Improving the Accuracy of Dental Impressions: A Study of Tray Adjustments and Materials

Keywords

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ABSTRACT

Objectives: This study evaluated the tensile bond strength of addition silicone impression material when used with custom trays featuring grooves and perforations, made from self-cure acrylic resin, visible light-cure (VLC) resin, and three-dimensional (3D) printed resin materials. Materials and Methods: Thirty-six custom trays were fabricated using self-cure acrylic resin (DPI Cold Cure), light-activated acrylic resin (Voco Individo Lux), and 3D-printed resin (Phrozen Aqua 4k). Each material group was divided into two subgroups based on retention methods: grooves and perforations. Tensile bond strength was tested using Digital Instron™ after applying tray adhesive (Coltene) and loading polyvinylsiloxane impression material (GC Flexceed). Data were analyzed using SPSS. Results: Perforated light-activated acrylic resin trays showed the highest tensile bond strength (P<.005). Grooved trays had lower, but significant bond strength, while self-cure acrylic resin trays showed the weakest bond. Conclusions: Light-activated acrylic resin trays with perforations provide superior tensile bond strength. Perforations enhance retention more than grooves, suggesting that tray material and surface design significantly affect impression accuracy. Clinical Relevance: Perforated VLC resin trays offer superior bond strength and should be considered to reduce impression distortion in clinical practice.

INTRODUCTION

The accuracy of a prosthetic device is crucial for the long-term success of prosthetic treatment. However, achieving this precision requires multiple clinical and laboratory procedures, where even minor errors can accumulate and result in misfits. A key factor in ensuring precision is the use of dental impression materials, which create a replica of oral tissues by producing a negative likeness or reverse copy of the surface being captured.[1,2]

Elastomeric impression materials, composed of rubbery polymers that are either chemically or physically cross-linked, are regarded as the most reliable impression materials for prosthodontic treatments.[3] These materials include Addition silicone, Condensation silicone, Polysulfides, and Polyether. Recent advancements have paved the way for modern elastomeric materials like Vinyl Polysiloxane Ether which can be used for final impressions. Of these, polyvinylsiloxane (PVS) is particularly favored for its excellent dimensional stability and accuracy with most shrinkage occurring within the first three minutes after removal from the mouth, high tear strength, and ease of use, making it ideal for capturing precise impressions in moist oral environments. To meet the standards of the American Dental Association's Specification Number 19; the material must precisely capture fine details of 17 microns or less.[4,5]

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The development of advanced materials and custom trays has enabled more accurate impressions, which are essential for successful prosthetic restorations as they directly influence the retention and stability of the prosthesis.[6] Custom trays made from self-cure resin, visible light-cure (VLC) resin, or heat-activated acrylic resin improve dimensional accuracy by maintaining consistent impression material thickness. The adherence of elastomeric impression materials to the tray is critical during removal from the oral cavity.[6,7] Additionally, factors such as the angulation or undercuts of the abutment tooth, the position of the prepared margin, and gingival retraction significantly affect the reliability of the impression.[8]

Despite extensive research on traditional custom tray materials, such as self-cure and light-cure resins, there remains a notable gap in the literature regarding the performance and clinical implications of 3D-printed trays. These trays have gained popularity due to their accuracy, reduced handling time, and simplified procedures. Key requirements for 3D-printed trays include adequate strength, sufficient bond strength with the impression material, and rigidity to prevent distortion during casting.[9] Fused deposition modeling (FDM) is a commonly used 3D printing method because of its simple material switching, low maintenance costs, and ability to operate without constant monitoring.[10] This study utilizes polylactic acid (PLA), a sustainable and renewable material, reflecting the dental industry's shift toward eco-friendly practices.[9,11]

Previous research has extensively explored tray surface modifications to enhance bonding with impression materials, focusing on mechanical and chemical interventions. Studies have demonstrated that incorporating grooves, perforations, or surface roughening into custom trays improves the tensile bond strength of impression materials by increasing mechanical retention.[7] Chemical surface treatments, such as primers or adhesives, have also shown potential in enhancing adhesion.[12]

While significant advancements have been made in understanding the effect of surface modifications, the literature lacks a comprehensive comparison of these techniques across varying tray materials, particularly with the advent of 3D-printed resins. Furthermore, limited data are available on the interplay between tray material composition and surface modifications, leaving a critical gap in understanding their combined influence on bonding efficacy. This study aims to address the existing gap in the literature by evaluating and comparing the tensile bond strength of addition silicone impression materials when used with custom trays incorporating grooves and perforations, made from self-cure acrylic resin, visible light-cure (VLC) resin, and 3D-printed resin materials. Incorporating sustainable materials, such as polylactic acid (PLA), in 3D printing aligns with the growing emphasis on environmentally friendly practices in dentistry.

Clinically, the strength of the bond between the impression material and the tray is critical during impression removal and ensures the accuracy of the final prosthesis. Factors such as grooves and perforations in custom trays improve mechanical retention, minimizing the risk of detachment or distortion during impression retrieval. By comparing the performance of traditional and 3D-printed trays, this study aims to offer evidence-based recommendations for material selection, ultimately improving the efficiency, accuracy, and sustainability of dental prosthetic procedures. By analyzing the bond strength across these materials, the current research seeks to provide a comprehensive understanding of how traditional and emerging tray materials perform in terms of impression retention and reliability.

MATERIALS AND METHOD

This *in-vitro* study was conducted in the Department of Prosthodontics and Crown & Bridge, at Manav Rachna Dental College, Faridabad. The study comprised 3 groups depending on the materials used- self-cure resin (SC), light-activated resin (VLC), and 3D-printed resin trays. Further, each group was subdivided into 2 groups depending on the surface modifications done-grooved and indented. This gives a total of 6 groups (Group 1 - SC grooved, Group 2 - SC perforated, Group 3 - VLC grooved, Group 4 - VLC perforated, Group 5 - 3D grooved, Group 6 - 3D perforated) as depicted in Figure 1 and Table 1.

The sample size was determined using nMaster 2.0 software, with a study power of 80% and a 95% confidence interval. The estimated minimum sample size per group was 12. The input parameters for the statistical analysis included an effect size f of 0.9560, an α error probability of 0.05, and 3 groups. The output calculations showed a noncentrality parameter λ of 9.23458, a critical F value of 7.11380, 2 numerator degrees of

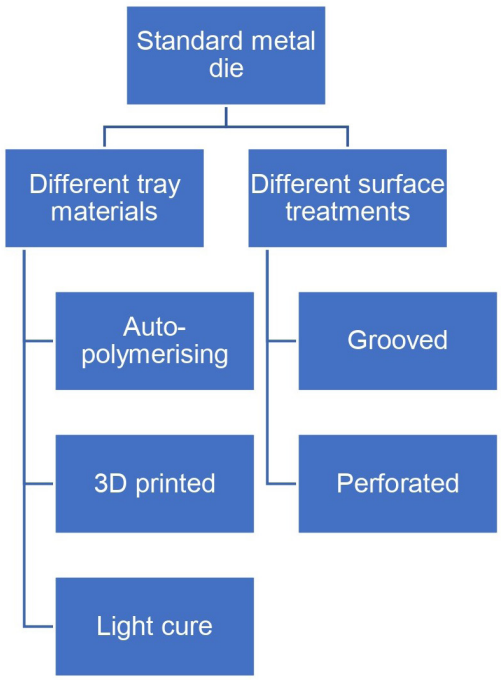

Figure 1: Schematic diagram depicting different tray materials and surface treatments

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Table 1. Sample distribution across different tray materials and modifications.

Group	Tray material	Modification	Manufacturer
Group 1	Self-Cure Acrylic Resin (SC)	Grooved	DPI
Group 2	Self-Cure Acrylic Resin (SC)	Perforated	DPI
Group 3	Visible Light-Cure Resin (VLC)	Grooved	VOCO
Group 4	Visible Light-Cure Resin (VLC)	Perforated	VOCO
Group 5	3D-Printed Resin	Grooved	WOL 3D (PLA)
Group 6	3D-Printed Resin	Perforated	WOL 3D (PLA)

3D, three dimensional; SC, self-cure; VLC, visible light cure

freedom (df), and 13 denominator df. The analysis confirmed that 12 samples per group were necessary, resulting in a total sample size of 36. The actual power of the test was 0.90342. The ethical committee approved the study protocol under the reference number MRIIRS/MRDC/FDS/IEC/2022/12.

To standardize the samples, two metallic master dies were designed as interlocking key and keyway components. When assembled, they created a central square mold cavity measuring 5 cm × 5 cm with a depth of 5 mm. The metal plates were milled using a CNC (computer numerical control) machine. The upper plate consisted of an aperture to facilitate fixation of hook. This metal die was used to fabricate self-cure (DPIR; ISO 9001:2015) and visible light-cured (VLC) trays (VOCO, LOT 2325407). A dental light cure unit (Model:01052-230V) was used to cure VLC trays *(Figure 2)*. 3D – printed trays (WOL 3 D) were designed and fabricated directly to standardized dimensions using Neptune 4 Pro.

Figure 2: LED UV Curing Chamber.

The trays were prepared 24 hours before the impression procedure to minimize the distortion, with surface modifications made using a 6-no. round carbide bur (ADA sp. No-23). Grooves and indentations were uniformly created using the same bur, spaced 1 cm apart, with a consistent depth equal to the full diameter of the bur (1.8 mm).

The testing was conducted at the Centre for Advanced Research, where a standardized procedure was followed for applying a single layer of tray adhesive (Dentsply® Caulk®), which was allowed to air dry according to the manufacturer's instructions *(Figure 3)*. Polyvinyl siloxane material (Dentsply® Aquasil Ultra®) was evenly dispensed into the trays and left undisturbed to set. The lower plate of the tray was secured to a clamp, and the upper member was fixed using a hook, allowing each specimen, with the impression material in place, to be mounted in the Digital Instron tensile testing machine [Hounsfield (UK) computerized model ISO 9001:2020]. A tensile load was applied to each sample at a cross-head speed of 1mm/min until failure occurred, with the tensile bond strength of the addition silicone measured digitally. The readings were recorded and the data was compiled, ensuring precision and reliability. The results were analyzed to compare the bond strengths of different tray materials and modifications, with each subgroup's data added and a graph plotted to show the mean ultimate tensile load for each subgroup. The analysis was performed using nMaster SPSS software.

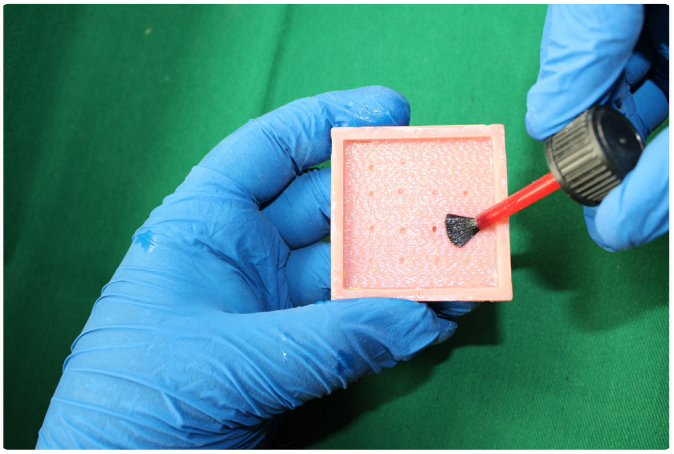

Figure 3: Application of tray adhesive.

RESULTS

The tensile bond strength testing results for polyvinyl siloxane materials with various tray materials and modifications are presented in Table 2 and Figure 4. The analysis shows notable variations in bond strength across the different tray types used. Specifically, the Self-Cure Grooved samples exhibited the lowest mean bond strength at 15.61±0.51N, followed by the Self-Cure Perforated samples with a mean strength of 27.29±0.57N. On the other hand, the Visible Light-Cured

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Table 2. Descriptives of tensile bond strength (newton) of poly-vinyl siloxane material with different tray materials and following different tray modifications.

	N	Mean (Newton)	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
SC GROOVED	6	15.61167	.518707	.211761	15.06732	16.15602	14.600	16.020
SC PERFORATED	6	27.29833	.571504	.233315	26.69858	27.89809	26.410	28.060
VLC GROOVED	6	48.05333	.258354	.105472	47.78221	48.32446	47.790	48.430
VLC PERFORATED	6	57.73667	.670065	.273553	57.03348	58.43986	56.970	58.820
3D GROOVED	6	38.02000	.473413	.193270	37.52318	38.51682	37.250	38.550
3D PERFORATED	6	39.40500	.773350	.315719	38.59342	40.21658	38.030	40.230
Total	36	37.68750	13.790484	2.298414	33.02147	42.35353	14.600	58.820

3D, three dimensional; N, Newton; SC, self-cure; Std, standard; VLC, visible light cure

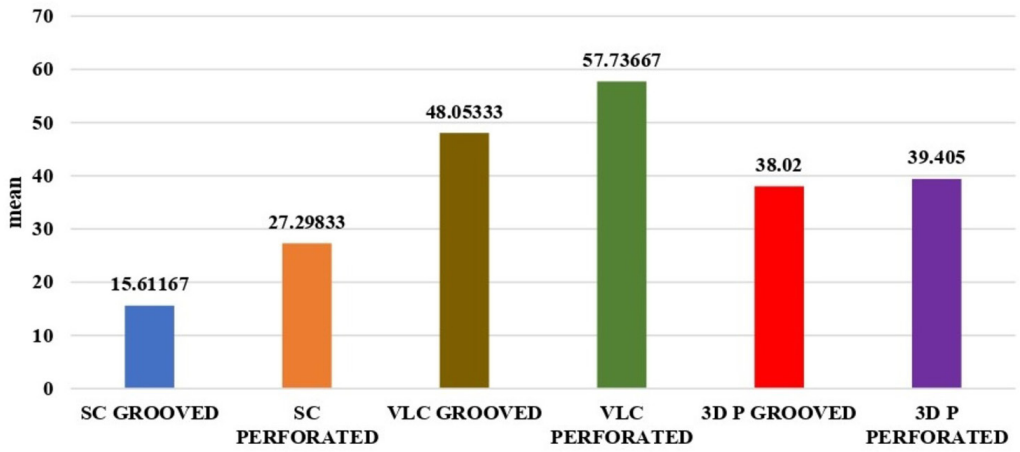

Figure 4: Mean tensile bond strength of each group.

(VLC) Grooved samples showed a significantly higher mean bond strength of 48.05±0.25N, and the Visible Light-Cured Perforated trays demonstrated the highest bond strength at 57.73±0.67N.

3D-Printed Grooved trays exhibited a mean bond strength of 38.02±0.47N, while the Perforated trays showed a slightly higher bond strength of 39.40±0.77N. Both values were greater than those of the Self-Cure materials but remained lower than the bond strengths of the VLC Grooved and Perforated trays.

The Self-Cure Grooved samples had the lowest individual tensile bond strength recorded at 14.600N, which was significantly lower than the other groups.

Statistical analysis through a post-hoc Bonferroni test *(Table 3)*, conducted after performing an ANOVA, revealed significant differences (P<.05) in the tensile bond strength across all groups. This indicates that the tray materials and their modifications play a crucial role in determining the bond strength of the impression material. The results suggest that modifications like perforations and the use of Visible Light-Cured resins generally enhance the tensile bond strength compared to other materials and tray configurations, with 3D-printed materials showing promising results in comparison to traditional Self-Cure acrylic resins.

DISCUSSION

In this study, light body polyvinylsiloxane and tray adhesive were used, with a focus on the materials used to design custom impression trays. Three types of materials were employed: self-cure acrylic resin, light-activated acrylic resin, and 3D-printed 4K resin. To enhance mechanical retention, the trays were modified by incorporating grooves in half and indentations in the other half of the tray. To date, no study has examined these materials using a combination of mechanical and chemical methods to enhance retention or assess their ultimate tensile strength against polyvinylsiloxane impression material.

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Table 3. Post-hoc comparison.

(I) Sample Number	(J) Sample Number	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval	
					Lower Bound	Upper Bound
SC Grooved	SC PERFORATED	-11.686667*	.327753	.000	-12.68356	-10.68977
	VLC GROOVED	-32.441667*	.327753	.000	-33.43856	-31.44477
	VLC PERFORATED	-42.125000*	.327753	.000	-43.12189	-41.12811
	3D P GROOVED	-22.408333*	.327753	.000	-23.40523	-21.41144
	3D P PERFORATED	-23.793333*	.327753	.000	-24.79023	-22.79644
SC Perforated	SC GROOVED	11.686667*	.327753	.000	10.68977	12.68356
	VLC GROOVED	-20.755000*	.327753	.000	-21.75189	-19.75811
	VLC PERFORATED	-30.438333*	.327753	.000	-31.43523	-29.44144
	3D P GROOVED	-10.721667*	.327753	.000	-11.71856	-9.72477
	3D P PERFORATED	-12.106667*	.327753	.000	-13.10356	-11.10977
VLC Grooved	SC GROOVED	32.441667*	.327753	.000	31.44477	33.43856
	SC PERFORATED	20.755000*	.327753	.000	19.75811	21.75189
	VLC PERFORATED	-9.683333*	.327753	.000	-10.68023	-8.68644
	3D P GROOVED	10.033333*	.327753	.000	9.03644	11.03023
	3D P PERFORATED	8.648333*	.327753	.000	7.65144	9.64523
VLC Perforated	SC GROOVED	42.125000*	.327753	.000	41.12811	43.12189
	SC PERFORATED	30.438333*	.327753	.000	29.44144	31.43523
	VLC GROOVED	9.683333*	.327753	.000	8.68644	10.68023
	3D P GROOVED	19.716667*	.327753	.000	18.71977	20.71356
	3D P PERFORATED	18.331667*	.327753	.000	17.33477	19.32856
3D Grooved	SC GROOVED	22.408333*	.327753	.000	21.41144	23.40523
	SC PERFORATED	10.721667*	.327753	.000	9.72477	11.71856
	VLC GROOVED	-10.033333*	.327753	.000	-11.03023	-9.03644
	VLC PERFORATED	-19.716667*	.327753	.000	-20.71356	-18.71977
	3D P PERFORATED	-1.385000*	.327753	.003	-2.38189	-.38811
3D Perforated	SC GROOVED	23.793333*	.327753	.000	22.79644	24.79023
	SC PERFORATED	12.106667*	.327753	.000	11.10977	13.10356
	VLC GROOVED	-8.648333*	.327753	.000	-9.64523	-7.65144
	VLC PERFORATED	-18.331667*	.327753	.000	-19.32856	-17.33477
	3D P GROOVED	1.385000*	.327753	.003	.38811	2.38189

*. The mean difference is significant at the 0.05 level. 3D, three dimensional; SC, self-cure; Std, standard; VLC, visible light cure

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Compilation of results and statistical analysis revealed that perforated visible light-activated acrylic resin trays (Group 4) achieved marked greater tensile bond strength than the other groups (P<.05), as shown in Table 1 and Figure 4. Group 3, which comprised grooved visible light-activated acrylic resin trays, had marked less tensile bond strength than group 4 but still higher than other groups. These results align with a similar study by Ashwini B.L. *et al.*[13], which found that VLC trays exhibited higher tensile bond strength compared to other tray types.

Comparing the tensile bond strength of addition silicone with grooved and perforated self-cure, light-cured, and 3D-printed resin tray materials, it was found that self-cure acrylic resin grooved trays exhibited the least ultimate tensile bond strength with polyvinylsiloxane material. This is consistent with a recent study by Agnihotri *et al.*[14], which assessed the dimensional precision of casts produced from various impressions techniques for implants and concluded that light-cure acrylic resin trays provide a more accurate impression than self-cure acrylic resin trays.

In a similar *in-vitro* study, Goel *et al.*[15] assessed the precision of implant casts produced using two types of custom trays and a specialized aluminum stock tray. Their findings showed no statistically significant difference in the precision of the casts achieved from the different trays. However, the light-cured trays demonstrated better results, followed by self-cured acrylic trays and the stock tray. These results align with the present study, where visible light-cured trays showed the highest bond strength, further supporting their effectiveness in achieving more accurate impressions. Payne *et al.*[16] assimilated the tensile bond strength of elastomeric impression materials attached to resin tray materials, discovering that the visible light-cured material exhibits a weak bond with siloxane if the air-inhibited, non-polymerized layer is not eliminated. In this study, grooves and indentations were made using a no. 6 round carbide bur at a depth of 1.8 mm, likely contributing to the highest tensile bond strength for perforated light-cured acrylic resin trays.

In the present study, a comparison was conducted to evaluate visible light-cure acrylic resin trays against 3D-printed trays. The findings indicated that 3D-printed PLA trays had lower tensile bond strength compared to light-cured acrylic resin trays. Xu Y. *et al.*[17] found that 3D-printed PLA trays reported greater bond strength, contradicting the present study. This discrepancy might be due to the absence of other macro-roughness to increase mechanical retention, as the present study subjected trays to macro-patterns with grooves and indentations. Sulong M.Z. *et al.*[18] showed that maximizing the surface energy of the impression tray greatly enhanced the effectiveness of polyvinyl siloxane adhesives.

When comparing mechanical retention methods, such as indentations and grooves, the perforated trays consistently demonstrated superior tensile bond strength and fewer adhesive failures *(Table 1)*. This aligns with an *in-vitro* study by Munjal S. *et al.*[5], which concluded that the grooved method showed lower tensile bond strength than other retentive methods.

The assessment of the tensile bond strength depicted in Newton (N) between addition silicone and visible light-cured resin material, as well as self-cure acrylic resin using grooves and indentations, revealed that the perforated visible light-cured resin material exhibited higher tensile bond strength. This was confirmed by the post-hoc test *(Table 2)*, highlighting average statically significant differences. Mean tensile bond strength was highest in VLC perforated material, followed by VLC grooved, 3D printed perforated, 3D printed grooved, self-cure perforated, and self-cure grooved. This concurs with a study by Patil R. *et al.*[7], which revealed that the VLC tray resin exhibited the greatest bond strength with polyvinyl siloxane impression material when both mechanical indentations and adhesive applications were applied.

The results of the present study rejected the null hypothesis, showing that different tray materials with various surface modifications influenced the ultimate tensile bond strength of elastomeric impression materials. Among the primary groups, light-cured acrylic resin demonstrated the maximum tensile bond strength, followed by 3D-printed acrylic resin, with self-cure acrylic resin ranking last. The modification of perforated trays led to greater bond strength compared to grooved trays across all sub-groups.

Therefore, light-cured perforated acrylic resin trays exhibited the highest tensile bond strength (58.820N), followed by light-cured grooved acrylic resin trays (48.430N). 3D-printed trays had higher bond strength (40.230N) than self-cure acrylic resin trays (28.060N), with the perforated sub-group outperforming the grooved sub-group. Self-cure acrylic resin trays demonstrated the lowest tensile bond strength, with the grooved sub-group showing the poorest performance (14.600N) *(Table 1)*.

Custom trays made from light-activated acrylic resin, especially when perforated; provide superior tensile bond strength, reducing the risk of impression distortion or material detachment. This improved retention leads to more precise replicas of oral tissues, resulting in better-fitting crowns, bridges, and dentures, ultimately enhancing patient satisfaction and treatment success. Conversely, trays with inadequate retention or less durable materials may lead to inaccuracies, potentially causing ill-fitting restorations that require adjustments or remakes, increasing chair side time and costs. By comparing different tray fabrication materials—including traditional options like Self-Cure and Visible Light-Cure (VLC) resins alongside modern 3D-printed trays—this research provides clinically relevant insights into how emerging technologies like 3D printing can complement or improve upon established methods. Understanding the tensile bond strength of these configurations is crucial for ensuring consistent, precise impressions, which are essential for achieving prosthodontic restorations with ideal marginal fit and patient satisfaction. The findings of this study lay the groundwork for future research and advancements in dental

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impression techniques. Future studies could investigate innovative materials for custom tray fabrication, such as bioresorbable polymers or advanced composites.

The integration of 3D printing, particularly Digital Light Processing (DLP) technology, into dentistry, has transformed the way custom trays are fabricated. DLP 3D printing offers unparalleled accuracy and speed by using a digital light source to polymerize liquid resins layer by layer, producing highly detailed and dimensionally stable trays.[19]

Nanotechnology applications and innovative surface modifications beyond grooves and indentations could be studied to determine their impact on tensile bond strength. Incorporating digital technology and 3D printing in dentistry has significantly enhanced the precision and customization of custom tray fabrication. Digital scanning accurately captures oral anatomy, enabling the production of highly precise 3D-printed trays that improve impression accuracy and the fit of restorations. This approach reduces human error, accelerates production times, and ensures consistent quality in tray fabrication. Digitization also allows for easy adjustments to tray designs, tailoring them to individual patient needs and optimizing overall prosthodontic outcomes.[20]

CONCLUSIONS

In order to determine the best mix of tray material and surface modification, the tensile bond strength at the interface between addition silicone and custom trays was examined. This study investigated the tensile bond strength of added silicone with three different types of custom trays: 3D-printed resin, self-cure acrylic resin, and light-cured acrylic resin. The results emphasized the importance of using the right tray material and application of surface treatment to have the best accuracy while creating dental impressions.

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

1. Light-cured acrylic trays demonstrated significantly superior bond strength with impression materials and adhesives, proving to be the most effective option when compared to self-cure PMMA and 3D-printed Polylactic acid trays.
2. Trays featuring indentations showed greater tensile bond strength compared to those with grooves across all groups.
3. The maximum tensile bond strength was observed in light-cured acrylic trays, followed by 3D-printed trays, with self-cure acrylic resin trays showing the lowest tensile strength.

CLINICAL IMPLICATIONS

Particularly when perforated, custom trays composed of light-activated acrylic resin provide exceptional tensile bond strength, reducing the possibility of material separation or imprint distortion. More exact oral tissue reproductions result from this improved retention, which also improves crown, bridge, and denture fit and raises patient satisfaction and treatment success. Future studies may examine novel materials like bioresorbable polymers or sophisticated composites for the creation of customised trays. Applications of nanotechnology and surface alterations other than grooves and holes may also be investigated to determine how they affect the strength of tensile bonds.

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