

Tensile Bond Strength between Custom Tray and Elastomeric Impression Material

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The aim of this study was to investigate how to achieve sufficient and stable adhesive strength between impression material and tray. Impression materials were molded between autopolymerizing resin columns, and tensile strength was measured as a function of these factors: tray storage time (1, 2, 4, 7, and 10 days), adhesive drying time (0, 1, 5, 10, and 15 minutes), and tray surface roughness (air abrasion, bur-produced roughness, and no treatment). Tensile bond strength was not affected by tray storage time throughout the entire evaluation period of 10 days. As for tray adhesive drying time, Reprisil and Exaimplant yielded extremely low values for drying times of 10 minutes or less ($P < 0.05$), while Imprint II and Impregum were not influenced by drying time. Vinyl polysiloxane achieved the highest adhesive strength with bur-produced roughness, which was significantly higher than with air abrasion or no treatment ($P < 0.05$), whereas polyether achieved the lowest value with bur-produced roughness ($P < 0.05$). It was concluded that surface treatment of custom tray should be adapted to the type of impression material used to achieve optimum bond strength.

Keywords: Elastomeric impression material, Custom tray, Tensile bond strength

INTRODUCTION

Fitness precision of a prosthetic device is one salient factor that contributes to the long-term success of a prosthetic treatment. However, a prosthetic treatment typically entails and involves many clinical and laboratory procedures (e.g., abutment tooth preparation, impression taking, cast and prosthesis fabrication). It should thus be highlighted that the sum of insignificant failures and potential processing errors at each step can detrimentally lead to a misfit. In this connection, dental impression materials play an important role as their primary function is to produce an accurate replica of the oral tissues.

Indeed, passive fit of implant prostheses is the key to long-term treatment success¹⁻³ — because superstructure, abutment, osseointegrated implant, and surrounding bone act as a unit^{4,5}. To the end of attaining a passive fit for the superstructure, it is very important that the position and orientation of implant be accurately transferred to the definitive cast⁹⁻¹³. As such, maintaining the dimensional accuracy of impression copings demands for the rigidity of polyether or vinyl polysiloxane (heavy body). The rigidity property is required to resist displacement arising from the removal of impression from the oral cavity, or due to routine laboratory procedures such as implant replica connection, reinsertion of impression coping into impression socket, or definitive cast fabrication^{3,14-16}.

For accurate registration of oral structures,

custom trays are recommended in that they provide a uniform thickness of the elastomeric impression material so as to improve the accuracy of impressions^{13,17,18}. Further, impression taking with a custom tray is easier and less obtrusive than with a stock tray. The custom tray advocates the use of wax spacers on the model to provide the uniform thickness. However, autopolymerization directly against wax spacers could decrease bond strength to the elastomeric impression material, as wax residue might remain on the custom tray surface¹³.

To be able to withstand the forces generated during the removal of set impression from the oral cavity, there must be sufficient adhesion between the impression material and tray^{13,19,20}. Similarly, it was expected that an unscrewing of impression guide pins in the oral cavity or re-screwing of implant replica during definitive cast fabrication might also cause a slight or partial separation of set impression material from the tray⁵. To improve adhesion between impression material and custom tray, suggestions included bonding with adhesive solutions, perforating or roughening custom tray surface with burs, or a combination of these two methods¹³. To date, application of adhesive solution on custom tray surface seems to be most effective in achieving the needed bond strength. However, due to consideration and priority for shortened chairside time, many prosthodontists tend to ignore or disregard the adhesive drying time recommended by the manufacturer. Further, use of adhesive solution

alone may not necessarily provide mechanical interlocking which is otherwise achieved with perforating or roughening the custom tray surface.

The aim of the present study was to investigate how to achieve sufficient and stable adhesive strength between impression material and autopolymerized resin custom tray for prostheses. To this end, it was hypothesized that adhesive strength would be affected by these factors: storage time of custom tray after fabrication, drying time of tray adhesive, and type of roughness produced on the tray surface.

MATERIALS AND METHODS

Materials used

To simulate a custom impression tray, a methyl methacrylate autopolymerizing resin (Ostron II, GC, Tokyo, Japan) (Table 1) was shaped into columns (2.5 cm diameter \times 2.2 cm height) with commercially available phenolic rings (Ring forms, Buehler, IL, USA). The liquid and powder of autopolymerizing resin were mixed according to manufacturer's instructions. Resin columns were then packed onto a glass plate to make an experimental side surface, which was flat and smooth as a control (Fig. 1a). To ensure a uniform thickness of impression material, a

jig produced a separation of 1.4 mm between the columns. After which, this inner space between columns was filled with two generic types of elastomeric impression material (Table 1). Imprint II Penta Heavy Body (3M ESPE, Seefeld, Germany) and Impregum Penta (3M ESPE) were machine-mixed (Pentamix II, 3M ESPE), while Exaimplant (GC, Tokyo, Japan) and Reprosil Heavy Body (Dentsply Caulk, Milford, DE, USA) were dispensed with auto-mix cartridges. Each elastomeric impression material was used with its respective tray adhesive (Table 1).

Tensile bond strength evaluation

1) Effect of tray storage time

To evaluate the effect of storage time after fabrication of custom trays, autopolymerizing resin columns were stored for 1, 2, 4, 7, and 10 days after packing into phenolic rings ($n=10$ for each storage time) at 23 ± 1 and $50 \pm 10\%$ relative humidity. After each storage interval, the experimental side of columns was roughened with a single application of tungsten carbide (Robot Carbide HP Cutters, No. SH251 E, Shofu Inc., Kyoto, Japan) (Fig. 1b). Then, the experimental surface of each column was uniformly coated with a single application of the

Table 1 Materials used in this study

Materials	Generic type	Brand names	Batch no.	Manufacture (Ingredients)
Impression tray	Autopolymerizing resin	Ostron		GC, Tokyo, Japan
		Powder	0406241	
		Liquid	0411102	
Electrometric impression material	Vinyl Polysiloxane	Imprint Penta Heavy body	163755	3M ESPE, Seefeld, Germany
		Exaimplant	0406231	GC, Tokyo, Japan
		Reprosil Heavy body	040610	Dentsply/Caulk, Milford, DE, USA
	Polyether	Impregum Penta	162229	3M ESPE, Seefeld, Germany
Tray adhesive		VPS tray adhesive	141698	3M ESPE, Seefeld, Germany (ethyl acetate, MQ resin, C9-C12-iso-alkanes, amorphous silica, hydrogen dimethyl methyl siloxane)
		Exaimplant adhesive	0306101	GC, Tokyo, Japan (silicone modified acrylic resin, etyl acetate)
		Cauld tray adhesive	031206	Detsply/Caulk, Milford, DE, USA (pressure sensitive silicone adhesive, ethyl acetate, violet colorant)
		Polyether adhesive	151975	3M ESPE, Seefeld, Germany (ethyl acetate, heptane, acetone polychloroprene, phenol resin, hydrotreated light naphtha(petroleum))

adhesive solution over a period of one minute and allowed to dry at room temperature for 15 minutes. These columns were mounted on the jig, and elastomeric impression material with a uniform thickness (1.4 mm) was molded between each pair of columns. These specimens were placed in a humidior at 37 and 100% relative humidity for six minutes. Adhesive strength between autopolymerizing resin and elastomeric impression material was evaluated in terms of tensile bond strength. To this end, specimens were attached to a universal testing machine (Autograph DSC-2000, Shimazu Co., Kyoto, Japan) and tested in tensile mode at a crosshead speed of 500 mm/minute.

2) Effect of tray adhesive drying time

To evaluate the effect of drying time of tray adhesives, the experimental surfaces of autopolymerizing resin columns roughened with a single application of tungsten carbide were uniformly coated with a single application of the adhesive solution within three seconds. These columns were allowed to stand to dry for 0 (Time 0), 1, 5, 10, and 15 minutes ($n=10$ for each drying time) at 23 ± 1 and $50 \pm 10\%$ relative humidity. Then, elastomeric impression material with 1.4 mm thickness was uniformly molded between each pair of columns. Specimens were placed in a humidior at 37 and 100% relative humidity for six minutes, and tensile bond strength was measured.

3) Effect of tray surface roughness

To evaluate the effect of surface roughness of custom trays, the experimental surfaces of autopolymerizing

resin columns were treated with air abrasion, tungsten carbide bur, or with no treatment (control). Each group consisted of 10 specimens. Air abrasion was completed with 50- μm aluminum oxide (Perlablast® micro, BEGO, Bremen, Germany) using a grit blaster (emission pressure: 0.4 MPa), whereby the nozzle was positioned 5 mm from the autopolymerizing resin substrate. Bur roughness was achieved with a single application of tungsten carbide. Then, the experimental surface of each column was applied the adhesive solution and dried at room temperature for 15 minutes. Following which, elastomeric impression materials with 1.4 mm thickness were molded between these columns, and these specimens placed in a humidior at 37 and 100% relative humidity for six minutes. Tensile bond strength was then measured.

Statistical analysis

All data were compared with two-way ANOVA and a series of Scheffé's *post hoc* tests. All statistical tests were run at 5% level of significance (SigmaStat® 3.1, Systat Software, Inc., CA, USA).

RESULTS

Surface texture by SEM observation

The experimental control surface was almost plain, though there were some small hollows with air bullas (Fig. 1a). As for the experimental surfaces treated with tungsten carbide bur or air abrasion (Figs. 1b and 1c, respectively), they showed different

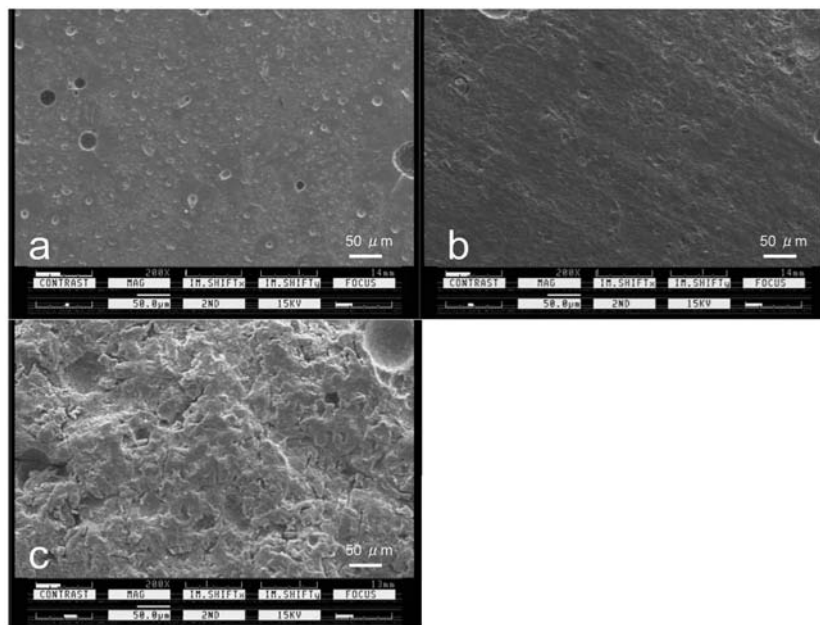


Fig. 1 Scanning electron microscopy images of custom tray material under different surface treatments: (a) control with no treatment; (b) bur-produced roughness; (c) air abrasion (magnification $\times 200$; white bar: 50 μm).

Table 2 Effect of storage time after fabrication of custom tray on tensile bond strength between elastomeric impression material and tray material (kPa)

Product		Storage time (mean (SD)) ^a				
		1 day	2 days	4 days	7 days	10 days
Imprint	Penta Heavy body	198.5(30.5)*AB	200.5(36.9)*A	211.0(30.1)*A	190.6(27.2)*A	215.2(35.3)*AB
Exaimplant		207.9(23.0)*AB	210.8(30.5)*A	226.3(42.3)*A	246.8(24.2)*B	238.8(24.4)*A
Reprosil	Heavy body	186.8(15.8)*A	186.2(18.2)*A	194.8(21.9)*A	195.2(18.5)*A	190.0(18.8)*B
Impregum	Penta	219.6(16.2)*B	218.0(32.0)*A	224.9(16.9)*A	218.4(19.5)*AB	210.4(17.2)*AB

With each product, mean values designated with the same letters (A, B) were not significantly different (P>0.05). With storage time, means designated with the same symbols(*) were not significant different (P>0.05).^aN=10

Table 3 Effect of drying time of tray adhesive on tensile bond strength between elastomeric impression tray material (kPa).

Product		Drying time (mean (SD)) ^a				
		Time 0	1 min	5 min	10 min	15 min
Imprint	Penta heavy body	158.8(33.7)*A	169.9(17.0)*A	179.1(11.9)*#A	211.6(33.9)#A	215.2(35.3)#A
Exaimplant		108.4(22.8)\$B	146.9(20.9)*A	148.3(19.2)*A	153.7(17.0)*B	238.8(24.4)#AB
Reprosil	Heavy body	111.4(25.7)*B	116.3(27.9)*B	121.5(19.8)*B	138.4(24.6)*BC	190.0(18.8)#AB
Impregum	Penta	177.7(8.0)*A	184.0(10.3)*B	181.1(10.5)*C	179.3(11.4)*C	210.4(17.2)#B

With each product, mean values designated with the same letters (A, B, C) were not significantly different (P>0.05). With storage time, means designated with the same symbols(*, #, \$) were not significant different (P>0.05).^aN=10

Table 4 Effects of surface roughness of custom tray on tensile bond strength between elastomeric impression material and tray material (kPa)

Product		Surface roughness (mean (SD)) ^a		
		Control	Bur roughness	Air abrasion
Imprint	Penta Heavy body	179.3(11.4)A	215.2(35.3)B	169.9(17.0)A
Exaimplant		167.8(14.8)A	238.8(24.4)B	159.4(22.8)A
Reprosil	Heavy body	89.1(19.9)A	190.0(18.8)C	136.4(22.1)B
Impregum	Penta	232.1(11.6)AB	210.3(17.2)A	235.3(29.4)B

With each product, mean values designated with the same letters (A, B, C) were not significantly different (P>0.05).^aN=10

types of surface roughness structure.

Tensile bond strength

1) Effect of tray storage time

For 10 days after fabrication of autopolymerizing

resin specimens, the tensile bond strengths of Imprint II, Reprosil, and Impregum were almost constant without any significant differences at 198-215 kPa, 186-195 kPa, and 218-224 kPa, respectively (Table 2). With Exaimplant, tensile bond strength values were highest at 7 and 10 days among all the evaluated impression materials (P<0.05, Table 2). Nonetheless, Exaimplant also showed a constant value (207-246 kPa) without significant differences.

2) Effect of tray adhesive drying time

With Imprint II, tensile bond strength immediately after tray adhesive application (Time 0, 158.8 ± 33.7 kPa) and at 1 minute after application (169.9 ± 17.0 kPa) were significantly lower than at 10 (211.6 ± 33.9 kPa) and 15 minutes (215.2 ± 35.3 kPa) after application (P<0.05, Table 3). With Exaimplant, tensile bond strength at Time 0 (108.4 ± 22.8 kPa) was significantly lower than at 1 (146.9 ± 20.9 kPa), 5 (148.3 ± 19.2 kPa), 10 (153.7 ± 17.0 kPa), and 15 minutes (238.8 ± 24.4 kPa) (P<0.05, Table 3). Further, tensile bond strength of Exaimplant at 1, 5, and 10 minutes were significantly different from that at 15 minutes (P<0.05, Table 3). With Reprosil and Impregum, tensile bond strengths at 0, 1, 5, and 10 minutes

after adhesive application were significantly lower than at 15 minutes ($P < 0.05$, Table 3).

3) Effect of tray surface roughness

Tensile bond strengths of vinyl polysiloxane materials with bur roughness were significantly higher than with air abrasion or controls with no treatment ($P < 0.05$, Table 4). On the other hand, with polyether, tensile bond strength with bur roughness was the lowest among air abrasion and no-treatment control with a significant difference ($P < 0.05$, Table 4).

DISCUSSION

To withstand the forces and stresses generated during the removal of set impression from the oral cavity, there must be complete not partial nor inadequate adhesion of the impression material to the custom tray; otherwise, the impression material will be pulled away or separated from the tray^{13,19,20}. However, since it remains to be clarified and quantified the clinically adequate amount of bond strength necessary to prevent detachment of impression from the tray, maximum bond strength is typically recommended. With a focus on achieving durable and stable adhesion, this study sought to examine how adhesive strength would be affected by these factors: (1) storage time after fabrication of custom tray; (2) drying time of tray adhesive; and (3) type of roughness produced on tray surface.

It has been recommended that impression taking be done with custom trays stored for three days after fabrication²¹. This was because distortion of custom trays due to polymerization shrinkage and residual stress relaxation occurred during this storage interval²¹. In other words, surface microstructure of custom trays might change with polymerization and volatilization of residual monomer. In this study, it was demonstrated that adhesion of each impression material to the custom tray through the tray adhesive was not affected by storage time. Among all the experimental storage times and evaluated impression materials, Exaimplant yielded the highest adhesive strength at 7 days after fabrication, although no significant differences were detected. Undeniably and inevitably, production of custom tray material and Exaimplant (including tray adhesive) by the same manufacturer could have positively influenced adhesive strength. However, it was also suggested that some chemical adhesion mechanism might have existed between these two materials, thereby enhancing adhesive strength.

All evaluated tray adhesives consisted mainly of ethyl acetate and silicon-modified resin, with a view to increasing the bond strength between elastomeric impression material and tray material. In terms of purpose and function, the tray adhesive serves to

clean the tray surface and increase the wettability of impression material, and thereby improve the adhesive strength between these two materials. In many cases, dental practitioners due to greater concern and priority for shortened chairside time choose to disregard the tray adhesive drying time as instructed by the manufacturer. Another reason for such deliberate disregard is the wrong notion that the manufacturer-indicated drying time is applicable to both stock and custom trays alike hence no need to be strictly adhered to for custom trays.

However, this study clearly demonstrated that shortened drying time for adhesive solutions directly affected the adhesive strength between impression material and tray material, especially in the cases of Reprosil and Exaimplant. Reprosil and Exaimplant showed extremely low values of tensile bond strength for drying times of 10 minutes or less, but the values rapidly increased from 10 to 15 minutes with significant differences. Therefore, for these two impression materials, tray adhesive drying time should be at least 15 minutes. It was suggested that Exaimplant was the most suitable impression material, as it showed the highest tensile bond strength value among all the evaluated impression materials at the drying time of 15 minutes. As for Imprint II and Impregum, they were hardly influenced by drying time. They already yielded high tensile bond strength values regardless of drying time.

As for the effect of tray surface roughness, all vinyl polysiloxane materials achieved the highest adhesive strengths with bur-produced roughness. Moreover, these impression materials except Reprosil yielded lower values than the controls for air abrasion treatment. It was speculated that the small size (50 μm diameter) of aluminum oxide particles used for air abrasion did not create sufficient surface roughness impact for vinyl polysiloxane impression materials when they were in contact with the tray surface. In addition, tray adhesives were speculated to play a role too. Tensile bond strength between vinyl polysiloxane impression materials and custom tray material might have been different if adhesive solution were diluted with a solvent such as acetone. Could tray adhesive could have enabled Reprosil impression material to have a higher hydrophilicity in combining with the -COH radicals on PMMA tray surface than other vinyl polysiloxane materials. In the same vein, Polyether adhesive for Impregum with a higher hydrophilicity achieved the strongest adhesion to the tray surface treated with air abrasion. Thus, it could also be suggested air abrasion increased the -COH radicals on PMMA tray surface, whereas tungsten carbide bur treatment did otherwise.

To date, clinically adequate adhesive bond

strength has not been quantified. At the same time, a perennial concern exists alongside on the sufficiency of bond strength to withstand forces generated during the removal of impression from the oral cavity, as well as to resist accidental displacement. In particular with implant prostheses, adhesion between set impression and tray must be of the highest value to attain passive fit of superstructure. A definitive cast demands for exact dimensional reproduction of the position and orientation of implant; otherwise, precise fit between implant abutment and superstructure will be compromised, thereby affecting long-term treatment success¹⁻⁵⁾. For example, unscrewing the impression guide pins in the oral cavity or re-screwing the matching implant replica in the impression might cause a slight or partial separation of impression material from the tray, thereby affecting cast accuracy⁵⁾. As a result, misfit-induced stresses in the superstructure, surrounding bone, or oral mucosa would lead to complications and mechanical failure.

Based on the results and findings of this study, it was concluded that the tray surface for vinyl polysiloxane impression materials should be roughened with a tungsten carbide bar. As for polyether impression materials, the tray surface should be abraded with aluminum oxide. To obtain durable and stable adhesion between tray and elastomeric impression material, drying time for of tray adhesive after application should be at least 15 minutes.

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