median line of the palate in the position connecting the mesiodistal center of the left and right first molars was measured as an indicator of palatal depth.

The stone casts were classified into three experimental groups: A mean width experimental group, with a palatal width within the mean value ±1 standard deviation (SD); a wide experimental group, with values larger than the mean value ±1 SD; and a narrow experimental group, with measured values smaller than the mean value ±1 SD the average palatal width was calculated for each group. The same classification was also made for palatal depth: A mean depth experimental group (Table 1a and b). The mean palatal depth was then calculated for each group.[11]

Preparation of the model

Ideal maxillary Class II partially edentulous stone cast was taken with missing left second premolar, first molar, and second molar. Rest seats were prepared on the distal part of the second premolar and the mesial part of first molar of the right side and a mesio-occlusal rest was prepared on the left first premolar.

Framework was designed in wax, and it includes a distal extension saddle and mesio-occlusal rest on first premolar of left side of the maxillary arch, and a rest on mesial part of the first molar and distal part of the second premolar on the right side and major connector, i.e., a single palatal strap connecting all these components. The cast model with waxed framework was laser scanned. Spline was extracted out of the scanned model and altered according to variations and surface was extracted out of spline and nodes were created that is total five models of the strap were designed and carried out for meshing.

Modeling

The scanned model was the model of the prototype for meshing and analysis. CATIA V5 software is used for modeling. CATIA V5 stands for computer aided three-dimensional (3D) interface applications. CATIA is modeling software by Desault systems, which are widely used for virtual prototyping. Modeling in CATIA allows the modeling person the ease of modeling and altering the prototype dimensions, surfaces can be created and controlled to get exact shapes at microscopic levels.

Dimensions of the models were modified according to measurements in Table 2 as they were derived from different palatal shapes. Thickness of the palatal strap was 0.7 mm at the deepest and center point in the palate and 1.5 mm in the edentulous area. Missing second premolar, first and second molar were replaced on the extension denture saddle. From the model clasps and resin denture base were excluded.

FEA

FEA was used to calculate the deflections generated in the various designs of major connectors. A graphic pre-processor of a FEA program, hyper mesh 12 was used to design the 3D finite element models. Five framework models with varying palatal shapes of the major connector were created keeping the rest of the components same for all the designs. For each design of a single palatal strap connector, three width and depth variations were considered and anteroposterior width of the palatal strap was kept at 13 mm.

Vertical depth of palatal vault

- Vertical depth from occlusal plane to palatal vault comprising of three FEA models (Figures 1-3), (1) Shallow, (2) average, (3) deep

Table 1a: Classification depending on palatal width measurements.

1	Experimental models	Average	Wide	Narrow
2	No. of casts	33	14	13
3	Mean palatal width	36.77 mm	39.06 mm	35.26

Table 1b: Classification depending on palatal depth measurements.

1	Experimental models	Average	Deep	Shallow
2	No. of casts	33	13	14
3	Mean palatal depth	22.07 mm	22.10 mm	19.77 mm

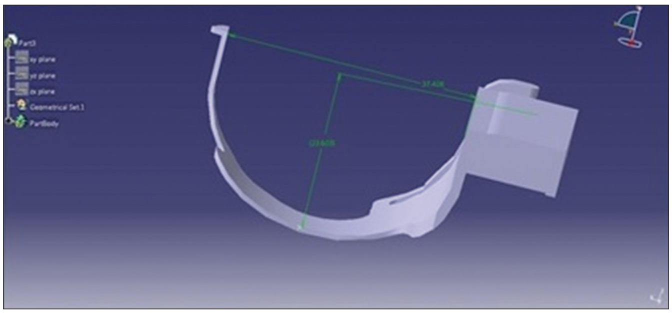

Figure 1: Average palatal finite element model.

Table 2: Comparing change in overall displacement of the frameworks in μm with different FE palatal models.

Model	Type	X-axis		Y-axis		Z-axis		Usum
	FE palatal model	Max	Min	Max	Min	Max	Min	Max
1	Average model	117	137	504	109	99	71	409
2	Deep model	110	147	111	507	96	382	424
3	Shallow model	124	147	119	372	79	414	455
4	Wide model	155	137	138	629	94	417	459
5	Narrow model	102	148	102	466	89	366	407

- For all three FEA models palatal average width was constant.

Width of palatal vault
- The distance in a straight line between the mesiodistal center of the palatal gingival margin of left and right molars (Figures 4 and 5)
- Three FEA models: (1) Wide, (2) average, (3) narrow
- For all three FEA models palatal average depth was constant.

All the above dimensions were derived by a statistical analysis based on measuring 60 dentate maxillary casts. In all palatal depth and width FEA models average palatal dimensions were common, so total five FEA models were generated for the study.

Finite element model was meshed into elements for palatal strap major connector they were defined by nodes in single palatal strap major connector in tetrahedral (solid 45) using hyper mesh. Models were prepared with CATIA, meshed by hypermesh and were analyzed with ANSYS 14.5. ANSYS post processing software program was used to display the deflection and stress patterns.

To simulate the considerable differences in resilience between the oral mucosa and the abutment teeth oral mucosa was excluded from the study. And support was taken from the alveolar bone with the ideal alveolar bone characteristics. A 20 N vertical biting force was directed simultaneously towards the center of the artificial teeth (total 60 N) i.e., saddle area. In order to simulate the retention force of a clasp, a 5 N vertical load was applied on the top surfaces of both of the rests of premolar area.

Artificial teeth was included in the framework to replace the missing teeth i.e., left second premolar, first and second molar. Since the deflections were not clearly visible on the framework along with the artificial teeth, they were eliminated from the resultant images. However, results were tabulated from the overall deflection of the framework on the cast model.

Results

This 3D FEA was done to evaluate the deflection in maxillary single palatal strap in different palatal shapes i.e., average, deep shallow, wide, and narrow.

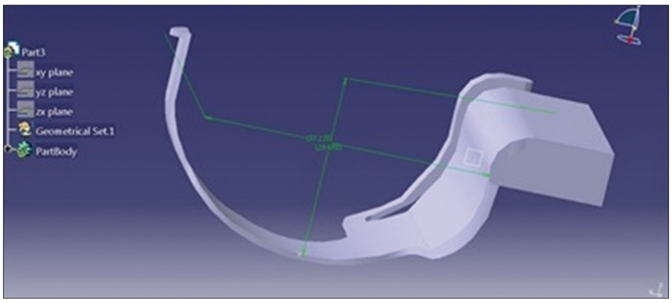

Figure 2: Deep palatal finite element model.

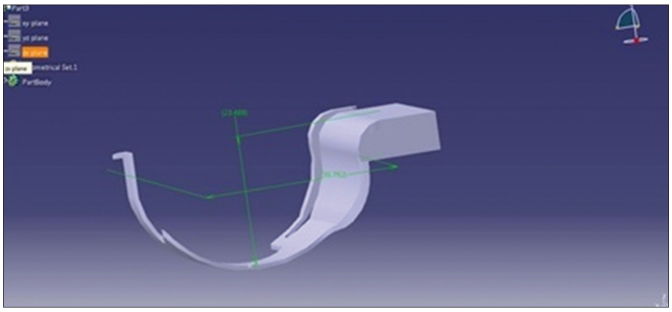

Figure 3: Shallow palatal finite element model.

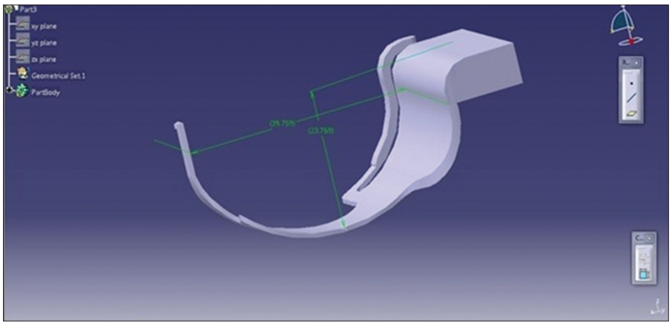

Figure 4: Wide palatal finite element model.

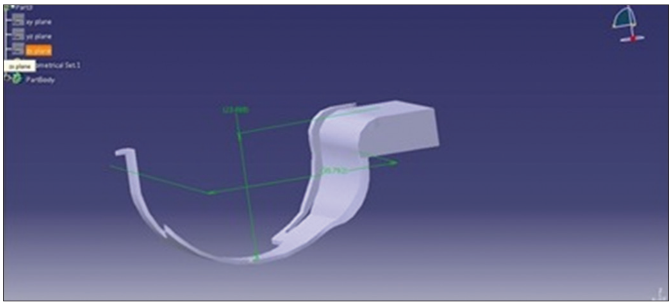

Figure 5: Narrow palatal finite element model.

A total of five FEA models were designed according to above-mentioned criteria and these models were studied under a constant load where vertical intrusive force is 40 N on saddle area and 5 N on each rest. The color plots obtained were studied and the maximum and minimum deflection and stress were noted in x, y, z axes and values were tabulated for each model.

Deflection in the FEA models comes in numerical values and in color coding. A maximum value is denoted by red color and minimum value by the blue color. In between the values were indicated by bluish green, green, greenish yellow, and yellowish red in the ascending order of deflection pattern distribution.

Table 2 shows the values of deflection of the single palatal strap in different palatal shapes in micrometer and pattern of deflection seen.

All the frameworks evidenced distal displacement values greater than buccal and vertical displacements. Maximum buccal displacement values were seen in deep model (110 µm), maximum distal displacement was seen in wide palatal strap model (138 µm) and in vertical direction maximum deflection of 99 µm was recorded in average model.

Resultant analysis of each of the model showed that the maximum displacement seen in the wide model (459 µm) and minimum value occurred in the average model (409 µm). Whereas the difference in average model (409 µm) and narrow model was smaller comparatively with other models. With narrow model (459 µm) difference was larger than the average model. The difference in displacement between deep model (428 µm) and shallow model (455 µm) was smaller, whereas the difference was larger between wide model (459 µm) and narrow model (407 µm).

Discussion

Davenport *et al*. said that the major connector should be rigid, protect the soft tissues, provide vertical support, achieve indirect retention wherever it is indicated, and also to maintain patient comfort.[12]

Major connector should be rigid to provide cross arch stabilization and distribute forces among the supporting structures. A study conducted by Kaires *et al*. has demonstrated that a modification in the mandibular major connector to reduce the rigidity increased the horizontal stresses over the abutment teeth.[13] Non-rigid major connectors were inefficient to distribute stresses and thereby placed greater stress on the individual abutments. The rigidity of maxillary major connectors can be enhanced by using the hard palate as an area of support. Supporting straps can be placed to make a more rigid engineered structure unlike mandibular major connectors, which must be of a U-shape. Maxillary designs that incorporate single broad palatal straps or anteroposterior palatal bars on different planes have been shown to be more rigid than U-shaped designs of similar weight.[5] It has been reported that an anteroposterior bar has excellent rigidity compared to other maxillary major connectors.[5,8] Moreover, it has also been reported that a palatal strap with increased anteroposterior width has mechanical strength equal to that of an anteroposterior bar.[7] However, distribution of tactile sensory spots throughout the palate is dense in the anterior portion and sparse in the deepest part of the palatine arch.[5]

The rigidity of the major connector is influenced by the rigidity of the framework. This present study was carried out to evaluate which of the different palatal shapes of major connector designs, work well in given Kennedy's maxillary Class II partial denture situation.

Oral mucosa covering the edentulous alveolar ridge vertically distorts by approximately 0.5 mm under 4 N of vertical force. This is considerably greater than the intrusion exhibited by the abutment teeth at approximately 0.02 mm.[4] To simulate the considerable difference in resilience between the mucosa and the abutment, the oral mucosa was excluded from the finite element models, while the occlusal rests were fixed in the vertical direction by the fixed natural teeth. Because of these extreme conditions, the calculated displacement values cannot be translated directly into predicted movement of the abutment and the mucosa. However, it is evident that frameworks with large deflection are likely to exert significant pressure on the supporting oral tissues.

In this study, single palatal strap major connector was used, and this major connector had three different palatal depths and widths at the midline, keeping all the other factors common for all the designs.

When the simulated loads were applied on the saddle area and on the rests of all 3D finite element models, they revealed that the framework generally displaced in three axes i.e. buccal, distal and vertical directions by the applied load.

Analysis of each of the model showed that the maximum displacement seen in the wide model and the shallow model. This suggests increasing the anteroposterior width of the palatal strap and reinforcing it. However, deflection in a narrow model was smaller as compared with other models. These suggests decreasing the anteroposterior width of the palatal strap.

Though the dimensions, geometry and properties of the models simulate the prosthesis, the natural teeth, and residual alveolar bone to a limited extent, it does not give an insight into the geometric behavior of aforementioned as a result of masticatory forces.

Conclusion

Within the limitations of the study, it can be concluded that: All the frameworks evidenced distal displacement values greater than buccal and vertical displacements. Maximum buccal displacement values were seen in the deep model, and maximum deflection was recorded in the distal direction with the average model.

Resultant analysis of each of the model showed that, the maximum displacement is seen in wide and shallow models. This suggests increasing the anteroposterior width of the palatal strap and reinforcing it. However, in narrow model deflection was smaller comparatively with other models. This suggests decreasing the anteroposterior width of the palatal strap.

In a given maxillary Class II situation single palatal strap maxillary major connector with different palatal shapes, wide model, and shallow model were least rigid frameworks among the rest of models. On observation of both values of displacement and stresses within framework reveal that average model had minimum values. Hence, the present study shows average model was most favorable design among the five finite models.

Acknowledgment
The authors are thankful to Mr. Pradeep Chikkamath M. Tech V.T.O Belgaum for helping in FEA.

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