Effect of Ridge-lap Surface Treatments on the Bond of Resin Teeth to Denture Base

Rafael L. X. Consani[a]/Hilka T. Naoe[b]/Marcelo F. Mesquita[c]/Mario A. C. Sinhoreti[d]/Wilson B. Mendes[e]

Purpose: To test in vitro the shear bond strength of resin teeth to an acrylic resin denture base given different ridge-lap surface treatments.

Materials and Methods: Ninety rectangular dies were made with wax and traditionally invested in metallic or plastic flasks. The stone molds were covered with silicone, in which were included an acrylic molar with a wax stick fixed on the ridge lap surface. After deflasking, the wax sticks were removed, the teeth were cleaned with detergent, the ridge lap surface was submitted to different treatments (unmodified, bur-cut grooves, aluminum oxide particle sandblasting, monomer swelling, and primer swelling), and the teeth were replaced in the silicone molds. Metallic flasks were placed in a thermopolymerizing unit to polymerize heat-curing denture-base polymer, and plastic flasks were placed in a domestic microwave oven at 900 W to polymerize microwaveable denture base polymer. After deflasking, the specimens were submitted to the shear bond test in an Instron machine at a cross-speed of 1 mm/min. Results were submitted to ANOVA and Tukey's test (5%).

Results: Shear bond strength values were influenced by the ridge-lap surface treatments only in the microwaved polymer. Sandblasting + monomer swelling and sandblasting + primer swelling interactions yielded lower strengths for microwaved polymer. Only the unmodified surfaces presented a significant difference when the resins were compared, where the microwaved polymer showed a higher value.

Conclusion: Different tooth ridge-lap surface treatments promoted different strengths of the tooth/resin bond.

Keywords: adhesive treatment, ridge lap surface, denture base, shear bond strength.

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Acrylic resin teeth have been widely utilized for processing prostheses, principally due to their ability to bond chemically to the denture base resin – in contrast to ceramic prostheses – owing to the similar chemical formulation of the materials.[24,36]

[a] *Professor, Department of Prosthodontics and Periodontics, Piracicaba Dental School, State University of Campinas, SP, Brazil. Developed methodology, supervised Naoe's degree, co-wrote manuscript, contributed substantially to discussion.*

[b] *Postgraduate Student, Dental Materials Program, Piracicaba Dentistry School, State University of Campinas, SP, Brazil. Idea, performed work in partial fulfillment of degree requirement, co-wrote manuscript.*

[c] *Professor, Department of Prosthodontics and Periodontics, Piracicaba Dental School, State University of Campinas, SP, Brazil. Co-wrote manuscript, optimized samples.*

[d] *Professor, Department of Restorative Dentistry, Piracicaba Dental School, State University of Campinas, SP, Brazil. Performed statistical analysis.*

[e] *Professor, Postgraduate Program, Pythagoras University, Belo Horizonte, MG, Brazil. Co-wrote manuscript, optimized samples.*

Correspondence: *Dr. Rafael Leonardo Xediek Consani, Piracicaba Dental School, UNICAMP, 901 Limeira Ave., Piracicaba, SP, Brazil. Tel: +55-19-2106-5296, Fax: +55-19-2106-5218. e-mail: rconsani@fop.unicamp.br*

Hot water-bath curing is proposed to be the most efficient and acceptable polymerization procedure for denture manufacturing and, consequently, for bonding teeth to denture base resin.[3] However, reports in the literature have demonstrated that microwaveable resin may be a satisfactory material;[2,34,43] the short polymerization time[20,31] provides an attractive alternative to hot water-bath polymerization.

Repair procedures in complete dentures are frequently necessary due to tooth fracture or bond failure between tooth and base resin, requiring a new bonding procedure or replacement of the resin tooth.[18,24,36,37] Insufficient thickness of the resin base in the anterior segment of the denture supported by implants may also cause prosthesis fracture or tooth displacement.[23,45] The literature shows that approximately 33% of repaired prostheses involve tooth replacement due to bond failures with the acrylic resin polymer of the denture base,[18] accidents, or mechanical fatigue during denture use.[13]

Deficient laboratory procedures may also prevent perfect bonding between the tooth and denture base resin, causing subsequent bond failures.[3,14,18,24] Wax residue contamination on the tooth ridge-lap surface may cause significantly weaker bonds between teeth and denture base resin.[14-16,36,37] Tooth/resin bond strength values may be affected by the

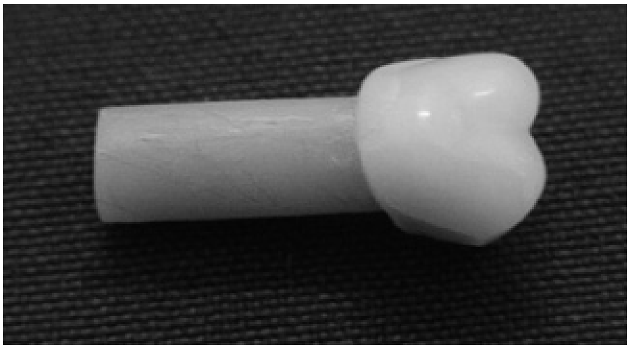

Fig 1 Specimen.

amount of cross-linking monomer added to the tooth acrylic resin, and by the amount of monomer existing on the resin base during denture processing.[27]

Chemical or mechanical treatments carried out on the ridge lap surface may increase the tooth/denture base resin bond strength.[5,16,30,33,41-44] Conflicting findings reported in the literature show that mechanical changes in the tooth ridge-lap surface from bur abrasion or bur grooving[7,16,37] or aluminum oxide particle sandblasting[10,30] did not present significantly different bond strengths when compared to the unmodified tooth surface. These findings contrast with other reports which state that such treatments improve bond strength.[12,13,16,30,33,41-44]

Other contrasting results relate to the use of primer agent[1,17] or monomer to soften the tooth ridge lap surface[1,7,24,29,37] before tooth bonding. For this bonding procedure to be effective, these chemical solutions must dissolve or soften the ridge lap surface of the teeth.[27]

It is probable that the conflicting findings mentioned above arise from the different methods used in these studies. According to a previous study, different commercial types of teeth and acrylic resin may also be responsible for the different results found in the literature.[5]

Based on these considerations, the present study aimed to test the shear strength of the tooth/resin bond, following the performance of different lap surface treatments employing chemical or mechanical procedures. Interactions between the treatments were also analyzed. The hypothesis tested in this in vitro study is that chemical and mechanical modifications of the tooth ridge-lap surface can cause different tooth/resin shear bond strengths.

MATERIALS AND METHODS

Ninety wax rectangular patterns (30 mm in length, 5 mm in height, and 10 mm in width) were traditionally invested in brass (Safrany Metallurgy; Sao Paulo, SP, Brazil) or plastic flasks (Classico Dental Products; Sao Paulo, SP, Brazil) with type III dental stone (Herodent Vigodent; Rio de Janeiro, RJ, Brazil) proportioned and manipulated following the manufacturer's recommendations. Identical model 34L white acrylic molars (Biotone IPN, Dentsply; Petropolis, RJ, Brazil) were used. The manufacturer reports that the Biotone tooth is made of highly cross-linked polymer chains, which interlace to form a three-dimensional interpenetrated polymer network (IPN). The formulation provides greater chemical and physical stability of the tooth, resulting in greater strength, hardness, and impermeability, surpassing other formulations of artificial teeth. The composition of the acrylic resin teeth is essentially poly (methyl methacrylate) beads and color pigments in a cross-linked polymer matrix. A semi-IPN layer exists between the PMMA bead and the cross-linked matrix; however, it is usually not evenly distributed in the tooth structure.[44]

The teeth with wax sticks (6 mm in diameter and 20 mm in length) attached to the ridge lap surface were partially embedded in the stone mold covered with a Zetalabor silicone layer (Zhermack; Rovigo, Italy). The resultant tooth/wax-stick unit was then covered with another layer of laboratory silicone.[12] 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 h.

The tooth/wax-stick unit 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 (Ype; Amparo Chemical; Amparo, SP, Brazil) 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 resin polymer, proportioned and manipulated according to the manufacturer's instructions.

The following treatments were carried out: 1. unmodified tooth ridge-lap surface; 2. ridge lap grooved with bur (groove in the center of the ridge lap, with a length of 2.0 mm and a width of 2.5 mm using a # 8 round bur); 3. ridge lap sandblasted with 100-µm aluminum oxide particles (Bio-Art; Sao Carlos, SP, Brazil) at an angle of 45 degrees and a distance of 1 cm for 10 s; 4. ridge lap swelling by monomer (Classico or Onda-Cryl monomers; Classico Dental Products) applied for 30 s with a small brush before packing;[5] and 5. ridge lap lightly abraded by bur + swelling by primer (Primer Connector, Heraeus Kulzer; Hanau, Germany) for 3 min and photoactivated for 90 s, according to manufacturer's instructions. Nine experimental groups were considered for each acrylic resin; unmodified, bur grooved, swelling by monomer, swelling by primer, sandblasting, bur grooved + swelling by monomer, bur grooved + swelling by primer, sandblasting + swelling by monomer, and sandblasting + swelling by primer.

Traditional and microwaveable pink acrylic resins (Classico Dental Products) were prepared according to the manufacturer's recommendations. Metallic flasks were placed in traditional clamps after final pressing in a hydraulic press (Linea H) under a load of 1250 kgf for 5 min. Forty-five heat-curing denture base polymer specimens (n = 5) were conventionally packed and polymerized in a hot water bath at 74°C for 9 h in a polymerizing unit (Termotron, Piracicaba; Sao Paulo, SP, Brazil). Forty-five microwaveable polymer specimens (n = 5) were conventionally packed and polymerized in a domestic microwave oven (Continental Domestic Line; Manaus, AM, Brazil) at 900 W for the cycle: 1.

Table 1 Results of two-way ANOVA

Variable	df	Sum of squares	Mean square	F	P
Resin (R)	1	36.6598	36.6598	3.4566	.06371
Treatment (T)	8	185.0674	23.1334	2.1812	.03847
R x T	8	164.2135	20.5266	1.9354	.06714
Error	72	763.6113	10.6057		
Total	89	1149.5521			

General mean = 12.14; variation coefficient = 26.81%.

Table 2 Mean shear strength values (MPa) of the tooth/resin bond in relation to acrylic resin polymers, independent of the ridge lap surface treatments

Acrylic resin polymer	Mean ± SD
Heat-cured	11.50 ± 3.05 [a]
Microwaved	12.78 ± 3.99 [a]

Identical lower case letters indicate no statistically significant difference (Tukey's test, $p < 0.05$).

Table 3 Mean shear strength values (MPa) of the tooth/resin bond in relation to the ridge lap surface treatments, independent of the acrylic resin polymers

Surface treatment	Mean ± SD
Unmodified	14.08 ± 4.81 [ab]
Monomer	11.48 ± 3.39 [ab]
Bur grooving	11.35 ± 3.44 [ab]
Sandblasting	11.81 ± 2.47 [ab]
Primer	12.29 ± 3.31 [ab]
Grooving + monomer	11.82 ± 3.33 [ab]
Grooving + primer	15.10 ± 3.06 [a]
Sandblasting + monomer	11.05 ± 3.01 [ab]
Sandblasting + primer	10.27 ± 3.72 [b]

Different lower case letters indicate statistically significant difference (Tukey's test, $p < 0.05$).

three min at 40% of the potency; 2. four min at 0% of the potency; and 3. three min at 90% of the potency. After flask bench cooling at room temperature, heat-cured and microwaved specimens were deflasked, the acrylic resin stick was finished with abrasive stones, and water stored at 37°C for 24 h.

Shear bond testing was performed in an Instron machine (Canton, MA, USA), using a 500-N load cell and cross-head speed of 1 mm/min. Compressive load was applied using a steel knife edge placed on the buccal tooth face near the bond surface margin. The shear bond strength (kgf/cm^2) was calculated as a function of the failure load (kgf) and tooth/resin bond area, using the equation: $SBS = F/\pi r^2$, where SBS = shear bond strength (kgf/cm^2); F = failure load (kgf); and πr^2 = tooth/resin bonding area (π = 3.1416 and r^2 = 0.09 cm^2; thus, 0.09 x 3.1416 = 0.28 cm^2). The results in kgf/cm^2 were transformed into MPa by multiplying by the constant, 0.098.

Data were submitted to two-way ANOVA, considering the factors resin, ridge lap surface treatment, and interaction. Since same-factor interactions were significant, differences were submitted to multiple comparison testing (Tukey HSD test at α = 0.05). Observation of the failure mode was performed under an optical microscope (EMZ-TR; Meiji Thecno; Tokyo, Japan) at 1.5X magnification.

RESULTS

Two-way ANOVA (Table 1) revealed a statistically significant difference in the tooth/resin shear bond strength (SBS) only for ridge lap surface treatment ($p < 0.03847$). Resin factor ($p > 0.06371$) and resin x treatment interaction ($p > 0.06371$) were not significant.

Table 2 shows that the shear bond strength values of the heat-cured denture base polymer and microwaved polymer bonded to teeth were not statistically significantly different when the tooth ridge-lap surface treatment was not considered.

Mean SBS values of the tooth/resin bond for the ridge lap surface treatment independent of the resin factor are shown in Table 3. A statistically significant difference was observed between the grooving + swelling by primer and sandblasting + swelling by primer treatments, with the latter presenting a lower bond strength. The other groups did not demonstrate any statistically significant differences between them, or

Table 4 Mean shear strength values (MPa) of the tooth/resin bond by acrylic resin polymer and ridge lap surface treatments

Surface treatment	Heat-cured polymer	Microwaved polymer
Unmodified	11.44 ± 3.90 a B	16.72 ± 4.42 a A
Monomer	9.84 ± 2.11 a A	13.12 ± 3.83 ab A
Bur grooving	11.60 ± 3.85 a A	11.10 ± 3.41 ab A
Sandblasting	11.31 ± 2.38 a A	12.32 ± 2.72 ab A
Primer	11.05 ± 2.40 a A	13.53 ± 3.87 ab A
Grooving + monomer	10.68 ± 2.75 a A	12.97 ± 3.76 ab A
Grooving + primer	13.38 ± 2.48 a A	16.82 ± 2.75 a A
Sandblasting + monomer	12.28 ± 3.23 a A	9.82 ± 2.48 b A
Sandblasting + primer	11.94 ± 4.73 a A	8.60 ± 1.31 b A

Different lower case letters in each column and different capital letters in each row indicate significant differences (Tukey's test, $p < 0.05$).

when compared to the grooving + swelling by primer and sandblasting + swelling by primer treatments.

Table 4 shows that the mean values of the shear strengths of the tooth/resin bonds for the ridge lap surface treatment factor were not significantly different when the heat-cured denture base polymer was considered. For the microwaved polymer, the unmodified and grooving + swelling by primer treatments presented statistically higher values than the sandblasting + swelling by monomer and sandblasting + swelling by primer groups. For comparison between polymers, only the unmodified surface of the microwaved polymer demonstrated a statistically higher value than the heat-cured denture base polymer.

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

In the current in vitro study, the research hypothesis that the tooth/resin shear bond strength could be adversely affected by the ridge lap surface treatment was partially accepted. The two-way ANOVA revealed significant differences in the shear bond strength for the ridge lap surface treatment. Resin and interaction were not significant (Table 1).

Independent of the other factors, the acrylic resin polymer material did not influence the shear strength of the tooth/resin bond, and results were not statistically significantly different (Table 2).

According to a previous study, microwaved polymer shows satisfactory mechanical behavior when the tooth/resin bond is considered,[28] has a lower amount of residual monomer,[19] and similar physical properties to the conventional resins.[28,32,34,39] The formulation of the microwaved polymer may lead to deficient interpenetration of the polymeric chains between the resin denture base and the tooth, resulting in decreased cross linkage and leaving fewer functional groups available for bonding.[35] This situation does not appear to adversely affect the shear bond strength, an observation that was supported by the statistical similarity of the findings for both resins in the current study. In addition, insufficient thickness of the resin base in the anterior segment of the denture supported by implants may cause prosthesis fracture or tooth displacement.[23,45] The literature shows that approximately 33% of repaired prostheses involve tooth replacement, due to bond failures with the resin of the denture base[18] or by accidental falling or mechanical fatigue during denture use.[13]

The formulation of the acrylic resin tooth is essentially polymethylmethacrylate with cross-linking monomer,[3] which improves the surface hardness and increases the abrasion resistance of the artificial tooth.[5] According to previous studies, this procedure decreases the bond strength when compared to the tooth without cross linkage.[11,38] For this reason, cross-linking monomer may not be uniformly distributed throughout the structure of the tooth. Thus, the gingival region of the resin tooth may present less cross linkage than the incisal area, which can, theoretically, improve the chemical bond between tooth and the acrylic resin polymer base.[41,44] As the type of tooth used in the study was the same for both acrylic resin polymers, it is possible to infer that the surface hardness levels of the teeth were the same and that their effects were similar for the conditions of bonding.

According to a previous study,[42] the swelling of the ridge lap surface of the teeth starts in the PMMA phase of the polymer beads, and the diffusion of monomers to the acrylic resin-polymer tooth increases with the increased polymerization temperature. This fact has been shown to improve the bond strength of the polymer tooth to the denture base polymer. In addition, the larger extent of diffusion of monomers from heat-cured resin into the tooth is not only due to higher polymerization temperature of the resin dough. Another explanation may be that the uncured resin remains in contact with the acrylic resin polymer teeth for a longer time before polymerization, improving the monomer diffusion.[42]

For the activation of heat-activated acrylic resin polymer, heat is necessary to decompose the molecules of benzoyl peroxide-releasing free radicals, which react with monomer molecules available and begin the growth of polymer chains.[3] The microwaves make the molecules of acrylic resin polymer vibrate more frequently, generating friction and thus heat. This heat starts the polymerization in the same manner as heated water, but at a faster rate.[25] These activation methods could promote similar conversion of monomer to polymer for the two polymer types, and probably similar mechanical properties, as previous reported.[6,28,32,39,46]

However, other factors that affect the bond strength of the artificial tooth to the denture resin base polymer have been investigated by different methods, and the results have been used to suggest technical procedures that can improve the bonding. Imperceptible traces of wax[14-16,36,37] and other contaminants[9,29] are commonly identified as the main cause of the failure of the tooth-resin chemical bonding. In the current study, the cleaning of the teeth was carried out with heated water and detergent solution, which probably reduced or eliminated the likelihood of imperceptible traces of wax remaining on the ridge lap surface before bonding.

The unpolymerized acrylic resin remains in contact with the surface of the tooth for a significantly shorter time in the microwave procedure than during conventional curing, causing less swelling of the surface, less interpenetration and, consequently, decreased bond strength.[35]

The lower strength of the tooth/resin bond can also be caused by uncontrolled increases in temperature, where the components of the base resin are heated above the boiling point of the monomer, resulting in the formation of porosity that weakens the resin.[3,10,35] Based on the similarities observed in the statistical analysis of this study, this phenomenon does not seem to have influenced the shear strength of the tooth-resin bond, when the two materials were compared. Inspection of the area under a light microscope at 1.5X magnification did not demonstrate porosity in the fractured surface of the acrylic resin polymer.

Physical modification of the tooth ridge-lap surface by abrasion or grooving is often used in experimental studies to increase the strength of the bond.[1,8,10,21,41] Table 3 shows that this did not occur in the present study, since no statistically significant difference was found between the unmodified group and other treatments; however, a statistically significant difference was observed between the grooving + swelling by primer and sandblasting + swelling by primer treatments, where the latter presented a decreased bond strength. This result appears to confirm previous studies showing that mechanical retentions do not significantly improve the strength of the tooth/resin bond.[7,15,16,37]

It has been shown, however, that mechanical retention can increase the bond strength between teeth and the resin of the denture base. As such, it is claimed that the retentions increase the surface area of the tooth, improving the bond strength.[1,7,8,21,41] In contrast, other studies report that the retentions do not improve the mechanical strength of the bond,[7,10,33,37] possibly confirming, in part, the results of the present study.

Analysis of tooth/resin bond fractures showed that the mass of the acrylic resin polymer often does not penetrate completely into the rough surface of the mechanical retention. The best bond strength can be attributed to the greater surface area of the bonding and better penetration of the mass of resin into the irregularities produced by the abrasion or retention procedure. Moreover, bur grooving may decrease or increase the strength of the bond in chemically similar acrylic resins. Nevertheless, trapping of air inside the irregularities causes inadequate penetration where the mass of resin is pressed. The empty spaces at the bottom of the retention may also contribute to the failure of the bond.[41]

The technique of sandblasting with aluminum oxide particles has been used to produce microroughness on the denture tooth ridge-lap surface. The surface energy of the sandblasted area is greater than the unmodified surface, improving the bond strength. However, a previous study related no improvement in the tooth/resin bond strength following sandblasting, as compared to that obtained by swelling the ridge lap surface of the tooth with monomer.[22]

In the current study, chemical treatment did not improve the strength of the tooth/resin bond, a result corroborated by previous studies where the application of bonding agent[1] or swelling by monomer of the unmodified surface of the tooth[29,37] also did not promote any increase in bond strength. Swelling by monomer partially dissolves the polymer of the tooth surface and promotes bonding by double bonds with the polymer of the denture base,[4] and can form a durable structure of semi-interpenetrating secondary polymer, improving the link between tooth and resin.[41,44] However, solvents, monomers, and adhesive agents have shown conflicting results in the literature.[4,16,17,30,33]

A previous study showed that there was no difference in the thickness of swollen layers of the heat-activated PMMA specimens treated with monomer for various lengths of time, whereas the means for the autopolymerized PMMA specimens differed significantly.[43] Considering the monomer diffusion effect on the resin denture base polymer, this finding is an interesting point when the bond strength of the denture base repair or denture tooth replacement is focused in oral use.

Application of the bonding agent on the tooth/resin interface has been shown to be able to improve bond strength.[16,17,30,33] Bonding agent increases the wettability of the tooth surface, promoting a solvent effect and favoring the monomer diffusion in the polymer of the resin base and tooth.[17] The use of a resin primer with 85% methyl methacrylate and 15% by weight of poly-methylmethacrylate caused dissolution of the tooth surface, increasing the bond strength.[30]

Table 4 shows that the values of shear strength of the tooth/resin bond for the treatment factor were not statistically significant when the heat-cured denture base polymer was considered. For the microwaved polymer, the unmodified and grooving + swelling by primer treatments were statistically different from the sandblasting + swelling by monomer and sandblasting + swelling by primer treatments, while the other groups showed no statistical difference. Comparison between the acrylic resin polymers in each treatment showed a statistically significant difference only for the unmodified group, with a higher value for the microwaved polymer.

It has been shown that the polymerization activation temperature affects the bonding of the resin base polymer to denture teeth. At higher temperatures, there is deeper penetration of the monomers of the denture base polymers into the denture teeth, showing thicker secondary IPN layer formation, which results in the higher bond strength.[44]

However, some studies have shown that mechanical changes or chemical treatments do not improve the strength of the tooth/resin bond,[1,7,12,15,16,24,29,37] confirming the results obtained with the heat-cured denture base polymer, where no treatment produced a statistically significant difference compared to the unmodified specimens. This result suggests that the bond of the heat-cured denture base polymer to the tooth is not dependent on the treatment types accomplished on the tooth ridge-lap surface. In addition, the bonding of denture base resin to the denture teeth occurs via secondary IPN formation. In this case, the polymerization activation plays a significant role because of the relationship between the temperature and the rate of diffusion.[44]

This is not the case with the microwaved polymer, where results show that the unmodified and grooving + swelling by primer treatments presented statistically higher bond strengths, when compared to sandblasting + swelling by monomer and sandblasting + swelling by primer treatments. This apparent contradiction is difficult to explain, especially when compared with other studies, in which control and swelling by monomer treatments resulted in lower values of impact strength[12] and shear bond strength.[13]

Maximum bite force, exerted by complete denture wearers, is commonly low (90 N) and shows a range of 10 to 410 N.[40] However, it should be emphasized that the shear bond strength of the tooth/denture base bond shown in this current study exceeds the magnitude of the force necessary for chewing foods. An interesting fact is that the chewing performance also depends on notches made in the denture teeth with the intent to increase the masticatory efficiency of the foods.[26] Another interesting consideration is that the tooth displacement from the complete denture may only occur due to mechanical fatigue from repeated chewing, accidental falling, or by incorrect laboratory technique.[13]

Further studies are necessary to evaluate whether the effect of the bite force can be correlated to the failure of the tooth/resin bond in complete denture wearers.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn:

1. Heat-cured and microwaved polymers did not present statistically different shear bond strength values when they were analyzed independently of other factors.
2. Regardless of acrylic resin, the treatments of the tooth ridge-lap surface showed statistically significant differences only between the grooving + swelling by primer and sandblasting + swelling by primer groups, the latter presenting a lower value.
3. None of the tooth ridge-lap surface treatments presented statistically significant differences for the heat-cured polymer. For the microwaved polymer, the unmodified and grooving + swelling by primer treatments presented statistically higher bond strength values when compared to the sandblasting + swelling by monomer and sandblasting + swelling by primer treatments. Only the unmodified specimens presented statistically significant differences when the resins were compared, with the heat-cured polymer presenting lower bond strength.

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Clinical relevance: The bond strength of the acrylic resin tooth/denture base polymer adhesion may be improved according to type of denture base and different mechanical or chemical treatments performed on the tooth's ridge lap surface, with best results obtained in this study using a microwave-curing polymer as denture base and the ridge lap swollen by primer.