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Research Article

Assessment of Marginal Fit of Single Fixed Posterior Interim Restorations with Chamfer and Feather Edge Finish Lines Implementing CAD-CAM and 3D Printing Technologies: An In-Vitro Study

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Abstract:
This in vitro study aimed to assess the combined effects of several digital manufacturing techniques (subtractive versus 3D printing) and distinct finish line designs (chamfer versus feather edge) on the marginal fit of posterior single interim crowns. Materials and Methods: Two specially designed stainless-steel dies, resembling mandibular first molars, were constructed to receive forty interim crowns (die A featuring a chamfer finish line and die B featuring a feather edge finish line). The interim crowns were designed (n=40) and categorized based on digital fabrication techniques into two primary groups (n=20): subtractive and 3-D printing. Each group is further subdivided into two equal subgroups (n=10) based on finish line design (chamfer and feather edge) as follows: Subtractive with Chamfer finish line group; SC, Subtractive with Feather edge finish line group; SF, 3D Printing with Chamfer finish line group; PC, 3D Printing with Feather edge finish line group; PF. Two-way ANOVA and Shapiro-Wilk tests were conducted for analysis. The findings indicated a significant interaction between finish line design and fabrication method ($p=0.015$), with SF exhibiting markedly higher marginal gap values than SC ($p<0.001$). The difference for printed restorations was not statistically significant ($p=0.137$). Furthermore, it was demonstrated that irrespective of finish line design, milled restorations exhibited substantially greater gap values than printed restorations ($p<0.001$). **Conclusions:** Interim crowns fabricated using 3D printing technology possess superior marginal fit compared to those that are milled.

Keywords: Feather edge, Chamfer, Provisional crown, CAD/CAM, Additive manufacturing, Marginal fit.

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Introduction

The provisional restoration plays a crucial role in fixed prosthetic therapy, serving as a temporary solution following tooth preparation until the final cementation of the permanent restoration. A well-constructed interim restoration is vital for ensuring the success of the final prosthesis (1). The primary objectives of this temporary restoration include protection of the pulp, management of soft tissues, maintaining the stability and proper positioning of the prepared tooth, and enhancing aesthetics (2). The importance of provisional restorations is particularly critical in cases where long-term use is required as part of comprehensive oral rehabilitation (3), emphasizing the need for careful consideration of biological factors (4). Among the various factors influencing the choice of a temporary crown, achieving an optimal marginal fit is essential to maintaining the biological health of the prepared tooth (5). Additionally, refining the gingival contour during the provisional phase plays a key role in promoting efficient plaque removal and minimizing the risk of microleakage in treated teeth (6, 7).

Marginal precision is a fundamental factor in the success of restorations. Poorly fitted margins can result in recurrent caries, pulp exposure, cement dissolution, increased tooth sensitivity, and periodontal complications (8, 9). A marginal gap not exceeding 120 µm is generally considered clinically acceptable; however, a definitive standard for optimal marginal precision remains unestablished (10). Molin et al. (11) reported that marginal gaps ranging from 50 to 100 µm are typically regarded as suitable for ensuring effective restoration outcomes.

The literature highlights several factors that influence the fit of crowns. These factors may be associated with tooth preparation, including preparation height (12), total occlusal convergence (13), finish line design (14), and surface topography (15), as well as the type and fabrication method of the crown (16, 17). Additional elements that impact crown fit include the choice of luting cement (18), cementation technique (19), cement spacer availability (20), and the type of resin used.

Methacrylate and Bis-GMA are the primary resin materials commonly used in the fabrication of interim restorations. Polymethyl methacrylate (PMMA) resin is the most widely utilized due to its ease of repair, excellent marginal fit, and superior strength characteristics (20).

The construction of interim restorations can be performed either manually or digitally and may involve direct or indirect techniques (21). Recently, digital fabrication has seen the emergence of both subtractive and additive methods. Subtractive fabrication utilizes pre-polymerized high-performance resin blocks, offering satisfactory mechanical properties (22, 23) and precision, while minimizing polymerization shrinkage and avoiding exothermic reactions (24). However, design flexibility may be limited by the capabilities of milling equipment and the material's inherent physical and mechanical properties. Despite these constraints, CAD/CAM restorations offer notable advantages, such as increased productivity and reduced laboratory time compared to traditional handcrafted approaches.

In contrast, additive manufacturing, or three-dimensional (3D) printing, has gained popularity as a method for achieving the final restoration shape through a layering process. Common 3D printing techniques include Stereolithography (SLA), Selective Laser Sintering (SLS), and Digital Light Processing (DLP). The primary benefit of 3D printing lies in its ability to reduce raw material consumption and shorten production times. A comparison of the properties of CAD/CAM-milled provisional resins and 3D-printed resins, used in the creation of temporary crowns or fixed dental prostheses, has yielded varied results (25).

The objective of this study is to evaluate the impact of digital manufacturing methods (subtractive versus 3D printing) and finish line designs (chamfer versus feather edge) on the marginal fit of temporary crowns. The null hypothesis posits that there are no statistically significant differences in marginal adaptation between milled and 3D-printed interim crowns on stainless steel models with different finish line designs.

Methodology

The present study involved the design of forty interim crowns, which were categorized into two primary groups based on fabrication technique: subtractive and 3D printing. Each group (n=20) was further subdivided into two equal subgroups according to the finish line design (chamfer and feather edge, n=10). The subgroups were as follows: Subtractive with Chamfer finish line (SC), Subtractive with Feather edge finish line (SF), 3D Printing with Chamfer finish line (PC), and 3D Printing with Feather edge finish line (PF).

Stainless steel dies A (featuring a chamfer finish line) and B (with a feather edge finish line) were specially designed and fabricated to simulate ceramic crown preparations for the first mandibular molar **Fig.1**. These dies were created using a standardized process with an engineering lathe machine. Each die was constructed according to the prescribed parameters for posterior tooth preparation to accommodate ceramic crowns (26), including an occlusal reduction of 1.5 mm, axial reduction of 1 mm, a total occlusal convergence of 6 degrees, and an occluso-gingival height of 4.5 mm. Die A featured a chamfer finish line with a thickness of 0.5 mm, while die B was prepared with a feather edge finish line. All angles were rounded, and the dies were polished to a smooth finish.

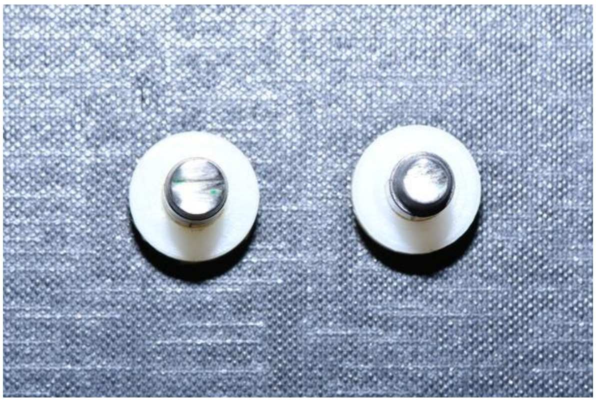

Fig. 1: The stainless steel dies

The stainless steel dies were coated with scan spray to minimize glare and ensure accurate optical impressions. A Bench Top Scanner (3Shape, Copenhagen, Denmark, Model No. 4) was employed to scan the chamfer finish line preparation **Fig.2** and feather edge preparation **Fig.3**, with the scans subsequently saved in STL format. The intermediate crowns were digitally designed using 3Shape software (Niels Juls Gade 13, 1059 Copenhagen K, Denmark), incorporating a 30 µm cement layer placed 1.0 mm above the finish line. The resulting STL files, including all design specifications, were sent for the production of both subtractive (SC and SF groups) and 3D-printed (PC and PF groups) interim crowns **Fig.4**.

For the fabrication of the twenty interim crowns in the subtractive groups, a five-axis milling machine, imes-icore 250 i (imes-icore GmbH, Im Leibolzgraben 1636132 Eiterfeld Hessen, Germany), was used to mill DC PMMA A1 Discs (Whitepeaks Dental Solutions, GmbH & Co., Germany). The crowns were then detached from the two supporting structures and finished using Jota Arkansas Stone 649 (Jota – Ruthi, Switzerland) to achieve a polished, smooth surface. All interim crowns were initially evaluated using a dental explorer and 3.5x magnifying loupes.

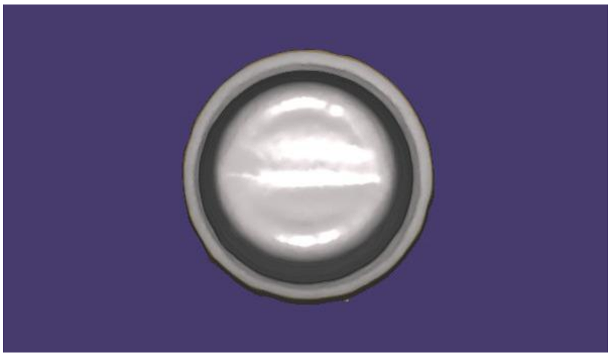

Fig. 2: The Chamfer finish line preparation

Fig. 3: The Feather edge finish line preparation

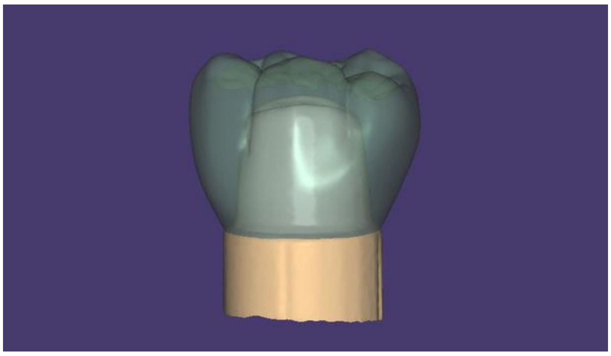

Fig. 4: The STL interim crowns

For the fabrication of the twenty 3D-printed interim crowns, the corresponding STL file for 3D printing was transmitted to the Rapidshape D30 3D printer (NextDent Soesterberg, Netherlands). A NextDent C&B resin specifically formulated for interim crowns was utilized (NextDent - Soesterberg, Netherlands). After the 3D printing process, the crowns were secured to the upper compartment with ten supporting structures and cured using the NextDent LC-3D Print Box (NextDent - Soesterberg, Netherlands).

Post-processing ultraviolet light heat treatment was performed to ensure complete polymerization of all crowns, thereby achieving enhanced mechanical properties. The heat treatment cycle was conducted over 30 minutes, utilizing blue ultraviolet light with a wavelength range of 315-400 nm and a total light output of 72 watts. This method is critical for ensuring the biocompatibility of the final product. Once the polymerization process was completed, all supporting structures were removed, and the crowns were finished and polished using Jota Arkansas Stone 649 (Jota – Ruthi, Switzerland, Patch number 649104001506) to achieve a flawless surface. An ethanol solution was then used to cleanse and disinfect the restorations.

Subsequently, the crowns were fitted onto the stainless steel dies and adjusted to achieve the desired accuracy **Fig.5**. The total thickness of each crown was measured at eight predetermined locations—midlabial, mesiolabial, distolabial, midlingual, mesiolingual, distolingual, middistal, and midmesial surfaces—using electronic calipers (Dial Caliper D; Aura Dental) with an accuracy of 0.1 mm.

Fig. 5: The finished and polished interim crowns

Measurement of vertical marginal gap: Distance of marginal gap:

A measuring stereomicroscope (Nikon Eclipse E600, Tokyo, Japan) connected to an IBM-compatible personal computer was utilized to capture photographs of each specimen at a fixed magnification of 45X. A computerized image analysis system (Image J 1.43U, National Institutes of Health, USA) was employed to evaluate the gap width both quantitatively and qualitatively. All measurable parameters, including frames, dimensions, and boundaries, were represented in pixels within the Image J software. These pixel measurements were subsequently converted to absolute units through system calibration. During calibration, the Image J software generated a scale, which was used to compare the object with a known reference (in this case, a ruler). The specimens were securely placed over their respective dies using a spring-loaded holding device designed specifically for this purpose.

The holding device was specifically designed with a central aperture at the base to engage an integrated indicator rod, allowing precise rotation of the die and coping for measurement purposes. A fine diamond disk was used to create an indentation at the base of the appliance, ensuring proper alignment with the stainless-steel die. To ensure an accurate fit, 10 temporary crowns from each group were placed onto the original stainless-steel master die, with each crown subjected to 30 N of axial force within the holding device. Under microscopic examination, indentations were made at four key locations on the stainless-steel master die—the midlabial, midlingual, middistal, and midmesial surfaces—using the diamond disk, and each site was marked with a fine pencil. Measurements were repeated five times at each location to ensure consistency. The marginal gap for each subgroup was calculated by averaging the gap values of the 10 interim crowns in each group. The collected data were then compiled, organized, and subjected to statistical analysis.

Statistical analysis:

Numerical data are presented as the mean, with 95% confidence intervals, standard deviation (SD), and the minimum and maximum values. The Shapiro-Wilk test was used to assess the normality of the data, following the methodology of Abdullah et al., with a sample size of 10 specimens per subgroup. Levene's test was applied to evaluate the homogeneity of variances. The data demonstrated a parametric distribution and homogeneity of variance, allowing for analysis using two-way ANOVA. Simple main effects were compared using the error term from the two-way model, with p-values adjusted through Bonferroni correction. A significance level of $p < 0.05$ was set for all tests. Statistical analysis was performed using R statistical software, version 4.1.3 for Windows.

Outcomes

Descriptive data for marginal gap values are presented in **Table 1** and **Fig. 6** and **7**. The results of the two-way ANOVA, shown in **Table 2**, revealed a significant interaction between finish line design and the fabrication process of provisional restorations ($p = 0.015$). The comparison of simple effects in **Table 3** indicated that milled restorations with a feather edge finish line had significantly larger marginal gap values compared to those with a chamfer finish line ($p < 0.001$). No statistically significant difference was observed for printed restorations ($p = 0.137$). Additionally, regardless of the finish line design, milled restorations consistently showed significantly larger gap values than printed restorations ($p < 0.001$).

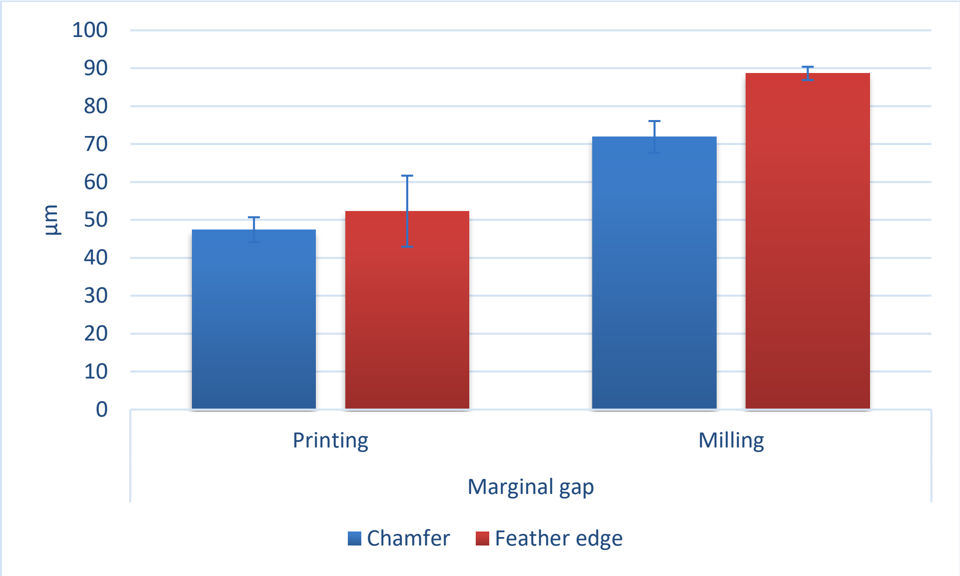

Fig. 6: Bar chart showing mean and standard deviation values of marginal gap (A).

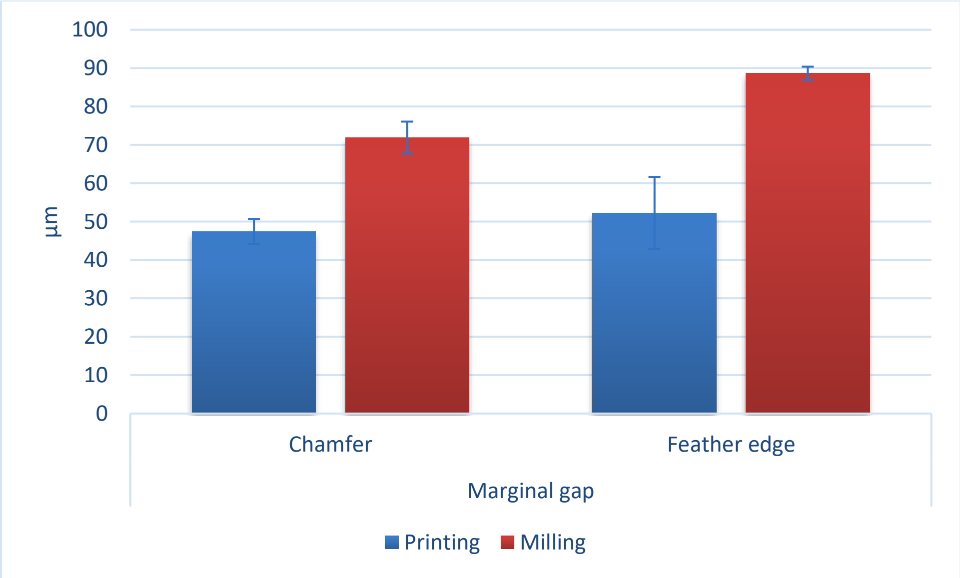

Fig. 7: Bar chart showing mean and standard deviation values of marginal gap (B).

Table (1): Descriptive statistics for marginal gap (µm)

Finish line design	*Fabrication technique*	*Mean*	*95% CI*		*SD*	*Min.*	*Max.*
			Lower	*Upper*			
Chamfer	***Printing***	47.42	44.78	50.05	3.29	43.50	50.80
	Milling	71.90	68.56	75.24	4.17	68.09	77.10
Feather edge	***Printing***	52.30	44.80	59.79	9.37	40.90	61.50
	Milling	88.63	87.23	90.03	1.75	86.60	90.50

95%CI= 95% confidence interval for the mean; SD=standard deviation; Min=minimum, Max=Maximum

Table (2): Two-Way ANOVA for

Parameter	*Sum of squares*	*df*	*Mean square*	*f-value*	*p-value*
Finish line design	700.67	1	700.67	**23.54**	**<0.001***
Fabrication technique	5548.26	1	5548.26	**186.41**	**<0.001***
Finish line * technique	210.80	1	210.80	**7.08**	**0.015***

*Significant (p<0.05)

Table (3): Comparison of simple main effects.

Technique / ***Finish line***	***Marginal gap (µm) (Mean±SD)***		***f-value***	***p-value***
	Chamfer	***Feather edge***		
Printing	47.42±3.68	52.30±10.47	**2.40**	**0.137**
Milling	71.90±4.66	88.63±1.96	**28.22**	**<0.001***
f-value	**60.41**	**133.08**		
p-value	**<0.001***	**<0.001***		

Discussion

The objective of this study is to evaluate the influence of various digital manufacturing processes (subtractive versus 3D printing) and different finish line configurations (chamfer versus feather edge) on the marginal fit of temporary crowns.

Temporary crowns can be fabricated using a range of techniques. Subtractive manufacturing offers several advantages, including high precision, reduced labor time, and cost-effectiveness. However, it is also associated with significant limitations, such as difficulty in producing complex geometries, material waste, and wear on the burs used for grinding. In contrast, additive manufacturing, or 3D printing, is gaining widespread adoption among dental professionals due to its ability to produce highly intricate designs, reduce operational time, and minimize material waste (27,28).

Provisional crowns produced using CAD/CAM technology are typically made from resin blocks or PMMA (29,30). These materials offer significant advantages, including minimal heat generation and the absence of polymerization shrinkage (31). For temporary crowns to be clinically effective, they must possess adequate fracture strength and maintain marginal integrity, regardless of whether they are fabricated using traditional methods or CAD/CAM technology (32). A recent meta-analysis reported that 3D-printed temporary crowns outperform both traditional and CAD/CAM milled crowns in terms of internal fit and marginal adaptation (33). The present study demonstrated that, regardless of the finish line design, milled restorations exhibited significantly larger marginal gap values compared to printed restorations (p < 0.001). Previous studies recommend a taper of 2° to 6° in preparations, since it provides optimal retention and resistance (34).

The marginal fit is a key factor in determining the long-term success of prostheses (35, 36). While scientific data remains limited, a marginal gap of less than 25 µm is generally considered ideal for optimal fit. However, clinically acceptable marginal gaps typically range from 50 to 120 µm (37, 38).

The current investigation found that the marginal gaps were within clinically acceptable limits, measuring (71.90±4.66) for SC, (88.63±1.96) for SF, (47.42±3.68) for PC, and (88.63±1.96) for PF. The impact of different finish lines on the marginal integrity of temporary crowns has been studied extensively. Sailer et al. (2017) assessed the effect of chamfer, shoulder, and feather edge finish lines on the marginal fit of PMMA crowns, finding a significant difference in the marginal gap, with chamfer finish lines providing the best adaptation, followed by shoulder and feather edge finish lines (39). Similarly, the present study revealed a significant interaction between finish line design and the method of provisional restoration fabrication (p = 0.015). The results demonstrated that milled temporary crowns with a feather edge finish line exhibited significantly larger marginal gap values compared to those with a chamfer finish line (p < 0.001), likely due to the increased risk of chipping associated with the thinner feather edge. In contrast, no significant difference was observed between the marginal gaps of printed temporary crowns (p = 0.137). Therefore, the null hypothesis, which proposed no significant differences in marginal adaptation between milled and 3D printed temporary crowns with varying finish line designs, was rejected.

The results of this study indicate that 3D-printed temporary crowns exhibit superior marginal fit, particularly in clinical applications with a chamfer finish line, when compared to CAD/CAM milled crowns. Conversely, CAD/CAM milled crowns demonstrated a significantly poorer marginal fit in preparations with a feather edge finish line. In such instances, modification of the digital design, such as increasing the thickness of the cement spacer, could potentially enhance the marginal adaptation. Additionally, chairside resin relining or repair may be required prior to cementation to achieve an optimal fit.

Given these findings, 3D-printed temporary crowns represent a more precise and reliable alternative, especially in cases where marginal integrity is critical to the success of the restoration.

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