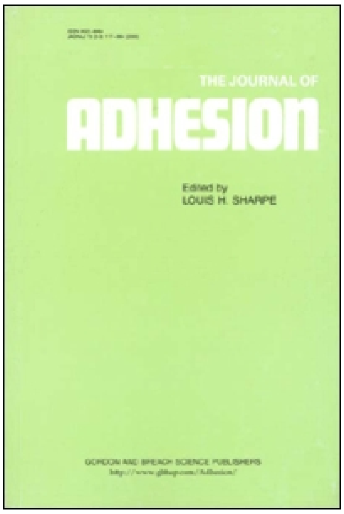

The Journal of Adhesion
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453635

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To cite this Article Consani, Rafael Leonardo Xediek , Manesco, Isabella Marques , Mesquita, Marcelo Ferraz , Correr-Sobrinho, Lourenço and Sinhoreti, Mario Alexandre Coelho(2008) 'Effect of Microwave Treatment on the Shear Bond Strength of Denture Tooth/Acrylic Resin', The Journal of Adhesion, 84: 11, 935 — 946

To link to this Article: DOI: 10.1080/00218460802505358

URL: http://dx.doi.org/10.1080/00218460802505358

The Journal of Adhesion, 84:935–946, 2008

ISSN: 0021-8464 print/1545-5823 online
DOI: 10.1080/00218460802505358

Effect of Microwave Treatment on the Shear Bond Strength of Denture Tooth/Acrylic Resin

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This study investigated the effect of microwave treatment on the shear bond strength of the denture tooth to acrylic resin adhesion, when the glossy ridge laps were unmodified, abraded, grooved, or etched by monomer. Eighty specimens ($n = 10$) were polymerized in a hot bath at 74°C for 9 hours, and deflasked after flask cooling. Specimens were soaked in 150 mL of distilled water and submitted to microwave treatment in a domestic microwave oven calibrated at 650 W for 3 minutes. Control specimens were not microwave treated. The shear bond strength test was performed in an Instron machine with a cross-speed of 1mm/minute. The ultimate fracture load value was transformed into shear bond strength as a function of the bonding area. Collected data were submitted to ANOVA and Tukey's test ($\alpha = .05$). Treatment by microwave energy significantly decreased ($p < .05\%$) the shear bond strength values in all ridge lap conditions used for the denture tooth/resin adhesion.

Keywords: Denture tooth adhesion; Microwave energy; Shear bond strength

INTRODUCTION

Prostheses sent from dental clinics to prosthetic laboratories are contaminated by pathogenic bacteria that may be transmitted to the

Received 18 February 2008; in final form 11 September 2008.
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technicians by direct contact or during denture finishing or polishing procedures [1,2].

A previous study has shown that microorganisms found in pumice slurry originate from contaminated prostheses that were polished without previous cleaning or disinfection [3]. In addition, sterile prostheses are commonly contaminated with pumice slurry or by microorganisms transferred from other prostheses during polishing procedures [4,5].

Microorganisms can cause prosthesis contamination by several mechanisms, such as during manufacturing procedures, manipulation by patients, or during clinical use. In an effort to eliminate or decrease cross-contamination, it is claimed that prostheses should be disinfected with suitable chemical solutions [1].

The chemical disinfection of prostheses has been suggested by many authors to avoid the cross-contamination promoted by pathogenic agent dissemination, using glutaraldehyde, sodium hypochlorite, iodoform, chlorine dioxide, or alcohol solutions [1,6–10]. However, chemical disinfection presents some disadvantages, such as prosthesis staining and oral tissue reactions in the patient [11,12].

To minimize the disadvantages of chemical disinfection, the use of microwave energy has been suggested as an alternative to prosthesis disinfection, with lower operational costs and ease of use [13]. Reports in the literature relate that microwave energy was originally used for thermally-activated acrylic resin polymerization [14]; however, the irradiation of resilient linings and acrylic resins in the presence of water in a domestic microwave oven can sterilize specimens contaminated by the fungi [12] *Candida albicans* or *Staphylococcus aureus* [13].

Taking into consideration the probability that the acrylic resin denture base is contaminated internally and externally [10], the use of microwave energy has been recommended as an ideal method for denture disinfection [15,16].

Disinfection of the acrylic resin by microwave has shown satisfactory results with regard to method effectiveness. The effects of microwave disinfection (500 W intensity for 3 or 15 minutes) on hardness, dimensional change, and flexural strength of the acrylic resin have shown that those parameters were not significantly changed by the disinfection procedure [13].

A previous study has shown that post-polymerization irradiation by microwave energy can also be an effective method for increasing the flexural strength of denture relining resins [17]. Recent findings showed that simulated disinfection by microwave irradiation improved denture base adaptation to the stone cast when the traditional clamp flask closure method was used [18] and significantly decreased the impact strength values of the tooth/resin bond, independently of the ridge lap surface conditions [19].

The fracture of the tooth/denture base bond may be caused by excessive stress or by fatigue. Conversely, a poor laboratory technique that impedes the formation of a satisfactory bond between tooth and resin base can also be responsible for many failures [20]. Previous studies have shown that imperceptible traces of wax on the ridge lap of the tooth seem to be the principal contaminant and have a highly significant detrimental effect on the bond, causing adhesive failure [21–23]. On the other hand, changes in the surface of the glossy ridge lap surface by grooving or abrasion do not make a significant difference when compared with unmodified surfaces [24], while a significant increase in bond strength was obtained when suitable bonding agents were applied [25].

Other studies have been developed with the purpose of demonstrating the influence of mechanical retentions on glossy ridge laps [26,27], and the monomer etching effect on the unmodified ridge laps [28–31], in the increase of the adhesive strength between tooth and denture base. In addition, few studies had been developed with the aim of characterizing the effect of microwave irradiation on the shear bond strength of the tooth/base resin adhesion, a critical condition that may modify the durability of the complete denture in oral use.

The purpose of this study was to verify the effect of microwave treatment on the shear bond strength of the denture tooth/acrylic resin adhesion, when the glossy ridge laps were unmodified, abraded, grooved, or etched by monomer. The research hypothesis tested was that the tooth/resin adhesion could be adversely affected by microwave treatment, independently of the conditions of the glossy ridge lap surface.

MATERIALS AND METHODS

The specimens for this investigation were made according to a previous study [19] in which the effect of impact strength on the denture tooth/acrylic resin bond was determined. For this purpose, wax rectangular mold patterns (30 mm in length, 5 mm in height, and 10 mm in width) were poured into a traditional brass flask (Safrany Metallurgy, Sao Paulo, SP, Brazil) with type III dental stone (Batch #00709, Herodent; Vigodent, Rio de Janeiro, RJ, Brazil) that was proportioned and manipulated following the manufacturer's recommendations.

After wax patterns removal, the stone mold was filled with a layer of laboratory silicone putty (Batch #25795, Zetalabor; Zhermack, Rovigo, Italy). Identical model 34L white acrylic molar teeth (Biotone; Dentsply, Petropolis, RJ, Brazil) with a wax stick (6 mm in diameter and 20 mm in length) attached at the ridge lap surface were partially embedded into the silicone layer. The resultant tooth/wax stick set was then covered with a layer of Zetalabor laboratory silicone putty. After dental stone isolation with petroleum jelly, the flask was completely poured with type III dental stone (Herodent) and pressed in a hydraulic press (Linea H, Sao Paulo, SP, Brazil) for 1 hour.

Following, the tooth/wax stick set was deflasked and the wax stick removed from the tooth ridge lap. The tooth was brushed with a solution of hot water and liquid detergent (Bombril-Cirio, Sao Paulo, SP, Brasil) to eliminate the wax residues, and rinsed with tap water. Specimens (Fig. 1) were made with the tooth ridge lap surface attached to the denture base acrylic resin, proportioned and manipulated according to the manufacturer's instructions. The following protocols were considered:

1. Tooth with no treatment;
2. Glossy ridge lap abraded with bur (abrasion with Maxi cut bur at medium cutting strength until obtaining visible surface roughness);
3. Glossy ridge lap grooved with bur (groove in the center of the ridge lap to a depth of 1.5 mm using a #8 round bur (compressive force perpendicular to the groove);

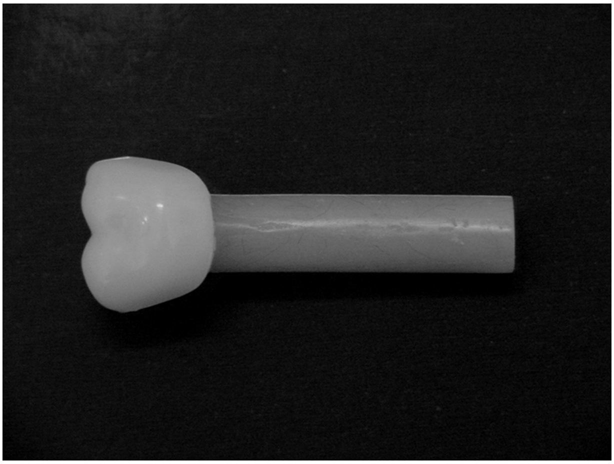

FIGURE 1 Specimen for shear bond test.

4. Glossy ridge lap etched by methyl methacrylate monomer (Classico Dental Products, Sao Paulo, SP, Brazil) applied for 30 seconds with a small brush before packing [31].

Pink acrylic resin (Classico Dental Products) was prepared using a solution with a ratio of 35.5 g polymer to 15 mL monomer, according to the manufacturer's recommendations. The flasks were placed in traditional clamps after final pressing in a hydraulic press (Linea H) under a load of 1,250 kgf for 5 minutes. Eighty specimens ($n = 10$) were conventionally packed, polymerized in a hot water bath at 74°C for 9 hours in a polymerizing unit (Termotron, Piracicaba, Sao Paulo, SP, Brazil), and deflasked after flask cooling at room temperature. Afterwards, the specimens were deflasked and the acrylic resin was finished with abrasive stones.

Specimens from the Protocols 5, 6, 7, and 8 were made similarly to the Protocols 1, 2, 3, and 4 with the exception that they were submitted afterwards to microwave treatment in a microwave oven (Continental Domestic Lines, Manaus, AM, Brazil) for 3 minutes at 650 W [12]. For this procedure, the specimens were immersed individually in 150 mL of distilled water in a glass container. The specimens were removed from this container with tweezers after water-cooling at room temperature. Before the shear bond strength test, all specimens microwaved, or not, were soaked in water and stored in an oven at 37°C for 24 hours.

Shear bond testing (Fig. 2) was performed on the non-microwaved (control) and microwaved specimens in an Instron machine (Canton, MA, USA), using a cross-speed of 1 mm/minute. The shear bond strength (kgf/cm^2) was calculated as a function of the load applied

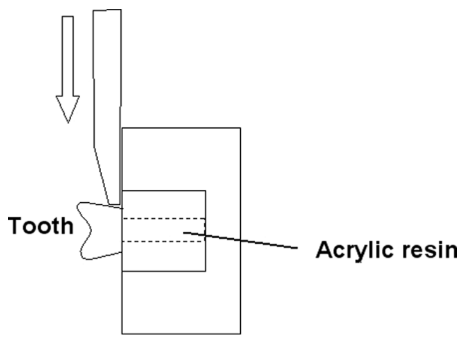

FIGURE 2 Schematic drawing of holding and loading arrangement.

at the moment of the specimen failure (kgf) and tooth/resin adhesion area, using the equation:

$$SBS = F/\pi.r^2,$$

where SBS = shear bond strength (kgf/cm^2), F = failure load (kgf), and $\pi.r^2$ = tooth/resin bonding area, where $\pi = 3.1416$ and $r^2 = 0.09\,cm^2$; thus, $0.09 \times 3.1416 = 0.28\,cm^2$. The results in kgf/cm^2 were changed to MPa by multiplying by the constant, 0.098.

Observation of the failure mode after shear bond test was under an optical microscope (EMZ-TR, Meiji Thecno Co., Tokyo, Japan), with $1.5\times$ magnification.

Statistical Analysis

Data were submitted to two-way analysis of variance (ANOVA), considering two factors (ridge lap surface condition and microwave treatment) and their interactions. Since same-factor interactions were significant, differences were submitted to multiple comparison testing (Tukey HSD test at $\alpha = .05$).

RESULTS

Two-way ANOVA (Table 1) revealed significant differences in the denture tooth/resin shear bond strength for the ridge lap surface condition ($p < .00001$), microwave treatment ($p < .00001$), and their interactions ($p < .00178$).

Shear bond strength means following the use, or not, of microwave treatment are shown in the Table 2. In the non-microwaved specimens, control and monomer etched groups presented lower means, but they were statistically different when compared with bur abrasion and bur grooving treatments, with no statistically significant difference between these latter treatments. In the microwaved specimens,

TABLE 1 Results of Two-Way ANOVA Statistical Analysis

Variation cause	*df*	Sum of squares	Mean square	F	*P*
Lap surface (Ls)	3	14977.263	4992.421	139.937	.00001
Microwave treatment (Mt)	1	9622.440	9222.440	269.721	.00001
Ls × Mt	3	612.486	204.162	5.727	.00178
Error	72	2568.637	35.675		
Total	79	27780.827			

General mean = 81.687; variation coefficient = 7.312%.

TABLE 2 Shear Bond Strength Means (MPa) and Standard Deviation in Relation to Microwave Treatment

	Microwave treatment	
Ridge lap condition	Non-microwaved	Microwaved
Control	78.26 ± 0.69 b A	56.29 ± 1.50 c B
Bur abrasion	108.17 ± 3.34 a A	87.59 ± 4.37 a B
Bur grooving	107.73 ± 1.89 a A	77.40 ± 4.99 b B
Monomer etch	76.44 ± 2.70 b A	61.59 ± 4.39 c B

Means followed by different lower case letters in each column and capital case letter in each row differ significantly by Tukey's test ($p < .05$).

however, control and monomer etched groups presented the lowest means, and were statistically significantly different when compared with bur abrasion and bur grooving treatments, which were statistically different from each other. When the non-microwaved and microwaved specimens were compared, all treatments showed means with statistically significant difference, and were lower in the microwaved specimens.

Mixed failures (adhesive, and cohesive in the acrylic resin) were predominantly observed in all groups. Adhesive and mixed (adhesive, and cohesive in the tooth) failures were not observed.

DISCUSSION

The aim of this study was to characterize and compare the effect of microwave treatments on the shear bond strength of the denture tooth/acrylic resin adhesion. In the current *in vitro* study, the research hypothesis that the tooth/resin adhesion could be adversely affected by the microwave treatment, independently of the different conditions of the ridge lap surface, was accepted. The two-way ANOVA revealed significant difference in the shear bond strength for the different ridge lap conditions and microwave treatment. The interactions between ridge lap surface conditions and microwave treatment were also significant (Table 1).

In the non-microwaved condition, control and monomer etched specimens demonstrated lower means that were statistically different when compared with bur abrasion and bur grooving surface specimens, which showed no statistically significant difference between each other (Table 2).

Although a rough ridge lap surface may trap wax residues, resulting in decreased bond strength [22], the denture base material and denture tooth selected may also influence the tensile bond strength of the tooth to the base [32]. Physical modification by retention grooves of different shapes on the ridge lap surface of the tooth had no significant effect on the bond strength [26,33], and grinding of this surface may only be beneficial to bonding in the absence of wax traces [23].

It is claimed that the use of modern synthetic detergents that effectively remove all traces of wax is necessary for preventing such failures [21]. Detergent solution was used in the current study to remove the traces of wax from the teeth. Thus, it is possible to presume that the results showing statistical significance may be due to the different treatments performed on the ridge lap surface of the teeth.

Studies have shown that painting with monomer or grinding the ridge lap of the tooth before denture packing did not improve the adhesion to the denture resin base [22,29]. Conversely, results from these treatments were not similar in the current study, in which control and monomer-etched specimens were statistically similar, and bur abrasion as well as bur grooving specimens significantly improved the tooth/resin bond (Table 2).

In the current study, the similarity of the shear bond strength values for control and monomer-etched specimens was probably due to the cross-linking agent added to the methylmethacrylate monomer of the denture teeth used. A previous study has shown that cross-linked monomers are used for improving surface hardness and abrasion resistance of the artificial tooth [31]. This procedure, however, results in decreased bond strength as compared with acrylic resin teeth with no cross-linking agent [34]. It was also shown that when the hardness of the tooth is increased, the bonding strength between the tooth and the denture base decreases [35].

Bond strength may be influenced by chemical interaction between the acrylic resin and the ridge lap surface of the tooth; however, a dramatic decreasing effect on failure load was observed when the tooth was painted with monomer alone [28] or when a highly cross-linked denture tooth was used [31].

Different changes on the ridge lap surface can result in significantly different bond strengths. Thus, mechanical retention by a grind or groove placed in the ridge lap of the tooth increased the shear bond strength values [31]. Conversely, in the current study, bur abrasion and bur grooving presented shear bond strength values with no statistically significant difference (Table 2). The finding of this investigation is in agreement with classic studies [24,26,28,30] and with a more recent study [19], which evaluated the bonding of the tooth to the acrylic resin base using bur retention on the ridge lap.

In an earlier study, the evaluation of the fractured specimen showed that the resin mass often does not penetrate into the groove made on the ridge lap of the tooth [30]. However, better bond strength may be attributed to a greater surface area and better penetration of the resin mass in the irregularities caused by bur abrasion [30].

A visual inspection of the fractured areas did not show the fracture mode, suggesting debonding due to deficient resin mass penetration into the irregularities of the ridge lap [31]. Thus, bur grooving may decrease or increase the bonding strength in similar chemical acrylic resins, and the reason for this apparent controversy is difficult to determine [31]. Within the limitations of the current study, the shear bond strength values presented by the tooth/resin adhesion do not agree with the findings of these previously mentioned authors [30,31].

Table 2 also shows the influence of the microwave disinfection on shear bond strength of the tooth/acrylic resin adhesion. Control and monomer etched specimens presented lower means that were statistically different when compared with bur abrasion and bur grooving treatments, which were statistically different.

Microwave treatment led to statistically significant different values of shear bond strength for different bur retention treatments (bur abrasion and bur grooving). The higher result for the bur abrasion specimens was probably due to the different surface texture caused by the bur abrasion procedure [19,30]. Regions of the denture base with minimal restriction to additional polymerization shrinkage promoted by microwave energy showed better adaptation to the stone cast [18]. It is probable that a similar phenomenon occurred on the flat surface of the ridge lap, improving the mechanical retention by resin shrinkage due to minimal restriction in the adhesion area. Conversely, the additional contraction of the acrylic resin decreased the retention in the deepest area of the groove. This decrease in retention is due to the stress induced in the groove by the additional polymerization that was afterwards accomplished with microwave energy [19]. In addition, the internal stress induced by the microwave energy treatment may also cause distortion of the denture resin base [13,15].

When the non-microwaved and microwaved specimens were compared, all ridge lap treatments showed means with statistically significant differences, and all means were lower in the microwaved specimens (Table 2).

Although flexural strength is not significantly altered by microwave energy polymerization, there was a small increase in the acrylic resin hardness [13]. An explanation for the increased hardness resulting from microwave polymerization might be the lack of water plasticizing effect occurring in the microwave-radiated specimens [13]. In the current study, the specimens were affected by microwave treatment, decreasing the shear bond strength values between tooth and acrylic resin.

A possible explanation for this fact is that the irradiation by microwave energy generates heat inside the acrylic resin [14], increasing the degree of conversion of autopolymerizing acrylic resins [36], and resulting in a decreased level of residual monomer [17]. Probably, the stiffness of the acrylic resin irradiated by microwave energy was increased, resulting in a decreased cohesive strength in the irradiated specimens [19]. In the current study, the lower strength was evident in all specimens irradiated by microwave energy.

In the present investigation, similarly to non-microwaved specimens, a greater shear bond strength value was also observed in the microwaved specimens submitted to bur abrasion and bur grooving treatments, when compared with control and monomer etched specimens. As claimed in the previous study [19], the stiffness of the resin volume trapped inside the ridge lap retention could be responsible for the decreased cohesive strength of the bonding in the microwaved specimens, which was more evident in the bur grooving than the surface roughness of the bur abrasion specimens.

The results from the shear test of the present study were similar to those of a previous study using the impact test [19]. It may be speculated that the findings are not dependent on the mechanical tests used, since the specimens were made in a similar way. In other words, the results obtained in these two mechanical tests depend on the similarity of the methodology carried out. Further studies are necessary to evaluate whether the effect of other mechanical tests may confirm, or not, this speculation based only on these studies.

The failure resulting from the shear bond test was predominantly mixed (adhesive and cohesive in the acrylic resin). This fact signifies that the cohesive strength of the tooth is greater when compared with the acrylic resin cohesive strength. Probably, the resulting bond failure will occur in the acrylic resin base when the denture is in use.

Maximal bite force in denture wearers, in general, demonstrates low compression forces (mean 94 N) and shows a great variation (10 to 410 N) [37]. On the other hand, changes in the denture-bearing mucosa and short height of the mandibular alveolar process decrease the bite force slightly [38], whereas a severe bone resorption can delay the improvement of maximum bite force in elderly patients with replaced complete dentures [39].

Although results showed that microwave treatment may be damaging to tooth/resin adhesion, it is possible that the displacement of the tooth from the denture base can only be due to repeated masticatory load (mechanical fatigue), due to accidental dropping during denture cleaning, or by poor laboratory technique that impedes a satisfactory bond between tooth and resin base.

Although attempts were made to characterize the influence of the microwave treatment on the tooth/resin bond, this study is limited in predicting the effect of other variables. Further studies are necessary to evaluate whether the effect of the decreased bite force may influence the denture base adaptation and stability, and tooth/resin base bond failure in complete denture wearers.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn: Microwave treatment significantly decreased the shear strength of the tooth/resin bond. In both microwaved and non-microwaved procedures, bur abrasion and bur grooving mechanical retention improved the shear bond strength when compared with the control and monomer etching treatments; however, the shear bond strength was lower in all microwaved specimens.

ACKNOWLEDGMENTS

This work was supported by PIBIC/CNPq/UNICAMP at Piracicaba Dental School, State University of Campinas.

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