Comparison of mechanical strength of palatal denture bases made from three commercially available high impact acrylic resin denture base materials in different palatal vault configurations – an invitro study

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Abstract

Objective: To investigate the mechanical fracture strength in fracture test of three commonly used high impact acrylic resin denture base materials in different palatal vault configurations. Methods: A total of 135 specimens were fabricated using three palatal vault configurations, out of which 45 specimens each were made from shallow, medium, and deep palatal vault configuration. These groups were again sub divided in to 15 specimens each with respect to three high impact denture base materials. These specimens were stored in water at room temperature, for 4 weeks and were subjected to fracture test using Universal Testing Machine. Results: There was a significant difference for mechanical fracture strength between the denture base materials in all the palatal vault configurations. n-BMA reinforced high impact acrylic resins exhibiting highest fracture strength. Fiber reinforced material had least fracture strength. Irrespective of the material used for the fabrication of denture base, there was a significant difference between palatal vaults. Shallow palatal vault showed maximum susceptibility to fracture, followed by medium and deep palatal vault. Conclusions: The shallow palatal vault base is inherently weaker and less resistant to fracture than medium and deep palatal vault.

Key words: Denture base; Fracture strength; Heat cure acrylic resins; Palatal vault.
Mechanical strength of palatal denture bases

Introduction
The material most commonly employed in the construction of dentures is poly methyl methacrylate resin. Despite its popularity in satisfying aesthetic demands, it is not very ideal in fulfilling the mechanical requirements of prosthesis. This is reflected in unresolved problem of denture fracture and accompanying cost effective repair (1). During function, the denture base is subjected to various stresses like compressive, tensile and shear stress leading to denture fracture. In order to withstand these stresses, the denture base should possess good mechanical properties. One of the important properties is fracture strength. It is the stress at which a brittle material fractures (2).

In the Prosthodontic literature, palatal shapes have been classified according to their cross-arch forms. Researchers analyzed the contours and concluded that the cross-arch palatal forms could be categorized as “V” shaped, “U” shaped, flat, or high, medium, low, rounded or combinations thereof (3-5).

Generally, palatal vault of various configurations can be classified into three groups as suggested by Johnson et al., viz. shallow, medium and deep (3). In case of maxillary denture, palatal vault shape may influence the fracture strength of heat polymerized acrylic resin denture base (6).

The objective of this study is to investigate the mechanical strength in fracture test of three commonly used high impact acrylic resin denture base materials in different palatal vault configurations.

Material and methods
Preparation of specimens:
Edentulous molds (figure 1) of different palatal vault configuration, shallow, medium and deep were used to make each working model. Thermoplastic sheets of 2mm thick were adapted on each working model using positive pressure thermal forming machine. The land area of the casts was trimmed and a hole was drilled from the base of the cast to the tissue surface of the palate, to facilitate vacuum formation, and to avoid air entrapment during the process of adaptation of thermoplastic sheets to the casts. The sheets were trimmed to the full depth of the sulcus; the border sulcus was filled with wax, flush to the top of the land area to produce a rolled periphery of the acrylic resin (7). After the record bases were sealed to the cast, invested in a standard flask (Jabbar and company) using dental plaster & dental stone in ratio of 1:1 by weight (8) standard acrylization procedure was used with short curing cycle.

Figure 1: Edentulous molds and cast of different palatal vault

Once processed, the denture bases were measured for thickness at randomly selected points using a millimeter gauge such as (6):
- Midline
- First premolar region – Right and Left
- Second molar region – Right and Left
- Anterior region
The denture base which measured in the range of 1.4-1.7mm thickness was selected
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as template to fabricate remaining specimens.

![Figure 2: Shallow, Medium and Deep palatal vault denture bases](image)

Figure 2: Shallow, Medium and Deep palatal vault denture bases

Figure 3: Specimen on Universal-Testing Machine (UTM).

Finishing and polishing was carried out using conventional technique as used for complete denture fabrication. A total of 135 specimens were fabricated using three palatal vault configurations and grouped as follows (figure 2):
- Group I: 45 Shallow palatal vault
- Group II: 45 Medium palatal vault
- Group III: 45 Deep palatal vault
Each group was further subdivided into 3 subgroups (named as Group A, Group B and Group C) each containing fifteen specimens.
- Group A: Fiber reinforced (Acralyn-H, Asian acrylates)
- Group B: Rubber reinforced (Lucitone199, Dentsply)
- Group C: n-BMA reinforced (Trevalon Hi, Dentsply)

These specimens were stored in water at room temperature, for 4 weeks. Later specimens were subjected to fracture test using Universal Testing Machine (figure 3).

Testing Procedure
Specimens were dried completely before placing them on the universal testing machine. The specimens were kept with the non-tissue side i.e., the polished surface on the platform of the Universal Testing Machine (UTM) (figure 4). The fracture tests were carried out on UTM at a cross head speed of 5mm/min. Force was applied via a specially profiled metal ring placed on the most prominent part of the palate. The readings were collected as data. The data was statistically analyzed. One way analyses of variance was used to test the difference between groups and Bonferroni comparison test was used for multiple comparisons between the groups.

Results
The mechanical strength in fracture test of three high impact acrylic resin denture base materials was compared in different palatal vault configuration.

The data was analyzed to check the statistical significance between Fiber reinforced (Acralyn-H), Rubber reinforced (Lucitone199) and n-BMA reinforced (Trevalon Hi.) high impact acrylic resins, and Shallow, Medium & Deep palatal vault.

Table 1 demonstrates that there was a significant difference for mechanical fracture strength between the denture base materials in all the palatal vault configurations. There was a definite trend with Group C material, i.e., n-BMA reinforced (Trevalon Hi) high impact acrylic resins exhibiting highest fracture
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strength of 962.06N, 1073.93N and 1168.13N in shallow, medium and deep palatal vaults respectively. In contrast, Group A (Fiber reinforced) material had least fracture strength of 691.72N, 905.21N and 1021.62N in shallow, medium and deep palatal vaults respectively. On multiple comparisons, each denture base material differed significantly for mechanical fracture strength from the other two materials in all palatal vaults (table 2).

Table 1: Comparison of fracture strength of denture bases between the three high impact resins in different palatal vault configuration

<table>
<thead>
<tr>
<th>Palatal vault</th>
<th>Groups</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow*</td>
<td>A</td>
<td>691.72</td>
<td>23.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>933.01</td>
<td>51.7</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>962.06</td>
<td>38</td>
</tr>
<tr>
<td>Medium*</td>
<td>A</td>
<td>905.21</td>
<td>58.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1060.33</td>
<td>38.6</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>1073.93</td>
<td>66.5</td>
</tr>
<tr>
<td>Deep*</td>
<td>A</td>
<td>1021.62</td>
<td>16.8</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1165.66</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>1168.13</td>
<td>13.3</td>
</tr>
</tbody>
</table>

*One way ANOVA, p<0.0001

Table 2: Comparison of mean fracture strength between the denture base materials in different palatal vaults

<table>
<thead>
<tr>
<th>Palatal vault</th>
<th>Group</th>
<th>Mean difference</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow</td>
<td>A</td>
<td>-241.29*</td>
<td>14.43</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>-270.34*</td>
<td>14.43</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>-29.04*</td>
<td>14.43</td>
</tr>
<tr>
<td>Medium</td>
<td>A</td>
<td>-155.12*</td>
<td>20.37</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>-168.72*</td>
<td>20.37</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>-13.6</td>
<td>20.37</td>
</tr>
<tr>
<td>Deep</td>
<td>A</td>
<td>-144.03*</td>
<td>7.37</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>-166.50*</td>
<td>7.37</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>-2.46</td>
<td>7.37</td>
</tr>
</tbody>
</table>

*The mean difference is significant at the 0.05 level.

However, the differences in strength between palatal denture bases made of rubber reinforced PMMA (Group B) and n-BMA reinforced PMMA (Group C) are not statistically significant.

Table 3: Mean Fracture Strength among different Palatal vault configurations

<table>
<thead>
<tr>
<th>Palatal vault</th>
<th>Mean ±SD</th>
<th>Palatal vault</th>
<th>Mean difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow†</td>
<td>862.26±128.4</td>
<td>Medium Deep</td>
<td>-150.89*</td>
</tr>
<tr>
<td>Medium†</td>
<td>1013.15±94.6</td>
<td>Deep</td>
<td>-111.98*</td>
</tr>
<tr>
<td>Deep†</td>
<td>1125.14±77.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*. The mean difference is significant at the 0.05 level.
†One way ANOVA, p<0.0001

Irrespective of the material used for the fabrication of denture base, when different palatal vault configurations were compared there was significant difference between shallow, medium and deep palatal vaults. It is clear from table 3 that shallow palatal vault showed maximum susceptibility to fracture with a mean force of 862.26N, followed by medium palatal vault with a mean force of 1013.15N, and deep palatal vault with a mean force of 1125.14N. In addition, the fracture strength of denture bases in each form of palatal vault differed from the others on multiple comparisons.

Discussion

PMMA has been established as principal material in denture base construction due to its good overall processing as well as user friendly properties. The denture base is subjected to load during function as well as parafunction. Under the load the maximum stress is on the palatal aspect of the denture base. Factors that contribute to the stress concentrations will enable the initiation and propagation of the cracks thereby influencing the rate of failure (9).

The flexural strength of maxillary denture bases in different palatal vault shapes with
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varying thickness of denture base was studied by Morris et al. It was shown that the shape of the palatal vault and the base thickness significantly affect the fracture resistance of denture bases. Increase in the base thickness will increase the fracture resistance of the shallow palatal vault base, but greater thickness, namely 4mm may not be clinically acceptable (6). In this research 1.4 -1.7mm thickness of denture bases were tested because it is clinically acceptable. The specimens were stored in water for four weeks. This long period of storage in water allowed any residual monomer to fully leach out (10). Each specimen was then subjected to loading on a Universal-testing machine. Force was applied via a specially profiled metal ring placed on the most prominent part of the palate at a cross head speed of 5mm/min to enable accurate assessment of the actual point of load at which fracture occurred. The testing conditions did not completely simulate the intraoral conditions as force was unidirectional and not multidirectional as seen in the oral cavity. The occlusal scheme was not taken into consideration, which may play a role in the amount of stress applied on the denture base.

The present study showed that there was significant difference in the strength of denture bases in different palatal vault configurations. The shallow palatal vault base is inherently weaker and less resistant to fracture than medium palatal vault and deep palatal vault, a study done by Morris et al., showed the similar results (6). When force acts on a body, resistance is developed to the external force. The internal reaction is equal in intensity and opposite in direction to the applied external force, and is called stress. Both the applied force and internal resistance (stress) are distributed over a given area of the body, so the stress in a structure is designated as force per unit area, represented as stress = force/area. By this equation we understand that, as the surface area of the structure under load is increased the stress is decreased. Perhaps this explains the higher tendency of fracture of shallow palatal vault bases, and lower tendency of fracture of deep palatal vault, because the surface area of shallow palatal vault is comparatively less than medium and deep palatal vaults.

Lambrecht and Kydd formulated a pattern of functional base deformation for maxillary dentures. He concludes that two types of deformation predominate; the first was extension, a flattening or straightening of the base at the midline. The second was compression, an increase in the curvature of the base at the midline (11).

Based on the above information, it is our hypothesis that during functional loading there is lateral extension of posterior part of the palatal aspect of the denture base, and rotation of denture base about the crest of the ridge. In patients with deep palatal vault, the height of contour in the anterior part of the palate may act as secondary stress bearing area, which may help dissipating stress occurring on the denture base. This perhaps explains high resistance to fracture of denture bases in deep palatal vault.

When the palatal vault is flat there is downward extension in posterior part of the palate, but there is no counteracting force dissipation effect by anterior slop of the palate. This perhaps explains high frequency of fracture in shallow palatal vault.

In non-uniform object shapes stress typically decreases as function of distance from the area of the applied force or applied pressure (12).

A three dimensional stress analysis of the denture base was done by Craig et al. They concluded that the stress in the denture bases are compressive with maximum value in areas beneath the
artificial porcelain teeth and lower stresses on the tissue bearing surface of the palate (13). Since the distance between the area of the force applied (ridge), and mid palatal region is less in shallow palatal vault compared to medium and deep palatal vault, this explains the increased susceptibility to fracture of shallow palatal vault bases and higher strength of deep palatal vault base.

The present study showed that there is significant difference between the three high impact acrylic resin denture base materials used. Fiber reinforced PMMA showed maximum susceptibility to fracture in all the palatal vault configurations. The rubber reinforced & n-BMA reinforced PMMA showed better resistance to fracture. There was no statistically significant difference in strength of rubber reinforced & n-BMA reinforced PMMA tested. The study done by Zappini et al., also showed similar results (14).

There are three routes to improve the impact properties of PMMA, development of an alternative material to PMMA, the chemical modification of PMMA and reinforcement of PMMA with other materials. Reinforcement of polymers with rubber is a well-established concept. The addition of rubbers to PMMA produces a resin that consists of a matrix of PMMA within which an interpenetrating network of rubber and PMMA is dispersed. A developing crack will propagate through the PMMA but will decelerate at the rubber interface. The objective of rubber reinforced resins is that they absorb greater amount of energy at a higher strain rate before fracture than the standard resin (15).

The strength of acrylic polymers can be improved significantly by the incorporation of acrylic copolymers such as n-butyl methacrylate (n-BMA). The copolymer is able to absorb energy on impact and thus protect the acrylic resin from fracture (16). This explains the highest fracture strength of n-BMA reinforced PMMA.

Chow discussed the essential requirements for obtaining fiber reinforced polymers with desirable properties. He proposed that an asymmetric inhomogeneous distribution of reinforcement across the thickness of the resin and subsequent appliance could inadequately reinforce areas which are under high stress and result in failure (15).

Conclusions
Fiber reinforced PMMA showed maximum susceptibility to fracture in all the palatal vault configurations. The rubber reinforced & n-BMA reinforced PMMA showed better resistance to fracture in all the palatal vault configurations. The shallow palatal vault base is inherently weaker and less resistant to fracture than medium and deep palatal vault. Thus, it's recommended to use a reinforced PMMA denture base or metallic denture base in shallow palatal vault.

References
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