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Effect of Labial Frenum Notch Size and Palatal Vault Depth on Stress Concentration in Maxillary Complete Dentures: A Finite Element Study

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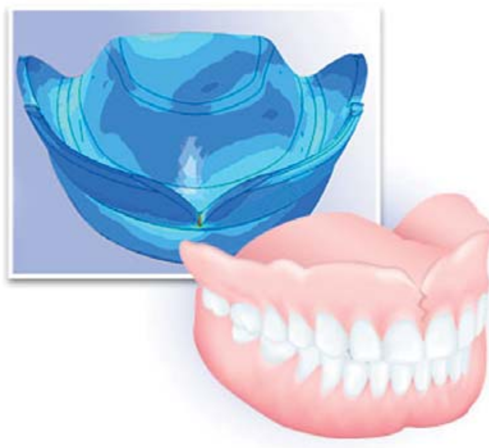

Abstract

Aim: Fracture is a common cause of acrylic resin denture failure due to crack development in a site of excessive concentration of stress in the denture. The purpose of this study was to evaluate the effect of labial frenum notch size and palatal depth on stress concentration in maxillary complete dentures.

Methods and Materials: Three-dimensional finite element models of maxillary complete dentures with different palatal vault depths (shallow, medium, and deep) and different frenum notch sizes (small, medium, and large) were constructed. The stress concentration was analyzed using Nastran software and displayed in terms of von Mises stress generated under two conditions: dropping on a hard flat surface from a standard distance and applying vertical load to the occlusal surface.

Results: The greatest stress concentration was observed in the labial frenum notch. Stress increased with an increase in the size of the labial frenum notch and a decrease in the depth of the palatal vault. The stress concentration in maxillary denture bases was greater when a vertical load was applied compared with dropping the denture on a hard surface from a standard distance.

Conclusion: Using finite element analysis, the presence of a large labial frenum notch and a shallow palatal vault increased the concentration of stress in maxillary complete dentures. Stress concentration in a maxillary denture base is much greater during the application of a vertical load than when dropping the denture on a hard flat surface.

Clinical Significance: The concentration of stress at the tip of a large frenum notch and in a shallow palatal vault could have a weakening effect on the maxillary complete acrylic resin denture base making it more vulnerable to fracture. In this scenario alternative denture base strengthening strategies, such as using a metal framework, should be considered in the fabrication of maxillary complete dentures.

Keywords: Acrylic resins, dental restoration failure, denture bases, maxillary denture, finite element analysis

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Introduction

A complete denture constructed from acrylic resin (polymethyl methacrylate) is susceptible to fracture.[1-3] Fracture can be caused as a result of impact if a denture is accidentally dropped on a hard surface or by fatigue failure when a denture base is repeatedly deformed under occlusal forces.[4] The most common types of fractures are de-bonding/fractures of denture teeth (33%) in complete and partial dentures followed by midline fractures of complete dentures (29%).[1] Fracture is more commonly seen in maxillary complete dentures and characterized by midline fractures.[1,5-7]

Usually a fracture can be attributed to the mechanical properties of the acrylic resin, unsatisfactory occlusion, or poor fit of the prosthesis while accidental trauma is also reported as a frequent cause.[8-13] Additional causes of midline fractures of maxillary dentures have been described as sharp frenum notches, diastemas, and maxillary tori.[6,7,9,14-16] A fracture is primarily initiated by material fatigue causing a crack which emerges from a location of high stress.[2,5-7,17-19]

Previous studies[20,21] have reported the deformation of denture bases occurs under masticatory loads. Several methods of experimental stress analysis have been used to examine deformation of complete maxillary dentures.[2] These methods have shown stress developed in the anterior palatal area is greater than stress developed in the posterior area of a maxillary denture.[16,18,22-26]

Maxillary denture bases undergo flexions during use and deform away from the palatal tissues. Therefore, fatigue of the denture base material might be a significant factor in the fracture.[21] Midline fracture has been shown to be the result of flexural fatigue failure due to cyclic deformation of the denture base during function.[1,5,8] However, fatigue is determined by both the number of cycles imposed and the shape of the structure subjected to cyclic loading. Static loading tests have indicated the depth of the palatal vault and the thickness of the base significantly affect the fracture resistance of denture bases.[10]

In order to understand and resolve the problem of complete denture fracture, it is essential to identify the regions of stress concentration. The finite element method is a numerical method which appears to overcome most problems associated with the earlier experimental methods.[2]

The purpose of this study was to determine the effect of frenum notch size and palatal depth on stress concentration in maxillary complete dentures using finite element analysis.

Methods and Materials

Three edentulous maxillary casts with the same alveolar arch but with different palatal vault depths were prepared from demonstration models of edentulous maxilla (Frasaco USA, Greenville, NC, USA).[10] The palatal vault depths included in the study were defined by the depth of the vault as measured from the crest of the alveolar ridge in the maxillary first molar region to the deepest area of the hard palate and were as follows:

- Shallow: 5 mm
- Medium: 10 mm
- Deep: 15 mm

The geometry of a maxillary upper denture base was approximated using the Coordinate Measurement Machine (CMM, DEA Torino, Italy) and Mechanical Desktop software (Mechanical Desktop AutoCAD, Autodesk Inc., San Rafael, CA, USA). The casts were waxed with one layer of base plate wax (Dentsply, Weybridge, Surrey, UK) which was modeled to represent the denture base with a 2 mm thickness. The CMM was programmed to touch the prepared casts. Three frenum notch sizes were designed using the AutoCAD software to the following lengths:

- Small = 2 mm
- Medium = 5 mm
- Large = 8 mm

The three different palatal vault depths of the denture bases were modeled with the small and large frenum notches, while the denture base with medium palatal vault and medium frenum notch was used as the control. The teeth were designed and copied from an artificial tooth mold using the AutoCAD software and electronically fitted onto the denture base profiles. The resulting seven digital maxillary denture models were merged using MSC visual Nastran software (Nastran MSC Software Co., Santa Ana, CA, USA) to create images like the one shown in Figure 1. Table 1 shows the number of nodes and elements of the models.

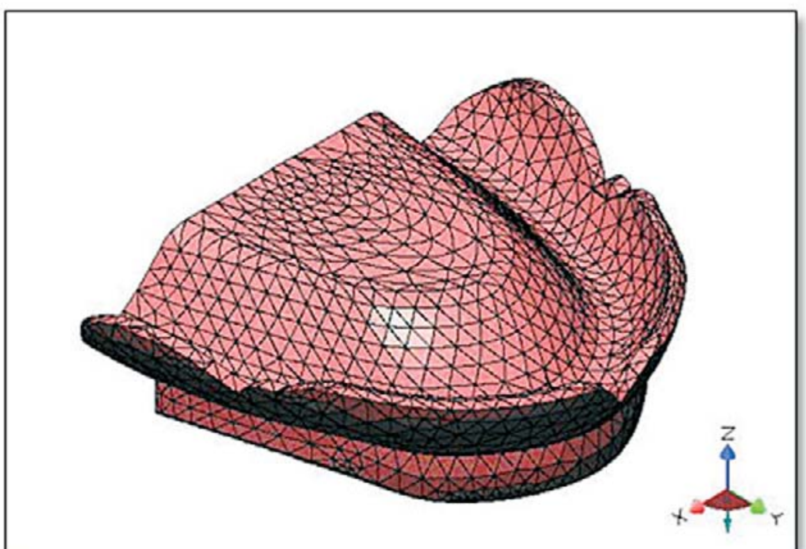

Figure 1. The FEA model which displays the shape of the maxillary denture.

Table 1. Nodes and elements of the studied models.

Types of Denture Designs	Nodes	Elements
Shallow vault, small frenum	18516	10725
Shallow vault, large frenum	17847	9821
Medium vault, small frenum	21076	12121
Medium vault, medium frenum	21076	12990
Medium vault, large frenum	20094	11451
Deep vault, small frenum	22991	13075
Deep vault, large frenum	22006	12457

The Young's modulus and Poisson ratio of the acrylic denture base were 1.06 GPa and 0.3, respectively.[18] The stress concentration of these models was analyzed using the MSC visual Nastran software under two conditions. The first condition was an accidental drop on a hard flat stone surface from a standardized height of 50 cm (Figure 2). The acceleration of gravity was 9.8 m/sec^2. A second condition[18,27] applied a static vertical load of 50N to the occlusal surfaces of the denture.

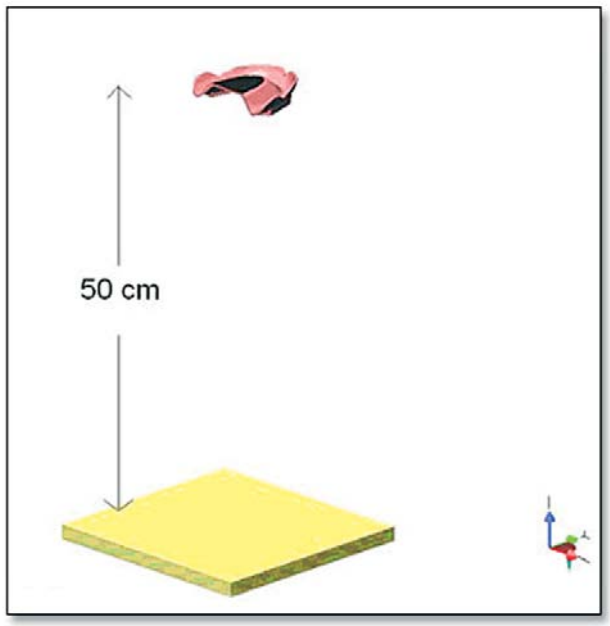

Figure 2. Dropping the model on a hard surface from 50 cm height.

Results

Table 2 shows results of the finite element analysis. The calculations pertain to the seven models of maxillary dentures tested under the two conditions described previously.

Color contoured diagrams of calculated von Mises stress shows the stress distribution within the maxillary complete denture (Figures 3 and 4). The highest stress concentration was observed in the labial frenum notch region for both conditions. The stress was much higher when a vertical load was applied than when the models were dropped on a hard stone surface. Stress increased with an increase in the depth of the labial frenum notch and a decrease in the depth of the palatal vault. The highest stress concentration was encountered with the combination of a shallow palatal vault and a long frenum notch during the application of both vertical load and dropping the denture on a hard surface.

Discussion

Denture fractures result primarily from flexural fatigue following repeated flexing of the denture

Table 2. The maximum stress concentration in the studied models generated by dropping them on a hard surface and applying a static vertical load (MPa).

Applied Force	Deep Vault		Medium Vault			Shallow Vault	
	Large Frenum	Small Frenum	Large Frenum	Medium Frenum	Small Frenum	Large Frenum	Small Frenum
50 cm Drop	.048	.007	.23	.20	.13	.31	.21
Vertical Load	1.44	.36	4.95	2.85	.066	11.3	7.05

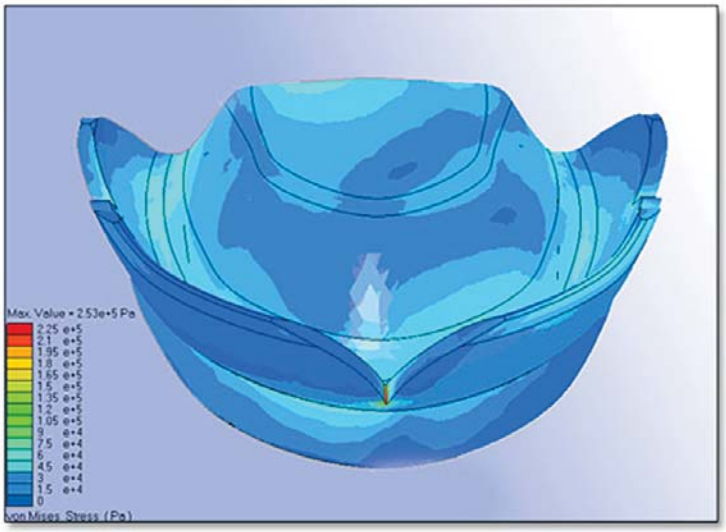

Figure 3. von Mises stress after dropping a denture with a medium palatal vault and a long frenum notch on a hard surface.

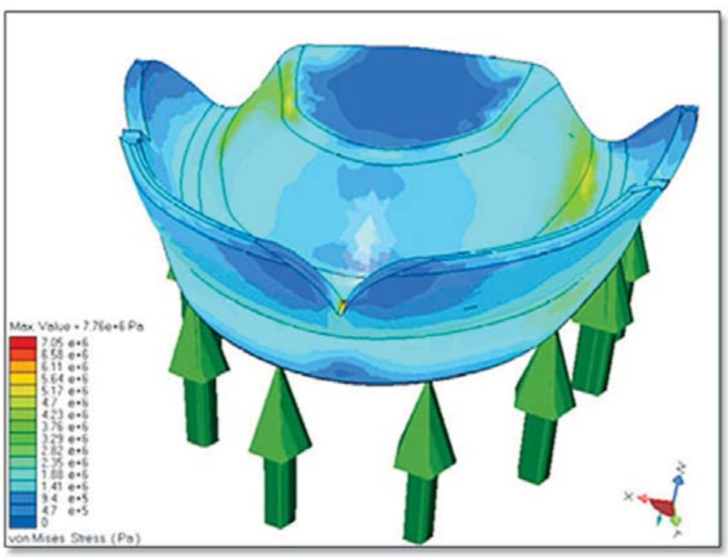

Figure 4. von Mises stress concentration resulting from the application of a vertical load in a maxillary denture with medium palatal vault with medium length of the labial frenum notch.

base. This type of failure can be explained by the development of microscopic cracks in areas of stress concentration.[2,5-7,20,28-30]

This study examined the effect of labial frenum notch size and palatal vault depth on stress concentration in maxillary complete denture bases using finite element analysis. Results showed a large frenum notch in combination with a shallow palatal vault caused more stress concentration in the frenum notch region during the drop test and when applying vertical load.

Denture bases with shallow palatal vaults appear to be inherently weaker and less resistance to fracture than those with medium or deep palatal vaults.[10] The maxillary denture base exists in two or more planes which can offer strong resistance to bending and twisting forces. This theory is similar to the L-beam principle used in building construction. The forces transmitted on different planes are counteracted more easily.[31] In a deep palatal vault the coverage of multiple palatal planes with different angles provides an even more effective L-beam design than does a shallow palatal vault.

Previous studies indicate stress always follows the same trend of increasing to a maximum at the tip of the frenum notch[16] and stress concentrates in anterior palatal areas of maxillary dentures rather than in posterior regions.[32]

Although loads act on the posterior area of the denture, fractures often begin in the anterior area where no teeth are in contact.[33] Evidence indicates the stress concentration effect of a labial notch in a maxillary denture is substantial.[16]

Many denture failures are the result of a large frenum notch or a midline diastema, and it is well known these characteristic features of a maxillary denture predispose it to eventual fracture due to stress concentration.[5,15,28] A longitudinal fracture line was first observed in the anterior region of the palatal aspect of a maxillary denture base. Fracture of the denture base may be due to the weakening effect of the frenum notch, concentration of stress in the anterior palatal region, material fatigue caused by repeated alternate force, or by the reduced strength of the base material as a result of unsatisfactory processing in the laboratory.[16,18,32,34]

Other investigators have reported *in vivo* deformation of complete maxillary dentures generally varies throughout the denture.[19,32,35,36] The stress pattern in complete maxillary dentures is patient specific and is influenced by such factors as denture base thickness, type of material used, the form and position of the teeth, as well as variations in the humidity and temperature of the oral cavity.[19,32,35,36]

The fracture strength of conventional polymethyl methacrylate based denture resins (not including the high-impact resin) has been reported to be 51 to 73 MPa.[13] The general stress level in dentures is reported to be around 4 MPa. However, higher stress levels of up to 10 MPa can be generated when other factors are present such as natural teeth occluding against a complete maxillary denture. The stress concentration in this study was less than the strength of the denture base resin. However, where stress concentration factors exist, the stress values increased three to seven fold.[16]

The results of the present study may not apply to *in vivo* situations because limitations such as the effect(s) of the mucosa was not considered in the stress analysis and the load analysis was conducted only in a vertical load. It has been shown oblique loads produce higher levels of stress in the labial notch region than vertical loads.[18]

Conclusion

With the limitations of this study, the following findings were found:

- A large frenum notch and a shallow palatal vault have a weakening effect on maxillary denture bases.

- The stress concentration in a maxillary denture base is much greater when applying a vertical load than when dropping the denture on a hard flat surface.

Clinical Significance

The concentration of stress at the tip of a large frenum notch and in a shallow palatal vault could have a weakening effect on maxillary complete acrylic resin denture bases making them more vulnerable to fracture. In this scenario alternative denture base strengthening strategies such as using a metal framework should be considered in the fabrication of maxillary complete dentures.

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