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ORIGINAL ARTICLE

Evaluation of shear bond strength of microwaveable acrylic resins in denture repair: A comparative study

GEORGE MARIATOS[1], MARIA FRANGOU[1], GREGORY POLYZOIS[1] & TRIANTAFILLOS PAPADOPOULOS[2]

[1]*Division of Removable Prosthodontics, School of Dentistry, University of Athens, Greece, and* [2]*Department of Biomaterials, School of Dentistry, University of Athens, Greece*

Abstract
Objective. Acrylic denture base fracture is a common mode of failure. Heat-cured, auto-polymerized, visible light-cured, and microwaveable acrylic resins have been used as repair materials. The aim of this study was to evaluate the shear bond strength of two microwaveable resins (Acron MC and Justi) and one auto-polymerizing acrylic resin (ProBase Cold) as denture repair materials as opposed to a heat-cured one using the non-flasking procedure after thermocycling and photoaging. ***Material and Methods.*** Ninety cylindrical specimens were made using the Vertex Rapid Simplified heat-cured acrylic resin. Each repair acrylic resin was poured on the specimen's surface using a cylindrical rubber mold with an internal diameter of 8.5 mm. Thirty specimens for each repair material were made. The control group consisted of 10 specimens from each group which were stored in water for 24 h at 37°C; another 10 specimens from each group were subjected to a thermocycling procedure (5–55°C for 1,000 cycles), while the remaining 10 specimens were subjected to a photoaging procedure. Shear bond strength was measured on a universal testing machine and mode of bond failure was examined under a stereomicroscope. Two-way ANOVA and the Bonferroni *post hoc* test were performed to identify statistical differences at $\alpha = 0.05$. ***Results.*** Justi's shear bond values were significantly inferior to those of ProBase Cold ($p < 0.05$) and Acron MC ($p < 0.05$). ProBase Cold and Acron MC acrylic resins exhibited similar values ($p > 0.05$) of shear bond strength. Thermocycling and photoaging did not affect the shear bond values of any of the materials under investigation ($p > 0.05$). ***Conclusions.*** ProBase Cold and Acron MC exhibited similar shear bond values. Justi repair material exhibited inferior bond strength compared with that of ProBase Cold and Acron MC. Aging procedures did not affect the bonding properties of any of the repair materials.

Key Words: *Acrylic resins, dentures, microwaves, repair*

Introduction

Acrylic resin fractures represent a common mode of failure for removable prostheses following clinical use. It has been estimated that 29% of the repairs carried out were due to denture base fractures, 33% to debonded/detached teeth and 38% to detachment of acrylic resin saddles from the metal framework and fracture of connectors in the all-acrylic resin partial dentures [1].

Although the suggested way of coping with acrylic resin fractures is the construction of a new prosthesis, this solution is a time-consuming and expensive procedure that deprives the patient of a prosthesis for a long period of time. Therefore, denture repair, either as a temporary or definitive measure, represents a frequent clinical procedure.

Acrylic resin repair presents the problem of repair material. The ideal repair material should possess high transverse and shear bond strength, dimensional accuracy, good esthetics, and should not cause any allergic reactions.

Heat-cured, auto-polymerized, visible light-cured and microwaveable resins have been used as repair materials. Auto-polymerizing acrylic resin has been widely used because of its simple application and low cost. Repair strength varies from 40% up to 90% [2–6] of the intact denture base material.

Conventional heat-cured acrylic resin has been proved merely comparable to auto-polymerizing resin despite the fact that the former demonstrates higher mechanical properties. It is argued that heat-cured acrylic resin produces viscous dough with low porosity resulting in inefficient wetness of the

Correspondence: Gregory Polyzois, Division of Removable Prosthodontics, School of Dentistry, University of Athens, 2 Thivon Str., Athens 115 27, Greece. Tel: +30 210 7461 129. Fax: +30 210 7461 189. E-mail: grepolyz@dent.uoa.gr

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fracture sites and consequently inferior adherence [4]. Repair strength values range from 42% to 96% [2,3,7,8] compared to intact denture acrylic resin.

Visible light-cured resins are characterized by accuracy of fit and high strength [9], but on the other hand, they exhibit low resistance to hydrolysis and high water absorption [10] resulting in inferior adhesive strength when used as repair material [11–15] with repair strength values ranging from 18% to 58% compared to the auto-polymerizing acrylic resin.

Microwaveable acrylic resin has made its appearance over the past two decades and is characterized by promising attributes including dimensional stability, high strength, simple implementation, and low residual monomer [16]. Its use as repair material has produced similar or even superior strength values compared to auto-polymerizing acrylic resin with values ranging from 63% up to 106% [6,8,17–20] of the intact denture acrylic resin.

Finally, it is noteworthy that several attempts have been made to reinforce the repair materials by incorporating metal wire or glass fibers. Both types of reinforcement provide a moderate increase in the repair strength ranging between 14% and 33% [5,21–24]. It should be borne in mind that the mechanical properties of the metal wire reinforcement depend on the configuration of the wire [5].

Depending on the repair material of choice, e.g. heat or auto-polymerized, a conventional denture flasking procedure requiring laboratory involvement might be necessary, and consequently the patient is deprived of his/her prosthesis for a varying period of time. On reviewing the literature, a recent publication has been found, in which denture base repair was performed with a direct, non-flasking procedure that allowed imminent repair [25]. The investigators involved in the study compared the shear bond strength of two auto-polymerizing resins and a microwaveable acrylic resin with that of a conventional heat-cured resin.

The purpose of the present study was to evaluate the shear bond strength of two microwaveable resins and one auto-polymerizing denture acrylic resin as opposed to a heat-cured one using the non-flasking procedure under two modes of aging, i.e. water thermal cycling and accelerated photoaging. The hypothesis tested was that there is no difference in the bond strengths among the three repair materials and that the mode of aging has no effect on the bond strength.

Material and methods

Denture base specimen construction

Ninety cylindrical blocks were constructed of conventional heat-cured acrylic resin (Vertex Rapid Simplified; Vertex-Dental B.V., The Netherlands) following the manufacturer's guidelines simulating the denture base. The acrylic blocks were 15 mm in diameter, in order to fit into the testing jig system.

Repair material specimen construction

The aforementioned cylindrical blocks were divided into three test groups. A cylindrical rubber split mold with an internal diameter of 8.5 mm was used in order to keep the dimensions of the test materials constant. Surface preparation of each block included trimming with up to 240-grit silicon carbide sandpaper and priming with the corresponding resin monomer for 3 min.

The first group was bonded with ProBase Cold (Ivoclar Vivadent, Liechtenstein) auto-polymerizing acrylic resin acting as the control group. Powder and liquid were mixed in a ratio of 15 g/10 ml according to the manufacturer's instructions and then poured into the rubber mold. Specimens were placed in a pressure unit at 55°C at 0.2 MPa for 20 min.

The second group was bonded with Acron MC (GC Corp., Tokyo, Japan) microwave polymerizing acrylic resin. Powder and liquid were mixed in a ratio of 43 g/100 ml according to the manufacturer's instructions and immediately poured into the rubber mold before reaching "dough" stage. As soon as "dough" stage was reached, the specimens were placed into a microwave oven of 2450 MHz at a power of 500 W for 3 min following the manufacturer's instructions.

The final group was bonded with Justi (Justi Products, Div. of American Tooth Industries, USA) microwave polymerizing acrylic resin. Powder and liquid were mixed in a ratio of 15 g/10 ml according to the manufacturer's instructions and immediately poured into the rubber mold before reaching "dough" stage. As soon as the "dough" stage was reached, the specimens were placed into a microwave oven of 2450 MHz at a power of 500 W for 3 min in accordance with the manufacturer's instructions. The aforementioned acrylic resins were tested, based on the fact that Acron MC and Justi were resins designed specifically for microwave curing, whereas Vertex Rapid and ProBase Cold were chosen as representing a commonly used heat-cured denture base resin and an auto-polymerizing denture repair material.

Aging conditions

Ten specimens from each group were stored in water at 37°C for 24 h before testing, defining the control aging procedure.

Another 10 specimens from each group were subjected to a thermocycling procedure for 1,000 cycles. Each thermal cycle consisted of 10 s at 5°C and 55°C, respectively, with a 2-s dwell time [26].

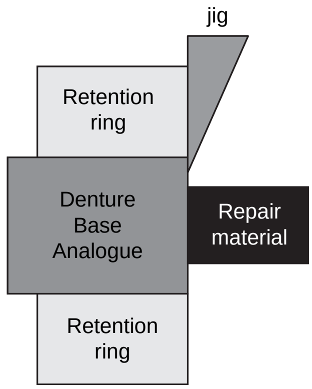

Figure 1. Schematic diagram of the testing jig.

The remaining 10 specimens from each group were subjected to a photoaging procedure using the SunTest CPS^{+} (Atlas Material Testing Technology LLC, Ill., USA) weathering apparatus. Weathering parameters consisted of 300–800 nm wavelength, 765 W/m^2 irradiance, 37°C water immersion and radiant exposure of 66.096 KJ/m^2 [27].

Shear bond strength measurement

Shear bond strength of the repair materials was tested in the Tensometer 10 universal testing machine (Monsanto Ltd., Swindon, UK) using a knife-edge shear test at a crosshead speed of 0.5 mm/min with a 1 KN load cell (Figure 1). Clinically the most important stress factors leading to bond failure are the shear stresses. For this reason the shear test was chosen as the more appropriate one to determine the bond strength of the different repair/denture materials under masticatory stresses. The force curve and maximum force needed to dislodge the repair material from the denture base were recorded. Bond strength was calculated in MPa by dividing the maximum force over the area of the bonding surface.

Fracture analysis

Fracture analysis was performed by microscopic examination at 50 × magnification using an optical microscope (Eclipse 200; Nikon, Japan). Mode of failure, depending on the percentage of the retained repair material on the surface of the acrylic base analogues, was arbitrarily considered as adhesive (up to 25%), mixed (25–75%) or cohesive (over 75%).

Statistical analysis

Statistical analysis included two-way ANOVA and *post hoc* comparisons using the Bonferroni test. The level of significance was set at $\alpha = 0.05$.

Results

Shear bond strength

Means and standard deviations of shear bond values are presented in Figure 2.

Two-way ANOVA revealed a statistically significant difference between the repair materials ($p < 0.05$). Using the Bonferroni *post hoc* test it was found that Justi repair material exhibited inferior shear bond strength compared with that for both ProBase Cold ($p < 0.05$) and Acron MC ($P < 0.05$) acrylic resins. Aging procedures did not alter the bonding properties of any of the repair materials ($p > 0.05$).

Mode of fracture

The percentages of failure type for each repair material are reported in Table I.

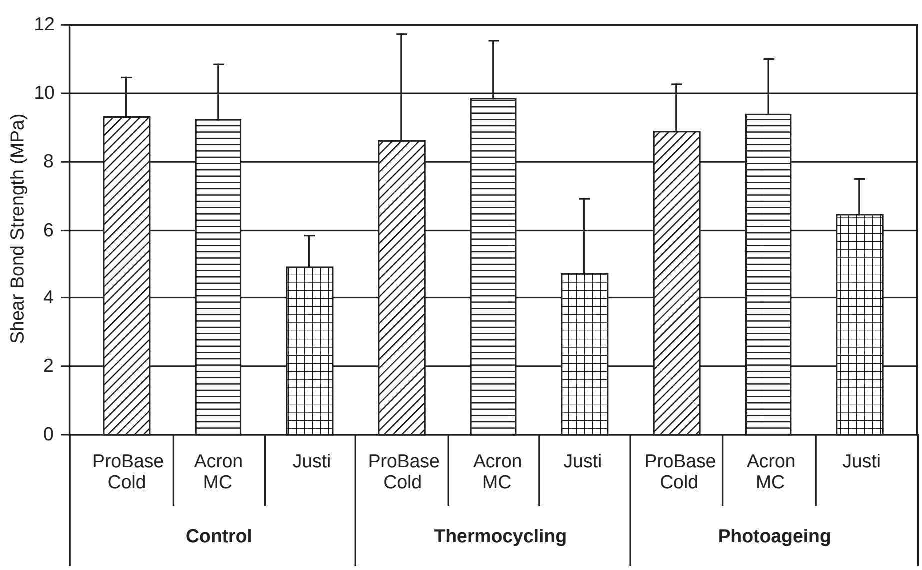

Figure 2. Shear bond strength mean values (MPa). Vertical bars indicate standard deviations.

Table I. Percentage (%) of modes in bond failure

	ProBase Cold	Acron MC	Justi	ProBase Cold	Acron MC	Justi	ProBase Cold	Acron MC	Justi
	Control			Thermocycling			Photoaging		
Cohesive	10	20	0	0	10	0	30	30	0
Mixed	30	30	30	10	40	0	40	60	10
Adhesive	60	50	70	90	50	100	30	10	90

ProBase Cold and Acron MC repair materials exhibited both adhesive and mixed types of fracture, while cohesive fractures were rare. Justi exhibited predominantly the adhesive type of fracture.

Discussion

The repair procedure for fractured denture bases has been extensively studied using various repair materials and reinforcement techniques. However, the standard repair procedure requires flasking of the fractured denture under laboratory conditions, a task that is expensive, time-consuming, and inconvenient for the patient, who is by force deprived of his/her dentures for varying periods of time. Our hypothesis that the repair materials exhibited the same bond strength was rejected.

The most important finding was the inferiority of the Justi repair material compared with the other two acrylic resins examined. On the other hand, Acron MC exhibited comparable and even slightly better, but not statistically different bonding strength compared with ProBase Cold auto-polymerizing acrylic resin. This finding is concordant with the study of Ng et al. [25], the only published study on denture repair applying the non-flasking procedure, demonstrating the clinical importance of Acron MC as a denture repair material. A slight difference with the aforementioned study was that, in our study, the mixing ratios proposed by the manufacturer were used, but the resin was poured quickly into the rubber mold before reaching the “dough” stage, whereas Ng et al. chose to increase the liquid ratio in order to obtain higher fluidity. In this way, possible deterioration of the physical properties of the material was avoided.

An important aspect of microwaveable acrylic resin is that it leaves a small amount of residual monomer compared to auto-polymerizing acrylic resin, resulting in minimal cytotoxicity and allergic response [28]. In view of this prospect, and given the fact that Acron MC exhibited similar shear bond strength to ProBase Cold, Acron MC has a clear advantage regarding clinical applications.

As far as the aging is concerned, our hypothesis was not rejected. Both the thermocycling and photoaging procedures failed to exert any effect on the bonding properties of any of the repair materials, reflecting their excellent behavior under a clinical environment.

Fracture analysis revealed that both ProBase Cold and Acron MC acrylic resins exhibited mainly adhesive and mixed types of fracture, while cohesive fractures were rare. On the other hand, Justi repair material exhibited a predominantly adhesive mode of failure, probably reflecting the inferiority of its bonding strength compared with the aforementioned materials under examination.

Compared to the study of Ng et al. [25], there seems to be a slight discrepancy concerning fracture analysis. These researchers observed mainly an adhesive mode of failure, but this is due to the fact that retention of the repair material on the base analogue’s surface up to 50% was set as adhesive. In our study, we sought to present a more elaborate fracture analysis by adding a mixed category of fracture. However, the present study did not simulate the repetitive cycling loading during mastication, and also the 1,000 thermal cycles applied did not reach the suggested 10,000 cycles representing a service year [29].

Within the limitations of this *in vitro* study the following conclusions were drawn: ProBase Cold and Acron MC exhibited similar shear bond strength values. Justi repair material exhibited inferior shear bond strength compared to ProBase Cold and Acron MC.

Aging procedures did not affect the bonding properties of any of the materials under examination.

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