Impact strength of 3D printed and conventional heat-cured and cold-cured denture base acrylics


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ABSTRACT

Purpose: To evaluate and compare the impact strength of 3D-printed resin to conventionally fabricated denture bases of heat-cured and cold-cured acrylic resin. Materials and Methods: Denture base materials were evenly divided into three groups (n = 25 each; N = 75): (1) 3D-printed material (Denture Base LP, Formlabs); (2) Heat-cured acrylic resin (Lucitone 199, Dentsply Sirona); and (3) cold-cured acrylic resin (Lucitone HIPA, Dentsply Sirona). The 3D-printed specimens were designed through computer-aided design (CAD) software (Autodesk Meshmixer) with the dimensions 64 mm long, 12.7 mm wide, and 3.2 mm thick, then printed with a desktop stereolithography printer (Form 2, Formlabs). Heat-cured and cold-cured acrylic resin specimens were fabricated through conventional (compression and pouring) methods. The impact energy was read directly from the impact tester in joules, and the cross-sectional area of each specimen was used to calculate the impact strength in kJ/m². Analysis of variance, Tukey multiple comparisons test, and a likelihood ratio $\alpha = .05$ were conducted. Results: The average mean impact strength was 8.9 kJ/m² for heat-cured acrylic resin, 11.2 kJ/m² for 3D-printed resin, and 14.9 kJ/m² for cold-cured acrylic resin. Tukey multiple comparisons test showed that the impact strength for the cold-cured group was significantly greater than the 3D-printed resin and heat-cured acrylic resin groups. Conclusion: Within the limitations of this study, the cold-cured acrylic (Lucitone HIPA) showed the greatest impact strength, followed by 3D-printed resin (Denture Base LP) and conventional heat-cured denture base materials (Lucitone 199), respectively. Int J Prosthodont 2021. doi: 10.11607/ijp.7246
INTRODUCTION

The number of edentulous subjects in total is on the decline for industrialized nations, however, the fractures in removable prosthetics remains as a problem since fractures not only occur in complete dentures but also in RPDs. A reasonable treatment option for edentulism is a removable prosthesis due to the prevalence of patients not eligible, clinically or financially, for full-mouth rehabilitation and implants. A known disadvantage of a removable prosthesis is the chance of impact fractures seen when the prosthesis is dislodged, falls out or suddenly dropped. This can be seen with a certain segment of the aging population that may have poor dexterity, or individuals with certain disorders that affect movement, like Parkinson’s disease. Lack of control, tremors, or sudden movements make handling the prosthesis a challenge.

Impact fractures often occur out of the mouth when there is a sudden blow to the denture or by accidental dropping. A study conducted in England and Wales found that nearly one million denture repairs were made every year.\(^1\) The impact strength of a removal prosthesis is of significant importance in predicting its clinical performance, as it measures the resistance of a material to fracture under an impact force. Denture fractures usually result from one of two different types of forces, namely flexural fatigue or impact failure.\(^1\) Impact strength is an important indicator reflecting the ability of a denture base material to resist functional and high impact forces as when the prosthesis encounters a dynamic load. The Izod impact testing simulate fractures that involves a measure of energy absorbed by the material before fracture.\(^2,3\) These tests have been widely used for evaluation of denture base materials.\(^4,5\)

Most dentures are constructed of an acrylic resin material. Fabrication with acrylic is within the standards of professionally acceptable prosthetic care. Conventional heat-cured
Polymethylmethacrylate (PMMA) is one of the most widely used denture base materials for a removable prosthesis. Despite many advantages, such as esthetics, stability, biocompatibility, ease of repair, conventional acrylics may display less effective mechanical properties that often result in denture base fractures.6,7

High impact, cold-cured denture base resin materials have been recently introduced to overcome some of the disadvantages related to fractures and fabrication time involved with conventional materials. These cold-cure pour acrylic resins are chemically activated using a tertiary amine polymerization process at room temperature. They allow for fabrication, repair, rebasing full and partial dentures at a fast rate than heat-cured processing resins. This enables improved labor productivity with a potential final product of comparable quality.

The latest technology used for processing dentures includes the option of 3D printing using Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) application. With computer-aided manufacturing (CAM), the denture could be fabricated by subtractive or additive manufacturing.8 Additive manufacturing by 3D printing involves adding layers of resin material, incrementally light activated, to build the prosthesis in the process. At this time, there are few studies regarding the mechanical properties of the 3D printed acrylic resin.

The aim of this in vitro study was to evaluate and compare the performance strength of 3D printed, heat-cured, and cold-cured acrylic resin denture base materials when subjected to impact testing. The null hypothesis was that denture base material type would have no effect on the outcome of impact strength performance.

MATERIALS AND METHODS

Denture Base Sample Preparation
Lists and description of materials used in this study are listed in Table 1. 3D printed samples were designed according to the dimensions ASTM standard D256 of 64 mm x 12.7 mm x 3.2 mm through a computer-aided design (CAD) program, (Meshmixer; Autodesk Research). A standard tessellation language (STL) file was made and exported to a print preparation software, PreForm (Formlabs). Supports were added to the bars, and then the bars were oriented to be printed vertically with the top of the bar parallel to the platform of the 3D printer (Figure 1). The STL file was sent to the desktop 3D printer (Form 2; Formlabs) to print a total of seventy-five bars using 3D printer resin (Denture Base LP, Formlabs), at a layer thickness of 50 µm. All 3D printed samples went through the manufacturer’s recommended post-cure processing; washing for 5 minutes in 96% isopropyl alcohol and then photo-cured for 30 minutes at 80 °C in 100% pure vegetable glycerin (Form Cure; Formlabs). All supports were removed. Twenty-five of the seventy-five 3D printed samples were used solely as the 3D printed specimens. The other fifty 3D printed samples were used as a template to fabricate the other two types of denture base material specimens; heat-cured (Lucitone 199, Dentsply Sirona) and cold-cured acrylic resins (Lucitone HIPA, Dentsply Sirona), n=25.

The cold-cured acrylic resin samples were fabricated through a pouring technique. The 3D printed patterns were invested using type-4 dental stone and hydrocolloid in a hydrocolloid metal flask. The stone cast was soaked in the water for 10-20 minutes prior to pouring the hydrocolloid mold material by the placement of sprue holes within the mold material. After the stone was set, patterns were removed from the mold, and the boil-out was simulated by placing the flask in a boiling water bath. Separating medium (Magicote; Nobilium) was painted on the surface of the type-4 dental stone. Cold-cured acrylic resin was mixed in a ratio of 20 g: 15 ml of
polymer to monomer for 15 seconds and then poured in the hydrocolloid mold through the sprue holes. The flask was placed in the water with sprue holds upright at 45 °C. The pressure pot was closed, applying 20 psi and cured for 30 minutes. The flask was allowed to cool, and then specimens were removed.

Heat-cured acrylic resin specimens were fabricated through a compression molding technique and processed with a conventional ejector-type, brass denture flask (Hanau) containing five 3D printed patterns. The patterns were invested in type-3 dental stone (Microstone, Whipmix) and type-4 dental stone (Hard Rock; Whipmix) for easy separation. Upon stone setting, patterns were removed from the mold, and the boil-out was simulated by placing the flask in a boiling water bath. A separating medium was painted on the surface of the dental stone and processed according to the manufacturer’s instructions using twenty-six cc of polymer and eight ml of monomer covered for nine minutes. The doughy mixture was packed, pressed and set for nine hours in a water bath curing unit (Hanau). All samples were rinsed and submerged in distilled water for 24 hrs at 37 °C. After storage, each acrylic sample was polished by using denture polishing burs and pumice on a rag wheel.

**Impact Testing**

The impact strength of each group of the materials was measured using the Izod method (unnotched specimens) with a one ft-lb (1.35J) hinge pendulum (Monitor Impact Tester, Testing Machines Inc.). The specimens were marked at the midline and secured into the pendulum impact test fixture to face the striking edge of the pendulum. The pendulum was released and allowed to strike through the specimen. The impact energy was read directly from the impact
tester in joules and cross-sectional area of each specimen was used to calculate impact strength in kJ/m$^2$ (Figure 2).

**Statistical Analysis**

The differences of denture base material on impact strength were evaluated through R statistical software. likelihood ratio test ($p<0.05$) and the error distribution was normal and was specified appropriately in the statistical model.9 One-way analysis of variance (ANOVA) was performed to test the differences in impact strength between the types of denture base material. Tukey's multiple comparisons of means test were used to compare the means of the three material groups ($\alpha = .05$).

**RESULTS**

Significant differences in mean impact strength (kJ/m$^2$) were shown among heat-cured, 3D printed and cold-cured acrylic resins respectively (Table 2). Tukey's multiple comparisons of means test showed that the impact strength for cold-cure acrylic resin was significantly greater, 14.9 than both heat-cured ($p<.001$), 8.9 and 3D printed resins ($p<.001$), 11.2 respectively, while the impact strength for 3D printed resin was significantly greater than the conventional heat-cured acrylic resin ($p<.001$) (Fig 3 and Table 3).

**DISCUSSION**

The current study investigated the impact strength of 3D printed, heat-cured (Lucitone 199), and cold-cured resins (Lucitone HIPA) using the Izod impact strength test. The results showed significant differences in impact strength depending on the denture base material used, and
therefore, the null hypothesis was rejected. The results indicate that the cold-cure resin material used in this study has comparably superior impact strength, making it suitable for use in patients requiring removable prosthesis especially the elderly patient with poor dexterity prone to drop dentures accidently. Impact strength is important to consider because, with dentures, it is crucial to prevent fractures or to predict their clinical performance.

The conventional heat-cured acrylic materials were showed to have significantly lower impact strength than the 3D printed resin group. This could be attributed to residual monomer, variances in powder to liquid monomer ratio, processing temperatures/ times and, post-curing processing.\textsuperscript{10} Schoeffel et al.\textsuperscript{10} observed thermocycling effectively reduced the mechanical properties of heat-cured acrylic denture base resins. As the conventional method is a temperature-dependent process, the temperature variations may also influence the water absorption of these materials.\textsuperscript{13} Hence the conventional heat-cured materials resistance to impact may be further confound when subjected to thermal stresses in the oral cavity by food intake.

The mechanism of reinforcement of the individual acrylic resin is often unknown, as most manufacturers of denture base materials are reluctant to reveal the exact composition of the products or the mechanisms of reinforcement used. The high impact cold-cure resin used in this study (Lucitone HIPA) is claimed to be a better and improved denture base material in the market. This agrees with the results of those found by Murphy et al.\textsuperscript{11} In their study, the author compared three denture base materials; a heat-cured, and two types of cold-cured resin with rubber-reinforced polymers. The results demonstrated that the cold cured resins with improved polymers had significantly higher impact values than the heat-cured resins. The authors stated that with the cold-cured resin, the residual dough remains soft throughout the process and
provides as a reservoir of material that compensates for the polymerization and thermal contraction.11

The 3D printed resin is an alternative to the conventional heat-cured acrylic resin. The greater impact strength of the 3D printed resin in this study (Denture Base LP), compared to the conventional material, may be both attributed to less human error in the automated processing and the resin’s compositional effects on mechanical properties. The impact strength between the 3D printed, heat-cured, and cold-cured resins in this study were similar to the findings in a study by Steinmassl et al., which evaluated the impact strength of milled and conventionally fabricated denture base resins.12 In their study, the authors compared five-milled CAD/CAM denture base resins with conventional heat-cured and cold-cured resins. They reported a varying range of impact strengths among the milled resins. Some were significantly higher than the conventional resins, as in this study; however, some were lower than the conventional ones. Therefore, the results of the current study must be interpreted with care as differing results may be due to differences in the resin compositions or post-processing procedures, or both. In other words, different printers and resin brands may contribute to differences in mechanical properties such as impact strength.

As with most studies evaluating impact strength in vitro, it would be beneficial to have a range of impact values for comparison when a denture in dropped and hits the ground in real-life. Since no such data is available, the reported outcomes are utilized for material group comparisons. As such, the drawbacks of this method include the inability to control for all the characteristics of the oral cavity such as temperature, lubricant, duration and frequency of force, and load.13 However, the risk of fracture when a patient drops their denture occurs when the denture is outside of the
mouth, and the impact strength is a predictable measurement of its clinical performance as a desirable material property. Therefore, the impact strength has been shown to be an important mechanical property for the success of a denture. Denture design, material construction, aging of denture in oral environment, along with loading method and possible residual stress within the materials are all factors that need further study.¹

**CONCLUSIONS**

Within the limitations of this study, which are only generalizable for the products applied, it can be concluded:

- Both cold-cured acrylic and 3D printed resins used in this study may be used as improved alternative materials to conventional heat-cured acrylic.
- Cold-cured acrylic shows greater impact strength compared to 3D printed resin and heat-cured acrylic materials.

**ACKNOWLEDGMENTS**

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**REFERENCES**


TABLES

**Table 1.** Materials used in this study.

<table>
<thead>
<tr>
<th>Material</th>
<th>Product name</th>
<th>Manufacturer</th>
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<tbody>
<tr>
<td>3D printing resin</td>
<td>Denture base LP</td>
<td>Formlabs, Inc</td>
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<tr>
<td>Heat-cure acrylic</td>
<td>Lucitone 199</td>
<td>Dentsply Sirona, Inc</td>
</tr>
<tr>
<td>Cold-cure acrylic</td>
<td>Lucitone HIPA</td>
<td>Dentsply Sirona, Inc</td>
</tr>
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<td>SLA 3D printer</td>
<td>Forms 2 SLA</td>
<td>Formlabs, Inc</td>
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<td>3D printing post-wash; 96% isopropyl alcohol</td>
<td>Form Wash</td>
<td>Formlabs, Inc</td>
</tr>
<tr>
<td>3D printing post-curing unit; 405n light</td>
<td>Form Cure</td>
<td>Formlabs, Inc</td>
</tr>
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<td>Silicone acrylic polishers; course, medium, fine</td>
<td>AcryliPro</td>
<td>Brasseler, USA</td>
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**Table 2.** One-way ANOVA Results of Acrylic Type on Impact Strength

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III sum of squares</th>
<th>df</th>
<th>Mean square</th>
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<tr>
<td>Corrected model</td>
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<td>226.704</td>
<td>868.021</td>
<td>&lt;.001</td>
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<tr>
<td>Intercept</td>
<td>10158.228</td>
<td>1</td>
<td>10158.228</td>
<td>38894.535</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Acrylics</td>
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<td>2</td>
<td>226.704</td>
<td>868.021</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

df = degrees of freedom
Table 3. Means (kJ/m³) and standard deviations of impact strength for three-material groups.

<table>
<thead>
<tr>
<th>Material</th>
<th>Means</th>
<th>Standard Deviations</th>
</tr>
</thead>
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<tr>
<td>Cold-cure</td>
<td>14.9&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Heat-cured</td>
<td>8.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.3</td>
</tr>
<tr>
<td>3D printed</td>
<td>11.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Means with different superscript letters indicate significant differences, p<0.05.
FIGURES

Figure 1. STL of 3D printed specimens and template pattern samples in Preform print preparation software.
Figure 2. Schematic representation of Izod Impact Testing of acrylic materials.
**Figure 3.** Means and standard deviations of impact strength of acrylics for heat-cure, cold-cured and 3D printed groups. Different lowercase letters are statistically significant compared to each other.