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Original Article

Evaluating the Mechanical Properties of Three Repaired Injection Molded PMMA Denture Resins: Fracture Force, Deflection, and Toughness

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ABSTRACT

Currently, broken dentures composed of high-impact acrylic polymers are difficult to treat. Therefore, the purpose of this study was to evaluate the fracture force, toughness, and deflection of three different types of thermoplastic denture base resins made of repaired injection-molded polymethyl methacrylate. The sample size for this in-vitro study was calculated using the G*power 3.0.10 program with an alpha error of 5% and a power of 80% in each group (groups A, B, and C) of 20 samples. Therefore, 60 high-impact injection-molded acrylic resin samples with dimensions of 39 × 4 × 8 mm were prepared, and a diamond disc was used to create a pre-crack along the designated centerline to a depth of 3.0 ± 0.2 mm. Probase cold, Triplex SR cold, and Lukafix light cure resin were used to repair the broken sections. The repaired site was tested using a three-point bending test, and the results were statistically examined using Tukey's post hoc test ($\alpha < 0.05$) and one-way ANOVA. Significant variations in flexural force, deflection, and fracture toughness between groups were shown by the statistical analysis. Group A showed an increase in fracture toughness of 245.06 N, a flexural strength of 24.0 Mpa, and a deflection of 0.14 cm. It was found that samples repaired using auto-polymerizing PMMA resin had substantial fracture force, deflection, and toughness. Therefore, the study concludes that compared with other resins, the auto-polymerizing resin can be utilized more effectively for auto-polymerizing PMMA resin repair.

Keywords: Injection molded acrylic resin, Denture fracture, Denture repair, Deflection, Toughness

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Introduction

Dentures can be constructed by microwave processing, compression molding, or injection molding of acrylic resin [1–3]. Because of its favorable qualities, PMMA is often treated using the compression molding method for denture construction [4]. Nevertheless, a dimensional shift ascribed to this method may be unavoidable. To resist fracture, the denture base acrylic resin must have Kmax (highest factor of loading intensity), fracture work Wf of 1.90 MPam1/2, and 900 J/m2, respectively, following ISO standard 1567:1981. However, cracks and fractures are frequent side effects of both injection-molded and compression-molded detachable prostheses. Among them, fatigue failure, extremely thin area, and thin flange near the frenum are the most frequent causes of midline fractures and cracks at the posterior cantilever area [5, 6]. Accordingly, Pryor created a plastic injection molding technology for dentures in 1942 [7]. In the closed mold, the continuous injection process with constant hydraulic pressure makes up for excessive shrinkage and creates a dense, robust, porosity-free plastic. According to studies, this injection-molded PMMA system exhibited improved water sorption, wear strength, deflection, and dimensional stability [8–10]. However, cracks and fractures are frequent side effects of both injection-molded and compression-molded detachable prostheses. Previously, auto-polymerizing resin glass fiber reinforcement, woven metal, visible light polymerized reline material, salinized glass fibers, and wires reinforced with Co-Cr or San-cobalt palatal bars were used to repair denture bases. These methods demonstrated notable outcomes when applied to traditional compression-molded PMMA dentures [11–14]. Restoring the denture to its original strength is the primary goal of denture repair. Several variables, including the fracture gap's breadth, the bevelling of the fracture surface, and the characteristics of the repair resin, affect the final strength following repair. Therefore, fracture strength and fracture toughness have an impact on the repaired denture base material's resistance to fracture [15]. Although injection-molded PMMA thermoplastic resin dentures are brittle, they cannot be fixed using the same material. Determining the flexural characteristics, such as strength, deflection, and toughness, is therefore essential following the repair of the broken denture base using additional auto-polymerizing and light-cure resins. The fracture toughness of repaired injection-molded polymethyl methacrylate denture base resins hasn't been examined in any prior research, nevertheless. Therefore, the purpose of this study is to assess the fracture force, toughness, and deflection of thermoplastic denture base resins made of injection-molded polymethyl methacrylate that have been repaired using two distinct auto-polymerizing resins and one light-curing resin. According to the study's null hypothesis, the three tested repair materials had the same fracture force, deflection, and toughness.

Materials and Methods

This in-vitro study was conducted in SRM Dental College from March 2018 to December 2019 and was approved by the institutional review board with the IRB number SRMDC/IRB/2017/MDS/NO.202 The sample size was estimated to be 20 samples per group, using G*power 3.0.10 software with a power of 80% and alpha error of 5% the sample size was calculated.

A master brass die was prepared according to ISO 20795.1.2013 with dimensions of 65 mm × 40 mm × 5 mm in brass. The master die was duplicated with an additional silicone impression material (Aquasil soft putty, Dentsply, Germany) to prepare the mold. The wax blocks were prepared from the mold **(Figure 1)** and processing was done using injection-molded PMMA resin (SR Ivocap High Impact, Ivoclar Vivadent, Liechtenstein) based on the manufacturer's instruction. The acrylic specimens were retrieved after the curing cycle was completed and checked for any irregularities. Then the specimens were trimmed and finished using acrylic stone trimmers and 600 grit sandpaper. Each specimen was cut into six equal samples measuring 39 mm in length, 4 mm in width, and 8 mm in height using a milling machine.

A total of 60 samples were made and their dimensions were verified using a digital micrometer (Digimatic Micrometer, Japan). The test samples were stored at 37 °C in water for 24 hrs before testing. The samples thus obtained were fixed lengthwise in the holding device and a mark was set exactly on the centreline of the sample. A pre-crack was cut with a diamond disc according to ISO 20795.1.2013 to a depth of (3.0 ± 0.2) mm along the marked centreline. Then the pre-crack was wet with a drop of glycerol and a sharp notch was made with a Double-sided 0.25 × 22 mm NTI Flex disc (Val Lab diamond disk, US) **(Figure 2)**. The notched samples were stored in a container with water at 37 ± 1 °C for 7 days before testing.

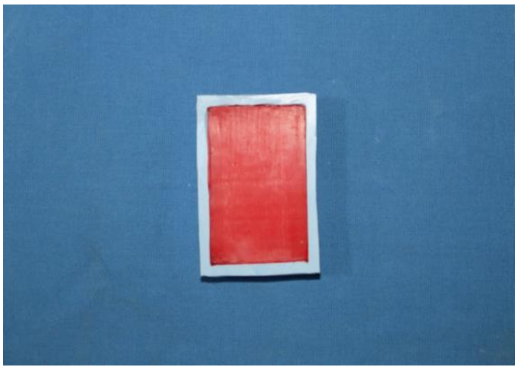

Figure 1. Wax pattern

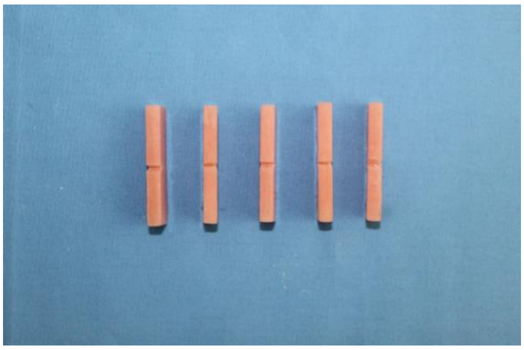

Figure 2. Repaired samples with a butt joint

For fracture toughness, the samples were staged on the Universal Testing Machine (Autograph Universal Testing Machine, Shimadzu Corp, Japan) so that the notch faced directly across from the load plunger. The specimen was subjected to a load at the midpoint until the crack nearly reached the other side. A measurement was made of the maximum load before fracture. Following fracture testing, the samples were split into three groups at random (n = 20) for repair, and they were explained as:

Group A: Repaired with Probase Cold, auto polymerizing resin (n = 20);

Group B: Repaired with Triplex SR cold, auto-polymerizing resin (n = 20);

Group C: Repaired with Lukafix, light-curable resin (n = 20).

Probase Cold (SR Triplex Cold Pink–V (541433AN), Ivoclar Vivadent, Liechtenstein) was used to repair the samples in group A. Triplex SR auto polymerizing resin (ProBase Cold Trial Kit pink-V (531487AN) Ivoclar Vivadent, Liechtenstein) was used to repair the samples in group B, while LukaFix light-curable resin (LUKAFix-Kit, pink, Indenco Dental goods, USA) was used to repair the samples in group C. A halogen lamp light-curing equipment (BlueLuxcer, Taiwan) was used to cure the group C samples for ten minutes at a wavelength of 360–480 nm and a voltage of 50/60 Hz. The gap was filled with group A, group B, and group C acrylic resin after the butt joint surface had been treated for three minutes with each acrylic resin's monomer liquid. Following polymerization, 600-grit sandpaper was used to polish and finish the surfaces of every repaired sample. The repaired samples were separated and kept in distilled water at 37 °C for seven days, and their fracture toughness was assessed. Three-point bending was used to test the repaired site, and the values obtained were statically analyzed with one-way ANOVA and Tukey's post hoc test ($\alpha \leq 0.05$). Statistical analysis was done with G*power 3.0.10 software.

Results and Discussion

The mean value of group A was 2.013, group B was 1.915, and group C was 1.753. The standard deviations of groups A, B, and C were 3.5581595, 7.7922529, and 9.7700762, respectively. **Table 1** shows the standard deviation and standard error for each group. The corresponding standard error values were 79, 1.74, and 2.18. In contrast, the 95% CI for the mean was lower for Group C (lower bound value of 1.479964 and higher bound value of 2.125036) and higher for Group A (lower bound value of 1.818730 and upper bound value of 2.549270).

The results of the ANOVA analysis of the values in **Table 2** showed that the group's sum of squares was 4510.614. Each group's mean square was 1127.653, and the F value was 20.904. Group A's post hoc Tuckey HSD value was statistically significant. Group A, which was repaired with the auto-polymerizing glue Probase Cold, had the highest fracture force (245.06 N), whereas group C had the lowest (181.90 N).

The average fracture force values for groups A, B, and C were 245.06, 229.55, and 181.90, respectively, as shown in **Table 3**. Thus, the mean fracture force values of group A samples were higher than those of groups B and C. In contrast, group C's deflection values in **Table 4** were greater than those of groups B and A. Group C samples had the most deviation, measuring 0.38 cm, whereas group A samples had the smallest, measuring 0.14 cm.

Table 1. The standard deviation and standard error of each group- descriptive fracture toughness

	N	Mean	Std. Deviation	Std. Error	95% Confidence interval for mean	
					Lower bound	Upper bound
Group A	20	2.013	3.5581595	.7956286	1.818730	2.549270
Group B	20	1.915	7.7922529	1.7424007	1.738613	2.232387
Group C	20	1.753	9.7700762	2.1846554	1.479964	2.125036
Total	60	5.681	9.8654739	1.5742283	1.679102	2.302231

Table 2. One-way analysis of variance (ANOVA) for fracture toughness

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	4510.614	4	1127.653	20.904	.000

Table 3. Mean fracture force of different repair resins incorporated into injection-molded PMMA

S/No	Group	Mean fracture force (N)
1.	Group A	245.06
2.	Group B	229.55
3.	Group C	181.90

Table 4. Mean deflection of different repair resin incorporated into injection-molded PMMA

S/No	Group	Deflection (cm)

1.	Group A	0.14
2.	Group B	0.24
3.	Group C	0.38

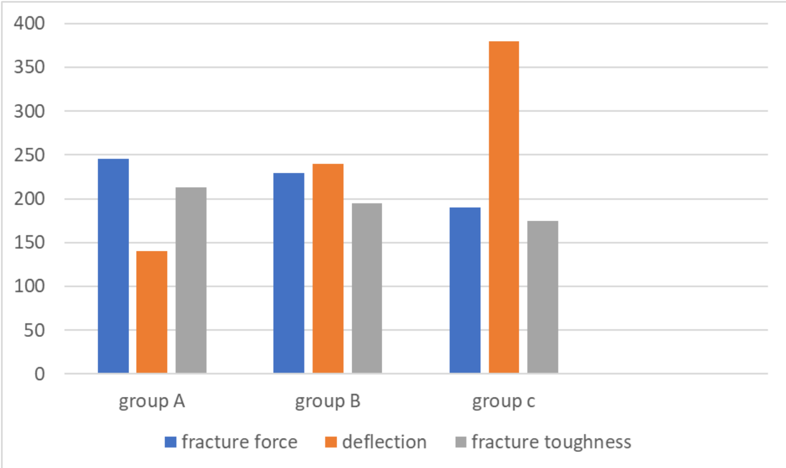

Figure 3. Graphical representation of fracture force, deflection, and fracture toughness plotted against the groups.

The mean and standard deviation for fracture force, deflection, and fracture toughness are displayed against the groups in **Figure 3**. The samples from group A displayed the least amount of deflection, whereas the ones from group C displayed the most. In comparison to group B and C samples, group A samples exhibited the highest fracture toughness, fracture fore, and minimal deflection.

To address the drawbacks of traditional heat-polymerized PMMA resin, Pryor [7] invented an injection molding technique in 1942. He discovered that a continuous injection technique on a closed mold produces a denser, stronger prosthesis by compensating for shrinkage. Improved mechanical characteristics, less polymerization shrinkage, and improved dimensional stability are the benefits of employing the injection-molded process. Any edentulous patient's typical biting force falls between 100 and 150 N, after which the prosthesis fractures.

When the denture base surpasses its maximum mechanical capacity and is subjected to flexural fatigue, it may fracture [16, 17]. It was said that the highest needed repair strength might be 75-85% of the original strength and that the flexural strength of a broken denture base could decrease to 22–65% of its original strength after repair. The repaired strength in this investigation exceeded 7.9–72.1% of the necessary strength. Conventional heat polymerizing PMMA resin was typically repaired after fracture utilizing a variety of technologies, including heat polymerized, microwave, or light polymerized resins. However, the most frequent fracture was near the repair site [18, 19]. Good strength, cost-effectiveness, shade matching, ease of application, speed, biocompatibility, and dimensional stability are all necessary for a repair to be considered satisfactory. In a study on repair strength using traditional heat polymerizing resin, researchers discovered that auto-polymerizing PMMA resin resulted in superior repair strength [20]. For the repaired prosthesis to sustain the masticatory strain, it must possess adequate fracture toughness. Prior research has been conducted to assess the fracture toughness of conventional heat-polymerized PMMA resin that has been repaired [21]. On injection-molded PMMA, no repair research has been conducted, though. Therefore, the fracture toughness of repaired injection-molded PMMA resin was examined in the current study.

Hamanaka *et al*. [8] evaluated the presence of good bond strength between auto-polymerizing resin and injection-molded thermoplastic denture base resins. Likewise, two sets of auto-polymerizing resins and one set of light-polymerizing resins were employed as repair materials in this investigation. The current study adopts the three-point bending test that Ban and Anusavice proposed after studying the impact of the test technique on the stress of brittle dental materials [22]. Researchers used auto polymerizing and heat-cure repair material, together with three distinct processing techniques, to investigate the impact of repaired surfaces on both self-cure and heat-cure PMMA acrylic resin with three repair joints: butt, round, and 45-degree bevel. They discovered that the strength of repairs made with butt joints varied [23].

Therefore, the butt joint served as a repair joint for the groups in this investigation. Three characteristics of the repaired injection molding resin—fracture force, toughness, and deflection—were tested. This study's findings are consistent with a study by Kostoulas *et al*. that examined fracture force, deflection, and toughness on repaired conventional heat polymerized polymethyl methacrylate denture base resins and found that the fracture force of the repaired resin was highest in group A samples and lowest in group C samples [24]. This is explained by the stronger link between injection-molded thermoplastic denture base resins and auto-polymerizing resin. Therefore, the auto-polymerizing resin-repaired samples' flexural strength was suitable for clinical applications.

The ability of the denture base material to withstand the spread of cracks caused by surface imperfections or notches is known as fracture toughness.

The 3-point bent test, which has been recommended to assess fracture force, deflection, and fracture toughness, is the international standard for determining the flexural characteristics of denture base resins. To ascertain the mechanical performance of repaired high-impact denture bases, the fracture toughness of the study was assessed. Contrary to the current investigation, researchers previously observed that denture bases repaired using auto-polymerizing resin had reduced flexural strength [25]. According to a 1997 poll on denture repair, 86% of respondents said auto-polymerized PMMA resin was a suitable repair material. The findings of this study support the survey's findings on toughness and recommend the use of auto-polymerizing resin as a high-impact denture base repair material [26]. Nevertheless, fracture toughness was computed, indicating that group C had more flexibility, and deflection was highest in group C and lowest in group A. In line with the current work, Polysois *et al*. conducted a study on the fracture toughness of traditional heat-cured PMMA and repaired it using auto-polymerizing glue, which resulted in an enhanced mean value [11]. The samples repaired with group A had a minimal deflection, indicating that they were more rigidly handled.

When compared to specimens treated with auto-polymerizing resin, which is in line with Andreopoulos's findings [27], specimens repaired with light polymerizing resin (Group C) showed extremely poor mechanical qualities. For high-impact denture bases, the light-cure resin might not be an appropriate repair material. It can be due to the repair area's decreased wettability, increased viscosity, high stiffness, and low flow rate [28-30]. The results of the present in vitro investigation show that the fracture toughness of high-impact injection molding resin is improved by autopolymerizing acrylic repair resin. This in-vitro study's shortcoming is its limited capacity to assess the repair material's efficacy in clinical settings. Therefore, additional clinical research in the future may help assess the high-impact injection molded PMMA dentures' mechanical qualities, longevity, and quality.

Conclusion

The study's limitations led to the conclusion that Group A samples fixed with auto-polymerizing PMMA resin had considerable fracture force, deflection, and toughness. Therefore, the current study showed that auto-polymerizing PMMA resin is a preferable option for repairing high-impact injection-molded PMMA resin that has fractures.

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Conflict of Interest: None

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Ethics Statement: The study was approved and completed as per the research protocol approved by the Institutional Review Board with the approval number SRMDC/IRB/2017/MDS/NO.202.

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