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Evaluation of Flexural and Shear Bond Strength on Digital Denture Base Resin Repaired by Different Resin Materials

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Abstract

Aim: The objective of this study was to assess the flexural and shear strengths of a denture base resin composed of Poly-Methyl-Methacrylate (PMMA) that had undergone milling using Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) and repair using acrylic resins that had been heat-, auto-, and light-polymerized subsequent to a range of chemical and mechanical surface treatments.

Material and Methods: 285 CAD/CAM milled resin specimens with rectangular shapes were created. A total of 15 specimens were preserved as controls, and the remaining 270 specimens underwent 3 mm-wide repairs. With resins that were heat-polymerized, auto-polymerized, and/or light-polymerized, the specimens from three groups (n = 90) were repaired, respectively. According to the method of surface treatment (MMA monomer, sandblasting roughened, and combination), the specimens of each primary repair resin were further separated into 3 subdivisions (n=30). The specimens underwent three-point flexural and shear bond strength tests (n=15). The one-way ANOVA test was used to analyze the maximum load required to fracture the specimens statistically.

Results: For CAD/CAM repair, the heat-polymerized PMMA resin produced a much stronger bond than the auto-polymerized and light-polymerized resins. Roughening plus MMA monomer produced a significantly stronger link than MMA monomer alone or MMA monomer plus roughening alone.

Conclusions: The use of heat-polymerized PMMA resin is recommended for CAD/CAM resin repair in combination with MMA monomer and roughening.

Keywords: Bond Strength , Digital Denture Base Resin, Repair, Flexural and Shear strength

Introduction

Removable dental prostheses can still be made using well-established traditional methods, which are still widely utilized in clinical settings [(1)]. These conventional complete denture techniques need numerous patient visits in addition to a lot of chairside and lab time [(2)]. CAD/CAM techniques can now be used throughout the whole denture production process thanks to recent developments [(3)]. The advantages of using computerized technologies include quicker denture production with fewer steps in the workflow, which can reduce the likelihood of mistakes [(2, 4)].

The bases of these dentures are frequently subjected to repeated loading during mastication as well as falls while handling, especially since the majority of the wearers are elderly people with limited physical dexterity [(5)]. These conditions can lead to denture base fractures, which require the use of repair methods to protect patients' health. The ideal repair methods would be simple, and affordable, and would ensure that the repaired prosthesis would have adequate mechanical resistance [(6)].

Denture bases made with typical PMMA-based resins may be readily repaired by dentists in the dental office, mostly by using self-curing acrylic resins. Furthermore, the literature discusses the use of rigid resin for self-curing relining in repair regions, along with surface treatments that improve its adhesive properties [(7, 8)]. Many methods have been documented for treating surfaces, including chemical treatments such as conditioning with MMA, acetone, chloroform, and ethyl acetate, and mechanical treatments such as surface roughening with abrasive sandpaper and aluminum oxide particles [(6, 9-11)].

A material's shear bond strength is the maximum load it can sustain before breaking under shear stress. A shear bond strength (SBS) test is often used to evaluate the strength of the connection between denture base resins [(12-14)]. Not only is the SBS test available, but there are other ways as well. Flexible bond strength (FBS) testing is a novel method for assessing bond strength[(15)]. SBS testing is the most common because it is simple and easy to prepare specimens for testing. No further treatment is required after the bonding procedure [(1, 15)].

There is limited knowledge regarding the mechanical properties of the materials used in a subtractive technique for creating removable prostheses and their potential for repair in research. This is mainly because of the problem of fatigue in denture base materials and the lack of literature on repairing denture bases made through CAD/CAM milling. The aim of this research was to evaluate the flexural and SBSs of a denture base resin made using a digital subtractive manufacturing process and then repaired using different chemical and mechanical techniques.

Materials and Methods

The investigation used 285 specimens, as per the methodology outlined in a prior study conducted by Viotto et al. (2022) [(6)], (15 sample/test). The objective was to detect an effect size of 20.04 with a power (1-β error) of 0.8, using a two-sided hypothesis test and a significance threshold (α error) of 0.05 for the data analysis. 270 CAD/CAM milled

specimens were divided according to the type of repair resin (heat-polymerized, auto-polymerized, and/or light-polymerized) into 3 main groups (n=90) and one unrepaired (intact) CAD/CAM milled resin; the control group (n=30). Each of the 3 experimental CAD/CAM groups was further subdivided into 3 subgroups (n =30) concerning the method of surface treatment (Chemical, mechanical, or combination). Each subgroup was then subdivided into 2 equal subdivisions (n=15) based on the type of test (flexural or shear).

Specimens preparation

A 5-axis milling machine (Dentsply Sirona in Lab MC X5, Germany) and CAD software (3Shape Cambridge) were utilized to create a rectangular specimen for flexural bond strength testing. The specimen has dimensions of 32.5 mm in length, 10 mm in width, and 3.3 mm in thickness. Additionally, a separate specimen with dimensions of 10 mm in length, 10 mm in width, and 2.5 mm in thickness was created for SBS testing [6, 16]. Finishing was done with silicon carbide paper (500 and 800 grit) by a single researcher [16, 17]. A total of 570 specimens were prepared (n=285/per test). Two specimens of each test (flexural and shear) were used to make a rubber-base impression index. According to ISO/FDIS No. 1567 recommendations, after polishing, all specimens were kept in distilled water at 37°C for 50±2 hours [6]. (Figure 1)

Surface modification

In the chemical surface modification, all bonded surfaces of each two surfaces of the specimens were prepared with diamond stone in a dovetail design for the flexural and shear strength test (Figure 1), the surfaces of each two of the prepared milled specimens were swabbed with an MMA solution (Veracril® Heat-cure resin, new-static Co., Brazil) by using a micro-brush in one direction for 180 seconds [6].

In the mechanical surface modification, the surfaces of each two of the prepared specimens were treated with a sandblaster (Wassermann Dental Machine, GmbH, Hamburg, Germany) at 2.5 bar emission pressure for 10 seconds at a distance of 1 centimeter then washed for 4 minutes in an ultrasonic bath to eliminate any sand residue [6, 16]. However, in the chemical-mechanical surface modification, the sandblasting was performed followed by treatment with MMA solution [6, 16, 18].

Repair procedures

The prepared specimens were placed on a premade rubber base impression index. For the heat-polymerizing repaired specimens' the resin was mixed (3:1 by volume) and applied to the repair area (dovetail gap) which slightly overfilled to the justification for finishing and shrinkage brought on by polymerization. Then, the repaired specimens were flasked in dental stone and then heat-cured at 60°C for 2 hours. For the auto-polymerizing and the light-polymerizing repaired specimens, the resin was applied to the repair area with a slightly overfilled and thick glass plate placed over the repaired specimen, and finger pressure for 10 minutes was applied to adapt the resin into the gap at room temperature [6, 18]. After 5 minutes

in the light-curing unit, the light-cured specimens in the rubber-base index were cured for a further 8 minutes on the opposite side [18]. The repair location was polished with 400 and 600-grit silicon carbide sandpaper after polymerization. The restored specimens' sizes were verified by using a digital caliper. The samples were then stored in water for seven days at 37 ^{o}C [6, 18]. (Figure 1)

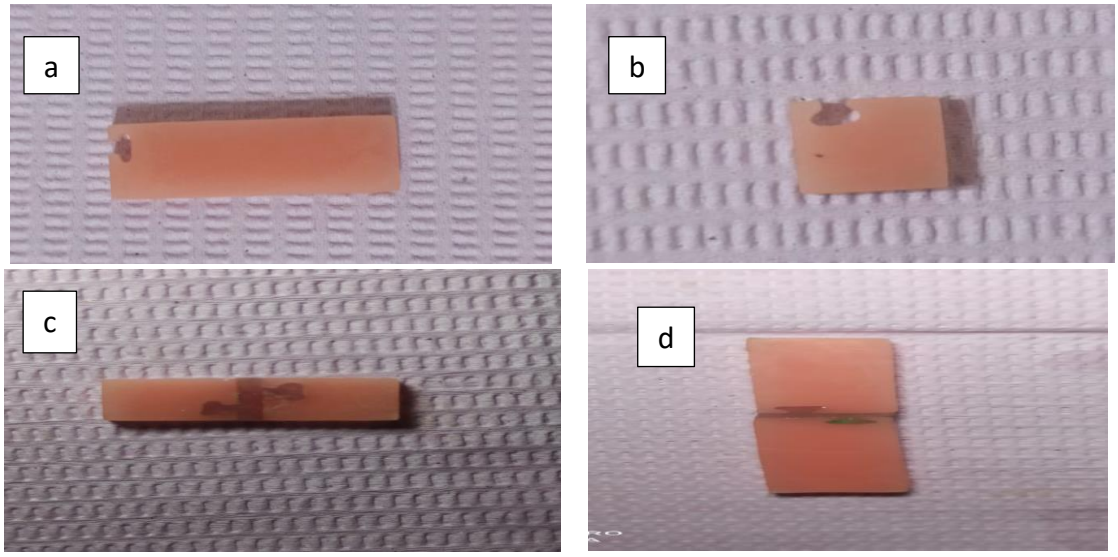

Fig. 1: A Figure showing specimens (a) before repair for the flexural test; (b) before repair for the shear test; (c) after repair for the flexural test; (d) after repair for the shear test.

Flexural and SBS tests

The flexural strength of all materials was tested using an Instron model 3345 universal testing machine, which is a kind of equipment that can perform many tests. The fixture, with a span length of 50 mm, is a machine component used to stabilize acrylic resin samples [18, 19]. Each individual sample was exposed to a 5 kilo-newton (KN) force, applied at 20 mm, with a crosshead speed of 5 millimeters per minute (mm/min)[18, 19]. Each sample was gradually subjected to a force perpendicular to the center until a fracture occurred during the test to compute the transverse strength using the maximum force applied with the following equation [20]; Flexural strength (FS) (N/mm^2) $=3WL/2bd^2$ where; W; is the load at fracture (N); L; is the distance between supporting wedges (50 mm); b; is the width of the sample (10 mm); d; is the thickness of the sample (2.5 mm).

However, in the shear bond test, each sample was affixed using a distinct loading jig. The SBS was evaluated using a 5 k.N. load cell and a crosshead speed of 1.0 mm/min [21]. During the test, each sample was progressively exposed to a tensile shear force until it fractured.

Statistical analysis:

The data's normality was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. A one-way ANOVA test was used to compare the shear and flexural bond stresses. A statistically significant criterion of $P < 0.05$ was used.

Results

The Shapiro-Wilk and Kolmogorov-Smirnov tests for normality showed that all groups' data is parametric. A One Way ANOVA test showed a significant difference (P<0.0001) in the averages of the tested groups for flexural and SBSs for repair materials with varied surface treatments (tables 1 and 2). The bond strength of heat-polymerized PMMA resin for CAD/CAM repair was greater than auto- and light-polymerized resins. The combination of MMA monomer and roughening increased bond strength, followed by roughening alone.

Table (1): Comparison of flexural strength results regarding the type of repair material and method of surface treatment

Variable	Intact	Heat-cure	Auto-cure	Light-cure	P-value
MMA	78.18 ± 1.01^{a}	27.18 ± 0.98^{bB}	16.94 ± 0.67^{cB}	8.00 ± 0.57^{dB}	<0.0001*
Sandblast	78.18 ± 1.01^{a}	23.32 ± 0.84^{bC}	12.98 ± 1.10^{cC}	5.42 ± 0.76^{dC}	<0.0001*
MMA + Sandblast	78.18 ± 1.01^{a}	35.40 ± 3.14^{bA}	21.83 ± 1.12^{cA}	12.19 ± 1.00^{dA}	<0.0001*
P-value		<0.0001*	<0.0001*	0*	

Table (2): Comparison of sear strength results regarding the type of repair material and method of surface treatment

Variable	Heat-cure	Auto-cure	Light-cure	P-value
MMA	453.21 ± 22.03^{aB}	315.38 ± 7.86^{bB}	26.57 ± 1.88^{cC}	<0.0001*
Sandblast	344.37 ± 6.96^{aC}	261.57 ± 22.65^{bC}	19.53 ± 3.51^{cB}	<0.0001*
MMA + Sandblast	551.19 ± 46.74^{aA}	405.08 ± 26.90^{bA}	35.84 ± 5.12^{cA}	<0.0001*
P-value	<0.0001*	<0.0001*	0.0006*	

Discussion

The most sophisticated CAM technique is milling from polymerized resin discs. Pre-polymerized acrylic resin is dimensionally stable and provides a better fit for milled CAD/CAM complete dentures while the resin in traditionally treated bases experiences polymerization shrinkage [(22)]. Better physical properties of pre-polymerized acrylic resin enable the construction of bases that are thinner than the palate [(23)].

The ideal repair methods would be simple, and affordable, and would ensure that the repaired prosthesis would have adequate mechanical resistance. [(6, 19)] Therefore, to determine the ideal repair material for CAD/CAM milled resin 3 different available repair resin materials (heat-, chemical-, and light-polymerized resins) were used in this current investigation.

Because it has been claimed that denture bases made with conventional resins based on PMMA can be repaired using straightforward procedures carried out in a dentist's office, primarily using self-curing acrylic resins, the self-polymerized PMMA resin was selected in the current investigation as a repair denture base resin. [(20, 24, 25)]. Few physicians favor light-polymerized resins to get beyond the drawbacks of both heat- and auto-polymerized acrylic

resins. In this current investigation, the light-polymerized resin was chosen as a repair resin because it offers some benefits, including superior color stability and lessened chemical sensitivity as a result of its low residual monomer concentration [(19)].

In this current investigation, the MMA monomer was selected because according to Viotto et al. (2022) [(6)], the use of the MMA monomer can dissolve a PMMA-based resin, which enables the chemical formation of new polymer chains at the bonding interface when this PMMA resin is repaired with an autopolymerized resin. Moreover, the surface treatment with MMA monomer for 180 seconds was chosen in this current in vitro study because it was stated that the use of MMA monomers for the condition of the PMMA resin for 180 seconds it was considerably increased the flexural strength [(6)]. In this experiment, the repair site dimension was maintained uniformly at 3 mm to reduce the volume of the repair material and, as a result, minimize polymerization shrinkage [(19)].

In comparison to other acrylic resins (auto or light-polymerized), heat-polymerized resin demonstrated higher fracture resistance and flexural strength when used to repair the broken PMMA denture in this investigation. Due to the structural similarity of the repairs, stronger chemical bonding and adhesion may have been possible with the use of bulk acrylic resin material [(19)]. Moreover, the presence of the monomer in the initial poor consistency resin mixture, together with the dissolution of the PMMA cracked edges, resulted in the formation of robust secondary semi-interpenetrating polymer networks [(26)]. It is also anticipated that additional heat exposure during repair will speed up the polymerization of bulk acrylic resin. [(19, 25)]. These results agree with the results of previous studies by Arioli Filho et al. (2011) [(26)] and AlQahtani and Haralur. (2020) [(19)] found that the PMMA resins which repaired with heat-polymerized resin had significantly higher bond strength than PMMA resin repaired with autopolymerized resin.

In this current investigation, the poor flexural and SBSs of auto-polymerized resins when compared to the heat-polymerized resin could be related to chemical polymerization initiators that provide less polymerization in the autopolymerized resin [(25)]. Moreover, Arioli Filho et al. (2011) [(26)] stated that compared to auto-cured resin, the heat caused quick polymerization and decreased the amount of leftover monomer. However, not all of the monomer in auto-polymerized resin is converted to polymer in denture repair, and it has been shown that the amount of leftover monomer affects other qualities.

When compared to auto-polymerized materials, heat-polymerized materials have been shown to have better mechanical characteristics [(26)]. Even though heat-polymerized resin repair strengths are promising, it is rarely used because of some unfavorable aspects, including the need to fabricate a split gypsum mold, higher laboratory costs, a higher risk of heat-induced deformation, longer polymerizing times, and the patient's lack of a denture during the repair process [(19, 26)].

Moreover, the inferior bond strengths of the light-polymerized resin when compared to the heat-, and auto-polymerized resins in this current investigation could also be due to the manual mixing and adaptation of the light-polymerized resins over the repair site is standard

procedure [27, 28]. In addition, it undergoes polymerization without pressure. Therefore, reduced mechanical performance is caused by the high likelihood of internal voids and faults being included. Furthermore, the PMMA polymer network may not be penetrated by light-polymerized resin dough as effectively as other repair resins with more residual monomers and lower viscosity resins [19, 27, 28].

Moreover, in this current in vitro investigation, the resin when combined with surface treatment with MMA monomer considerably increased flexural and SBSs. This could be attributed to the formation of new polymer chains at the bonding interface due to the solvent action of the MMA monomers and the formation of chemical bonds between the CAD/CAM PMMA milled resin and the repaired PMMA (heat or auto-polymerized) resins of similar chemical composition [6, 19, 29]. Additionally, it was mentioned that the MMA monomer and PMMA repair resin have a direct chemical bond that is on the opposite side. Covalent chemical connections between unreacted groups (C=C) of the bonding agent, which depend on the pace of new material copolymerization with these unreacted groups, first join denture base resin and repair resin [30-32].

The flexural and shear bond results of this investigation revealed that the combination of sandblasting with the MMA monomer treatment resulted in higher bond strength than the MMA monomer alone. This might be explained by the fact that changes in surface morphology caused the mechanical interlocking between the denture base resin and repair resin to be strengthened by the application of monomer to the repair surface. This would increase the bond strength and increase the flexural and SBSs [30]. This may also be related to the sandblasting procedure used in surface treatment, which increases the surface bonding area and improves micromechanical retention [29].

Conclusions

Within the constraints of this investigation, it is suggested that heat-polymerized PMMA resin be used in conjunction with MMA monomer and roughening for CAD/CAM resin repair.

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