Effect of Microwave Disinfection Procedures on Torsional Bond Strengths of Two Hard Chairside Denture Reline Materials

Ana Lucia Machado, DDS, MSc, PhD;[1] Larry C. Breeding, MSc, DMD;[2] and Aaron D. Puckett, PhD[3]

Purpose: This study evaluated the potential effects of denture base resin water storage time and an effective denture disinfection method (microwave irradiation at 650 W for 6 minutes) on the torsional bond strength between two hard chairside reline resins (GC Reline and New Truliner) and one heat-polymerizing denture base acrylic resin (Lucitone 199).

Materials and Methods: Cylindrical (30 × 3.9 mm) denture base specimens ($n = 160$) were stored in water at 37°C (2 or 30 days) before bonding. A section (3.0 mm) was removed from the center of the specimens, surfaces prepared, and the reline materials packed into the space. After polymerization, specimens were divided into four groups ($n = 10$): Group 1 (G1)—tests performed after bonding; Group 2 (G2)—specimens immersed in water (200 ml) and irradiated twice (650 W for 6 minutes); Group 3 (G3)—specimens irradiated daily until seven cycles of disinfection; Group 4 (G4)—specimens immersed in water (37°C) for 7 days. Specimens were submitted to a torsional test (0.1 Nm/min), and the torsional strengths (MPa) and the mode of failure were recorded. Data from each reline material were analyzed by a two-way analysis of variance, followed by Neuman-Keuls test ($p = 0.05$).

Results: For both Lucitone 199 water storage periods, before bonding to GC Reline resin, the mean torsional strengths of G2 (2 days—138 MPa; 30 days—132 MPa), G3 (2 days—126 MPa; 30 days—130 MPa), and G4 (2 days—130 MPa; 30 days—137 MPa) were significantly higher ($p < 0.05$) than G1 (2 days—108 MPa; 30 days—115 MPa). Similar results were found for Lucitone 199 specimens bonded to New Truliner resin, with G1 specimens (2 days—73 MPa; 30 days—71 MPa) exhibiting significantly lower mean torsional bond strength ($p < 0.05$) than G2 (2 day—86 MPa; 30 days—90 MPa), G3 (2 days—82 MPa; 30 days—82 MPa), and G4 specimens (2 days—78 MPa; 30 days—79 MPa). The adhesion of both materials was not affected by water storage time of Lucitone 199 ($p > 0.05$). GC reline showed a mixed mode of failure (adhesive/cohesive) and New Truliner failed adhesively.

Conclusions: Up to seven microwave disinfection cycles did not decrease the torsional bond strengths between the hard reline resins, GC Reline and New Truliner to the denture base resin Lucitone 199. The effect of additional disinfection cycles on reline material may be clinically significant and requires further study.

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A DENTURE MAY require relining of the intaglio surface as a result of tissue changes over time. Hard chairside relining is easier, faster, and more convenient than the use of laboratory-relining system[1] and has been used to regain the adaptation of the denture base to the residual ridges.[2,3]

It has been demonstrated that dentures may become contaminated with microorganisms,[4] and cross-contamination of the prostheses may occur when the infected units are pumiced in dental laboratories.[5] In addition, the presence of *Candida* species has been reported in denture wearers who

[1]Associate Professor, Department of Dental Materials and Prosthodontics, UNESP, Araraquara Dental School, São Paulo, Brazil.

From the Department of Care Planning and Restorative Sciences, School of Dentistry, University of Mississippi Medical Center, Jackson, MS.

[2]Professor and Chair.

[3]Professor.

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Correspondence to: Ana Lucia Machado, Faculdade de Odontologia de Araraquara – UNESP, Rua Humaitá, no 1680, Araraquara, São Paulo, Brazil, CEP 14801-903. E-mail: cucci@foar.unesp.br or almachado98@uol.com.br

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have denture stomatitis.[6] Therefore, denture disinfection has been recommended to avoid cross-contamination and prevent denture-related stomatitis.[4,7,8]

Microwave irradiation has been suggested as a simple and effective method for denture disinfection, and different regimens have been tested.[9-11] More recently, studies have demonstrated that the effectiveness of microwave disinfection is improved when the specimens are irradiated while immersed in water. Dixon et al[7] reported that 5 minutes of irradiation in water killed all *Candida albicans* present on a denture base resin and the two soft liners evaluated. Microwave irradiation for 6 minutes in water at 650 W, performed on three hard chairside reline materials also proved to be completely effective against potentially pathogenic microorganisms, such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Bacillus subtilis*, and *C. albicans*.[12] Although the lethal action of microwave irradiation on various microorganisms has been documented, the mechanism of destruction is not fully understood. While some studies maintain that the effect of microwave irradiation on microorganisms is directly of thermal character,[13,14] others claim that killing of the organisms probably also resulted from the nonthermal effects of microwaves.[15,16] The exact nature of the lethal effects of microwave irradiation has yet to be elucidated by further research.

The selection of a disinfection method should be based not only on its effectiveness against microorganisms, but also on its effects on the denture materials. Investigations evaluating the effect of microwave irradiation on the dimensional stability[9,17] and the hardness[7] of denture base resins have suggested that the changes observed were not clinically significant; however, it is possible that microwave irradiation may adversely affect the other properties of hard chairside reline resins not previously investigated. One concern is the strength of the bond between the reline and the denture base materials.[3,18-22] A strong bond is needed to prevent delamination of the liners, staining, and bacteria retention.[18,23] In addition, it has been suggested that better bonding contributes to a higher flexural strength of the relined denture base.[24]

It is known that water immersion of acrylic resins may result in sorption and solubility.[25] It has also been shown that water sorption and solubility depend on the material composition,[26] and significant differences between heat-polymerized denture bases and autopolymerizing reline resins have been observed.[19,26] These differences in water sorption and solubility patterns may cause stresses to occur at the reline resin–denture base interface, decreasing the bond strength. In addition, Braden[25] demonstrated that the water temperature has a marked effect on the diffusion of water into acrylic resins. Therefore, the heat generated by microwave disinfection may enhance the water sorption rate. The absorbed water could act as a plasticizer[27,28] and decrease the bond strength between the denture base and the reline resin.[20,21] Conversely, the unreacted monomers, which also have a plasticizing effect,[29,30] can gradually be leached from the reline and denture base materials.[31,32] In addition, a reduction in residual monomer content from the heat generated during microwave disinfection and the radiation itself could be expected.[30,33] The bond between hard chairside reline materials and denture base acrylic resins occurs by cross-linkage of the surface molecules between the parent acrylic resin and the new material.[18,34] Therefore, it is likely that the time elapsed between the denture fabrication and the relining procedure could influence the bond strength. In addition, during clinical use, the acrylic resins are immersed in saliva or soaked in solutions of denture cleansers or water, resulting in water absorption.[35] The water content in the denture base acrylic resin may potentially influence the bond strength; however, little information has been reported regarding this issue.[36]

The aim of this study was to evaluate the potential effects of denture base resin water storage time and an effective denture disinfection method (microwave irradiation at 650 W for 6 minutes) on the torsional bond strength between two hard chairside reline resins (GC Reline and New Truliner) and one heat-polymerizing denture base acrylic resin (Lucitone 199).

Materials and Methods

This study evaluated the effect of denture base resin water storage time before bonding and microwave disinfection on the torsional bond strengths of two hard reline resins and one denture base resin. The relining resins were polymerized between two cylinders of the denture base resin. For each reline material, four experimental groups were made and tested. Group 1 (G1) specimens were tested immediately after bonding

Table 1. Materials Information Supplied by Manufacturers

Product	*Manufacturer*	*Composition*		*Lot No.*
		Powder (P)	*Liquid (L)*	
GC Reline	GC America Inc., Alsip, IL	PEMA†	Butoxyethyl methacrylate†	0306112
		BPO†	Benzyl methacrylate†	
		SiO_2†	MMA†	
			1,6-HDMA†	
			p-tolyldiethanolamine†	
			ethyl-p-dimethylaminobenzoate†	
New Truliner	The Bosworth Company, Skokie, IL	PEMA‡	Alkyl methacrylate‡	0303-144
		BPO‡	Alkyl phthalate‡	
		TiO2‡	n,n DMPT‡	
		Cd pigments‡		
Lucitone 199	Dentsply International Inc., York, PA	PMMA§	MMA§	P-031007
			EGDMA§	L-0201311

PEMA = poly (ethyl methacrylate); BPO = benzoyl peroxide; SiO_2 = silicon dioxide; MMA = methyl methacrylate; 1,6-HDMA = 1,6 hexanediol dimethacrylate; TiO_2 = titanium-dioxide; Cd = cadmium; n,n DMPT = dimethyl-p-toluidine; PMMA = poly (methyl methacrylate); EGDMA = ethylene glycol dimethacrylate.

†GC America Inc., GC Reline Material Safety Data Sheet, January 2003.

‡HARRY J. BOSWORTH COMPANY, New Truliner Material Safety Data Sheet, August 2002.

§DENTSPLY International Prosthetics, Lucitone 199 Material Safety Data Sheet, May 2004.

and served as control. Group 2 (G2) and Group 3 (G3) specimens were submitted to microwave disinfection (two and seven cycles, respectively) before being tested. Group 4 (G4) specimens were stored in water for 7 days after bonding.

The names of the resins, manufacturers, composition, and lot numbers are presented in Table 1.

One hundred and sixty cylindrical specimens of Lucitone 199 material, 33 mm long and 3.9 mm diameter, were prepared. Cylindrical brass dies were invested in hard but flexible silicone (Sil-Tech Super, Ivoclar Vivadent Inc., Amherst, NY), further supported by stone (Die-Keen Green, Heraus Kulzer, South Bend, IN) using a conventional denture processing flask. The silicone was used to facilitate the removal of the specimens after processing. When the stone had set, the flask was opened, the brass dies were removed, and the silicone and stone surfaces were coated with tinfoil substitute (Coe-Sep, GC America Inc., Chicago, IL). Lucitone 199 denture base resin was mixed according to the manufacturer's instructions and packed into the molds with three trial closures using a hydraulic press (Hanau Hydraulic Press, Buffalo, NY). The specimens were processed in a water bath (Kavo EWL TYP 5518, Leutkirch, Germany) using the short cycle recommended by the manufacturer. After polymerization, the processed dental flask was left to cool at room temperature for 30 minutes, then was placed under running water for 15 minutes. After the specimens had been removed from the flasks, half ($n = 80$) were stored in water at 37°C for 2 days, and half ($n = 80$) were stored for 30 days under the same conditions. For each storage period, 40 specimens were bonded to GC Reline material and 40 were bonded to New Truliner material.

After the storage periods, each specimen was removed from the water and bisected with a diamond saw (Leco VC-50, LECO Corporation, St. Joseph, MI) to obtain parallel flat bonding surfaces. A 1.5-mm thick section was then removed from each flat surface using a grinder/polisher (Ecomet I, Buehler Ltd., Evanston, IL) with 240 grit silicon carbide paper (LECO Corporation), to provide a 3-mm space to simulate clinical relief of the denture base for the relining procedure. The prepared surfaces were cleaned with detergent for 20 seconds, washed with running water, and blot-dried. For GC Reline material, the bond surface was coated with the bonding agent using a brush and allowed to dry for approximately 10 seconds. For New Truliner material, the liquid (monomer) was applied to the bond surface to remove any detergent film. The New Truliner bonding agent was then applied with a brush to moisten the bond surface. The two halves of each denture base cylinder specimen were replaced in their silicone molds within the flasks. The hard reline materials were proportioned and mixed as recommended by the manufacturers of each product, and the resin mix was introduced in the space between the two denture base acrylic resin cylinders and packed.

After polymerization, the specimens of each storage period/hard reline material combination ($n = 40$) were divided into four groups ($n = 10$). Specimens in G1 were not exposed to any disinfection procedure, and the tests were performed after polymerization. G2 specimens were submitted to two cycles of microwave disinfection (specimens immersed in 200 ml of water, and irradiated with 650 W for 6 minutes), simulating disinfection when dentures are sent to the laboratory and before the denture is returned to the patient. During the microwave irradiation, the water in which the specimens were immersed started to boil (100°C) after approximately 1 minute and 30 seconds, and remained at this temperature until the end of the 6-minute disinfection time. The irradiated specimens and the microwave oven were allowed to cool to room temperature before the next cycle. The microwave oven used in this study was a household oven with turntable (Ewave, Model EW11E2B, MC Sales & Marketing Inc., Schaumburg, IL). The microwave oven was rated 1000 W; however, the true power output was experimentally determined to be 650 W. To evaluate the repeated exposure of the bonded specimens to microwave irradiation, the specimens in G3 were exposed to seven total cycles of microwave irradiation (specimens irradiated daily, and stored in water at 37°C between exposures). Specimens in G4 were not exposed to disinfection, and remained immersed in water at 37°C for 7 days.

A MTS 858 Bionix System (MTS Corp., Minneapolis, MN) was used to evaluate the torsional bond strength of the hard reline materials to the Lucitone 199 denture base resin. The specimens were tightly positioned in the grips, and a uniform torsional load rate of 0.1 Nm/min was applied.[37,38] Test Ware SX (MTS Corp.) control software was used to record the force and the angle throughout the testing. The maximum achievable rotation during the test was 98°. The torsional data were used to obtain force versus angle curves for each specimen tested. All GC Reline specimens fractured during the test; however, some New Truliner specimens did not break. For the specimens that failed, the torsional strength (TS) was calculated using the equation: $TS = 2F/c^3$, where F is the force (N) recorded at break, and c is the radius (mm) of the specimens at the bond surface (the actual radius of each specimen was measured before bonding).[37] For the specimens that did not break, the torsional strength was calculated using the maximum force (N) recorded during the test as the F value in the equation. After the test, the hard reline material–denture base acrylic resin interface was analyzed visually and the mode of failure was characterized as cohesive, adhesive, or mixed mode, depending on whether the fracture surface was in the hard liner, at the denture base–hard liner interface, or in both.

Because of the different behaviors of the materials during the test, the statistical analysis was performed on each individual material. Two-way analysis of variance (ANOVA) was applied to study the effect of the two main factors: (1) denture base water storage time before bonding to the reline resins and (2) microwave disinfection. Newman-Keuls post hoc comparison test was applied to the results to determine whether significant differences existed among the means. A significance level of $p \leq 0.05$ was established.

Results

Two-way ANOVA revealed that, for both materials, there were significant differences in the torsional strengths among the groups ($p < 0.05$), whereas no significant differences were detected between the two periods of water storage of Lucitone 199 specimens before bonding ($p > 0.05$).

The torsional mean values and standard deviation of GC Reline and New Truliner are shown in Table 2. For both materials, G1 specimens exhibited significantly lower mean values ($p < 0.05$) than the other three groups evaluated. Microwave irradiation (G2 and G3) or immersion in water at 37°C for 7 days (G4) significantly increased

Table 2. Torsional Test Results (MPa) for GC Reline and New Truliner

Materials Lucitone 199 (days before bonding)/Reliner	*Torsional Bond Strengths (MPa) After Treatments*			
	G1, after bonding	*G2, after two cycles of disinfection*	*G3, after seven cycles of disinfection*	*G4, after 7 days immersion in water at 37°C*
GC Reline (2 days)	108 ± 14 A, a	138 ± 6 A, b	126 ± 10 A, b	130 ± 16 A, b
GC Reline (30 days)	115 ± 17 A, a	132 ± 12 A, b	130 ± 17 A, b	137 ± 12 A, b
New Truliner (2 days)	73 ± 10 B, c	86 ± 14 B, d	82 ± 7 B, de	78 ± 11 B, e
New Truliner (30 days)	71 ± 12 B, c	90 ± 6 B, d	82 ± 9 B, de	79 ± 12 B, e

Statistical comparison was not made between the two reline materials.
Vertically, means with the same capital letter were not significantly different from each other ($p > 0.05$).
Horizontally, means with the same small letter were not significantly different from each other ($p > 0.05$).

the torsional mean values for both materials ($p <$ 0.05). No significant differences were noted when groups G2, G3, and G4 were compared ($p > 0.05$) for the GC Reline material. New Truliner exhibited no significant differences between groups G2 and G3; G3 was not significantly different from G4 ($p > 0.05$).

Visual examination after de-bonding indicated that all GC Reline material specimens showed a combination of cohesive–adhesive failure (mixed mode). Nineteen of the 40 Lucitone 199 specimens stored in water 2 days before bonding to New Truliner, did not fail during the test (G1—2; G2—7; G3—5; G4—5); whereas, for the 30-day storage in water period ($n = 40$), fourteen specimens did not fail (G2—6; G3—6; G4—2). Examination of the broken specimens demonstrated that New Truliner hard reline material exhibited adhesive failure at the interface with the denture base acrylic resin cylinders.

Discussion

Microwave disinfection did not decrease the torsional bond strength of the reline resins to the Lucitone 199 denture base resin. Also, storage of the denture base Lucitone 199 in water at 37°C for 2 days or 30 days, before bonding with the hard reline materials, showed no significant effect on the mean torsional bond strengths.

The bond strength between the hard chairside reline resins and the denture base acrylic resin was evaluated using a torsional test, because this test exerts a significant shear stress similar to the stresses that occur clinically. Also, a uniform stress, which is less dependent on parallelism and specimen geometry than in the three-point bending test set-up,[38] is exerted on the bonded surfaces. The results revealed that microwave disinfection or immersion in water at 37°C for 7 days significantly increased the mean torsional values for both hard reline materials. These results could be attributed to the effect of the experimental conditions on the relative amount of residual monomer and water molecules within the materials. It has been demonstrated that both unreacted monomer remaining after processing[31,39] and water molecules that are absorbed into the polymer[25] can act as plasticizers and adversely affect the mechanical properties of the polymerized resins.[27-30] When the acrylic materials were immersed in water, two processes may have led to a reduction in the residual monomer content: monomer release[31,32] and further polymerization reaction of the free radicals remaining within the polymerized resin.[33]

The results of the present study showed that there were no significant differences between the mean torsional values of the GC Reline specimens submitted to two cycles of microwave disinfection and those submitted to seven cycles or 7 days of immersion in water at 37°C. Similar results were observed for New Truliner, with the exception that the mean torsional values of the specimens submitted to two cycles of microwave disinfection were slightly but significantly higher than those of the specimens immersed in water at 37°C for 7 days. These findings suggest that irradiating the specimens soon after polymerization might have accelerated the reduction of residual monomer and increased the degree of polymerization. Therefore, the increase in the mean torsional values was achieved earlier.

The absence of effect between the two water storage periods of Lucitone 199 before bonding with the hard chairside reline resins, is in general agreement with Minami et al.[36] These investigators found that the shear bond strengths of one autopolymerizing reline resin were not significantly influenced by the water content of the denture base resin. The absence of significant differences between the two storage periods observed in the present study may be a result of the surface preparation of the bonding surface, which removed the superficial layer. Clinically, the reline procedure involves removing some of the internal denture surface to ensure adequate thickness of the reline material and removal of the contaminated surface layer,[23] and to expose fresh underlying resin.[18] Therefore, the results from the present study seem to show that the hard reline materials GC Reline and New Truliner will bond similarly to newly processed or aged dentures.

Analysis of the fracture sites showed that GC Reline material failures were primarily mixed mode (adhesive at the interface and cohesive within the reline material itself), and all specimens fractured suddenly and completely during the test. These findings indicate that GC Reline resin is brittle and the bond strength to the denture base is close to the cohesive strength of the material, causing the mixed failure mode. GC Reline material contains the cross-linking agent

1,6 hexanediol dimethacrylate, which may have formed a polymer network structure,[40] where sliding between the polymer chains would be more difficult, causing the material to behave in a brittle manner. The cohesive failure within the reline resin may be evidence that the bonding agent of GC Reline resin, which is based on methyl methacrylate and acetone,[41] facilitated the dissolving and swelling of the denture base surface, and the diffusion of polymerizable materials, mainly monomers, from the reline resin. Thus, an interpenetrating network at the interface between the denture base and the reline material was formed.[22,34]

All New Truliner specimens that failed during the test displayed adhesive fracture through the interface between the hard reline and Lucitone 199. Arima et al[23] studied the composition and effect of denture base surface primers for reline acrylic resins and reported that the brush application of the Kooliner reline resin liquid (isobutyl methacrylate), produced no obvious changes in the denture base surface when compared with the control. In the present study, the New Truliner monomer was applied to the bond surface before the brush application of the bonding agent, in accordance with the manufacturer's instructions. The New Truliner monomer is also based on isobutyl methacrylate; therefore, it is likely that its application on the denture base acrylic resin before applying the bonding agent offered no advantages, and the adhesion may have relied primarily on the effect of the bonding agent. The constituent bonding agent of New Truliner is methyl methacrylate.[23] These primers, which contain primarily methacrylate monomers, have a relatively low ability to dissolve the denture base resin surface. It was observed that the brush application of New Truliner bonding agent produced only a slight softening of the denture base surface, and no obvious change was observed with the immersed specimens.[23] These aspects may explain the adhesive failure mode observed for the New Truliner specimens.

During the torsional test, some of the New Truliner specimens showed a plastic deformation without rupture within the reline material or separation from the hard denture base during the initial rotation. These results indicate that New Truliner reline resin exhibits a ductile behavior and that the cohesive strength of this reline material was greater than the bond strength to denture base resin. Arima et al[26] evaluated the properties of some autopolymerizing reline acrylic resins and observed that New Truliner showed the lowest mean transverse strength value and the highest transverse deflection. This high flexibility was related to the composition of the material. A plasticizer, such as alkyl phthalate, acts to partially neutralize secondary bonds or intermolecular forces that normally prevent the resin molecules from slipping past one another when the material is stressed.[40] Isobutyl methacrylate (alkyl methacrylate) also acts as a plasticizer, because it increases the backbone separation of the polymer molecules through pendant groups and decreases the intermolecular interactions.[40] The differences in composition between the two hard chairside reline resins were reflected in the ductile behavior observed for New Truliner. Another observation from the present study was that more of the New Truliner specimens did not break after exposure to microwave irradiation or immersion in water for 7 days, indicating some additional plasticization of the material; however, further studies are needed to confirm this hypothesis.

The present study has limitations, because only two of the many available hard autopolymerizing reline materials were evaluated and the study was entirely in vitro. Laboratory tests do not simulate the many masticatory forces that dentures are subjected to clinically, and the test specimens do not simulate the actual denture configuration. However, laboratory tests are helpful in comparing and evaluating the effect of different factors on the bond strengths of dental polymers. The results from the present study indicated that microwave disinfection had no deleterious effect on the bond strengths between the hard chairside reline materials GC Reline and New Truliner and the denture base acrylic resin Lucitone 199.

Conclusions

Within the limits of this in vitro study, the following conclusions can be made:

1. Microwave disinfection and immersion in water at 37°C for 7 days significantly increased the mean torsional bond strength values of the hard chairside reline resins GC Reline and New Truliner to the denture base acrylic resin Lucitone 199 ($p < 0.05$).

2. There was no statistically significant difference between results for 2-day versus 30-day Lucitone 199 water storage prior to relining ($p > 0.05$).
3. GC Reline material exhibited a mixed failure mode (adhesive–cohesive), whereas New Truliner reline material failed adhesively across the denture base resin.
4. All GC Reline specimens failed during the torsional test and exhibited brittleness. New Truliner material exhibited a ductile behavior, and some of these specimens did not break during the test.

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