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Effects of Washing Time and Method on the Surface Roughness and Translucency of 3D-Printed Resin Materials*

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SUMMARY

Objectives: *Three-dimensional (3D) printed resin restorations require a washing process to remove residual surface resin. However, the effects of different washing methods and durations on the properties of these resins remain unclear. This study aimed to investigate the impact of various post-washing methods and durations on the surface roughness and translucency of 3D-printed resin materials.* ***Methods***: *3D-printed resin specimens were washed using three methods: ultrasonic bath (U), rotary washer (RW), and manual brushing (MB) (n=12). The control group was rinsed for 10 seconds without further processing, leaving residual resin. All specimens were washed with isopropyl alcohol for 3, 6, 10, or 30 minutes and post-cured for 30 minutes. Surface roughness (SR) was measured using a mechanical profilometer (DR230, Dragon Electronics, Beijing, China), while translucency (TP) was assessed with a spectrophotometer (EasyshadeV, VITAZahnfabrik, Germany) using the CIEDE$_{2000}$ system. Statistical analysis was performed with IBM SPSS Statistics 25.0.* ***Results***: *The washing method and duration had a statistically significant effect on SR and TP. Among all methods, U was the least abrasive across all time intervals. SR was significantly higher in the MB group compared to the RW group ($p<0.05$). Additionally, TP was highest in the 30-min U group and lowest in the 6-min MB group, with a statistically significant difference ($p<0.05$).* ***Conclusion***: *Washing method and duration significantly affect the surface quality and translucency of 3D-printed resins. The ultrasonic bath resulted in the smoothest surface, while manual brushing increased roughness. Longer ultrasonic washing improved translucency, highlighting the need for optimized washing protocols.*

Keywords: 3D printing, Resin restorations, Surface roughness, Translucency Parameter, Washing methods, Washing duration

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Introduction

Recent advancements in CAD/CAM technology have significantly improved treatment efficiency and restoration quality in dentistry[1,2]. Among these advancements, three-dimensional (3D) printing, or additive manufacturing, has gained widespread use due to its ability to fabricate objects through a precise layer-by-layer process. This technique offers several advantages, including reduced material waste, lower noise and heat emissions, and the elimination of tool wear associated with subtractive manufacturing[3-6]. In dentistry, 3D printing is commonly used to fabricating dental models, surgical guides, crowns, denture bases, clear aligners, and metal restorations.[7-9]. Among the various 3D printing technologies, stereolithography (SLA) and digital light processing (DLP) are widely used[5]. Both methods rely on ultraviolet (UV) light sources to cure liquid photopolymers and require a post-printing washing step to remove uncured resin[10]. The standard workflow for vat-polymerization 3D printers consists of three main

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stages: printing, washing, and post-curing[11]. Washing is typically performed using solvents such as isopropyl alcohol (IPA) or tripropylene glycol monomethyl ether (TPM) to dissolve residual monomers. Various washing techniques, including rotary washing systems and ultrasonic baths, have been employed to enhance cleaning efficiency[12,13]. Despite its importance, post-washing protocols vary across manufacturers, making it difficult to establish standardized guidelines. Insufficient washing can leave a sticky resin layer on the surface, which cannot be corrected by UV curing. Conversely, prolonged exposure to solvents may lead to resin absorption, resulting in swelling, polymer network degradation, and a decline in mechanical properties. Therefore, optimizing post-washing duration is crucial for maintaining the structural integrity and optical quality of 3D-printed restorations.[14] This study aimed to evaluate the effects of post-washing methods and durations on the surface roughness and translucency of 3D-printed resin materials. The first null hypothesis proposed that washing methods would not significantly influence these properties, while the second null hypothesis stated that washing duration would have no effect. By analyzing different post-washing protocols, this study seeks to contribute to the development of standardized post-processing techniques, ultimately enhancing the clinical performance and durability of 3D-printed dental restorations.

Materials and methods

Sample preparation

The overall experimental workflow is illustrated in Fig. 1. The specimens were designed using CAD software (Blender, Amsterdam, The Netherlands) (Fig. 2). All designed models were converted into STL (Standard Tessellation Language) files and imported into 3D printing software (3D Sprint, 3D Systems, Rock Hill, SC, USA). Support structures for the rectangular specimens were generated using software (Fig.3). One hundred fifty-six specimens were fabricated using a DLP printer (Nextdent 5100 3D printer, 3D Systems, Rock Hill, SC, USA) with a 50 µm layer thickness and horizontal angulation. The resin printing material utilized was Nextdent C&B resin (3D Systems). This resin is a light-curable polymerizable, micro filled hybrid biocompatible Class IIa material specifically designed for crowns and bridges. The chemical composition of the resin is detailed in Table 1. The printer was calibrated according to the manufacturer's guidelines, including laser intensity settings, synchronization between the printer and software, and adjustments to resin properties for each specific batch. All specimens were manufactured simultaneously, with all procedures carried out by the same person. After printing, the specimens were carefully removed from the build platform using a removal tool. Then, a total of 156 specimens were randomly assigned to 12 groups (n = 12) based on the rinsing method (ultrasonic bath; U, rotary washer; RW and manual brushing; MB) and four different rinsing durations (3, 6, 10, and 30 minutes).

Ultrasonic Method

Following the printing process, the specimens were fully immersed in a container filled with IPA and subjected to their designated rinsing durations in an ultrasonic bath (Coxo Clean 25 Ultrasonic Cleaner, COXO, Foshanchen, China) (AC 220~240V 50/60 HZ - Power: 160W).

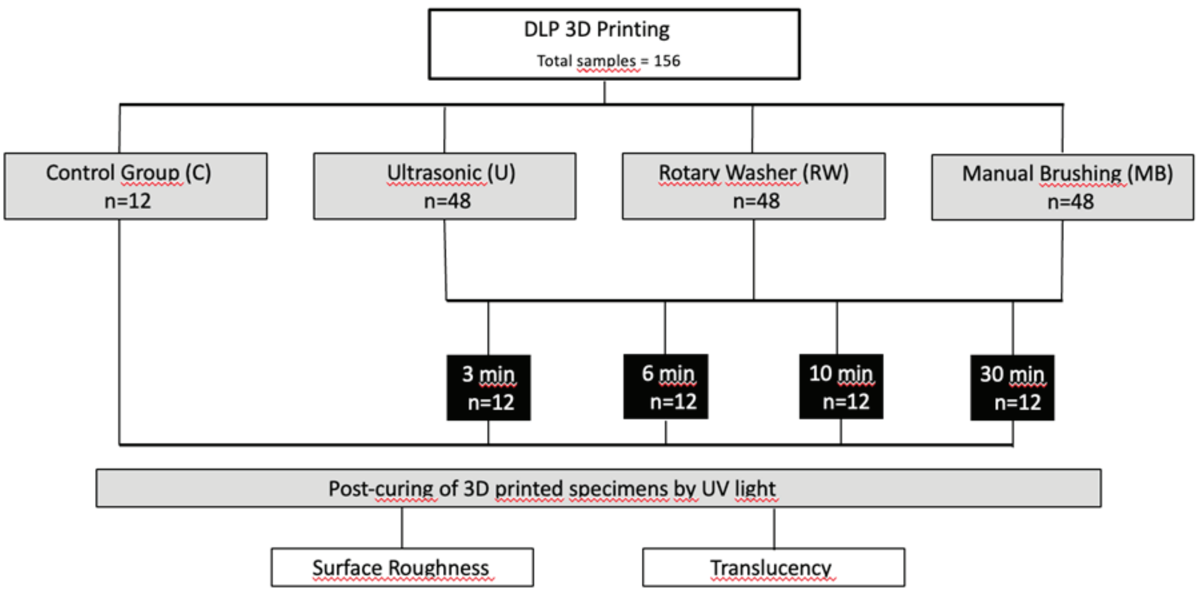


Figure 1. Workflow of overall experiments

Table 1 Summary of 3D printing photopolymer resin used in this study

Product	Composition	Manufacturer
Next Dent C&B MFH	Micro Filled Hybrid with >60% of Methacrylic oligomer	NextDent B.V., Soesterberg The Netherlands

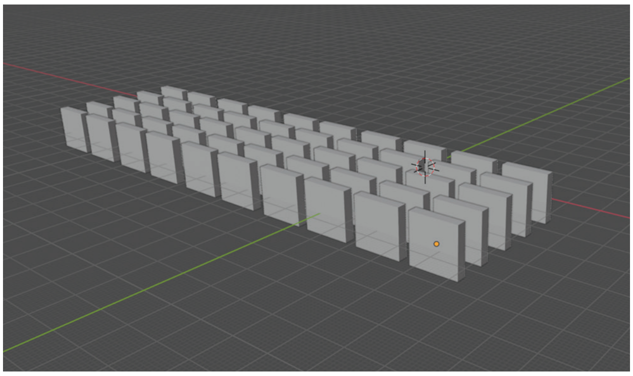


Figure 2. Designed specimens in Blender CAD Software

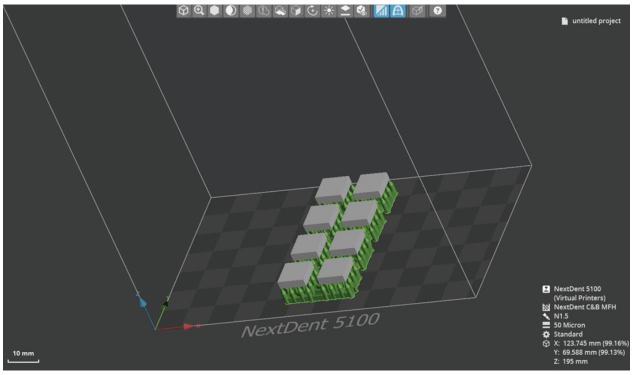


Figure 3. Overview of the printing direction of the specimens used for tests.

Rotary Washer Method

The specimens in the rotary washer group were rinsed according to the manufacturer's instructions (Anycubic Wash & Cure 3 Plus, Anycubic Technology Co., Shenzen, China). During the specified rinsing durations of 3, 60, 10 and 30 minutes, the printed specimens washed separately and remained attached to the build platform so that they did not come into contact with each other. After rinsing, they were carefully removed from the platform using a spatula.

Manual Brushing Method

In the manual brushing method, the IPA solvent was poured into a rinse bucket. The specimens were then placed in the bucket and cleaned using a toothbrush within the IPA solvent, following the same designated time intervals as shown in Fig.4

The control group specimens that were manually submerged and rinsed for 10 seconds without undergoing a post-washing procedure, leaving residual liquid resin on their surfaces. After the washing process, the specimens were manually dried and then immediately cured in a post-curing chamber (LC 3D Print Box, 3D Systems) for 30 minutes as recommended by manufacturer. After polymerization process support structures were removed, the specimens were kept in a light-blocking container at room temperature until the measurements were conducted. IPA was used as the cleaning agent. IPA is the most common solvent used to wash unpolymerized resin from the surface of 3D printed restorations [13].

Figure 4. The three different equipment for rinsing methods: (A) Ultrasonic washer (B) Rotary washer and (C) Manual brushing method.

Measurement of surface roughness

After post-curing, five samples from each group were randomly selected for analysis. Surface roughness analysis of all specimens was conducted using a mechanical profilometer (Surface Roughness Tester DR230, Dragon Electronics Co, Beijing, China). Each sample was measured at three equidistant points from the center, with a scanning speed of 0.25 mm/sec and a cut-off length of 0.80 mm. The arithmetic mean of the recorded values (Ra, µm) was calculated and documented.

Measurement of Translucency Parameter

To assess the impact of post-washing method and duration on the translucency of the resins, twelve specimens (10 x 10 x 3mm) were printed. The luminosity coordinates (L*) and color values (a* and b*) of the printed specimens were recorded using a commercial spectrophotometer (VITA Easyshade® V, Vita Zahnfabrik, Bad Säckingen, Germany). The device was calibrated according to the manufacturer's guidelines, with the tip positioned perpendicularly to the sample surfaces.To determine the translucency parameter the L*, a*, and b* coordinate values were measured over both black and white backgrounds and applied to the CIEDE2000 (1:1:1) color difference formula.

$$TP_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)},$$

Statistical Analysis

Statistical analysis was performed using Kolmogorov-Smirnov tests, and for evaluating the study data, 2-way ANOVA test and post hoc Bonferroni tests were performed to analyze differences between groups. The significance level (α) for all statistical analyses was set at 0.05. Sample size calculation for this study used an analytical software program (G Power 3.1.9.2; Kiel University, Kiel, Schleswig-Holstein, Germany). A sample size of 12 per group was required to obtain an effect size f of 0.45 and 80% power at 5% α error.

Results

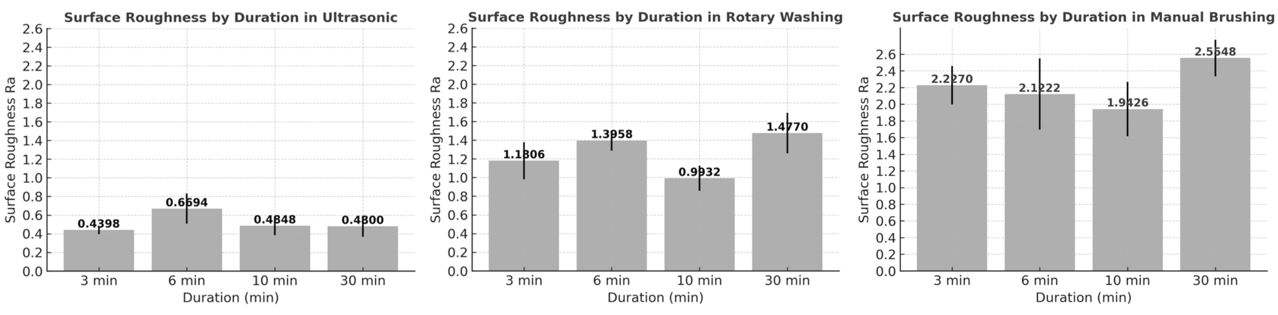
Surface Roughness

Surface roughness (SR) was lowest among Control Group (CG) (0,168 ± 0,0633, mean ± standard deviation) and highest among 30min. Manual Brushing Group (MB30) (2,55480 ± 0,219). The washing method for all time intervals (3min,6min,10min,30min) found to significantly affect the surface roughness ($p < 0.001$). Ultrasonic cleaning (0,518 ± 0,137) was significantly the least abrasive washing method between RW (1,26 ± 0,249) and MB (2,21 ± 0,366) for all time intervals ($p < 0.001$). SR was significantly higher in the MB group (2,21 ± 0,366) than in the rotary washing (RW) group (1,26 ± 0,249) for all time intervals. Extending washing time 3min to 6min did not significantly affect SR for all groups ($p > 0.05$) however increasing washing time from 6min to 10min significantly raised SR both for RW and MB groups ($p<0.005$). As well as extending washing time from 10min to 30min significantly increased SR both for RW and MB groups ($p < 0.001$). There was no significant difference in SR between time intervals for U group ($p > 0.05$).

Table 2. Surface roughness in each group according to the washing time

		Washing Time(min)							
		3min.		6min.		10min.		30min	
Material	Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	U	0.439^{Aa}	0.044	0.669^{Aa}	0.161	0.484^{Aa}	0.099	0.480^{Aa}	0.113
NextDent C&B	RW	1.180^{Ba}	0.198	1.395^{Bac}	0.106	0.993^{Bab}	0.134	1.477^{Bc}	0.216
	MB	2.227^{Ca}	0.229	2.122^{Cab}	0.426	1.942^{Cb}	0.326	2.554^{Cc}	0.219

Note: Same superscript uppercase letters represent no significant difference in columns at the .05 level. Same superscript lowercase letters represent no significant difference in rows at the .05 level.



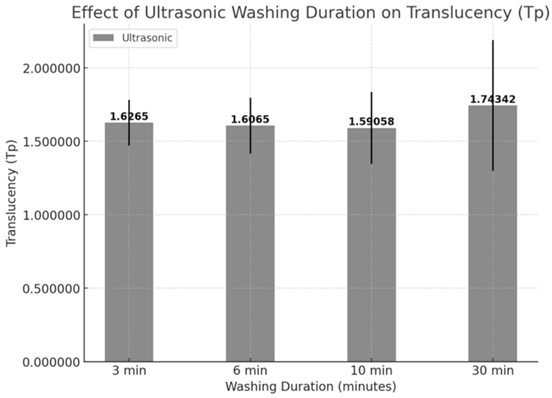
Translucency Parameter

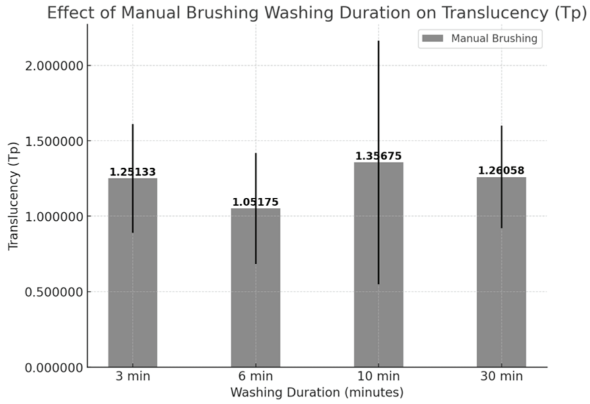
Translucency parameter (TP) was highest among U30 group (1,74 ± 0,44) and lowest among M6 group (1.051 ± 0.367). Both washing duration and method were found to significantly affect the TP ($p < 0.001$). The TP significantly increases with extended washing time in RW group ($p<0.001$) however there was no significant interaction between washing time and TP in U and MB groups ($p> 0.05$).

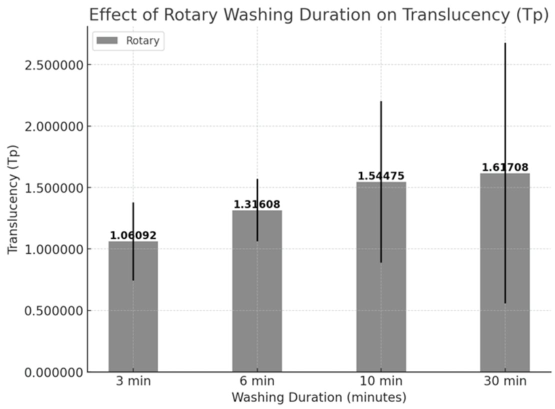
Table 3. Tranlucency parameter in each group according to the washing time

Material	Group	Washing Time(min)							
		3min.		6min.		10min.		30min	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
	U	1.626^{Aa}	0.155	1.606^{Aa}	0.190	1.590^{Aa}	0.244	1.743^{Aa}	0.445
	RW	1.060^{Ba}	0.318	1.316^{Aac}	0.254	1.544^{Abc}	0.657	1.617^{Ac}	1.060
NextDent C&B	MB	1.251^{ABa}	0.360	1.051^{BAa}	0.367	1.356^{Aa}	0.807	1.260^{BAa}	0.341

Note: Same superscript uppercase letters represent no significant difference in columns at the .05 level. Same superscript lowercase letters represent no significant difference in rows at the .05 level.







Discussion

This study evaluated the effects of post-washing methods and durations on the surface characteristics and translucency of 3D-printed resin materials These findings confirm that post-washing methods and durations play a significant role in determining the final surface characteristics, leading to the rejection of the null hypothesis. Surface roughness is a crucial factor in the clinical success of dental prostheses, as increased roughness facilitates bacterial adhesion, potentially leading to complications such as denture stomatitis[15-17]. Additionally, rough surfaces contribute to staining and discoloration, which in turn compromises esthetic outcomes[16-18]. Given the layered nature of additive manufacturing, optimizing post-processing conditions is essential to achieving clinically acceptable surface properties.[18, 19]

3D-printed photopolymer resins, similar to light-cured composite materials, undergo an oxygen-sensitive free radical polymerization process. Oxygen inhibition during photopolymerization leads to the formation of a residual uncured di-methacrylate monomer layer, compromising surface properties. This oxygen-inhibited layer is generally considered undesirable. However, it plays a beneficial role in enhancing interlayer adhesion during the layer-by-layer fabrication process in 3D printing. The primary function of post-rinsing is to remove this uncured layer before the post-polymerization step, thereby improving the mechanical properties and surface integrity of the final printed restoration.[20]

Among the tested post-washing methods, ultrasonic washing produced the lowest surface roughness values (0.4398–0.6694 µm) with minimal variation across different washing durations. In contrast, rotary washing exhibited moderate roughness (0.9932–1.4970 µm), with the highest values observed at 30 minutes, suggesting that prolonged mechanical agitation may contribute to surface irregularities. Manual brushing resulted in the highest roughness values (1.9626–2.5548 µm), indicating that this method introduces significant surface irregularities, likely due to abrasive action creating micro-grooves.

Katheng et al.(20) found that ultrasonic washing for 15 minutes optimized surface roughness, hardness, and polymerization degree. While both studies support ultrasonic washing as the most effective method, the present study suggests that shorter durations (3–10 minutes) may achieve similar benefits while minimizing potential solvent-induced surface alterations.

Nowacki et al.[21] found that 10 minutes of washing reduced surface roughness significantly, with no further improvement after that. The present study also found that ultrasonic washing for 3 minutes resulted in the statistically lowest roughness($p<00.005$). Nam et al.[22] reported that while ultrasonic cleaning effectively removes residual resin, prolonged exposure may cause surface degradation, reinforcing the need to optimize washing duration rather than focusing solely on solvent type.

In addition to surface roughness, translucency is another critical factor in the esthetic integration of 3D-printed restorations. Since translucency is influenced by surface quality, polymer network integrity, and post-processing conditions, evaluating the effect of washing duration and method on this parameter is essential. This study found that both washing duration and method significantly affected TP, with the highest value in the U30 group and the lowest in M6 ($p<0.005$). Ultrasonic washing resulted in consistently high translucency values, suggesting that this method effectively removes residual resin without altering optical properties. In contrast, rotary washing showed a gradual increase in TP with extended washing time, indicating that prolonged mechanical agitation may enhance light transmission.

Manual brushing led to more variable TP values, with the lowest translucency at 6 minutes, likely due to surface irregularities and residual monomers. These findings emphasize the importance of optimizing post-washing protocols, as ultrasonic washing provides consistent optical performance, while rotary washing may improve translucency with careful duration control. To the best of our knowledge, no previous studies have specifically investigated the combined effects of washing duration and method on translucency in 3D-printed resin materials. Further research should focus on validating these findings and investigating the impact of different post-washing parameters on both mechanical and optical properties.

Conclusion

The results of this study indicate that both post-washing methods and durations play a crucial role in determining the surface roughness and translucency of 3D-printed resin materials.. Ultrasonic washing resulted in lower roughness and stable translucency, while rotary washing showed improved translucency over time. Manual brushing led to higher roughness and variability.

Further studies are required to establish standardized post-washing protocols and evaluate their long-term clinical impact on 3D-printed dental restorations.

References

1. BAYNE SC, HEYMANN HO. CAD/CAM in Dentistry: Present and Future Applications. Quintessence International. 1996;27(6).
2. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. British dental journal. 2008;204(9):505-11.
3. Abduo J, Lyons K, Bennamoun M. Trends in computer-aided manufacturing in prosthodontics: a review of the available streams. International journal of dentistry. 2014;2014(1):783948.
4. Atzeni E, Salmi A. Economics of additive manufacturing for end-usable metal parts. The International Journal of Advanced Manufacturing Technology. 2012;62:1147-55.
5. Van Noort R. The future of dental devices is digital. Dental materials. 2012;28(1):3-12.
6. Stansbury JW, Idacavage MJ. 3D printing with polymers: Challenges among expanding options and opportunities. Dental materials. 2016;32(1):54-64.
7. Dawood A, Marti BM, Sauret-Jackson V, Darwood A. 3D printing in dentistry. British dental journal. 2015;219(11):521-9.
8. Bhargav A, Sanjairaj V, Rosa V, Feng LW, Fuh YH J. Applications of additive manufacturing in dentistry: A review. Journal of Biomedical Materials Research Part B: Applied Biomaterials. 2018;106(5):2058-64.
9. Dodziuk H. Applications of 3D printing in healthcare. Kardiochirurgia i Torakochirurgia Polska/Polish Journal of Thoracic and Cardiovascular Surgery. 2016;13(3):283-93.
10. Bayarsaikhan E, Lim J-H, Shin S-H, Park K-H, Park Y-B, Lee J-H, et al. Effects of postcuring temperature on the mechanical properties and biocompatibility of three-dimensional printed dental resin material. Polymers. 2021;13(8):1180.
11. Revilla-León M, Meyers MJ, Zandinejad A, Özcan M. A review on chemical composition, mechanical properties, and manufacturing work flow of additively manufactured current polymers for interim dental restorations. Journal of Esthetic and Restorative Dentistry. 2019;31(1):51-7.
12. Xu Y, Xepapadeas AB, Koos B, Geis-Gerstorfer J, Li P, Spintzyk S. Effect of post-rinsing time on the mechanical strength and cytotoxicity of a 3D printed orthodontic splint material. Dental Materials. 2021;37(5):e314-e27.
13. Mostafavi D, Methani MM, Piedra-Cascón W, Zandinejad A, Revilla-León M. Influence of the rinsing postprocessing procedures on the manufacturing accuracy of vat-polymerized dental model material. Journal of Prosthodontics. 2021;30(7):610-6.

14. Papanu J, Hess D, Soane D, Bell A. Swelling of poly (methyl methacrylate) thin films in low molecular weight alcohols. Journal of applied polymer science. 1990;39(4):803-23.
15. Komalsingsakul A, Klaophimai A, Srisatjaluk RL, Senawongse P. Effect of the surface roughness of composite resins on the water contact angle and biofilm formation. Mahidol Dental Journal. 2019;39(2):75-84.
16. Gad MM, Fouda SM. Current perspectives and the future of Candida albicans-associated denture stomatitis treatment. Dental and medical problems. 2020;57(1):95-102.
17. Jamshidinia M, Kovacevic R. The influence of heat accumulation on the surface roughness in powder-bed additive manufacturing. Surface Topography: Metrology and Properties. 2015;3(1):014003.
18. Shim JS, Kim J-E, Jeong SH, Choi YJ, Ryu JJ. Printing accuracy, mechanical properties, surface characteristics, and microbial adhesion of 3D-printed resins with various printing orientations. The Journal of prosthetic dentistry. 2020;124(4):468-75.
19. Solakoğlu EU, Gürgen S, Kuşhan MC. Surface topography of nickel-based superalloy manufactured with direct metal laser sintering (DMLS) method. Surface Topography: Metrology and Properties. 2019;7(1):015012.
20. Katheng A, Prawatvatchara W, Tonprasong W, Namano S, Kongkon P. Effect of Postrinsing Times and Methods on Surface Roughness, Hardness, and Polymerization of 3D-Printed Photopolymer Resin. European Journal of Dentistry. 2025;19(01):154-64.
21. Nowacki B, Kowol P, Kozioł M, Olesik P, Wieczorek J, Wacławiak K. Effect of post-process curing and washing time on mechanical properties of mSLA printouts. Materials. 2021;14(17):4856.
22. Nam OH, Chung S-Y, Hyun H-K, Ye JR, Jeong Y, Oh S-E, et al. Influence of postprinting cleaning methods on the cleaning efficiency and surface and mechanical properties of three-dimensionally printed resins. The Journal of Prosthetic Dentistry. 2024;132(4):838. e1-. e9.

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