The Effect of Surface Preparation of Acrylic Teeth

ABSTRACT

Purpose: To investigate whether the chemical bond between acrylic teeth and heat polymerized PMMA can be altered by chemical and/or mechanical treatment. Materials and methods: One hundred fifty acrylic teeth were divided in groups of 10. Their ridge lap surface underwent mechanical and/or chemical treatments: 1) no treatment, 2) air-abrasion with Al_2O_3 particles, 3) acid etching with phosphoric acid, 4) application of composite resin bonding agent, 5) application of MMA and ethylmethylketone bonding agent, 6) PMMA monomer application. The teeth were then placed in heat polymerized acrylic resin. Each specimen was compressed with a universal testing machine. Descriptive statistics, one-way ANOVA (α=0.05) and Tukey's HSD test were used. A scanning electron microscope (SEM) was also used to study the fracture areas. Results: Statistically significant differences ($p<0.001$) in the bond strength were found. The strongest bond (239.41 N), was noted in the group treated with sandblasting followed by PMMA monomer application. Conclusions: Mechanical and/or chemical preparations affect significantly the bond strength between the acrylic resin denture teeth and the PMMA denture base. Air abrasion was the most effective treatment, either alone or combined with other treatments.

Keywords

Compressive Strength
Surface Treatment
Acrylic Denture Base
Bonding Strength
Acrylic Resin
Denture Teeth

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INTRODUCTION

Acrylic teeth are the most popular artificial teeth for denture construction since their introduction in the market in 1940.[1] Unlike porcelain teeth, acrylic teeth can be chemically bonded with the denture base resin.[2-7] However, debonding of acrylic teeth from the denture base can still occur and cause frustration to both patient and dentist. According to previous studies debonding and fracture of the acrylic resin teeth are the most frequent complications for denture patients.[8-13] It has been estimated in the past that teeth debonding accounted for one third of the complications that occurred in complete dentures a year or two after their fabrication.[14,15] This complication usually happens in the anterior region of the denture and may be attributed to the smaller ridge lap area available for bonding, in combination with the oblique direction of the stresses encountered during function.[16-18] It should be mentioned however that, debonding may also be the result of contamination of the joining surfaces during laboratory procedures either with wax, or/and sodium alginate.[19-22]

New methods and materials have been tried in the past in an effort to improve the quality of removable complete dentures.[23-28] More resistant artificial denture teeth have been developed too, as strict standards have been set by several international standards institutions.[29-35] Cross linked, IPN, and resin modified acrylic teeth have been manufactured for that purpose. These teeth have better mechanical and physical properties.[36,37] As a result, their ridge lap surface cannot be easily dissolved by the liquid monomer during packing. This procedure though, is very essential for the creation of a strong bond between the teeth and the PMMA resin.[38]

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After the dissolution of the tooth polymer, the polymer of the PMMA resin must react with the acrylic tooth polymer, to form an interwoven polymer network.[39-41] It seems however that, the wear and strength superiority of the newly introduced denture teeth is unfortunately accompanied by failure of the bond between the teeth and the PMMA resin base.[42]

Various methods of preparing the teeth have been introduced in the literature in order to reduce the risk of debonding. Wax elimination by treating the ridge-lap surface of the teeth with chemical solvents and/or warm/boiling water, has been presented as an effective method.[8,41,43] Mechanical or chemical modification of the ridge-lap surfaces of the teeth by using air abrasion,[20,44-49] acid etching,[50,51] grinding with diamond burs,[41,52-55] and application of monomer[16,45,56-58] or other solvents[21,58-62] to the teeth before packing have also been proposed. The use of bond enhancers has also been suggested in the past.[37,46,51,63]

There is conflicting evidence in the literature regarding the benefit of the above proposed preparations of the teeth, with some authors finding no benefit,[37,40,41,44,52,57,58,64] and others finding that there is some advantage.[21,36,46,48,49,56,58-62,65-67]

The purpose of this study was to investigate whether the bond in the interface of acrylic teeth and heat polymerized PMMA can be increased by mechanical and/or chemical methods. The null hypothesis was that neither the mechanical nor the chemical methods can increase this bond.

MATERIALS AND METHODS

A heat polymerized acrylic resin (Rapid Simplified; Vertex-Dental B.V., Zeist, Netherlands) and 150 identical acrylic teeth (A71 Creapearl; Creation Willi Geller, Meiningen, Austria) were used for the purposes of this study. Only maxillary right central incisors were used, as they provided a wide palatal surface to facilitate the application of compression force.

The materials used for the chemical and mechanical preparation of the ridge-lap surface of the teeth are listed in Table I. The air-abrasion procedure was based on a previously existed protocol.[37] The teeth were treated with 100μm Al_2O_3 particles under a pressure of 4 bar for a period of 10 sec, at 1cm distance, with a sandblasting device (GOBI 2; Wassermann Dental-Machinen GmbH, Hamburg, Germany). Powder remnants were removed from the ridge-lap surface of the teeth first by using de-ionized water in an ultrasonic bath and then by rubbing it with ethyl alcohol saturated cotton pads. The acid etching treatment of the acrylic teeth was performed by applying 35% orthophosphate acid (GLUMA Etch 35 Gel; Heraeus Kulzer, Hanau, Germany) for 30 sec. The phosphoric acid was then washed out with water and the teeth were dried before packing, using air-spray. The composite resin bonding agent (GLUMA 2Bond; Heraeus Kulzer) was applied on the ridge-lap surface of the teeth, remained for 20 sec and was then dried out with oil-free compressed air for another 20 sec. For the application of the acrylic teeth bonding agent (Vitacoll; Vita Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany), the manufacturer's instructions were followed. The bonding agent was applied on the tooth surface using a small brush, and remained there for 5 min. Finally, the PMMA monomer was applied on the ridge-lap surface for 60 sec before packing.

Fourteen experimental groups were generated from the previously described tooth surface treatments and their combinations. Each group consisted of 10 acrylic resin teeth. The teeth in the control group didn't receive any mechanical or chemical treatment. *(Table 2)*

Five identical stainless steel molds were fabricated, in order to construct the acrylic denture specimens. Each mold consisted of four parts, which by two formed two cylindrical chambers *(Figure 1)*. The inner dimensions of these chambers had a 30 mm diameter, 10 mm height (part A), and 30 mm diameter, 30 mm height (part B). In the middle of the two external parts of the mold a small hole with a diameter of 3 mm allowed the excess of the acrylic resin to escape. Part A was filled with dental wax (Medium soft No. 3 pink base plate wax; Coltene/Whaledent Inc., Cuyahoga Falls, OH) and a tooth was incorporated in the middle of it by using a dental surveyor (Ney Surveyor; Dentsply Sirona Inc., York, PA). Only the ridge-lap surface of the tooth was embedded in the wax. Part B was then filled with polyvinyl-siloxane (Deguform; Degudent, Hanau/Hesse, Germany) and the two parts were reassembled and locked for 30 min, until the polyvinyl-siloxane was completely polymerized, according to the manufacturer's recommendations. The mold was then disassembled and the dental wax was removed first by hand and then with steam.

Table 1. Materials used for the chemical and mechanical treatment of the ridge-lap surface of the teeth.

Treatment	Symbol	Materials
Air Abrasion	(A)	Al_2O_3 particles (100μm)
Acid Etching	(E)	GLUMA Etch 35 Gel (Heraeus Kulzer)
Composite resin bonding agent	(B)	GLUMA 2 Bond (Heraeus Kulzer)
Bonding agent for acrylic teeth	(V)	V Vitacoll (VITA Zahnfabrik)
Organic solvent	(M)	Rapid Simplified (Vertex-Dental BV)

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Table 2. Experimental groups

Group	Surface Treatment	Symbol
1	None (Control)	C
2	Air abrasion	A
3	Acid etching	E
4	Air abrasion and bonding agent	AB
5	Air abrasion and Vitacoll	AV
6	Air abrasion and monomer	AM
7	Acid etching and monomer	EM
8	Acid etching and bonding agent	EB
9	Monomer	M
10	Monomer and bonding agent	MB
11	Vitacoll	V
12	Acid etching and Vitacoll	EV
13	Monomer and Vitacoll	MV
14	Air abrasion and acid etching	AE
15	Bonding agent	B

This procedure was repeated 5 times, resulting in the fabrication of 5 identical polyvinylsiloxane molds which were used for the positioning of the acrylic teeth *(Figure 2)*. The ridge lap was the only surface which was accessible when the teeth were in the molds. Part A of the mold was then filled with acrylic resin (Rapid Simplified; Vertex-Dental B.V.) *(Figure 3)*. Then the parts were re-assembled and the mold was placed in boiling water for 30 min according to the manufacturer's instructions *(Figure 4)*. The acrylic specimen, including the acrylic base and the tooth was then removed from the mold *(Figure 5)*. A total of 150 specimens was fabricated.

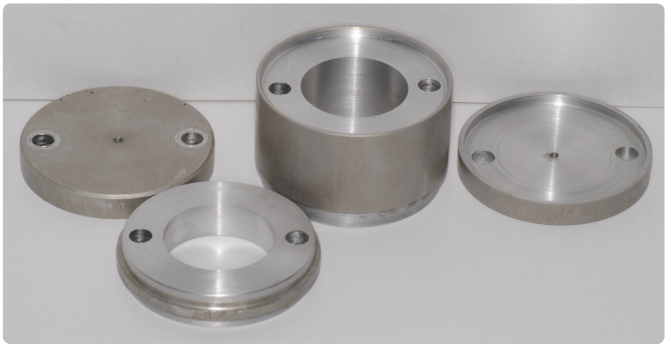

Figure 1: One of the 5 molds used for the purposes of this study, disassembled.

Figure 2: An acrylic denture tooth placed in silicone, with only the ridge lap surface accessible.

Figure 3: PMMA acrylic resin packing.

Figure 4: A mold assembled during the packing process.

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Figure 5: An acrylic denture tooth with the corresponding PMMA resin base after the polymerization process.

Each specimen was tested with a universal testing machine (M350-10kN; Testometric Co Ltd., Rochdale, United Kingdom). A static load was applied at the middle of the palatal side of the tooth at a 135 degree angle to its long axis, simulating a Class I Angle relationship *(Figures 6)*.[34,68] The specimens were loaded at a speed of 1mm/min, until failure. Destructive loads were recorded for each sample. An optical microscope (PM-10M; Olympus Corp., Tokyo, Japan) was employed to observe the ridge lap surface of all teeth for PMMA remnants. The failure was described as adhesive when the fracture path ran clearly along the interface and no PMMA debris were observed on the acrylic tooth surface. The failure was described as cohesive when the fracture path did not run clearly on the interface, and remnants of PMMA resin were bonded on the dental ridge-lap surface. A fracture which was partially adhesive and cohesive was characterized as a mixed fracture. Finally a scanning electron microscope (SEM) (8640-A; Jeol USA Inc., Tokyo, Japan), was used to observe the fracture area and correlate the effectiveness of the mechanical and chemical treatments of the teeth surface to the bond strength between tooth and denture base *(Figures 7* and 8). Descriptive statistics, 1-way ANOVA (α =.05) and Tukey HSD tests were used for the statistical analysis.

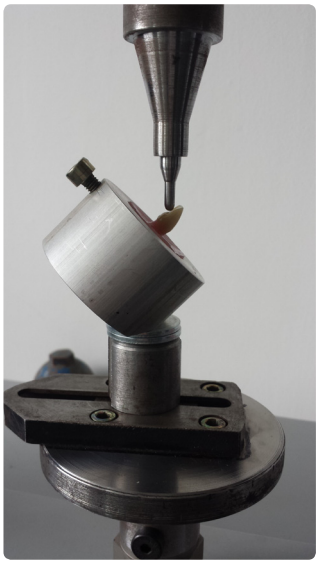

Figure 6: The compression testing apparatus.

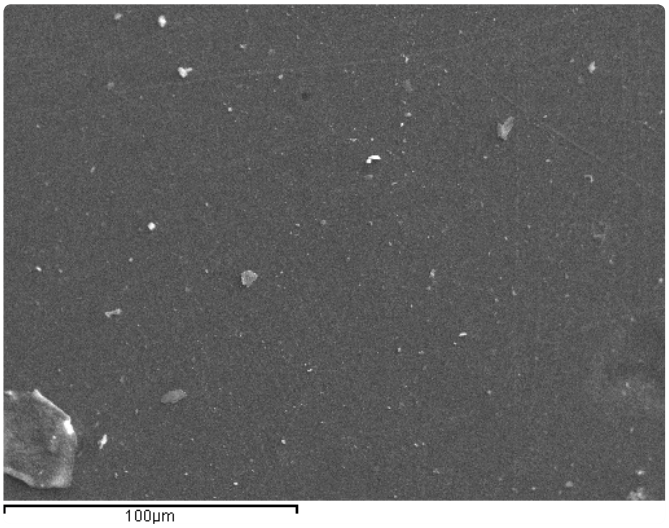

Figure 7: SEM picture of a specimen which presented adhesive failure.

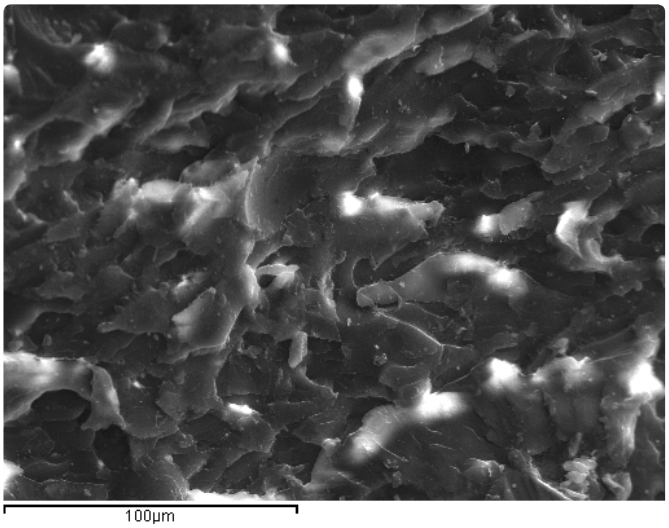

Figure 8: SEM picture of a specimen which presented cohesive failure.

RESULTS

The means, standard deviations, and the minimum and maximum compression failure loads for the 15 groups are listed in Table 3 and Figure 9. The mean failure loads ranged between 28.69 N and 239.41 N.

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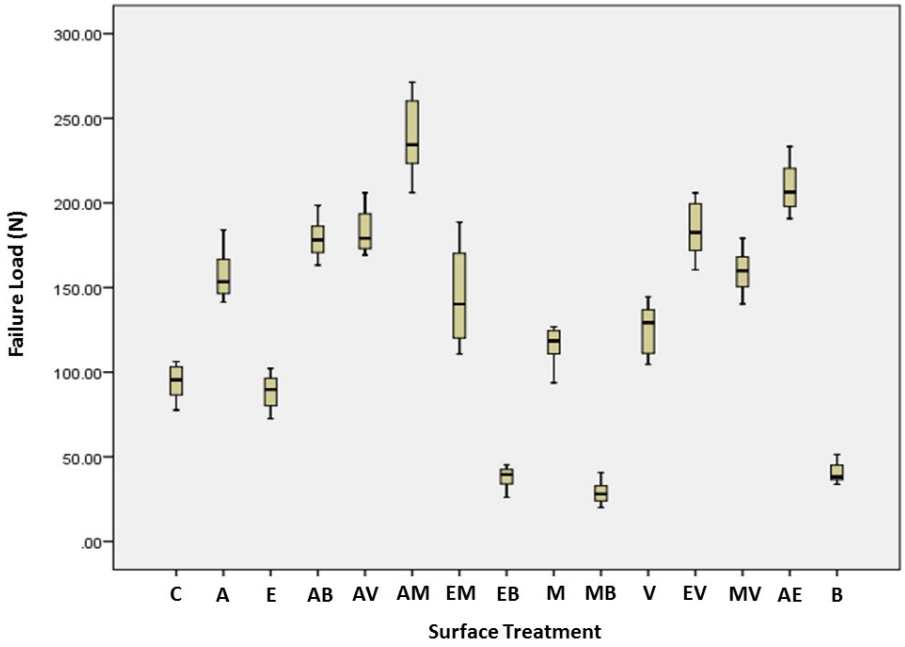

Figure 9: Box plot diagram for the different groups.

Table 3. Descriptive statistical analysis

Group	Mean	SD	Std. Error	Lower Limit (95% C.I.)	Upper Limit (95% C.I.)	Minimum	Maximum
C	94.61	9.75	3.08	87.63	101.59	77.58	106.22
A	157.42	13.89	4.39	147.49	167.36	141.36	184.02
E	88.39	10.72	3.39	80.72	96.06	72.58	102.26
AB	178.57	11.12	3.52	170.62	186.53	163.27	198.60
AV	183.07	12.17	3.85	174.37	191.78	169.14	206.05
AM	239.41	22.88	7.23	223.04	255.77	206.15	271.36
EM	146.35	28.68	9.07	125.84	166.87	110.76	188.64
EB	37.70	6.19	1.96	33.28	42.13	26.03	45.28
M	115.21	10.92	3.45	107.40	123.01	93.73	126.82
MB	28.69	6.09	1.93	24.33	33.05	20.09	40.70
V	125.78	14.45	4.57	115.44	136.11	104.61	144.54
EV	183.97	14.57	4.61	173.55	194.39	160.46	205.89
MV	160.22	11.31	3.58	152.13	168.31	140.33	179.05
AE	208.42	13.46	4.26	198.79	218.04	190.76	233.30
B	40.61	6.10	1.93	36.24	44.97	33.78	51.40
Total	132.56	63.84	5.21	122.26	142.86	20.09	271.36

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The 1-way ANOVA revealed significant differences ($p<0.001$) among the different tested groups *(Table 4)*. Tukey's HSD test *(Table 5)* revealed that groups MB (monomer and bonding agent), EB (acid etching and bonding agent), and B (bonding agent) presented the lowest failure loads with no statistically significant differences among them, while AM (air abrasion and monomer) presented the highest failure loads. The control group presented higher failure loads than MB (monomer and bonding agent), EB (acid etching and bonding agent), B (bonding agent) and E (acid etching). However, no statistically significant difference was found between control and E (acid etching), and control and M (monomer). The biggest failure loads were observed in AM (air abrasion and monomer) and AE (air abrasion and acid etching), which were 239.41N and 208.42N respectively. These groups differed statistically ($p<0.001$) both to each other and the rest of the groups.

Table 4. One-Way ANOVA

	Sum of Squares	df	Mean Square	F	P
Between Groups	580368.50	14	41454.89	208.51	.0001
Within Groups	26840.69	135	198.82		
Total	607209.10	149			

Table 5. Tukey HSD test
Subset for α=.05

Group	1	2	3	4	5	6	7	8	9	10
MB	28.69									
EB	37.70									
B	40.61									
E		88.39								
C		94.61	94.61							
M			115.21	115.21						
V				125.78	125.78					
EM					146.35	146.35				
A						157.42	157.42			
MV						160.22	160.22			
AB							178.57	178.57		
AV								183.07		
EV								183.97		
AE									208.42	
AM										239.41

Means for groups in homogeneous subsets are displayed

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The type of failure for the specimens of each group is presented in Table 6. In all groups parts of PMMA resin were found on the majority of the teeth surfaces, with the exception of groups C (control), EB (acid etching and bonding agent), MB (monomer and bonding agent), and B (bonding agent). Adhesive failure was the most common type of failure, for the groups that presented destructive loads bigger than the control group.

Scanning electron microscopy revealed a smooth surface in teeth of groups B (bonding agent), EB (phosphoric acid application), and C (control). On the contrary, air-abraded specimens presented a significant surface roughness.

Table 6. Type of failure in specimens of each group

Group	Adhesive	Cohesive
C	8	2
A	0	10
E	4	6
AB	1	9
AV	0	10
AM	0	10
EM	0	10
EB	7	3
M	4	6
MB	8	2
V	2	8
EV	1	9
VM	4	6
AE	0	10
B	9	1

DISCUSSION

The results of the present study indicate that the mechanical and/or chemical treatments of the ridge-lap surface of artificial acrylic teeth, affect the bond between the later and the PMMA base material. Therefore, the null hypothesis should be rejected. These data agree with experimental studies which were carried out in the past. Bond strength enhancement has also been proved by Barpal *et al*,[9] Vallittu *et al*,[38] Nishigawa *et al*,[45] Saavedra *et al*,[46] and Cunningham *et al*.[64] The results from Rupp *et al*[3] and Morrow *et al*[20] revealed a deterioration of the bond strength, while no benefit from surface treatments was presented by others.[2,52,64]

Numerous experimental designs exist in the literature, all aiming to explore the effectiveness of various surface treatment methods on the bond between acrylic teeth and the PMMA denture base resin. Many of them focus on national standards that are determined by national organizations.[29-35] Tensile,[3,4,10,11,28,54,55,57] shear,[51,53,56,61,63] compression,[12,20,47,48,59] and finite element analysis tests,[13] have been performed in the past.

The design of the present study was based on the Japanese National Standards,[34] as the direction of the forces applied on the teeth reproduces the intraoral conditions better. The force application was at a 135 degree angle based on the average contact angle of the anterior teeth in Angle Class I patient. Many authors have applied the force using the same angle with that of the present study,[47,59,62] while others have loaded the teeth at 30 degrees[12] and 90 degree angles.[48] Likewise, differences in the materials, polymerization techniques, and methods of surface treatments in different studies do not allow a safe comparison and outcome.

The present study has demonstrated that the AM group (air abrasion and monomer) developed the strongest bond. Air-abrasion (A) by itself improved the bond but not equally effectively, while treatment with monomer (M) didn't present a clinically significant difference from the control group. The inability of monomer to increase by itself the bond strength was also proven by Morrow *et al*,[20] Spratley *et al*,[21] Adeyemi *et al*,[41] and Patilsch *et al*.[57] An interesting finding is that the combination of monomer with composite resin bonding agent (group MB) produced the weakest bond. A possible explanation of these results might be that air-abrasion provides a bigger connection area for the PMMA resin and thus possibly enhance the mechanical retention. This explanation is also suggested by the significant surface roughness revealed with SEM photography in the air abraded groups. It is also remarkable that the type of failure can also be correlated with the surface roughness. Apart from the PMMA remnants on the tooth surface of cohesively failed specimens, the morphology of the remaining area appears to be significantly rougher in these groups, when compared to the rest. Conversely, groups which presented lower failure loads presented smooth tooth surfaces on the SEM photographs and higher percentages of adhesive failure.

In the comparison of the effectiveness of the two bonding agents in the reinforcement of the bond strength between teeth and PMMA base, Vitacoll (MMA monomer and ethylmethylketone), presented the best results. Scanning electron microscopy revealed that Vitacoll bonding agent generated shallow craters on the tooth surface, while composite resin bonding agent created a smooth surface, even smoother than this of the control group, having as a result the adhesive failure of nine out of ten specimens.

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No standardized air-abrasion protocol has been published in the literature.[45,46,48] The size of the Al_2O_3 particles, the angle and the distance from the tooth surface, the pressure and duration can differ. The present study reproduced the air-abrasion protocol suggested by Consani *et al*.[37] However the results of the present study are in contrast with that of Consani *et al*, who found no benefit from the air abrasion treatment. On the contrary, in the present study sandblasting proved to significantly reinforce the bond between the acrylic tooth and PMMA denture base. The different type of teeth used in these experiments can be a possible explanation for this disagreement. Consani *et al*. [37] experimented on IPN artificial teeth, which present an interwoven polymer network, while cross linked teeth were used in the present study.

Acrylic teeth mainly consist of linear polymethyl-methacrylate chains. A cross-linking agent is used to create a more complex polymer network, improve strength and prevent crazing of the polymer.[42] However, according to previous studies, cross-linking seems to downgrade the strength of the tooth-denture bond.[6,54] Nonetheless, the cervical portion of the tooth is less cross-linked compared to the incisal part of it.[66] IPN teeth polymer network is more complex compared to that of cross-linked teeth. Moreover, IPN polymer network contains a silica filler which further improves the teeth's hardness. Air-abrasion didn't prove to be effective in Consani and co-workers' research, probably due to the hard surface of the IPN teeth they tested.[37]

The literature suggests that monomer application can be employed to enhance the tooth-base bond.[4,25,48,51,58,64,67] The bond-enhancement mechanism is probably related to the monomer's dissolution ability. According to Sperling,[25] when a solvent reacts with a polymer the latter's surface gets swollen due to the diffusion of the solvent inside the polymer. The base and tooth polymer chains react and copolymerize through this procedure, and this results in the creation of a secondary structure with IPN characteristics, which reinforce the tooth-base bond.[21,51] The diffusion of the monomer inside the polymer chains depends on many parameters, such as time, temperature, solvent, and polymer structure.26 The depth of diffusion of the solvent into the acrylic tooth structure is both time and temperature related.[21]

The time of solvent application has been arbitrary chosen in the past.[16,21,37,40,50,56,67] In the present study the monomer remained in contact with the tooth surface for 60 sec, based on the research of Barbosa *et al*,[67] who compared the effectiveness of monomer to the bond between teeth and base resin, under different application times. This study concluded that when the monomer application exceeded 60 sec the bond strength deteriorated, probably due to its evaporation.

In group M, where monomer application was the only treatment, no statistical significant difference was found with the control group (C). When composite resin bonding agent followed the monomer application, a weaker bond developed, probably due to the entrapment of free monomer by the bonding agent. This has as a result the obstruction of the interpenetrated polymer network structure.

All the surface treatments that included Vitacoll bonding agent and Al_2O_3 particles air abrasion alone or in combination with other modifications, provided a stronger bond. On the contrary, groups treated with monomer solvent, composite resin bonding agent and phosphoric acid provided no benefit to the bond (groups E, EB, MB, B).

In complete denture patients the average forces applied in the anterior and posterior regions, are 40 and 100N respectively.[68] These values may vary due to gender, race and age differences.[68] Haraldson *et al*, estimated that this force in the incisor segment varies from 8 to 12N.[68] According to these values, it seems that all groups, besides acid etching and bonding agent (EB), monomer and boding agent (MB), and bonding agent (B), can provide a tooth-denture bond, which will be satisfactory for most clinical cases. It should be mentioned that theoretically even the control group can ensure a satisfactory tooth-base bond. Of course enhancement of the strength of the bond offers the additional safety needed in cases where variables such as malocclusion, bruxism and laboratory errors cannot be prevented.

Further *in-vitro* studies with cyclic-loading and different types of denture teeth, as well as, long-term clinical trials are needed in order to draw definitive results.

CONCLUSIONS

Within the limitations of this study the following conclusions can be drawn:

1. The majority of acrylic denture teeth surface treatments, with the exception of acid etching (E) and monomer (M), affect their bond strength with the PMMA denture base resin.
2. Air-abrasion proved to be the most effective treatment. When combined with bonding agent or monomer application, the destructive loads were 220 - 253% higher compared to those of the control group.
3. Composite resin bonding agent developed weaker bonds between denture teeth and PMMA base, compared to Vitacoll bonding agent.
4. Groups which developed strong bonds presented significant surface roughness.
5. 90-100% of the specimens in groups A, AB, AV, AM, and AE presented a cohesive failure. The bond strength developed between acrylic teeth and denture PMMA base in these groups was superior to that presented in groups B and EB. More than half of the specimens in groups B and EB presented an adhesive failure.

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