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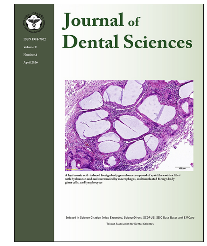

Original Article

Effect of vacuum sealing and heat treatment on the accuracy of castable resin patterns for denture frameworks fabricated using digital light processing

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Abstract *Background/purpose:* Although three-dimensional (3D) printed castable resin patterns have been used for denture framework fabrication, resin deformation influences accuracy. This study aimed to verify the effect of vacuum sealing and heat treatment on the accuracy of castable resin patterns for denture frameworks fabricated using digital light processing (DLP).
Materials and methods: A simplified major connector was digitally designed on the master cast simulating the maxillary palate. Based on the different post-processing procedures and durations after post-processing, thirty-six specimens were divided into six groups after being printed using a DLP printer within castable resin materials. Specimens were subjected to one of three post-processing methods after rinsing: post-curing directly (control), vacuum sealing before post-curing (VS), or vacuum sealing followed by heat treatment before post-curing (VSH). The specimens were subsequently scanned 1 or 3 h after post-processing ($n = 6$). The trueness and precision were subsequently analyzed by calculating root mean square (RMS) values. A two-way analysis of variance and Tukey's post-hoc test were performed ($\alpha = 0.05$).
Results: Although the duration after post-processing did not have a statistically significant effect on the trueness and precision ($P > 0.05$), different post-processing procedures

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demonstrated a statistically significant effect on the trueness and precision ($P < 0.001$). The VSH group demonstrated the lowest RMS value of trueness and a lower RMS value of precision than the VS group ($P < 0.05$).
Conclusion: Vacuum sealing combined with heat treatment significantly improved the trueness and precision of DLP-printed castable resin patterns for dentures.

Introduction

In recent years, the manufacturing methods of metal frameworks for removable partial dentures or complete dentures using computer-aided design and computer-aided manufacturing (CAD/CAM) have become popular.[1–3] Digital milling and traditional methods have increasingly been replaced by additive manufacturing methods owing to their high cost and technical limitations.[4–6] In direct metal manufacturing methods, such as selective laser melting (SLM) or selective laser sintering (SLS), metal frameworks can be directly printed,[7,8] whereas in digital light processing (DLP) or stereolithography (SLA), resin patterns are manufactured using photopolymerizable resin, and then cast in the same way as in the conventional lost-wax method to obtain metal frameworks.[9–12] Although the direct metal manufacturing method has been proven to be as accurate as or better than the traditional lost-wax casting method, it has certain limitations concerning its applications.[4,13–15] SLM or SLS metal printing has disadvantages such as the limited types of useable metals and the high cost of the processing device.[4,14,16] Another challenge is the limitation of design software programs, which necessitate casting when the framework pattern is being milled or printed.[17] Therefore, the method of fabricating frameworks with 3D-printed castable resin patterns has attracted more attention because it can be applied to existing processing machines at lower costs.[18]

Printing parameters and strategy, such as dimensional characteristics, build orientations, support structure density parameters, and post-rinsing time, demonstrated significant influence on the accuracy for 3D-printed resin prosthesis.[3,11,12,19] Among the various types of 3D printers, DLP printers are considered advantageous for fabricating dental prosthesis owing to their superior efficiency and cost-effectiveness. However, the accuracy of the DLP-printed resin patterns for denture frameworks is considered inferior owing to resin polymerization and contraction.[1,2] Usually, resin patterns fabricated by DLP are rinsed with alcohol, then post-cured directly, and their support structures are removed before investing. Resin deformation occurs during this post-processing procedure, which can influence the accuracy of printed resin patterns.[12,14] Accuracy improvements in the fabrication of denture frameworks can reduce the chairside time for adaptation, prevent complications, and improve patient satisfaction.[20] Therefore, establishing a more accurate post-processing procedure for fabricating 3D-printed resin patterns with reduced deformation is warranted. Accordingly, this study focused on applying novel methods to the DLP-printed resin patterns of denture frameworks for improving accuracy.

In this study, vacuum sealing and heat treatment were conducted to minimize this deformation during post-processing procedures. Vacuum sealing may serve as an effective strategy for reducing oxygen inhibition during post-curing, thereby enhancing the degree of polymerization and mechanical performance of photopolymer-based resins.[21] Moreover, it may help minimize deformation by stabilizing the printed structure in a fixed position and reducing internal stress. However, no studies have demonstrated whether this method can improve the accuracy of 3D-printed photopolymer-based dental resins. Applying the vacuum-sealed method to the fabrication process of 3D-printed resin patterns of denture frameworks or other printed dental resin materials could be a predictable and accurate method. Heat treatment, which is also called annealing, is a process in which plastic is heated to a certain temperature, maintained at that temperature for a definite period, and then slowly cooled to room temperature.[22] DLP-printed castable resin for denture frameworks is typically composed of acrylate-based photopolymers, which require post-curing for improving the mechanical strength. However, rapid post-curing processes can result in non-uniform polymerization and residual internal stresses, particularly in large or complex geometries.[4,11] Additionally, these materials are formulated to enable clean burnout, often at the expense of thermal robustness, making them more sensitive to heat and light than conventional dental resins. Annealing can result in the release of internal stresses and enhance the degree of polymerization of certain resin materials.[22,23] Based on these considerations, heat treatment was applied to the DLP-printed castable resin patterns for denture frameworks after vacuum sealing to suppress deformation and improve dimensional accuracy.

The deviations increase for some 3D-printed resins after the post-processing procedure over time, which influence the accuracy and dimensional stability.[24] The change in deviation over time may vary for different resin materials. In this study, the effect of duration (1 and 3 h) after post-processing on the accuracy of DLP-printed resin patterns was also evaluated.

This study aimed to compare the trueness and precision of printed resin patterns fabricated using three different post-processing methods and at different durations after post-processing. The null hypothesis was that different post-processing methods and durations following the post-processing would not affect the trueness and precision of the castable resin pattern.

Materials and methods

A simplified master cast simulating the maxillary palate was designed (Fig. 1A) and fabricated using a photopolymerization resin (AR-M2; KEYENCE, Tokyo, Japan) by a 3D printer (AGILISTA-3200; KEYENCE). The master cast was duplicated with polyvinyl siloxane impression material (Duplicone; SHOFU, Tokyo, Japan), and working casts were fabricated using Type IV dental stone (Moderock II; SHOFU). Marked lines were drawn on the working casts and copied to each cast so that the design and printed specimens could be accurately reset on the casts along the lines in the following steps.

The master cast was scanned by a laboratory scanner with an accuracy of 7 μm (E3; 3Shape, Copenhagen, Denmark), and the framework of a simplified major connector with a thickness of 1.0 mm (Fig. 1B) was designed using CAD software (Dental System; 3Shape). One square and one round convex shape were designed diagonally on the opposite side of tissue surface of the specimen as reference points.

The sample size was calculated using G*Power (version 3.1.9.7; Heinrich-Hein-University, Dusseldorf, Germany), assuming an effect size $f = 0.57$, $\alpha = 0.05$, and power $= 0.80$. A total of 36 samples (six per group across six groups) was determined for detecting both main and interaction effects in a two-way factorial design. The specimens were divided into six groups according to the different post-processing procedures and durations after post-processing. Detailed information about the groups is presented in Table 1. The specimens (Dima Print Cast emerald; Kulzer GmbH., Tokyo, Japan) were printed using a DLP printer (cara Print 4.0; Kulzer GmbH.). The layer thickness of printing was 50 μm, and build orientation was set as 150°. The specimen was set in the center of the building platform, and support structures were set on the opposite side of tissue surface. After printing, the specimens were rinsed twice for 1 min each with 99 % isopropyl alcohol (IPA) (2-Propanol; FUJIFILM Wako Pure Chemical Corporation, Osaka, Japan) in an ultrasonic cleaning machine (Ultra Sonic cleaner AU-50C; Aiwa Medical Industry Co., LTD., Saitama, Japan) according to the material instructions. In the control (CON) group, specimens were directly post-cured for 2 min at 40 °C using the default mode of the post-curing machine (cara Print LEDcure, Kulzer GmbH.). In the vacuum-sealed (VS) group, after removing the support structures, specimens were vacuum-sealed (S-WAVE Vacuum Sealer; SHOFU) with the working cast (Fig. 2) and post-cured in the same condition as in the CON group. During vacuum sealing, the specimens were first reset on the working casts according to the marked lines and reference points, placed in vacuum packs, and vacuumized with a vacuum instrument to fix them in the correct position. In the vacuum-sealed and heat-treated (VSH) group, after removing the support structures, specimens were vacuum-sealed with the working cast, submerged in water heated to 90 °C for 5 min, and then post-cured in the same condition as in the CON group. Heat treatment parameters were determined with reference to the resin's glass transition temperature and preliminary experiments. After finishing post-processing, all the specimens were stored in a dark environment. The specimens were scanned 1 or 3 h after post-processing and exported to the standard tessellation language (STL) format. In the CON group, the support structures were removed just before scanning. In the VS and VSH groups, the sealing packs were opened just before scanning.

Table 1 Group details.

Group	Post-processing procedures			Durations after post-processing
	Vacuum sealing	Heat treatment	Post-curing	
CON	–	–	○	1 h
				3 h
VS	○	–	○	1 h
				3 h
VSH	○	○	○	1 h
				3 h

CON: Control group.
VS: Vacuum-sealed group.
VSH: Vacuum-sealed and heat-treated group.

All the specimens were lightly coated with titanium dioxide powder (High-resolution scanning spray; 3M, St. Paul, MN, USA) with an average particle size of 3 μm for obtaining better and consistent scanning data. The specimens were scanned using the E3 scanner under the "Copy Denture" mode. The tissue surface was scanned first, followed by the opposing surface. The software automatically aligned and merged the two surface scans to generate the complete 3D data of the resin pattern.

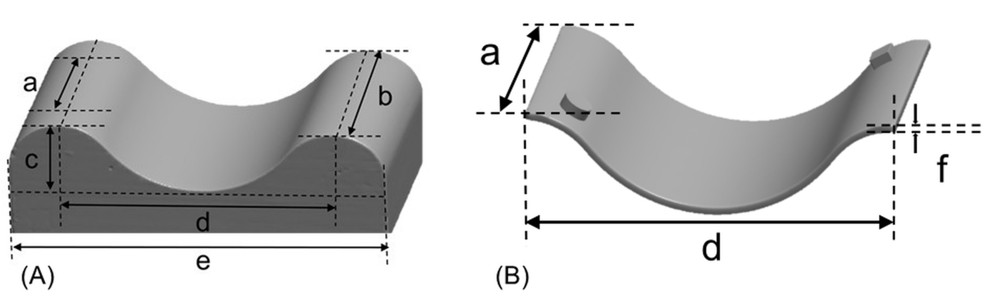

Figure 1 Cast and specimen design diagram. (A) Design of simplified master cast. (B) Design of simplified major connector. All dimensions are represented by lowercase letters (mm): a = 30, b = 40, c = 12, d = 50, e = 70, f = 1.

Figure 2 Vacuum sealing method. A specimen positioned on a working cast was sealed using a vacuum sealing device.

To evaluate the trueness, the root mean square (RMS) was calculated by superimposing the STL file of the specimen onto the originally designed STL file (Artec Studio 12 Professional, Artec 3D, Tokyo, Japan) according to the reference points on the specimens' surface. During superimposing, the scanned data were initially aligned manually by selecting three corresponding reference points, followed by the best fit alignment function. To evaluate the precision, the RMS was calculated by superimposing the STL files of the specimens in each group, which resulted in 15 combinations per group. Before calculating the RMS values, the opposite side of tissue surface was digitally eliminated. Only the tissue surfaces were used to calculate the RMS values. The RMS values were calculated using the following formula:

$$RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}$$

where x_i is the measured value, and n is the total number of points measured in each analysis.

Surface deviation color maps were generated to illustrate the distribution of deviations between the scanned specimens in each group. For comparing the trueness, the maximum critical value was set at $\pm$ 500 μm and the maximum nominal value at $\pm$ 100 μm. For comparing the precision, the maximum critical value was set at $\pm$ 300 μm and the maximum nominal value at $\pm$ 60 μm.

The Shapiro–Wilk test was conducted to confirm the normality of the data, and Levene's test was used to assess the homogeneity of variances. Upon confirming that the assumptions were met, a two-way analysis of variance (ANOVA) and Tukey's post-hoc test were performed ($\alpha = 0.05$) (IBM SPSS Statistics, v25; IBM Corp, Armonk, NY, USA) to compare the differences between three different post-processing procedures and two different durations after post-processing.

Results

Tables 2 and 3 and Fig. 3 show the RMS values and results of the statistical analysis of trueness. Although the duration after post-processing did not have a statistically significant effect on the RMS values of trueness ($P = 0.053$), different post-processing procedures demonstrated a statistically significant effect on the RMS values ($P < 0.001$). The VSH group showed the lowest RMS values ($P < 0.05$). Fig. 4 shows the surface deviation color maps of trueness, which display the distribution of deviation between the original CAD and scanned specimen STL files. Areas of acceptable deviation were shown in green, indicating minimal dimensional change. In the VS group, color maps revealed negative deviation (blue to deep blue) at the center, indicating deformation towards the mucosa, and positive deviation (yellow to red) along the margins, suggesting contraction towards the center of the specimen.

Tables 4 and 5 and Fig. 5 show the RMS values and results of the statistical analysis for precision. Although the duration after post-processing did not have a statistically significant effect on the RMS values of precision ($P = 0.429$), different post-processing procedures had a statistically significant effect on the RMS values ($P < 0.001$). Except for the CON and VSH groups that exhibited no significant differences between each other ($P > 0.05$), other groups with different post-processing procedures and the same duration after post-processing showed significant differences between each other ($P < 0.05$). Fig. 6 presents the color maps of the precision deviation, with the VSH group showing a lower deviation.

Discussion

This study evaluated the trueness and precision of the DLP-printed resin patterns of removable dentures to verify

Table 2 Trueness analysis of DLP-printed resin patterns under different post-processing procedures and durations. All measurements are in mm.

Post-processing	Duration of 1 h	Duration of 3 h	*P*-value of two-way ANOVA		
	Mean RMS (SD)	Mean RMS (SD)	Post-processing	Duration	Post-processing × Duration
CON	0.12 (±0.03)[Ba]	0.15 (±0.08)[Ba]	<0.001	0.053	0.907
VS	0.22 (±0.05)[Aa]	0.26 (±0.04)[Aa]			
VSH	0.06 (±0.02)[Ca]	0.08 (±0.02)[Ca]			

DLP: Digital light processing.
RMS: Root mean square.
SD: Standard deviation.
CON: Control group.
VS: Vacuum-sealed group.
VSH: Vacuum-sealed and heat-treated group.
Analyzed by the two-way analysis of variance and Tukey's post hoc test.
Different superscript letters indicate statistically significant differences between the groups.
Uppercase letters denote comparisons of column means, and lowercase letters indicate comparisons of row means ($P < 0.05$).

Table 3 *P* value of Turkey's post hoc analysis for trueness.

Group	CON	VS	VSH
CON	—	<0.001	0.007
VS		—	<0.001
VSH			—

CON: Control group.
VS: Vacuum-sealed group.
VSH: Vacuum-sealed and heat-treated group.

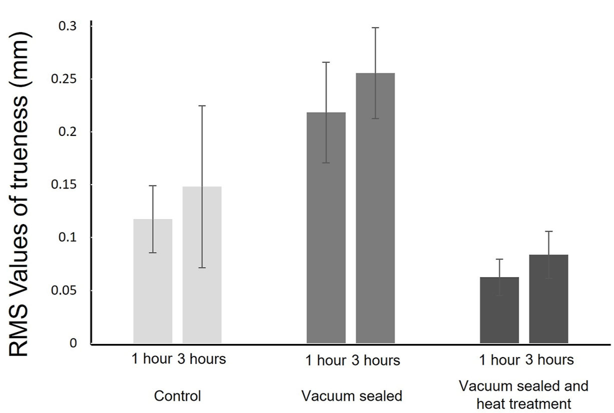

Figure 3 Comparison of RMS values of trueness among specimens in different groups. RMS: Root mean square.

whether the novel post-processing methods including vacuum sealing and heat treatment could improve the accuracy. The duration after post-processing was also considered as a factor that influenced accuracy. Herein, the different post-processing methods significantly influenced the RMS values of trueness and precision, while the duration after post-processing had no significant influence. Thus, the null hypothesis of this study was partially rejected. The results indicated that the vacuum-sealed method with heat treatment might be effective for fabricating more accurate 3D-printed castable resin patterns of denture frameworks with fewer deformations. Improved trueness and precision through the combination of vacuum sealing and heat treatment in the post-processing procedures are expected to contribute to a better fit of final denture frameworks, thereby reducing chairside adjustment time and improving clinical efficiency.

In the present study, the simplified master cast was designed with a vertical maxillary alveolar height of 12 mm, based on average population data derived from the classification of the edentulous jaws.[24] This region is prone to deformation due to its extended span and was selected to sensitively assess the dimensional changes after post-processing.[19] The use of a simplified model minimized the influence of confounding factors and facilitated accurate alignment and RMS deviation analysis, ensuring reproducibility and precision in comparative evaluation. The build orientation was set as 150° when printing the castable resin patterns according to previous study.[3,11,12]

The results indicated that vacuum sealing may have resulted in concentrated stress during post-curing when specimens were repositioned on the cast. And the opening of the packs may have resulted in a release of internal stress, potentially increasing the amount of deformation. In contrast, annealing could mitigate such deformation. The castable resin used in this study is a photopolymer specifically designed for DLP-based investment casting. According to the preliminary experiments, prolonged exposure to heat may cause deformation or discoloration; therefore, a 5-min heat treatment at 90 °C was adopted as an initial reference parameter, with the aim of providing preliminary insights for future optimization. The annealing temperature is usually set at 20—30 °C below the glass transition point.[22,25] In this study, the heat treatment was performed using a water bath set to 90 °C because the glass transition point of the castable resin pattern was approximately 110 °C. At this temperature, heat enables amorphous molecules to move freely, thereby releasing internal stresses and strains and enhancing the degree of polymerization.[22,23] Since post-curing machines rely on light polymerization and lack precise temperature control or uniform heat distribution at 90 °C, a water bath was

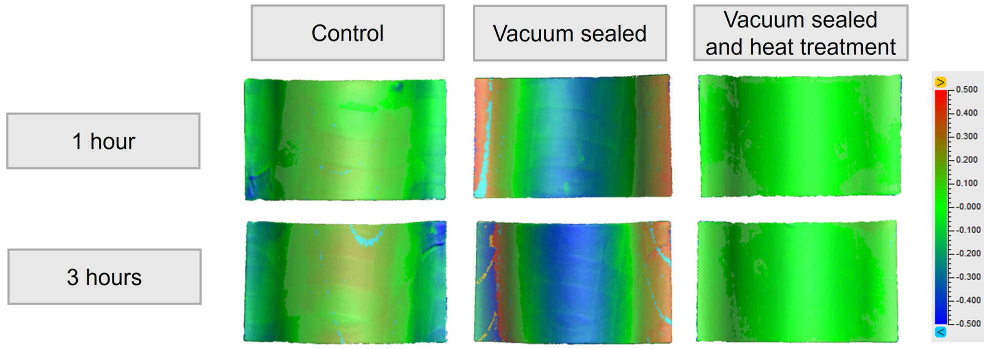

Figure 4 Color maps of trueness deviation for different post-processing procedures and durations after post-processing. Green indicates minimal deviation, blue to deep blue indicates deformation toward the mucosal surface, and yellow to red indicates deformation opposite to the mucosal surface. The color bar represents the magnitude (mm) and direction of specimen deviation compared to the designed data.

Table 4 Precision analysis of DLP-printed resin patterns under different post-processing procedures and durations. All measurements are in mm.

Post-processing	Duration of 1 h	Duration of 3 h	*P*-value of two-way ANOVA		
	Mean RMS (SD)	Mean RMS (SD)	Post-processing	Duration	Post-processing × Duration
CON	0.08 (±0.02)^{Ba}	0.11 (±0.04)^{Ba}	<0.001	0.429	0.077
VS	0.14 (±0.05)^{Aa}	0.13 (±0.05)^{Aa}			
VSH	0.08 (±0.02)^{Ba}	0.08 (±0.02)^{Ba}			

DLP: Digital light processing.
RMS: Root mean square.
SD: Standard deviation.
CON: Control group.
VS: Vacuum-sealed group.
VSH: Vacuum-sealed and heat-treated group.
Analyzed by the two-way analysis of variance and Tukey's post hoc test.
Different superscript letters indicate statistically significant differences between the groups.
Uppercase letters denote comparisons of column means, and lowercase letters indicate comparisons of row means ($P < 0.05$).

Table 5 *P* value of Turkey's post hoc analysis for precision.

Group	CON	VS	VSH
CON	–	<0.001	0.328
VS		–	<0.001
VSH			–

CON: Control group.
VS: Vacuum-sealed group.
VSH: Vacuum-sealed and heat-treated group.

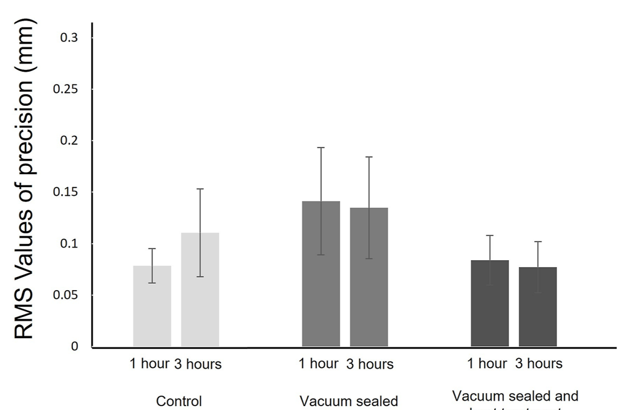

Figure 5 Comparison of RMS values of precision among specimens in different groups. RMS: Root mean square.

employed to ensure consistent heat treatment. Because heat treatment cannot be performed separately, resin patterns must be fixed to the working casts to ensure that the resin patterns do not deform during heat treatment; thus, vacuum-sealing methods may also be necessary for heat treatment.

The accuracy measured in this study was clinically acceptable according to the frameworks with internal discrepancies ranging from 0.050 mm to 0.426 mm in previously reported studies and reviews.[26–29] Herein, the minimum average RMS value of trueness was 0.06 mm, while the maximum average trueness value was 0.26 mm. Moreover, the minimum average precision value was 0.08 mm, while the maximum average precision value was 0.14 mm.

The deviations increased over time for some 3D-printed resins after post-processing, which was probably

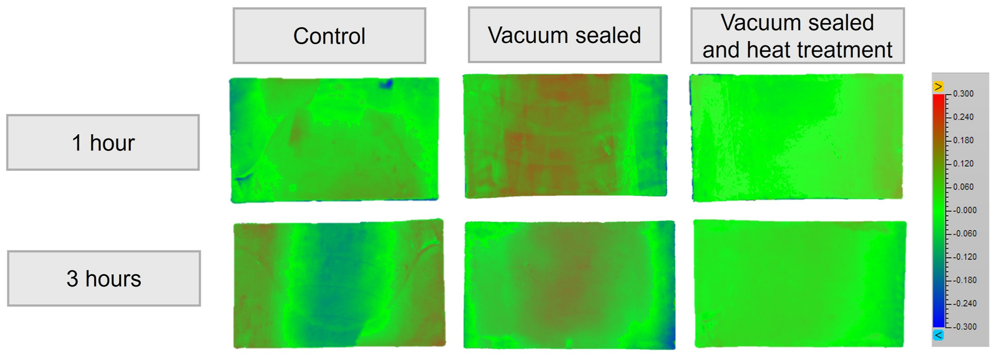

Figure 6 Color maps of precision deviation for different post-processing procedures and durations after post-processing. Green indicates minimal deviation, blue to deep blue indicates inward distortion, and yellow to red indicates outward bulging. The color bar represents the magnitude (mm) and direction of deviation between scanned specimens.

attributable to the continuing post-curing effect.[26,30] In the preliminary experiment, scanning was performed immediately, 1, 3, 6, 12, and 24 h after post-processing, with two or three samples per group. After analyzing the results, the changes of RMS values after 6, 12, and 24 h were found to be minimal. Since these time intervals are less relevant in actual manufacturing situations, they were not included in the final experimental design. Though no significant difference in the deformation was observed between the specimens scanned 3 h after post-processing and those scanned 1 h later in this study, it remains unclear whether post-cured resin patterns undergo larger deformations over time. Further detailed research is warranted to refine our understanding of the relationship between deformation and duration.

From a practical perspective, the proposed combination of vacuum sealing and heat treatment can be feasibly implemented in dental laboratories. Vacuum sealing machines, commonly used in other industries, are relatively affordable and easy to operate. Heat treatment can be conducted using a heat oven, pressure pot, or water bath, which are already available in many dental labs for other purposes. Although this process adds a step to the workflow, it does not significantly increase the processing time or technical complexity, and may ultimately save time by reducing the need for remakes or chairside adjustments.

This study was limited to comparing the accuracy of the DLP-printed resin patterns, not the accuracy of the finished metal frameworks. Another limitation was that a simplified major connector design was used, which did not simulate the actual design of denture frameworks. In addition, only a single type of castable resin was evaluated, limiting the generalizability of the findings across different materials. In future studies, more complicated designs, such as those including clasps, and other designs should be considered. Moreover, a broader range of printable resins should be investigated to validate the applicability of the proposed methods. Furthermore, heat treatment conditions should be studied in greater detail to improve the accuracy of printed castable resin patterns.

In summary, the printing strategy, materials and post-processing methods including vacuum sealing and heat treatment described in this study have been demonstrated to be effective. The results of this study were expected to provide novel methods in post-processing procedure of 3D-printed materials for prosthesis in reflecting on how to further improve accuracy.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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References

1. Oh KC, Yun BS, Kim JH. Accuracy of metal 3D printed frameworks for removable partial dentures evaluated by digital superimposition. *Dent Mater* 2022;38:309—17.
2. Torii M, Nakata T, Takahashi K, Kawamura N, Shimpo H, Ohkubo C. Fitness and retentive force of cobalt-chromium alloy clasps fabricated with repeated laser sintering and milling. *J Prosthodont Res* 2018;62:342—6.
3. Hussein MO, Hussein LA. Optimization of digital light processing three-dimensional printing of the removable partial denture frameworks; the role of build angle and support structure diameter. *Materials* 2022;15:2316.
4. Rokhshad R, Tehrani AM, Nahidi R, Zarbakhsh A. Fit of removable partial denture frameworks fabricated from 3D printed patterns versus the conventional method: an in vitro comparison. *J Prosthet Dent* 2024;131:1144—9.
5. Fathi HM, Al-Masoody AH, El-Ghezawi N, Johnson A. The accuracy of fit of crowns made from wax patterns produced conventionally (hand formed) and via CAD/CAM technology. *Eur J Prosthodont Restor Dent* 2016;24:10—7.
6. Prabhu R, Prabhu G, Baskaran E, Arumugam EM. Clinical acceptability of metal-ceramic fixed partial dental prosthesis fabricated with direct metal laser sintering technique-5 year follow-up. *J Indian Prosthodont Soc* 2016;16:193—7.
7. Bajunaid SO, Altwaim B, Alhassan M, Alammari R. The fit accuracy of removable partial denture metal frameworks using conventional and 3D printed techniques: an in vitro study. *J Contemp Dent Pract* 2019;20:476—81.

8. Carneiro Pereira AL, Martins de Aquino LM, Carvalho Porto de Freitas RF, Soares Paiva Tôrres AC, da Fonte Porto Carreiro A. CAD/CAM-fabricated removable partial dentures: a case report. *Int J Comput Dent* 2019;22:371—9.
9. Srinivasan M, Kamnoedboon P, McKenna G, et al. CAD-CAM removable complete dentures: a systematic review and meta-analysis of trueness of fit, biocompatibility, mechanical properties, surface characteristics, color stability, time-cost analysis, clinical and patient-reported outcomes. *J Dent* 2021;113: 103777.
10. Mai HY, Mai HN, Kim HJ, Lee J, Lee DH. Accuracy of removable partial denture metal frameworks fabricated by computer-aided design/computer-aided manufacturing method: a systematic review and meta-analysis. *J Evid Base Dent Pract* 2022; 22:101681.
11. Hussein MO, Hussein LA. Trueness of 3D printed partial denture frameworks: build orientations and support structure density parameters. *J Adv Prosthodont* 2022;14:150—61.
12. Demirel M, Diken Türksayar AA, Donmez MB, Yilmaz B. Effect of 3D printing technology and print orientation on the trueness of additively manufactured definitive casts with different tooth preparations. *J Dent* 2024;148:105244.
13. Snosi AM, Lotfy SM, Thabet YG, Sabet ME, Rizk FN. Subtractive versus additive indirect manufacturing techniques of digitally designed partial dentures. *J Adv Prosthodont* 2021;13:327—32.
14. Carneiro Pereira AL, Bezerra de Medeiros AK, de Sousa Santos K, Oliveira de Almeida É, Seabra Barbosa GA, da Fonte Porto Carreiro A. Accuracy of CAD-CAM systems for removable partial denture framework fabrication: a systematic review. *J Prosthet Dent* 2021;125:241—8.
15. Ciocca L, Maltauro M, Pierantozzi E, et al. Evaluation of trueness and precision of removable partial denture metal frameworks manufactured with digital technology and different materials. *J Adv Prosthodont* 2023;15:55—62.
16. Conceição P, Portugal J, Neves CB. Evaluation of removable partial denture metal frameworks produced by digital methods—a systematic review. *Appl Sci* 2023;13:10824.
17. Rokhshad R, Mazaheri Tehrani A, Zarbakhsh A, Revilla-León M. Influence of fabrication method on the manufacturing accuracy and internal discrepancy of removable partial dentures: a systematic review and meta-analysis. *J Prosthet Dent* 2025; 133:724—35.
18. Osman-Latib Y, Owen CP, Thokoane M. A preliminary study on the accuracy of cast metal removable partial denture frameworks produced from wax, printed, and milled patterns. *Int J Prosthodont (IJP)* 2023;36:730—7.
19. Katheng A, Kanazawa M, Komagamine Y, Iwaki M, Namano S, Minakuchi S. Effect of post-rinsing time and method on accuracy of denture base manufactured with stereolithography. *J Adv Prosthodont* 2022;14:45—55.
20. Conceição P, Portugal J, Franco M, Alves NM, Marques D, Neves CB. Comparison between digital superimposition and microcomputed tomography methods of fit assessment of removable partial denture frameworks. *J Prosthet Dent* 2024; 131:479—86.
21. Neoh SP, Khantachawana A, Santiwong P, Chintavalakorn R, Srikhirin T. Effect of post-processing on the surface, optical, mechanical, and dimensional properties of 3D-printed orthodontic clear retainers. *Clin Oral Invest* 2025;29:48.
22. Jagger RG, Milward PJ, Jagger DC, Vowles RW. Accuracy of adaptation of thermoformed poly(methyl methacrylate). *J Oral Rehabil* 2003;30:364—8.
23. Shah MB, Ferracane JL, Kruzic JJ. R-curve behavior and toughening mechanisms of resin-based dental composites: effects of hydration and post-cure heat treatment. *Dent Mater* 2009;25:760—70.
24. Cawood JI, Howell RA. A classification of the edentulous jaws. *Int J Oral Maxillofac Surg* 1988;17:232—6.
25. Wickramasinghe S, Do T, Tran P. FDM-based 3D printing of polymer and associated composite: a review on mechanical properties, defects and treatments. *Polymers (Basel)* 2020;12: 1529.
26. Yan S, Zhou JL, Zhang RJ, Tan FB. Evaluation of the influence of different build angles on the surface characteristics, accuracy, and dimensional stability of the complete denture base printed by digital light processing. *Heliyon* 2024;10: e24095.
27. Souza Curinga MR, Claudino Ribeiro AK, de Moraes SLD, do Egito Vasconcelos BC, da Fonte Porto Carreiro A, Pellizzer EP. Mechanical properties and accuracy of removable partial denture frameworks fabricated by digital and conventional techniques: a systematic review. *J Prosthet Dent* 2025;133: 85—95.
28. Maruo R, Shimpo H, Kimoto K, Hayakawa T, Miura H, Ohkubo C. Fitness accuracy and retentive forces of milled titanium clasp. *Dent Mater J* 2022;41:414—20.
29. Soltanzadeh P, Suprono MS, Kattadiyil MT, Goodacre C, Gregorius W. An in vitro investigation of accuracy and fit of conventional and CAD/CAM removable partial denture frameworks. *J Prosthodont* 2019;28:547—55.
30. Ling L, Taremi N, Malyala R. A novel low-shrinkage resin for 3D printing. *J Dent* 2022;118:103957.