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Original Article

Comparative Evaluation of Bond Strength of Elastomeric Impression Materials with Different Tray Materials using Different Tray Adhesives: An *In Vitro* Study

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ABSTRACT

Introduction: Incomplete adhesion between the impression material and the tray can result in indelible deformity. Particularly, when the impression is removed with force, it can result in disengagement between the impression and the tray material. This can cause misshaping and warping of the final impression which ultimately leads to an inaccurate working model and poor fitting prosthesis.

Purpose: This study aims to compare and evaluate the bond strength between three different medium body elastomeric impressions with four different tray materials with the use of impression-specific, universal, and an unconventional adhesive.

Materials and Methods: Three medium body elastomeric impression materials (PVS, PE, and VXSE) and four custom tray materials (auto-polymerizing PMMA, Type II PMMA, Visible light-cure, and 3D printed Polylactic acid tray material) were used. For each impression material, three tray adhesives were used (impression-specific, universal, and unconventional adhesive). The trays were subjected to mechanical and chemical surface treatment by placing vertical and horizontal grooves with a bur and by applying tray adhesives. The tensile bond strength was tested using a Universal Testing Machine (INSTRON).

Results: Auto-polymerizing PMMA and 3D printed Polylactic acid trays showed significantly higher bond strength with all the impression materials and adhesives when compared to Type II PMMA and Visible light-cured trays. Impression-specific adhesives (Caulk, 3M ESPE and Identium) and Unconventional adhesive (Loctite, Cyanoacrylate) showed significantly higher bond strength with all the trays and impression materials when compared to Universal (Medicept) adhesive.

Conclusions: The use of either auto-polymerizing PMMA and 3D printed polylactic acid tray materials in combination with impression-specific adhesives and macroscopic roughening of the trays is suggested for better bonding between the tray and the impression materials.

Key words: Bond strength, Custom trays, Elastomers, Medium body, Tray adhesives

INTRODUCTION

Impressions play a crucial role in dentistry in general and in prosthodontics in particular. Successful indirect restoration requires distinct working casts or models which result from accurate impressions. The impression tray is a device used to carry, confine and control the impression material, while the impression is made. The choice of materials and techniques for fabricating custom trays is extensive, ranging from auto polymerizing, heat-activated acrylic resins, visible light-curable resins to thermoplastic resins. In the recent years, computer-aided design (CAD) and additive manufacturing technologies are also being used for custom tray fabrication. Fabricating a custom tray for final impressions is favored due to its merits. The

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key concept of using a custom tray is that it ensures a uniform thickness of impression material throughout the tray. Due to this, elastomeric impression materials undergo polymerization proportional to their thickness which is very beneficial. The custom tray's rigidity reduces the potential for distortion of impression compared to flexible stock trays.[1] In addition, the custom tray design minimizes the amount of material required for each impression, thereby reducing the cost per impression.[1] Hence, it is pivotal to properly bind the impression material to the rigid tray with the right adhesive. Bonding between conventional or 3D printed custom trays with impression material is an essential factor. For trays to be clinically effective, they must be rigid, firm. Dimensionally stable and should ensure adequate retention of the impression material. The impression material should remain attached to the tray in some way or the other. This retention can be acquired by either mechanical or chemical means. The mechanical means is usually by macroscopic roughening and the chemical means is by tray adhesive application. This study focuses on comparing and evaluating the bond strength of three different medium elastomeric impression materials (Polyvinyl siloxane, Polyether and Vinylsiloxane ether) to four different tray materials (auto-polymerizing PMMA, Type II PMMA, Visible light-cure, and 3D printed tray material) with the use of impression-specific (Caulk, 3M ESPE, Identium), universal (Medicept), unconventional (Loctite) adhesives.

MATERIALS AND METHODS

Three medium body elastomeric impression materials (PVS, PE, and VXSE) and four custom tray materials (auto-polymerizing PMMA, Type II PMMA, Visible light-cure, and 3D printed Polylactic acid tray material) were used. A total of 360 tray samples were fabricated, of which 120 were used for PVS, 120 were used for PE, and 120 were used for VXSE impression material. For each impression material, three tray adhesives were used (impression-specific, universal, and unconventional adhesive) [Figure 1].

Fabrication of Tray Samples

The tray samples were fabricated according to ADA specification no. 19 for elastomeric impression materials. One tray sample constituted of: (i) A tray of 30 mm × 4.5 mm thickness and 24 mm × 2 mm thickness hollow space for impression material and (ii) a solid disk of 30 mm × 2.5 thickness. A stainless-steel wire (gauge 19) was embedded on the opposite surface of both the tray specimens as a means of attachment to the universal testing machine [Figure 2]. Auto-polymerizing PMMA and Type II PMMA tray specimens were mixed in the ratio of 3:1 in a clean porcelain container, and were placed in the mold created from putty. For the fabrication of visible light-cured tray samples, vacuum-formed thermoplastic sheets were used instead of putty material to create the mold space. Light cure resin tray sheets were cut and placed into thermoplastic molds and were cured in a visible-light curing unit at 70–80 F for 2 min. For 3D printed trays, the polymethylmethacrylate trays and disks were scanned (Up3d UP300 3D Dental Laboratory Scanner). The looped SS wire was also scanned along with the trays and the disks. The scanned samples were designed using CAD software (OpenSCAD 2015.3-2, Windows) to obtain 3D data, and the samples were manufactured in a commercially available FFF 3D printer. With a margin width of 5 mm, a raft layer was formed to hold the tray samples. The raft layer had a thickness of 100 μm and the infill density was about 100%. After printing, the PLA tray samples were detached from the raft layer and were garnered. All the trays were fabricated 24 h before testing for tensile strength [Figure 3].

Surface Treatments

The surface of the tray was prepared by placing vertical and horizontal grooves with an inverted cone bur at a depth of 0.5 mm and even spaces of 10 mm. Later, the two strokes of tray adhesive were applied with a clean brush to the tray surfaces and were allowed to dry in the open air for 15 min. The, the trays were loaded with each impression material. All the samples were tested for tensile bond strength after 30 min of the setting of impression material using a Universal Testing Machine (INSTRON). Testing was performed in the tensile mode at a cross-head speed of 5 mm/min, set at full-scale load until separation failure was observed.

RESULTS

The maximum load (N) and the ultimate tensile strength (MPa) to separate the impression material from the tray were recorded. The numbers presented were mean of the samples' maximum load. The statistical analysis was performed using Statistical Package for the Social Sciences version 15.0, the statistical analysis software. The data were analyzed by analysis of variance test (ANOVA). The data were compared as a function of tray groups [Table 1] and as a function of adhesives [Table 2].

From the results obtained in the above study [Table 1], it can be deduced that the tensile bond strength achieved by both conventional auto-polymerizing PMMA trays and the new 3D printed Polylactic acid trays with all the three elastomeric impression materials and tray adhesives was similar. Among all the trays, auto-polymerizing PMMA and 3D printed Polylactic acid trays showed the highest tensile bond strength to medium-body elastomeric impression

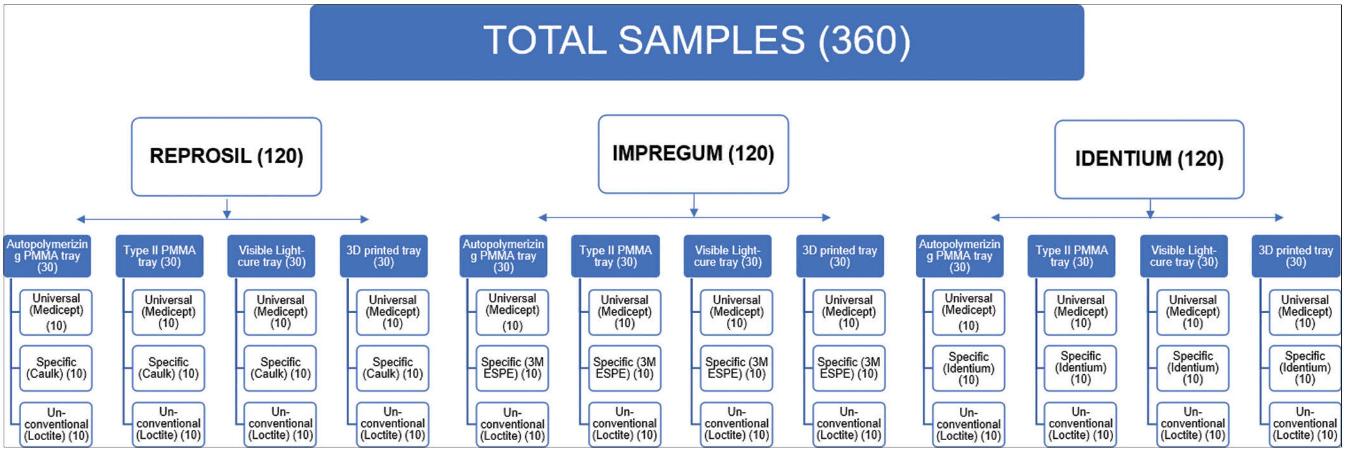

Figure 1: Schematic representation of distribution of the samples

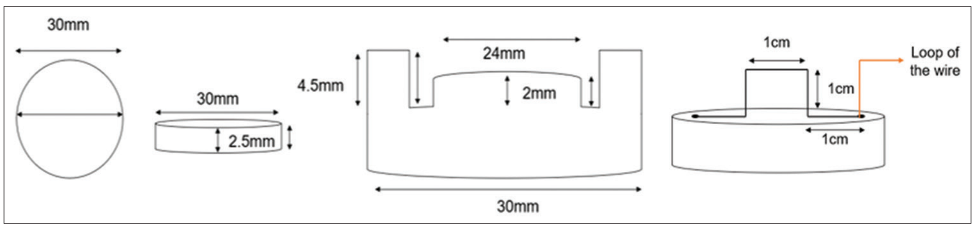

Figure 2: Schematic representation of the stainless-steel die and tray sample with embedded wire

Figure 3: Tray samples: Auto-polymerizing PMMA, Type II PMMA, visible light-cure, and 3D printed PLA (from left to right)

materials with all the three adhesives. The *P*-values of the one-way ANOVA tests were <0.05, depicting a high statistically significant difference between the trays. The tensile bond strength achieved by visible light-cured trays was the least when compared to the other three tray materials with all the three impression materials and adhesives.

When the tensile bond strength achieved was compared as a function of adhesives [Table 2], the results obtained depicted that universal tray adhesive (Medicept) showed significantly lower bond strength than impression-specific adhesives (Caulk, 3M ESPE, and Identium) and unconventional (Loctite) adhesive. There was no such significant difference between specific and unconventional adhesives. In the case of polyether and vinylsiloxane ether impression materials, no statistical significance was observed among the three adhesives with visible light-cured trays.

DISCUSSION

Impressions are fundamental and play an essential role in dentistry. Accurate duplication of oral tissues and teeth is essential for a successful treatment outcome. Making an impression is the first step toward any treatment modality. Impression materials have also evolved from the most popular being irreversible hydrocolloid to the latest combination of elastomers (Vinylsiloxane ether). Elastomeric impression materials are available in the market in different consistency options, which include light body, medium body, heavy body, and putty consistency. Of these,

Table 1: Comparison of tensile bond strength of three impression materials as a function of tray groups with three adhesives by one‑way ANOVA test

I. Comparison as a function of Tray Groups

IMP MATERIALS	TRAY GROUPS	ADHESIVES					
		Specific		Universal		Unconventional	
		Mean	f‑value and significance	Mean	f‑value and significance	Mean	f‑value and significance
PVS (REPROSIL)	Auto ‑PMMA	112.651	47.6897 (*P*=127E‑2)	64.86	17.4137 (*P*=3.75E‑07)	114.695	47.1 (*P*=1.51E‑12)
	Type II PMMA	90.01		44.905		89.293	
	VLC	41.62		28.537		44.252	
	3D PLA	115.79		62.73		115.81	
PE (IMPREGUM)	Auto ‑PMMA	115.13	61.8923 (*P*=2.78E‑14)	62.22	14.3053 (*P*=2.69E‑06)	118.43	45.0864 (*P*=2.81E‑12)
	Type II PMMA	85.67		42.33		89.78	
	VLC	41.22		41.682		49.68	
	3D PLA	117.43		69.02		116.14	
VSXE (IDENTIUM)	Auto ‑PMMA	114.889	94.6739 (*P*=1.11E‑16)	66.88	9.9206 (*P*=0.0000661)	114.23	63.5174 (*P*=1.88E‑14)
	Type II PMMA	92.69		44.12		94.04	
	VLC	43.41		43.13		39.35	
	3D PLA	116.074		64.98		116.58	

p‑values ≤ 0.05 depicted in green (statistically significant)

Table 2: Comparison of tensile bond strength of three impression materials with tray groups as a function of adhesives by one‑way ANOVA test

II. Comparison as a function of Adhesives

IMP MATERIALS	ADHESIVES	TRAY GROUPS							
		Auto ‑ PMMA		Type II PMMA		VLC		3D PLA	
		Mean	f‑value and significance	Mean	f‑value and significance	Mean	f‑value and significance	Mean	f‑value and significance
PVS	Specific	112.651	14.5159	90.01	14.5159	41.62	3.5979	115.79	90.3241
	Universal	64.86	(*P*=2.15E‑12)	44.905	(*P*=5.24E‑05)	28.537	(*P*=0.0412)	62.73	(*P*=1.10E‑12)
	Unconventional	114.695		89.293		44.252		115.81	
PE	Specific	115.13	53.566	86.67	16.1246	41.22	0.9372	117.43	149.958
	Universal	62.22	(*P*=5.55E‑16)	42.33	(*P*=2.47E‑05)	41.682	(*P*=0.4041)	69.02	(*P*=5.33E‑15)
	Unconventional	118.43		89.78		49.68		116.6778	
VSXE	Specific	114.889	127.0765	92.69	21.5517	43.41	0.2855	116.074	207.2751
	Universal	66.88	(*P*=1.83‑14)	44.12	(*P*=2.55E‑06)	43.13	(*P*=0.7539)	64.98	(*P*=1.11E‑16)
	Unconventional	114.23		94.04		39.35		116.58	

p‑values ≤ 0.05 depicted in green (statistically significant), p‑values ≥ 0.05 depicted in red (statistically insignificant)

the most commonly used consistencies are the medium and light body.

The medium body consistency is used primarily for making implant impressions as well as in fixed and removable treatments. Medium body elastomers or Monophase impression materials are suitable to be utilized as both the tray material and syringe material.[2] Its viscosity ensures that excess flow does not occur when it is loaded on an impression tray. However, when expressed through syringe tip, they can exhibit an apparent lowered viscosity that should be appropriate for intrasulcular impressions.[3] Hence, this study was conducted on three medium body elastomeric impression materials: Polyvinyl siloxane (Reprosil, Dentsply), Polyether (Impregum, 3M ESPE), and Vinylsiloxane ether (Identium, Kettenbach).

Beatriz *et al.*[4] studied the influence of trays on the accuracy of the impression made with elastomers and concluded that an ideal thickness of 2–3 mm of tray material is required to reduce distortion and avoid permanent deformation. About 2–3 mm of the thickness of tray material is ideal and will be sufficient to obtain a precise impression. Elastomeric impressions are found to be more accurate with a cross‑sectional thickness of 2 mm.[5] Various authors have also reported that the ideal thickness of elastomeric impression material is between 2 and 4 mm.[1,4] Hence, in the present study, the trays were fabricated with a thickness of 2.5 mm, and a spacer was placed to make sure that a constant thickness of 2 mm of impression material.

It has been demonstrated that auto polymerizing acrylic resins should be made 24 h before the impression procedure.[6,7] All the custom tray materials were fabricated 24 h before the impression procedure, although it is required only for auto‑polymerizing PMMA and Type II PMMA trays.[1] This is done for standardization. Visible‑light cure tray materials were fabricated in a thermoplastic mold so that it allows for the transmission of light from the light-curing unit.

With respect to surface treatments of the tray, the use of both the chemical and mechanical methods was suggested to increase the retention of the tray to the impression material.[2,8,9] Sankar[8] in their study concluded that alumina blasting produces an etched surface and adhesive being viscous may not wet the tray surface. They also concluded that large irregular spaces created by bur may be more conducive to wetting. Similar results were reported by Xu *et al*.,[10] who found that grit/sandblasting with aluminum oxide reduced the already present surface roughness of fusion deposited trays and weakened the bonding between impression and adhesive. Hence, in the present study, inverted cone tungsten carbide bur (FG35) at a depth of 0.5 mm was used. Evenly spaced vertical and horizontal grooves were placed at a width of 10 mm from each other. Perforating the tray was also not encouraged as studies have shown that perforations created high concentration stresses within limited material at perforation and also it decreased the overall strength and rigidity of the tray.[11]

The tray adhesives were applied as two strokes by same operator for standardization and were dried for about 15 min before loading the impression material onto the tray. Several authors have reported the tensile bond strength between the tray and the impression material as a function of tray adhesive drying time. Most of the studies suggested that 15 min of drying time was sufficient to acquire a significant increase in bond strength.[12-17]

In the present study, the trays were allowed to dry in the open air. The study conducted by Kothari *et al*.[17] showed that open-air drying the trays after the application of tray adhesives for 15 min allowed the solvent in the adhesive to completely evaporate. As a result of solvent evaporating entirely, the layer of the adhesive bonded to the impression material is exposed.

While the impression-specific adhesives (Caulk, 3M ESPE, and Identium) were specific for each impression materials (PVS, PE, and VSXE), the universal adhesive (Medicept) and unconventional adhesive (Loctite) were used for all three impression materials. A biocompatible and medically graded adhesive was also compared with impression-specific and universal adhesives. This unconventional adhesive: Loctite which is basically composed of cyanoacrylate and marketed by Henkel adhesives has also been used in a study conducted by Arshad *et al*.,[18] in their study, they concluded that with the use of this adhesive, there was a decrease in screw loosening and have obtained significantly higher detorque values. Hence, this adhesive was studied along with other routinely used tray adhesives. The Henkel adhesive portfolio provides a wide range of medical device adhesives that are compliant with ISO 10993 biocompatibility standards. These include: Henkel Loctite PRISM 4011, 4013, Loctite 349, and Loctite 180680.[19] In the current study, Henkel Loctite PRISM 4011 adhesive was used.

In the current study, the testing for tensile bond strength was done after 30 min from the setting of the impression material. Various other authors have conducted the tensile test after the set of impression material as per the manufacturer's instructions.[20-23] However, in the present study, the test was performed after 30 min of loading of impression material onto the tray surface. This was done considering the time lapse after making the impression in a clinical scenario.

The results of the present study depicted that the tensile bond strength achieved by both auto-polymerizing PMMA trays and the 3D printed Polylactic acid trays with all the three elastomeric impression materials and tray adhesives was higher than that of Type II PMMA and visible light-cured trays. This result was consistent with the study conducted by Xu *et al*.[24] who also reported greater bond strength with 3D printed PLA and conventional trays. This might be due to the difference in solubilities by the solvent in tray adhesive to the tray material.[25] Conventional acrylics (auto-polymerizing PMMA) have a heterogeneous structure of resinous matrix with varying sizes of filler particles.[11] 3D printed Polylactic acid trays also were reported to have an inherently present surface roughness.[24] This heterogeneous structure and surface roughness of auto-polymerizing PMMA trays and 3D printed PLA trays might have provided an increased surface area for the solvent of the tray adhesive to act on which resulted in their higher bond strength with the impression material. Type II PMMA trays are known to have less polymerization shrinkage and have less residual monomer and consequently less heterogeneous structure than the conventional PMMA trays[26] which explains decreased bond strength with the impression materials when compared to conventional PMMA and 3D printed PLA trays. Visible light-cured trays, on the other hand, show near-complete polymerization and almost no residual monomer,[1] hence showing fewer microporosities when compared to other trays. This might be the reason why visible light-cured trays showed the least bond strength with the impression materials when compared to other tray materials.

When the tensile bond strength achieved was compared as a function of adhesives, the results obtained depicted that universal tray adhesive (Medicept) showed significantly lower bond strength than impression-specific adhesives (Caulk, 3M ESPE, and Identium) and unconventional

(Loctite) adhesive, except in the case of polyether and vinylsiloxane ether impression materials, this result was not significant with visible light-cured trays.

Similar results were reported by other authors.[27] A custom tray's ability to retain the impression material is dependent on the potential of the adhesive solvent to dissolve the tray resin. This might be because impression-specific adhesives had specific reactive adhesives which contributed to higher adhesive capability with the impression material. Furthermore, these reactive adhesives contain a clear flammable liquid: methyl acetate. This liquid is often used as a solvent, which is a functional ingredient in dissolving the tray surfaces.[27] While impression-specific adhesives have high distinctiveness and affinity with the impression materials, this is often lacking with universal adhesives. Yi *et al*.,[28] also in their study, suggested the use of tray adhesives of the same company as that of impression material as they have shown highest bond strength than other combinations. Unconventional adhesive (Loctite) used in the study is primarily composed of 2-octyl cyanoacrylate monomer molecules. These monomers of 2-octyl cyanoacrylate quickly polymerizes in an exothermic reaction which helps in adhesion.[29]

As for polyether and vinylsiloxane ether, there was no statistical significance among three adhesives, when using visible light-cured trays. Possibly, this is because polyether and vinylsiloxane ether contain both polar (C=O) groups which are hydrophilic, and non-polar (CH3) groups which are hydrophobic. Hence providing a more wetting surface for the adhesives to act upon. This finding was in accordance with the study conducted by Oboudi SF *et al*.[30]

The results of the current study implied that auto-polymerizing PMMA and 3D printed Polylactic acid trays showed significantly higher bond strength with all the impression materials and adhesives. This was followed by Type II PMMA trays. Visible light-cured tray materials showed the least bond strength with all the impression materials. Impression-specific adhesives (Caulk, 3M ESPE, and Identium) and unconventional adhesive (Loctite, Cyanoacrylate) showed significantly higher bond strength with the trays and impression materials when compared to Universal (Medicept) adhesive.

Limitations

1. As it is an *in vitro* study, oral mucosal conditions could not be simulated.
2. The tray samples taken in the study had flat surfaces as opposed to multiplanar surfaces of the custom trays used in the oral cavity.
3. The samples constituted of tray surfaces opposing each other, while this is not the case *in vivo*, as the impression material is opposed by teeth or oral mucosa on one side.

CONCLUSIONS

Within the limitations of the study, it can be concluded that,

1. Auto-polymerizing PMMA and 3D printed Polylactic acid trays showed significantly higher bond strength with the impression materials and adhesives and are the best choice of custom tray materials when compared to Type II PMMA and visible light-cured trays.
2. Visible light-cured tray materials showed significantly lower bond strength with the impression materials and adhesive.
3. Impression-specific adhesives (Caulk, 3M ESPE, and Identium) showed significantly higher bond strength with the trays and impression materials when compared to Universal (Medicept) adhesive. Unconventional adhesive (Loctite, Cyanoacrylate) showed bond strength similar to that of impression-specific adhesives.

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