



Effect of Wax Pattern Fabrication Technique and Convergence Angle of the Preparation on the Accuracy of Full Veneer Metal Crowns: An in Vitro Study

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ABSTRACT

Background and aim: To compare the marginal and internal adaptation of full veneer crowns cast from wax patterns fabricated by three-dimensional printing and conventional wax-up technique employing two different convergence angles.

Material and methods: Two metal master dies, each with a convergence angle of 6 and 12-degrees, were duplicated 24 times to obtain 48 stone dies. Twelve dies from each group were randomly chosen for conventional wax-up (Group A) and the other twelve for the three-dimensional printed wax pattern (Group B) fabrication. Cobalt-chromium full veneer crowns were cemented onto the dies using glass ionomer cement. The cemented crowns and dies were sectioned in the midline buccolingually to measure the marginal and internal gaps using a stereomicroscope and digital image analysis software (Image J). Data obtained were recorded in microns, and an independent 't' test was used to compare quantitative parameters between categories.

Results: Group B showed a statistically significant reduction in marginal discrepancy in crowns with a 6-degree taper (114.4 ± 37.5) compared to Group A (160.4 ± 58.1). Group B did not demonstrate any significant difference when the 6-degree and 12-degree tapers were compared, but Group A showed a significant improvement in marginal and internal adaptation with the 12-degree taper.

Conclusions: For the 6-degree taper, three-dimensional printing resulted in better marginal and internal fit than conventional wax patterns. Conventional and three-dimensional Printing offered similar accuracy within the acceptable range for a 12-degree taper.

1. Introduction

The critical step in the fabrication of a fixed restoration is the formation of an accurate wax pattern. The marginal and internal fit of a restoration depends on the quality of the wax pattern. The maximum marginal gap permissible for a clinically acceptable full veneer crown is $120 \mu\text{m}$.^[1] Defective margins can initiate a chain of events starting with gingival inflammation, cement leakage, and secondary caries, ultimately resulting in the questionable prognosis of the tooth and the restoration.^[2] The even distribution of the luting cement along the axial and occlusal surface determines the internal fit. Recommended cement space for a complete coverage restoration is 20 to $40 \mu\text{m}$,^[3] but for clinical acceptability, the possible range of internal fit is approximately 50 to $100 \mu\text{m}$.^[4] Increased cement space can result in increased cement thickness, leading to increased water sorption hydrolytic breakdown of luting cement^[5, 6] and eventually affects the stability and retention of the restoration.

The manual wax-up technique is sensitive and time-consuming. During the manual production procedure, removing the wax pattern from the die can cause deformation, affecting the fit of the final restorations.^[7] Also, minor defects are challenging to identify because of the glossy nature of wax.^[8] Other inherent properties of wax, such as its high coefficient of thermal expansion and elastic memory, can adversely affect the marginal fit of final restoration. With advancements in digital dentistry, wax pattern fabrication has gradually shifted from conventional to digital mode. Both additive and subtractive methods have proven to be effective. Additive manufacturing using three-dimensional (3D) Printing saves time and labor.^[9, 10] and enables the fabrication of high-quality complex patterns with reduced material wastage.^[11] Thermoplastic materials like waxes, resins, liquid ceramics, or fused filaments are a few of the materials that can be 3D-printed. With the introduction of printable patterns, research on the accuracy of new digital technologies in wax pattern production is necessary. The present study tries

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to shed light on this aspect by comparing the accuracy of fit of metal copings cast from conventional and 3D-printed wax patterns on dies with 6-degree and 12-degree convergence angles.

2. Material and methods

Two maxillary right first molar typhodont teeth (Confident, India) were prepared with chamfer margin and convergence angle of 6 and 12-degrees for fabrication of metal master dies. In order to maintain a uniform convergence angle, tooth preparation was carried out using a handpiece mounted parallel to the vertical arm of the surveyor (Surveyor Milling Machine, Marathon-103, Saeyang Microtech Co., South Korea). A custom-made device was fabricated to attach the handpiece to the surveyor (Fig. 1).



Fig. 1. The handpiece is attached to the surveyor using a custom-made device.

The maxillary typhodont jaw (Confident, India) was fixed on the cast holder with its base parallel to the floor. The image of a protractor printed on an Over Head Projector (OHP) sheet is positioned on the vertical arm of the surveyor to check for the parallelism of bur during preparation. Bur with a 3-degree taper is held parallel to the 90-degree mark in the protractor to prepare the tooth with a convergence angle of 6-degrees (Fig. 2).

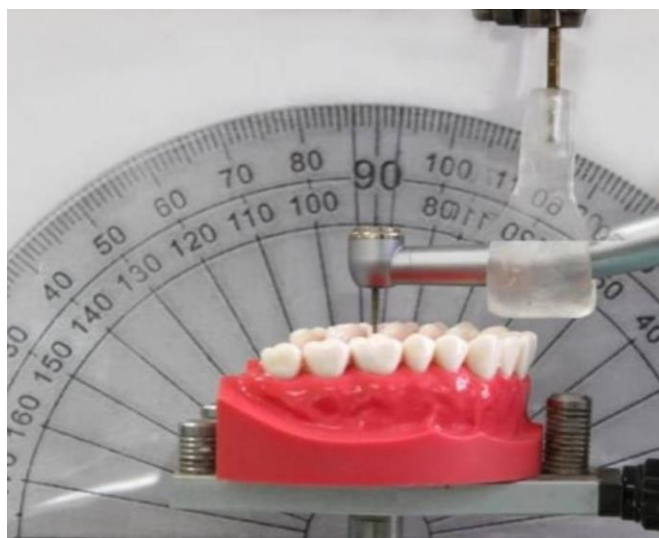


Fig. 2. Tooth preparation with 6-degree taper.

Two lines were drawn on the OHP sheet, each 3 degrees from the 90-degree line. The bur was held parallel to these lines to prepare the tooth with a 12-degree convergence angle (Fig. 3). The teeth were prepared using round end tapered fissure bur (Mani TR 12, India) to create a uniform Chamfer of 1mm. The metal master dies with 6 degrees and 12 degrees were fabricated. Each master die was duplicated 24 times using polyvinyl siloxane impression material (3M ESPE soft putty, 3M India) and poured with die stone (CLASSIC TM Type IV die stone). The silicone mold was treated with a surface tension-reducing agent (True Blue Surface wetting agent, Georg Taub Products, U.S.A.) and dried by air before pouring the die stone. The dies were left to set for 60 minutes, then separated from the mold and trimmed to have a smooth base.



Fig. 3. Tooth preparation with 12-degree taper.

Conventional wax-up technique (Group A)

Twelve dies with a 6-degree convergence angle (Subgroup A1) and twelve with a 12-degree convergence angle (Subgroup A2) were randomly selected from each group to receive manual wax patterns. The dies were coated with die hardener (Renfert, GmbH, Hilzingen, Germany) and blow-dried. The die spacer (Renfert, GmbH, Hilzingen, Germany) was applied in 3 strokes to get a 40 μ m even thickness on all surfaces, 1 mm from the margin. This was followed by applying a separator (Renfert, GmbH, Hilzingen, Germany) to remove the wax pattern from the die easily. The dies were initially dipped in melted wax to form a coping, and then medium hard crown wax (GEO Crowax, Renfert, GmbH, Hilzingen, Germany) was added sequentially to build up the wax patterns.

3D printing of wax pattern (Group B)

The master die was coated with a reflecting spray (Renfert, GmbH, Hilzingen, Germany), scanned using 3D Scanner (Open Tech 3D SRL, ITALY) utilising a scanning software (Exoscan, Exocad DentalCAD, Germany) to produce 3D-printed wax patterns, 12 each for dies with 6-degrees (Subgroup B1) and 12-degree taper (Subgroup B2). The cement gap of 40 μ m thickness was set 1 mm away from the margin, similar to that of the conventional pattern. Then, the digital design was saved as an STL (Standard Tessellation Language) file and transferred to the wax printer (Sonic 4K Mini, Phrozen, Taiwan). The wax patterns were then printed on one run of the wax printer. The printed crowns were subjected to light curing for 1 minute. The wax patterns were then cleaned and dried. A 3D-printed wax pattern was generated and used to standardize all the conventional wax patterns with the help of a sectioned putty index. The wax patterns were invested shortly after

fabrication to avoid deformation. The wax patterns were spread using sprue wax (Renfert GEO, GmbH, Hilzingen, Germany), 3 mm thick on buccal cusps. Cobalt-chromium alloys (Scheftner Starbond CoS, Germany) were used to cast the crowns. All crowns were identical and polished using conventional burs, stones, rubber, and polishing wheels. The crowns and dies were cleansed thoroughly using steam pressure bench dried and seated on their respective dies. After visually assessing the seating, they were cemented onto the respective dies using glass ionomer cement (GC Corporation, Tokyo, Japan) according to the manufacturer's instructions.

The cement was mixed with an agate spatula, filling up to half of the metal crowns, and then seated on the corresponding dies. The cement was allowed to be set under a constant pressure of 50. Newton applied for 3 minutes using standard weights. The crowns were left on their dies for a further 24 hours at room temperature (Fig. 4). The cemented crowns and dies were aligned and embedded in acrylic resin and then sectioned in the midline buccolingually by using a water jet cutter (KMT Waterjet, Germany). A stereo microscope (LEICA S8AP0, Leica Microsystems Wetzlar, Germany) with a built-in camera was used to estimate the marginal and internal gap. A digital image analysis system (Image J 1.43U, National Institute of Health, USA) was then used to measure and qualitatively evaluate the cut section at six different points, i.e., two occlusal, two axial (one on each side of the surface) and two marginal points (Figs. 5 and 6). The values were obtained in micrometres (μm).



Fig. 4. Cemented crown die assemblies.

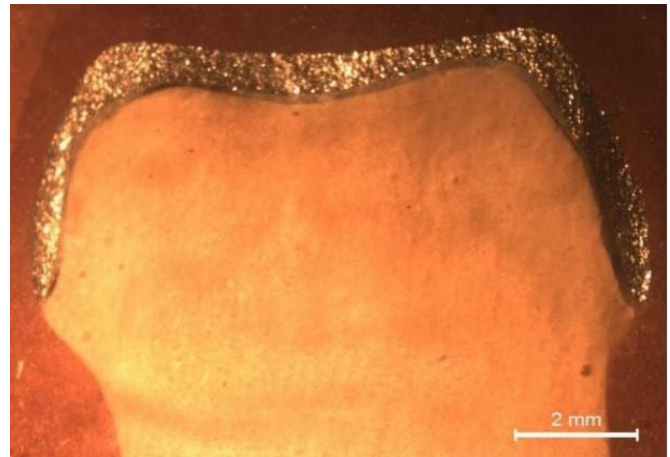


Fig. 5. Stereo microscopic image showing sectioned crown die assemblies with 6-degree taper.

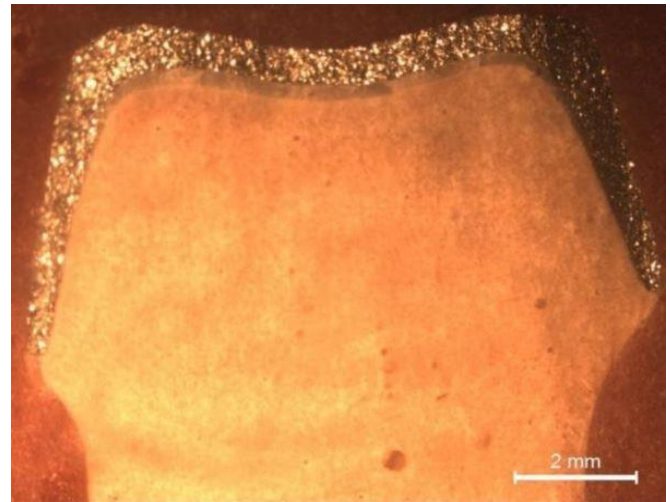


Fig. 6. Stereo microscopic image showing sectioned crown die assemblies with 12-degree taper.

3. Results

The results were tabulated, and the data were analyzed using the computer software Statistical Package for Social Sciences (SPSS) version 20.0. Data were expressed in their mean and variance. An Independent t-test was used to compare the marginal and internal adaptation with 6-degree and 12-degree taper. For all statistical interpretations, $p < 0.05$ was considered the threshold for statistical significance. There were two main groups - Group A (conventional wax pattern, $n=24$) and Group B (3D-printed wax pattern, $n=24$) and four subgroups- Subgroup A1 (conventional wax pattern on dies with a 6-degree taper), Subgroup A2 (conventional wax pattern on dies with a 12-degree taper), Subgroup B1 (3D-printed wax pattern on dies with a 6-degree taper) and Subgroup A2 (3D-printed wax patterns on dies with a 12-degree taper). When the wax pattern fabrication techniques were compared, the lowest mean marginal and internal discrepancy (114.4 ± 37.5 and 148.8 ± 50.3) were given by crowns cast from 3D-printed wax patterns on dies with 6-degrees (Subgroup B1) taper. There was a statistically significant improvement in marginal adaptation in Subgroup B1 compared to Subgroup A1 with a 6-degree taper (Table 1). Full veneer crowns' marginal and internal adaptation showed no significant difference with a 12-degree taper for Group A and Group B (Table 2).

Table 1. Marginal and Internal adaptation of full veneer crowns with 6-degree taper measured in micrometres.

	Technique	Mean	SD	N	T-test	P-value
Marginal adaptation	Conventional technique	160.4	58.1	12	2.31*	0.031
	3D Printing technique	114.4	37.5	12		
Internal adaptation	Conventional technique	194.1	67.6	12	1.86	0.076
	3D Printing technique	148.8	50.3	12		

* significant at 0.05 level.

Table 2. Marginal and Internal adaptation of full veneer crowns with 12-degree taper measured in micrometres.

	Technique	Mean	SD	N	T-test	P-value
Marginal adaptation	Conventional technique	97.9	29.2	12	1.92	0.067
	3D Printing technique	129.7	49.3	12		
Internal adaptation	Conventional technique	142.4	45.5	12	0.41	0.685
	3D Printing technique	152.4	71.8	12		

When the convergence angle was compared, it was found that in Group A, the marginal and internal adaptation (97.9 μm and 142.4 μm) of crowns with 12-degree taper (Subgroup A2) was significantly better than 6-degree

taper (Table 3). However, Group B did not demonstrate any statistically significant difference between the subgroups (Table 4). An independent t-test was used to compare the marginal and internal adaptations between the groups.

Table 3. Marginal adaptation and Internal adaptation of full veneer crowns cast from conventionally produced wax patterns on die with 6-degree and 12-degree taper measured in micrometres.

	Convergence angle	Mean	SD	N	T-test	P-value
Marginal adaptation	6-degree	160.4	58.1	12	3.33**	0.003
	12-degree	97.9	29.2	12		
Internal adaptation	6-degree	148.8	50.3	12	2.2*	0.039
	12-degree	142.4	45.5	12		

**significant at 0.01 level.

*significant at 0.05 level.

Table 4. Marginal adaptation and Internal adaptation of full veneer crowns cast from 3D-printed wax patterns on die with 6-degree and 12-degree taper measured in micrometres.

	Convergence angle	Mean	SD	N	T-test	P-value
Marginal adaptation	6-degree	114.4	37.5	12	0.86	0.399
	12-degree	129.7	49.3	12		
Internal adaptation	6-degree	194.1	67.6	12	0.14	0.888
	12degree	152.4	71.8	12		

4. Discussion

The margin of a complete coverage restoration meets the finish line of the tooth preparation in a smooth and nonobtrusive manner, ensuring a proper fit at the interface. However, discrepancies may often creep in due to several factors involved in the fabrication process of the restoration. These can result in marginal discrepancies and misfits on the internal surface. The current study's marginal gap is the vertical distance between the crown margin's most extended point and the prepared tooth's external marginal line. The Internal gap is the perpendicular distance between the framework and the abutment teeth at two occlusal and incisal surfaces.^[12, 13] The two variables influencing the seating of the restoration in the study are the wax pattern fabrication technique and the preparation's convergence angle. 3D wax printing technology for fabricating metal copings appears promising as the metal copings fabricated with this method exhibit excellent marginal fit. When the various digital systems of wax pattern fabrication - milling, stereolithography, and 3D Printing - were compared, 3D Printing resulted in the finest marginal adaptation.^[14] Moreover, 3D Printing seems to be an economically viable alternative to the other two CAD-CAM techniques. Hence, it is imperative to explore the potential of this versatile technique of wax pattern fabrication for casting full coverage restorations. As per the results of the study, for preparations with low convergence angle (6-degrees), marginal and internal gaps observed in Co-Cr crowns fabricated from 3D-printed patterns were 114.4 µm and 148.8µm, and conventional patterns were 160.4 µm and 194.1 µm respectively. Similar values were observed in conventionally cast wax patterns when the effects of different luting types of cement on the marginal fit of metal-ceramic crowns were compared to 6-degree taper, where the mean marginal adaptation varied from 155 µm to 170 µm.^[15] Compared to the Conventional group, a significant reduction in marginal and internal fit was observed in Co-Cr crowns fabricated from 3D-printed patterns. The results were consistent with previous studies wherein three different techniques for wax pattern fabrication were compared. Although the DMLS technique yielded the best results, 3D Printing resulted in better marginal adaptation than the conventional technique.^[16-18] McLean and von Fraunhofer suggested a clinically acceptable maximum marginal gap of 120 µm.^[11] Moldovan et al. approximated the values of 100 µm for marginal misfit as good and values of 200– 300 µm as acceptable.^[19] Thus, the clinical acceptance of marginal gaps varies across studies. Earlier research has established a positive correlation between convergence angle and seating discrepancy of complete veneer crown restoration.^[20] In the current study, when the convergence angle increased from 6 to 12-degrees, the marginal and internal discrepancy of crowns made from conventional wax patterns showed a significant decrease from 160.4 µm to 97.9 µm and 148.8 µm to 142.4 µm respectively. When the accuracy of seating of cast metal fixed partial denture on the abutment teeth with 0-degrees, 6-degrees, 12-degrees, and 20-degrees were compared, the reasonable marginal discrepancy was noted in the 12-degree taper with optimum retention and resistance.^[21] However, conclusive evidence cannot be drawn as other authors reported contradictory results.^[22] At a 12-degree convergence angle, when the marginal fit of 3D-printed, CAD CAM, and conventional wax patterns were compared, 3D-printed patterns produced an improved marginal fit for the final restoration compared to the conventional technique.^[23] The 3D-printed cast pattern crowns in the current research did not exhibit any significant differences in marginal and internal fit even with 12-degree taper, suggesting the accuracy of the material and the technique of 3D Printing. The elimination of human error in this additive technology resulted in consistent results proving the reliability of the technique. The material used for pattern fabrication should have zero or minimal expansion and high mechanical properties to prevent distortion during the investment

setting and burn without residue. Even supported bridges with 3D-printed wax patterns resulted in superior marginal fit compared to conventional hand waxing techniques before and after porcelain firings.^[24] The inherent inaccuracy and repeatability of the scanner and, therefore, the tolerance of the CAD-CAM instrumentation and the 3D printer can introduce errors resulting in compromised restorative outcomes.^[25] This study showed that for crowns with 6-degree taper, crowns fabricated from 3D-printed wax patterns showed more accuracy. However, with an increase in convergence angle, both conventional and 3D-printed groups showed similar accuracy, and there was no statistically significant difference between the two groups. Hence, it can be concluded that 3D-printed wax patterns produce metal crowns with consistent accuracy of fit even at 6 and 12 degrees taper.

Limitations

The results of this research need further validation as no comparative evaluation of marginal accuracy was done before and after cementation. Thermocycling of the cemented restorations has not been done before assessing the marginal and internal fit, as it can influence the longevity of the restoration. Various parameters to obtain confirmative and consistent estimates of the marginal and internal discrepancy of the novel 3D printed technology need further research.

5. Conclusion

For the conventional group, the marginal and internal adaptation of the full veneer crown increases with an increase in convergence angle. Meanwhile, for the 3D-printed group, the marginal and internal adaptation of the full veneer crown decreases with an increase in convergence angle. However, the result was not statistically significant. The following conclusions were drawn from the study:

1. For a 6-degree convergence angle, 3D Printing resulted in a statistically significant reduction in marginal and internal discrepancy compared to conventional wax patterns.
2. For a 12-degree convergence angle, the marginal and internal discrepancy between conventional and 3D Printing falls within an acceptable range with no statistically significant difference.

Conflict of Interest

The authors declared that there is no conflict of interest.

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