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Fracture Resistance of Acrylic Dental Resins After Water and Alcohol Immersion

Effects on Cohesion and Adhesion

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Abstract

Acrylic resins continue to be popular in denture-base and maxillofacial prosthetic applications; the clinical longevity of such resins depends upon the polymerization technique and the exposure to the environment. This in vitro experiment compared fracture resistance of four acrylic resin materials: a representative heat-cured denture-base resin (Lucitone 199), a representative self-cured acrylic resin (Jet Denture Repair Acrylic), a cold-cured orthodontic acrylic resin (Orthocryl®), and a representative 3D-printed denture-base resin (NextDent Denture 3D+). One hundred and twenty standardized bar-shaped specimens were made and each split into four parts (n = 30 per material). Each group was further divided into three immersion conditions (n = 10): distilled water for 3 days, ethanol for 3 days, and ethanol for 10 days. Fracture resistance was then tested after immersion in a universal testing machine in a three-point bending test and the maximum fracture load was measured in Newtons. One-way analysis of variance and post hoc test by Tukey were used to analyze the data at a significance level of $p < 0.05$. Scanning electron microscopy was also used to investigate representative fractured surfaces in order to determine the fracture morphology. There were significant differences between the tested materials ($p < 0.001$). The acrylic resin with the highest fracture resistance was heat-cured and the minimum was with self-cured acrylic resin. The cold-cured orthodontic resin showed moderate performance and the 3D-printed resin was better than self-cured acrylic but still worse than heat-cured acrylic. The use of alcohol as a test material had an adverse influence on the material used and the more time the material was immersed in alcohol the more it deteriorated. The mechanical results were confirmed through SEM observations which revealed better fracture-surface integrity in the heat-cured group with more pronounced voids, microcracks, or structural discontinuities in the weaker groups. In the constraints of this in vitro experiment, heat-cured acrylic resin exhibited the most desirable fracture and solvent degradation resistance.

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Introduction

The material most frequently applied on production of removable dentures is acrylic resin because of the desirable characteristics such as ease of handling, biocompatibility, aesthetics and affordability. There are numerous kinds of acrylic resins, and some of the most common ones include heat-cured and self-cured (auto polymerized or cold-cured) acrylics used in dental practice. The polymerization approach is significant in the definition of the mechanical characteristics of the denture base, and the possible effect on fracture resistance, longevity, and clinical performance [1].

In the field of prosthodontics, denture fractures are frequent which results in patient discomfort, reduction of functional abilities and extra financial cost of repairing or replacing the device. Masticatory forces, accidental drops, and material fatigue may lead to fractures, and therefore, the choice of a proper acrylic resin is also an important factor in the field of prosthetic dentistry [2].

Acrylics that are heat-cured, polymerized at controlled heat and pressure, tend to have better mechanical strength, lower porosity and higher fracture resistance because of enhanced polymer conversion and the minimization of remaining monomers. Self-cured acrylics, which are cured at room temperature by chemical activation, are more practical to use in chairside repairs, relines, and temporary prostheses, but tend to have a higher porosity and reduced mechanical properties [3].

Cold-cured Orthocryl is a polymethyl methacrylate (PMMA) self-polymerizing resin that is used in the creation of denture base and repair. It cures at room temperature with a chemical activator (e.g., benzoyl peroxide) and a liquid monomer in contrast to heat-cured acrylics. It is fast processed and it is therefore applicable in quick denture adjustments and temporary dentures. Nevertheless, it has less mechanical strength and more residual monomer content than heat-cured resins, which could influence long-term durability [4].

Dental models, surgical guides, temporary crowns, and dentures are fabricated using 3D printer acrylic resins (usually photopolymerizable dimethacrylate-based material, e.g., urethane dimethacrylate or UDMA) through stereolithography (SLA) or digital light processing (DLP). These resins are very precise, have a smooth surface finish and are fast to prototype. Nevertheless, they can have worse mechanical characteristics (e.g., flexural strength, wear resistance), and to use them efficiently, it is important to post-cure them [5].

However, in the current situation, the fractured acrylic resin surfaces should be evaluated in the context of fracture morphology and internal structural integrity instead of adhesive bonding to the tooth tissues. In this case, surface features related to material continuity and failure pattern, including voids, microcracks, interlayer separation, roughness variation, and features of crack propagation were evaluated by SEM examination in this study that could assist in elucidating variations in mechanical performance after immersion [6].

Although the conventional and digitally manufactured denture base resins continue to widen in their application, there are few instances of direct comparative evidence when heat-cured, self-cured, cold-cured orthodontic and 3D-printed acrylic are compared within the same size of specimen and with the same conditions of solvent exposure. Moreover, not many studies have used mechanical testing coupled with fracture-surface SEM evaluation following water and alcohol immersion. Thus, the current experiment aimed at comparing fracture resistance of four acrylic resin systems stored in distilled water and ethanol and correlating the mechanical results with the surface characteristics at the end of fracture. The null hypothesis was that significant difference would not be observed between the tested materials or immersion conditions.

This paper has presented a comparative study on fracture resistance of four resin types of acrylics that include heat-cured acrylic, self-cured acrylic, Orthocryl denture resin and 3D-printed acrylic resin. The three subgroups of each material group were further divided according to the immersion medium (distilled water and alcohol). All the specimens were measured with a universal testing machine (UTM) in flexural strength. Also, scanning electron microscopy (SEM) was used to measure the post-fracture cohesion and adhesion properties.

Materials and Methodos

Our study was carried on 120 specimens, The specimens were divided into four major groups based on the materials used: 30 self-cure acrylic specimens, 30 heat-cure acrylic specimens, 30 Orthocryl acrylic specimens, and 30 3D-printed acrylic resin specimens (Table 1). Each major group was further subdivided into three subgroups according to the immersion process: distilled water, alcohol for 3 days, and alcohol for 10 days, with each subgroup containing 10 specimens.

The four material groups employed in the current research were standardized to representative commercial products whose manufacturer specifications are well documented to enhance traceability and reproducibility in the updated manuscript.

Bar specimens were standardized to a length of about 64 mm, width of 10 mm and thickness of 3 mm and prepared in a metallic mold. Testing was preceded by verifying all the dimensions with a calibrated digital caliper. The dimensions were chosen to provide an approximation to internationally used denture-base flexural testing geometry of acrylic resin materials.

Fabrication of Specimens

Vaseline was applied evenly on interior surfaces of dental flasks. Dental stone was prepared as per the manufacturer guidelines, vibrated to eliminate air bubbles and wax patterns were prepared. The stone was left to set, coated with cold mold seal separating medium and the wax was removed by boiling in water (4–6 minutes). Remaining wax was carefully cleaned off, and molds air-dried, then worked in by type of resin:

• Heat-Cured: Polymer and monomer were combined (2:1 by weight), filled and allowed to cure at 100°C in 2 hours.
• Self-Cured: Mixed at 2:1 ratio by weight, and processed at room temperature with pressure.
• Cold-Cured Orthodontic: 2:1 weight ratio, cured at Ivomet, 55°C and 2.5 bar in 20 minutes.
• 3D-Printed Resin: Printed with SLA/LCD and a layer thickness of 0.05 mm, cleaned in >90% isopropyl alcohol and cured under UV.

They were all finished and polished on acrylic burs, stone burs and a mixture of pumice and Tripoli with muslin wheels so that the specimens would have smooth glossy surfaces without any change in dimensions.

There were 120 specimens that produced 10 specimens per immersion subgroup in each material type. This balanced experimental design has helped to directly compare materials that were placed under the same storage conditions and has offered ample framework to use one-way ANOVA analysis of fracture resistance in four material groups and three immersion subgroups.

Each material group was split into three storage conditions (n = 10 per subgroup), with 3 days in distilled water, 3 days in ethanol, and 10 days in ethanol. Inclusion of ethanol storage was methodologically justified due to reported changes in surface and bulk properties of acrylic denture-base resins in ethanol-laden environments such as hardness, roughness, modulus and flexural strength through solvent-related softening and structural destabilization.

Testing For Flexural Strength

Following the immersion process, flexural testing was performed using a universal testing machine in three-point bending set-up and the maximum load at fracture was registered in Newtons. In standardized ISO 20795 denture-base polymer flexure test, the test item is clamped on 3.2 mm diameter supports separated at 50 mm and recent denture-base trials with 64 × 10 × 3.3 mm bar test items have typically used a crosshead speed of 5 mm/min. Fracture resistance is thus reported in the present study as the highest load to cause specimen failure during three-point bending.

Scanning electron microscopy was used to provide a qualitative characterization of the fracture-surface morphology of representative fractured specimens of each subgroup. The SEM analysis aimed at determining porosity, microcracks, irregular fracture topography, and crack-propagation features, and

in the case of the 3D-printed group, structural discontinuities that could be consistent with interlayer weakness. The SEM examination was not quantitative but interpretive, to correlate the fracture-surface appearance with the values of fracture resistance that were measured.

Statistical analysis was performed to compare fracture resistance among the four tested resin types. The data were summarized as mean ± standard deviation, and intergroup differences were evaluated using one-way analysis of variance followed by Tukey's post hoc test for pairwise comparisons, with statistical significance set at $p < 0.05$ (Tables 3 and 4). This analytical strategy is appropriate for comparing multiple independent denture-base material groups in vitro.

Results

A Universal Testing Machine was used to measure the fracture resistance values of the four types of resin (Table 2 and Figure 1). There were 30 samples per group, totaling 120 samples, which were tested. The highest load (Newton) at which fracture occurred was measured as fracture resistance.

Statistical analysis was performed to compare fracture resistance among the four tested resin types. The data were summarized as mean ± standard deviation, and intergroup differences were evaluated using one-way analysis of variance followed by Tukey's post hoc test for pairwise comparisons, with statistical significance set at $p < 0.05$ (Tables 3 and 4). This analytical strategy is appropriate for comparing multiple independent denture-base material groups in vitro.

One-way ANOVA demonstrated a statistically significant difference in fracture resistance among the four tested resin types ($F = 46.29$, $p < 0.001$). Based on the reported sums of squares, the effect size was large ($\eta^2 = 0.545$), indicating that resin type explained a substantial proportion of the total variance in fracture resistance. Tukey's post hoc analysis showed significant pairwise differences among all tested materials. Heat-cured acrylic resin exhibited significantly higher fracture resistance than self-cured acrylic resin, cold-cured orthodontic acrylic resin, and 3D-printed resin. These findings indicate that heat-cured acrylic resin showed the most favorable mechanical performance under the present in vitro conditions.

Comparative Analysis of SEM Images of Fractured Acrylic Resin Surfaces (all figures presented at ×50 magnification) (Figures 2 to 13).

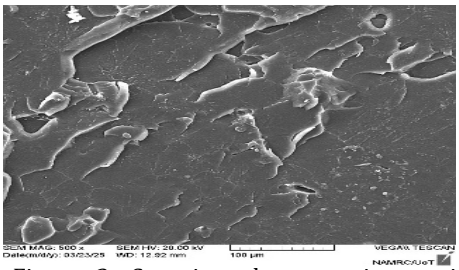

Figure 2. Scanning electron microscopic (SEM) (×50) micrograph of a fractured surface of a cross section of a sample of a specimen from the Heat-Cure Acrylic Resin.

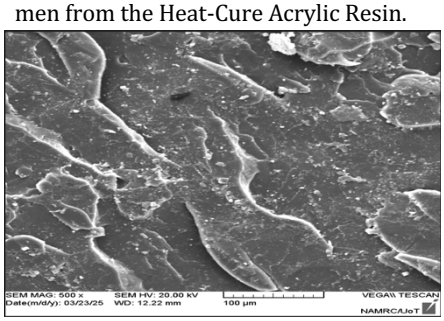

Figure 3. Scanning electron microscopic (SEM) (×50) micrograph of a fractured surface of a cross section of a sample of a specimen from the Cold-Cure Ortho Acrylic Resin.

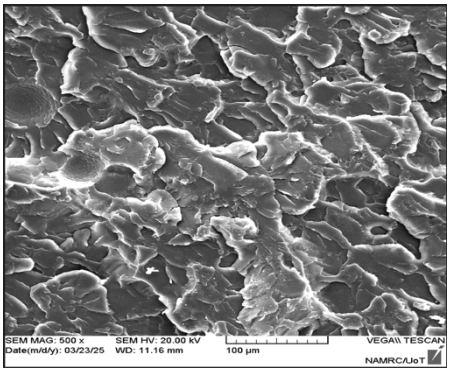

Figure 4. Scanning electron microscopic (SEM) (×50) Micrograph of a fractured surface of a cross section of a sample of a specimen from the Self-Cure Acrylic Resin.

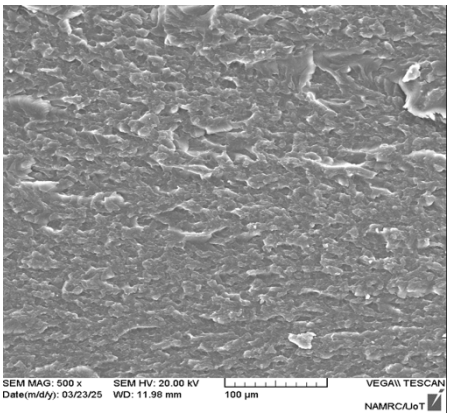

Figure 5. Scanning electron microscopic (SEM) (×50) Micrograph of a fractured surface of a cross section of a sample of a specimen from the 3D-Printed Acrylic Resin.

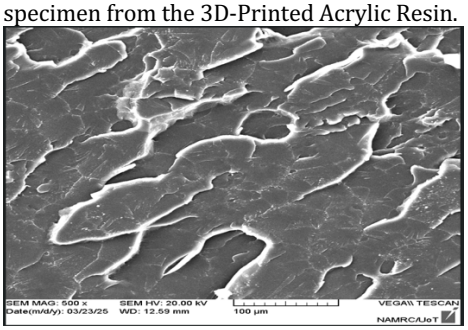

Figure 6. Scanning electron microscopic (SEM) (×50) Micrograph of a fractured surface of a cross section of a sample of a specimen from the Heat-Cure Acrylic Resin.

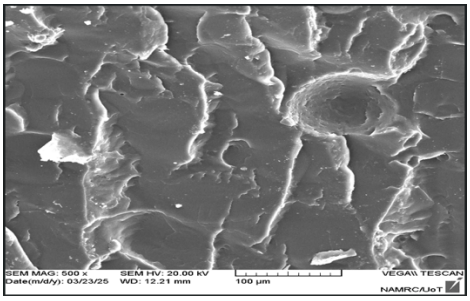

Figure 7. Scanning electron microscopic (SEM) (×50) Micrograph of a fractured surface of a cross section of a sample of a specimen from the (Cold-cure ortho acrylic resin.

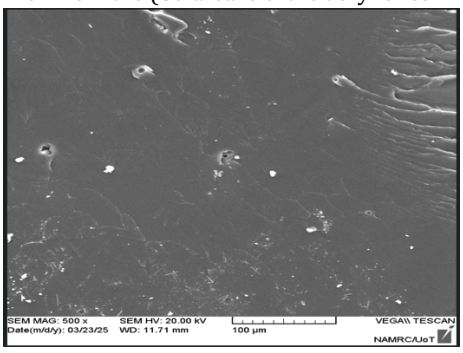

Figure 8. Scanning electron microscopic (SEM) (×50) Micrograph of a fractured surface of a cross section of a sample of a specimen from the (Self-cure acrylic resin).

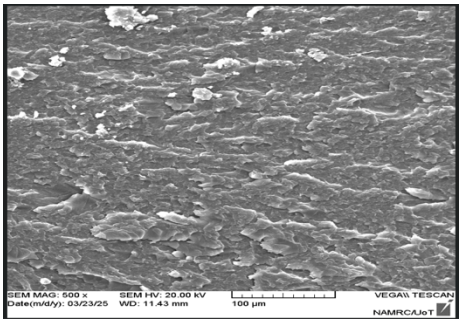

Figure 9. Scanning electron microscopic (SEM) (×50) Micrograph of a fractured

surface of a cross section of a sample of a specimen from the (3D-printed acrylic resin).

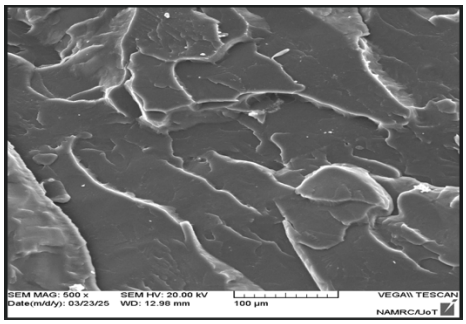

Figure 10. Scanning electron microscopic (SEM) (×50) Micrograph of a fractured surface of a cross section of a sample of a specimen from the Heat-Cure Acrylic Resin.

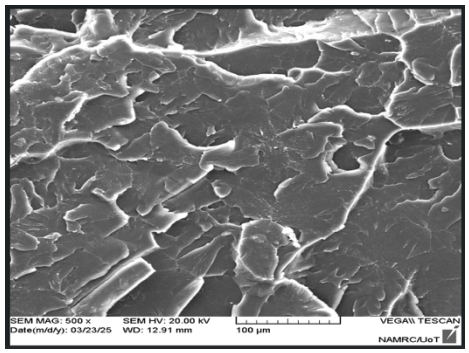

Figure 11. Scanning electron microscopic (SEM) (×50) Micrograph of a fractured surface of a cross section of a sample of a specimen from the (Cold-cure ortho acrylic resin).

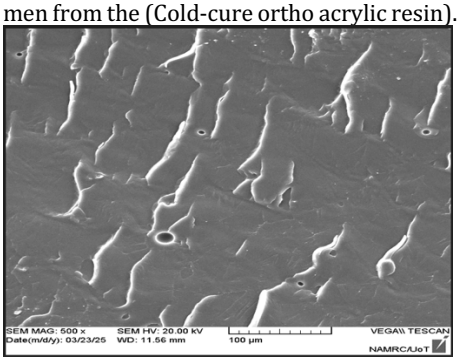

Figure 12. Scanning electron microscopic (SEM) (×50) Micrograph of a fractured surface of a cross section of a sample of a specimen from the (Self-cure acrylic resin).

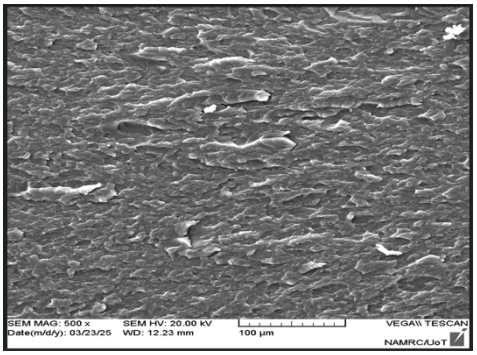

Figure 13. Scanning electron microscopic (SEM) (×50) Micrograph of a fractured surface of a cross section of a sample of a specimen from the (3D-printed acrylic resin).

Comparison of the Four Materials After 3 Days of Water Immersion

Based on the SEM analysis and the expected properties of each material, comparison in terms of intermolecular cohesion and adhesion after exposure to distilled water:
Ranking (Best to Worst Performance)
- Heat-Cure Acrylic Resin: High cross-linking density provides strong cohesion and resists water absorption. Minimal cracks/swelling in SEM. Adhesion: Stable bonding between polymer chains; no delamination observed.
- Cold-Cure Ortho Acrylic Resin: Moderate resistance to water. May show slight surface roughness/swelling but retains structural integrity. Adhesion: Slight particle aggregation but no major layer separation.
- Self-Cure Acrylic Resin: Porous structure leads to weaker cohesion (visible voids/cracks in SEM). Absorbs more water, causing swelling. Adhesion: Particle clustering indicates reduced bonding strength.
- 3D-Printed Acrylic Resin: Weakest adhesion due to layer-by-layer printing. SEM shows clear delamination between layers after hydration. Cohesion: Prone to microcracks along layer boundaries.

Comparison of Acrylic Resins Post-Alcohol Immersion

Ranking (Best to Worst)
- Heat-cure acrylic resin: High cross-linking density ensures strong cohesion and alcohol resistance.
- Cold-cure ortho acrylic resin: Moderate cohesion but may lack filler reinforcement.
- Self-cure acrylic resin: Faster curing leads to lower mechanical strength than heat-cured.
- 3D-printed acrylic resin: Layered structure is prone to interfacial weakness and alcohol penetration.

Comparative Analysis of Four Acrylic Resins After 10-Day Alcohol Immersion

Ranking (Best to Worst):
- Heat-cure: Best cohesion and adhesion due to high cross-linking density from thermal curing.
- Cold-cure ortho: Good resistance but less robust than heat-cure.
- Self-cure: Variable performance; depends on curing conditions.
3D printer: Worst performance due to layered fabrication and low alcohol resistance.

In summary:
- Heat-cure acrylic resin is the most alcohol-resistant, ideal for durable applications.
- 3D printer resin is unsuitable for prolonged alcohol exposure.
- Cold-cure ortho and self-cure resins are intermediate but require further optimization.

Discussion

The current research established that the fracture resistance of the heat-cured acrylic resin was the highest with the self-cured acrylic resin showing the lowest. Such results are in line with the prior studies that indicated that heat polymerization leads to an increase in the extent of conversion and cross-linking density, thus increasing the mechanical strength and lowering the content of residual monomer [7]. However, self-cured acrylics have been repeatedly found to have elevated amounts of unreacted monomer, which contributes to poor performance in mechanical and biological fields [8].
This research revealed an intermediate performance of cold-cured orthodontic acrylic resin, which is consistent with previous publications stating that cold-curing techniques result in materials with moderate strength and relatively high porosity levels as compared to heat-cured resins [9]. On the same note, SEM analysis showed presence of voids and microcracks in self-cured and cold-cured samples, which is consistent with previous morphological research that associates porosity with poor durability [10].
In the case of 3D-printed resins, it was shown that the performance was better than that of self-cured acrylics, but much lower than that of heat-cured materials in fracture resistance. This aligns with earlier reports that the layer-by-layer printing technique creates anisotropy and poor interlayer bonding that makes printed resins more prone to microcracking and delamination under stress [1,11]. Moreover, the resistance to solvents has also been studied among 3D-printed materials, which are also reported to be susceptible to alcohol exposure, indicating that clinical use of this technology might be restricted to provisional appliances unless resin formulations are improved [12].
The additional stress on the resilience of heat-cured acrylics was achieved with the immersion experiments in distilled water and alcohol. These findings agree with the other research works that have found out the hydrolytic stability of heat-cured resins, which can be explained by the dense polymer matrix [7]. Conversely, the sharp decline of 3D-printed resins in the presence of alcohol supports recent studies that the materials are highly susceptible to solvent-induced plasticization and interfacial weakening [13].

Combined, the current results support the literature evidence that heat-cured acrylic resins are the gold standard in the fabrication of denture bases because they have a better mechanical performance. Meanwhile, they also give additional reasons as to why 3D printing, however increasingly practiced in clinical settings, is still limited in the materials used, which needs to be improved to deliver similar long-term results [9,11].

The results of the current study must be discussed in the constraints of an in vitro study. The oral environment was not simulated entirely since it did not include cyclic fatigue loading, thermocycling, salivary enzymes, pH fluctuation and prolonged clinical aging. Moreover, the protocol of immersion was restricted to distilled water and ethanol and, thus, represents the choice as opposed to a comprehensive oral exposure environment. The SEM analysis was qualitative, and the revised material table was standardized with representative commercial products having publicly available specifications as opposed to the undocumented original package identities. Such limitations ought to be considered in the extrapolation of the current findings to the performance of long-term clinical performance.

Conclusion

- Heat-cured acrylic resin exhibited better fracture resistance and microstructural stability, which supports earlier findings about its high level of polymerization and cross-linking.
- Self-cured acrylic resin was the poorest performing, as previous research has identified a relationship between high porosity and incomplete polymerization and low strength.
- Cold-cured orthodontic resin was intermediate to heat- and self-cured resins, and it backs the previous reports of moderate performance due to lower curing efficiency.
- 3D-printed resin, despite being better than self-cured acrylic, is hampered by interlayer weakness and solvent sensitivity, which is congruent with the recent research on additive manufacturing in dentistry.

Future studies should aim at optimizing resin formulations and 3D-printing parameters to eliminate these mechanical constraints.

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Table 1. Commercial identity, manufacturer details, country of origin, and principal composition of the materials used in the study.

Material group	Representative commercial product	Manufacturer	City	Country	Principal composition	Public product identifier	Batch / lot
Heat-cured acrylic resin	Lucitone 199 Denture Base Resin	Dentsply Sirona / Dentsply LLC	York, Pennsylvania	USA	Powder is predominantly poly(methyl methacrylate); liquid contains methyl methacrylate with ethylene glycol dimethacrylate as cross-linking component	Representative powder identifier: MFR# 688111	Not publicly fixed; package-specific
Self-cured acrylic resin	Jet Denture Repair Acrylic	Lang Dental Manufacturing Co., Inc.	Wheeling, Illinois	USA	Powder contains polymer (CAS 9011-14-7) < 90% and benzoyl peroxide < 2%; liquid contains methyl methacrylate monomer	Powder SDS family: Self Curing Denture Powder / Jet Denture Repair Powder 004	Not publicly fixed; package-specific
Cold-cured orthodontic acrylic resin	Orthocryl® classic	DENTAURUM GmbH & Co. KG	Ispringen	Germany	Powder is polymer (PMMA); liquid contains methyl methacrylate 90 to <95% and ethylene dimethacrylate 5 to <10%	Powder clear: 160-112-00; liquid clear: 161-100-00	Not publicly fixed; package-specific
3D-printed acrylic resin	NextDent Denture 3D+	Vertex-Dental B.V. / NextDent by 3D Systems	Soesterberg	The Netherlands	Ethoxylated bisphenol A dimethacrylate ≥75%, 7,7,9(or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate 10–20%, 2-hydroxyethyl methacrylate 5–10%, silicon dioxide 5–10%, diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide 1–5%, titanium dioxide <0.1%	Product family: NextDent Denture 3D+	Not publicly fixed; package-specific

Table 2. Descriptive statistics of fracture resistance.

Resin Type	Number of Samples	Mean (N)	Standard Deviation (N)	Minimum (N)	Maximum (N)
Heat-Cured Acrylic Resin	30	890.2	72.6	810	980
Self-Cured Acrylic Resin	30	685.7	65.3	600	750
Cold-Cured Orthodontic Acrylic Resin	30	730.4	68.9	650	810
3D-Printed Resin	30	775.6	70.4	700	850

Heat-cured acrylic resin exhibited the highest mean fracture resistance (890.2 N ± 72.6 N), while self-cured acrylic resin had the lowest (685.7 N ± 65.3 N).

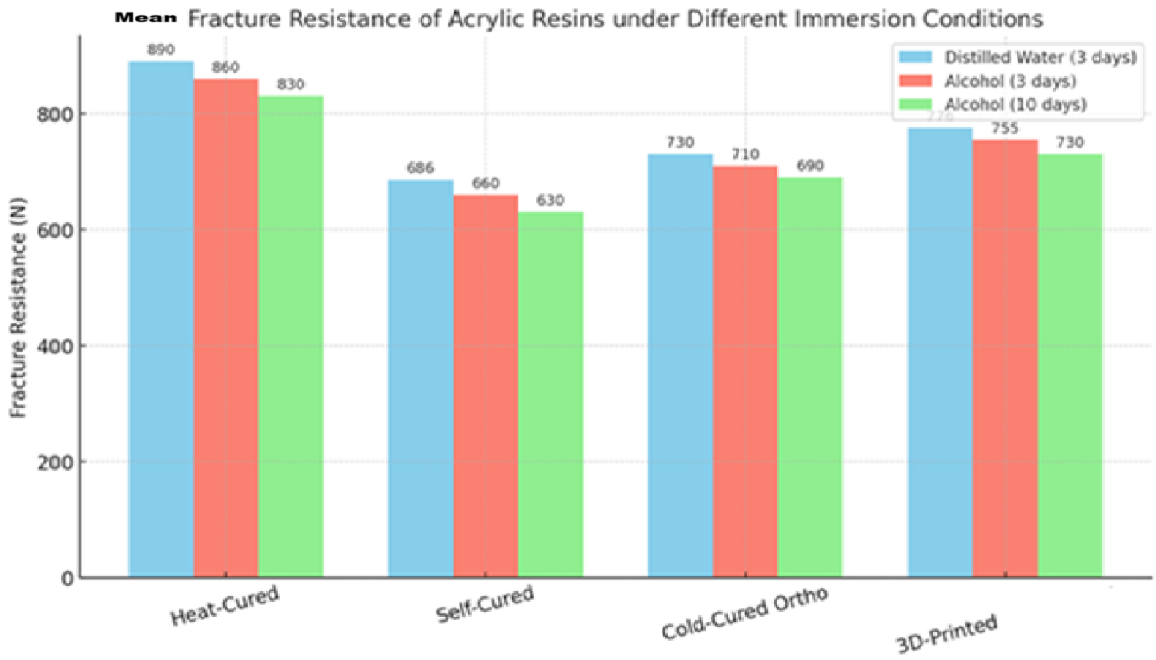

Figure 1. Bar chart comparing fracture resistance of the four acrylic resin materials under three immersion conditions:

- Blue bars → Distilled water (3 days, baseline)
- Red bars → Alcohol (3 days)
- Green bars → Alcohol (10 days)

Table 3. ANOVA analysis.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Between Groups	670123.45	3	223374.48	46.29	<0.001
Within Groups	560346.20	116	4830.57		
Total	1230469.65	119			

Table 4. Post-hoc Tukey's pairwise comparisons.

Comparison	Mean Difference (N)	p-value
Heat-cured vs. Self-cured acrylic resin	204.5	<0.001
Heat-cured vs. Cold-cured orthodontic resin	159.8	<0.001
Heat-cured vs. 3D-Printed resin	114.6	<0.001
3D-Printed resin vs. Self-cured acrylic resin	89.9	<0.001
3D-Printed resin vs. Cold-cured orthodontic resin	45.2	0.045
Cold-cured vs. Self-cured acrylic resin	44.7	0.048