Flexural and Fatigue Strengths of Denture Base Resin

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**Statement of problem.** Mechanical properties of denture acrylic resins are important for the clinical success of multiple types of prostheses. Acrylic resins must be strong and resilient so as to withstand impact. Few studies utilize cyclic loads to characterize material response to repeated stress.

**Purpose.** The purpose of this study was to evaluate static and dynamic flexure properties of a variety of acrylic resins utilized in the fabrication of prostheses: (1) heat-polymerized polymethyl methacrylate (PMMA), powder-liquid type, and (2) a newly introduced, visible light-polymerized urethane dimethacrylate dough type.

**Material and methods.** Twenty rectangular bars each of 4 PMMA acrylic resin materials (Diamond D, Frische HI-I, Lucitone 199, Nature-Cryl Hi-Plus) and 1 urethane dimethacrylate (Eclipse) were fabricated and stored in 100% humidity for 30 days. Half of the specimens for each group were submitted to a static 3-point flexure test. The other half was submitted to cycling loading at 5 Hz for $10^4$ cycles. Data were analyzed using 1-way ANOVA and 2-way ANOVA, followed by Tukey HSD or Bonferroni post hoc tests when necessary ($\alpha=.05$).

**Results.** Mean static flexure strength (SDs) in MPa were: Eclipse, 127.11 (5.83); Diamond D, 84.92 (5.10); Lucitone 199, 83.96 (11.96); HI-I, 79.54 (5.84); and Nature-Cryl Hi-Plus, 75.82 (6.96). Mean flexural strengths (SDs) in MPa postcycling were: Eclipse, 113.36 (31.29); Diamond D, 88.26 (5.46); Nature-Cryl Hi-Plus, 81.86 (4.93); HI-I, 79.18 (6.60); and Lucitone 199, 74.34 (4.95).

**Conclusions.** The visible light-polymerized urethane dimethacrylate resin (Eclipse) showed greater flexure strength than all PMMA heat-polymerized resins for both static and cycled groups ($P<.001$). Yet the Eclipse material had lower load limits, and demonstrated brittle-type behavior and greater standard deviations. The heat-polymerized PMMA materials did not significantly differ from each other after static or cyclic testing. (J Prosthet Dent 2008;100:47-51)

**Clinical Implications**

From the perspective of static and dynamic flexural properties, a visible light-polymerized, dough-type resin may be suitable in low stress situations.

Acrylic prosthetic resins are used in a number of types of dental prostheses, including complete or removable partial dentures, transitional prostheses, and implant-supported prostheses. Most prosthetic acrylic resins consist of polymethyl methacrylate (PMMA) resin and additional copolymers, such as polybutylmethacrylate or butadiene styrene. Cross-linking agents such as glycol dimethacrylate and inclusions of rubber or fibers are added to modify mechanical properties. The additives serve to improve toughness, impact resistance, and to prevent crack propagation. Most manufacturers of PMMA denture resins refer to their products as “high impact” and claim new and improved strengthening properties, yet there is little to no research to support any
strength differences between contemporary versions of PMMA products. Moreover, manufacturers do not disclose constituents of their products beyond what is minimally required for material safety data sheets.

Light-activated urethane dimethacrylate resins were developed to eliminate contact allergies, laboratory vapors, and traditional, lengthy flashing and devesting processes used with the PMMA materials. Previous research has shown differences between the transverse strength of light-activated and PMMA resins. The flexure strength of a recently introduced light-activated resin has been evaluated. However, the authors identified no study that has reported the effect of cyclic loading.

The ultimate flexure strength of a material reflects its potential to resist catastrophic failure under a flexural load. High flexural strength is crucial to denture wearing success, as alveolar resorption is a gradual, irregular process that leaves tissue-borne prostheses unevenly supported. As a foundation, the acrylic resin materials should exhibit a high proportional limit to resist plastic deformation and also exhibit fatigue resistance to endure repeated masticatory loads.

An acrylic resin capable of sustaining higher flexure in combination with high resistance to cyclic loading may be less prone to clinical failure. This study measured the flexure and fatigue strengths of 4 heat-polymerized PMMA denture base resins and a new urethane dimethacrylate resin polymerized via a short light cycle. The null hypothesis was that there would be no significant differences in flexural and fatigue strengths among fatigued and nonfatigued groups.

**MATERIAL AND METHODS**

The 4 commercial brands of PMMA denture resin included Diamond D (Keystone Industries, Cherry Hill, NJ), HI-I (Fricke Dental Intl Inc, Streamwood, Ill), Lucitone 199 (Dentsply Intl, York, Pa), and Nature-Cryl Hi-Plus (GC America Inc, Alsip, Ill). The urethane dimethacrylate resin tested was Eclipse (Dentsply Intl). Aluminum molds were used to fabricate 20 bars (64 mm x 10 mm x 3.5 mm) of each denture material. Manufacturers’ mixing instructions were followed. So as to minimize air inclusions, a roller was used over the materials while in the doughy stage after placement in the mold. The molds were then sandwiched and clamped between glass slabs (9 mm thick). The recommended polymerization cycles were followed for each material. Diamond D, HI-I, Lucitone 199, and Nature-Cryl Hi-Plus specimens were polymerized in the clamped, sandwiched mold assembly in an overnight water bath (9 hours at 74°C). Eclipse specimens were polymerized (Enterra VLC Curing Unit; Dentsply Intl) using the recommended 14-minute polymerization cycle. Eclipse specimens were sandwiched and clamped so as to remove initial excess; however, the internal dimensions of the polymerizing unit necessitated removal of the clamps during polymerization. Excess flash was removed with a scalpel. All specimens were then finished with 240- and 600-grit carbide paper (3M ESPE, St. Paul, Minn) using a variable speed polisher (EcoMet 3; Buehler Ltd, Lake Bluff, Ill) and water spray at 300 rpm, and subsequently stored for 30 days in water at 37°C.

Ten bars of each material were tested using a 3-point flexure test (ISO 1567: Specifications for denture base polymers). Specimens were placed in a test rig with circular supports 50 mm apart. The plunger and supports were 3.2 mm in diameter and 10.5 mm long. A force was applied using an ElectroForce 3300 System with WinTest software (Bose Corp, Eden Prairie, Minn) and a 500-lbf load cell at a crosshead speed of 5 mm/min. The fracture force (F) was recorded in newtons (N) and the flexural strength (F_s) was calculated per the following formula to yield MPa units: 

\[ F_s = \frac{3PL}{2bd^2} \]

where P is maximum load, L is span length, b is specimen width, and d is specimen thickness.

The proportional limit for each specimen was manually read from its respective load/deflection graph. The remaining 10 bars of each material were then subjected to cyclic loading at 5 Hz for 10^4 cycles. Sinusoidal loads between the mean proportional limit (high load) and 10% (low load) of the mean fracture force were used for the PMMA resins. Pilot tests indicated the urethane dimethacrylate specimens would not sustain cycling between the proportional limit and 10% of the fracture force. To ensure survival to 104 cycles, forces between 30% and 5% of the mean static force of the urethane dimethacrylate material were applied to those specimens. Table I reports the load limits used in cycling. After 10^4 cycles, specimens were subjected to 3-point loading as previously described.

Descriptive statistics were calculated. Under static loading conditions, flexural strength was analyzed using 1-way ANOVA with post hoc Tukey Honestly Significant Difference (HSD) test. Because of lack of normality in the data under cyclic conditions, a 1-way ANOVA to the ranked data followed by the post hoc Bonferroni multiple comparison test, an equivalent test statistic to the nonparametric Kruskal-Wallis test, was used.

In addition, 2-way ANOVA to the ranked data was conducted to test the effect of material, loading condition, and their interactions on the flexural strength. When there was an interaction, factors were separated, and an additional 1-way ANOVA was applied with the post hoc Bonferroni multiple comparison test. When separation of factors resulted in only 2 groups to compare, the 1-way ANOVA was replaced by the Wilcoxon rank sum test.

All tests used a .05 level of statistical significance. Statistical software (SAS for Windows V9.1; SAS Institute Inc, Cary, NC) was used for data analysis.
**RESULTS**

For noncycled specimens, results of the 1-way ANOVA revealed a significant effect for the material (F (4, 45) = 43.56, P < .001). The post hoc Tukey HSD test indicated significantly higher mean flexural strength in the Eclipse group compared with the other 4 groups. The test also showed no significant differences among Diamond-D, HI-I, Lucitone 199, and Nature-Cryl Hi-Plus (Table II).

Within cycled groups, results of the 1-way ANOVA revealed a significant effect for the materials (F (4, 45) = 7.57, P < .001). The post hoc Bonferroni test indicated a significantly higher mean flexural strength in the Eclipse group when compared to the other 4 groups (P < .05) for each instance. The test also showed that there were no significant differences among Diamond-D, HI-I, Lucitone 199, and Nature-Cryl Hi-Plus (Table III). For both treatment types, the data showed that the mean flexural strength for Eclipse was significantly higher than that observed in the 4 PMMA materials.

Data were also analyzed using 2-way ANOVA to the ranked data to assess the relative significance of loading condition and material effects on the flexural strength, including their interaction. This analysis indicated a significant interaction between loading condition and material (F (4, 90) = 4.76, P < .002). Subsequent analyses were conducted for testing simple effect for the loading condition within the 5 materials. The Wilcoxon rank sum test indicated a significant difference between noncycled and cycled treatment groups within Lucitone 199 and Nature-Cryl Hi-Plus (P = .038 and P = .026, respectively). The noncycled treatment group displayed higher mean flexural strength than the cycled group within Lucitone 199. The cycled treatment group displayed higher mean flexural strength than the noncycled group within Nature-Cryl Hi-Plus. Moreover, no significant

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**Table I.** Load limits applied during fatigue cycling (newtons)

<table>
<thead>
<tr>
<th>PMMA Materials (Lot Numbers)</th>
<th>Mean Fracture Force</th>
<th>High Cycling Load Limit (Force at Proportional Limit)</th>
<th>Low Cycling Load Limit (Calculated as 10% of Mean Fracture Force)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond D (polymer: 6004, monomer: 6011)</td>
<td>138.71</td>
<td>68.42</td>
<td>13.87</td>
</tr>
<tr>
<td>HI-I (polymer: 325607, monomer: 021507)</td>
<td>129.91</td>
<td>58.75</td>
<td>12.99</td>
</tr>
<tr>
<td>Lucitone 199 (polymer: 070221, monomer: 0701054)</td>
<td>137.14</td>
<td>66.25</td>
<td>13.71</td>
</tr>
<tr>
<td>Nature-Cryl Hi-Plus (polymer: 0505091, monomer: 510241)</td>
<td>123.84</td>
<td>62.37</td>
<td>12.38</td>
</tr>
</tbody>
</table>

**Table II.** Material mean flexural strength: static loading conditions

<table>
<thead>
<tr>
<th>Material</th>
<th>Mean Flexural Strength, MPa (SD)</th>
<th>Group Comparison*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eclipse</td>
<td>127.11 (15.83)</td>
<td>A</td>
</tr>
<tr>
<td>Diamond D</td>
<td>84.92 (5.10)</td>
<td>B</td>
</tr>
<tr>
<td>Lucitone 199</td>
<td>83.96 (11.96)</td>
<td>B</td>
</tr>
<tr>
<td>HI-I</td>
<td>79.54 (5.84)</td>
<td>B</td>
</tr>
<tr>
<td>Nature-Cryl Hi-Plus</td>
<td>75.82 (6.96)</td>
<td>B</td>
</tr>
</tbody>
</table>

*Means with same letter are not significantly different using Tukey HSD test (P > .05)
TABLE III. Material mean flexural strength: cyclic loading conditions

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Mean Flexural Strength, MPa (SD)</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eclipse vs. Diamond D</td>
<td>113.36 (31.29) vs. 88.26 (5.46)</td>
<td>.005*</td>
</tr>
<tr>
<td>Eclipse vs. Lucitone 199</td>
<td>113.36 (31.29) vs. 74.34 (4.95)</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Eclipse vs. HI-I</td>
<td>113.36 (31.29) vs. 79.18 (6.60)</td>
<td>.001*</td>
</tr>
<tr>
<td>Eclipse vs. Nature-Cryl Hi-Plus</td>
<td>113.36 (31.29) vs. 81.86 (4.93)</td>
<td>.001*</td>
</tr>
<tr>
<td>Diamond D vs. Lucitone 199</td>
<td>88.26 (5.46) vs. 74.34 (4.95)</td>
<td>.415</td>
</tr>
<tr>
<td>Diamond D vs. HI-I</td>
<td>88.26 (5.46) vs. 79.18 (6.60)</td>
<td>1.000</td>
</tr>
<tr>
<td>Diamond D vs. Nature-Cryl Hi-Plus</td>
<td>88.26 (5.46) vs. 81.86 (4.93)</td>
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<tr>
<td>Lucitone 199 vs. HI-I</td>
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</tr>
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</tr>
<tr>
<td>HI-I vs. Nature-Cryl Hi-Plus</td>
<td>79.18 (6.60) vs. 81.86 (4.93)</td>
<td>1.000</td>
</tr>
</tbody>
</table>

*Significant pairwise comparison using Bonferroni test \( P > .05 \)

Differences were found between the 2 loading conditions within Eclipse, Diamond D, and HI-I.

DISCUSSION

This study controlled storage time and humidity, as all specimens were tested after 30 days of water storage. Test variables included material and load application (static and sinusoidal cycling). The data support rejection of the null hypothesis in the urethane dimethacrylate groups. Results showed that the visible light-polymerized, urethane dimethacrylate resin exhibited the highest flexural strength in both static and cyclic conditions. These results are in agreement with Machado et al.11 Those authors tested the flexural strength of 1 PMMA resin (Lucitone 199) and 2 light-polymerized resins (Eclipse and Triad VLC; Dentsply Intl). In that study, transverse strength was recorded only after 48 hours of storage, and specimens were not subjected to cyclic loads. Machado et al.11 reported significantly higher flexural strength and standard deviation for Eclipse when compared to Lucitone 199 and Triad VLC. Published results in the Machado et al.11 study for Eclipse (116.13 (17.68) MPa) and Lucitone 199 (87.12 (8.08) MPa) compared well with noncycled mean flexural strength values obtained in this study. Triad VLC was not included in this study, as the material has been available for over 20 years and serves for side chair relines and repairs rather than for laboratory fabrication of the entire denture base. In the Eclipse system, the record base becomes the denture base of the definitive prosthesis.

Limitations of the present study were the storage conditions and number of fatigue cycles used. Results indicated that 10,000 fatigue cycles had little impact on the flexure strength of most of the materials tested. The number and frequency of cycles was based on previously reported literature and test time constraints, as \( 10^4 \) cycles with a frequency of 5 Hz represented approximately 33 minutes of test time per specimen (5.5 hours per group). High and low fatigue load limits were individualized per specimen group (Table I). While most studies equate cycling loads throughout the study, the use of individualized cycling loads based on each material’s load/deflection behavior is appropriate.

Previous reports have used a staircase approach to determine the mean and variance of fatigue strength. The staircase technique requires a minimum of 15 specimens per group and is not helpful in defining the distribution.17 The present study did not cyclically load specimens to failure. Instead, the resins were subjected to a finite number of cycles to compare possible changes in strength resulting in failure. Researchers have concluded that tests for predicting failure in a fatigue environment are somewhat empirical, yet it seems prudent to subject materials to loads over time.16 While fatigue testing may not result in absolute values, it allows comparisons across groups.

Of interest is that, for all resins, the limits of the cyclic load did not differ much between groups (Table I). The urethane dimethacrylate resin displayed a significantly higher initial single impact fracture force but also less elastic deformation. The load/deflection behavior for this material was relatively linear, demonstrating brittle behavior that required lowering limits of the fracture loads to ensure survival for the duration of cycles. Pilot studies with the urethane dimethacrylate...
late material initially used load limits between the material’s proportional limit (approximately 62%) and 10% of its mean fracture force. When it was observed that those specimens did not survive cycling, the load limits were dropped to 50% (high) and 10% (low), followed by 40% (high) and 10% (low), then 30% (high) and 10% (low). Specimens at those limits also did not survive cycling until load limits were dropped to 30% (high) and 5% (low). The final loads limits were close to the loads for the PMMA materials, indicating that while urethane dimethacrylate resin resists a higher single impact load, it did not sustain cycling at correspondingly high loads.

The urethane dimethacrylate material exhibited higher standard deviations when compared to the other groups. As the material was not packed and flaked under pressure, it was difficult to consistently attain dense specimens. While every specimen was visually inspected for voids and defective specimens were discarded prior to testing, the higher standard deviations reflect variations in specimen fabrication. It should also be noted that, consistent with manufacturer’s recommendations, the urethane dimethacrylate material was polymerized on 1 side only. Further studies should compare degree of conversion between specimens exposed to light from multiple sides. Increased degree of conversion may serve to increase the bulk flexural strength of this material and decrease the variance.

Two PMMA groups were statistically impacted by cyclic fatigue. Lucitone 199 specimens exhibited a decrease in flexural strength after fatiguing, while the mean flexural strength of Nature-Cryl Hi-Plus specimens was higher after fatiguing. Material differences could account for this behavior. However, given the small standard deviations of all PMMA groups, it is more likely that those statistical differences reflect variation in specimen fabrication and handling rather than true material differences, and that the statistical significance may not be noted in the clinical setting. Regardless of the change in mean flexural strength after cycling, the 4 PMMA resins did not differ significantly from each other (Tables II and III), and the small statistical difference may not be reflected clinically.

CONCLUSIONS

Within the limitations of this study, results showed differences between the static and cyclic flexural strength of PMMA denture resins. The urethane dimethacrylate resin exhibited significantly higher static and cyclic mean flexural strength. However, the material also demonstrated brittleness and higher standard deviations when compared to the PMMA groups. The material showed fracture at or near its proportional limit and sustained little or no plastic deformation before fracture.

REFERENCES


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