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Marginal Accuracy and Periodontal Tolerance of Three Different Types of Mock Ups Compared with the Final Restoration in Anterior Esthetic Region

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Marginal Accuracy and Periodontal Tolerance of Three Different Types of Mock-ups Compared With the Final Restoration in the Anterior Esthetic Region

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Abstract

Purpose: This clinical study aimed to evaluate the marginal accuracy and periodontal tolerance of three different types of mock-ups (conventionally constructed, milled using computer-aided design/computer-aided manufacturing, and mock-up on three-dimensional printed cast) and compared with the final restoration in the anterior esthetic region. **Patients and methods:** A total of 30 patients with esthetic dental defects were enrolled in this study and were divided into two equal groups based on their clinical presentation: group 1 included cases with color or texture defects, while group 2 was involved in defects in size, spacing, or alignment. Each group was further subdivided into three subgroups according to the mock-up fabrication technique: subgroup A employed conventional methods, subgroup B utilized computer-aided design/computer-aided manufacturing milling, and subgroup C involved mock-ups on three-dimensional printed cast. Accuracy was evaluated by scanning the constructed mock-ups with a laboratory scanner and saving them as standard tessellation language files. The final restorations were milled, scanned, and saved as separate standard tessellation language files. The mock-up and restoration files were coregistered, segmented, and superimposed to assess dimensional discrepancies. The mock-ups were also placed in the patient's mouth, and periodontal conditions were evaluated at intervals two times, at baseline and after 2 weeks postcementation of the final restorations. **Results:** The analysis revealed that there were statistically significant differences in marginal accuracy between tested groups, while there was an insignificant difference regarding the periodontal tolerance between different tested groups. **Conclusion:** Methods of mock-up construction significantly affect marginal accuracy compared to the final restoration, but the fabrication techniques have no impact on the periodontal condition.

Keywords: Computer-aided design/computer-aided manufacturing milled mock-up, Conventional mock-up, Marginal accuracy, Mock-up on the three-dimensional printed cast, Periodontal tolerance

1. Introduction

It is undeniable that the influence of a person's smile on his social interactions has grown significantly. Concurrently, dentistry has increasingly embraced a minimally invasive approach to conserve natural tooth structure whenever feasible. Ceramic laminate veneers represent this approach, offering a conservative restoration technique that harmonizes natural esthetics [1].

Esthetic dental treatment includes various stages, among which the mock-up stage stands out as a crucial step in dental esthetic rehabilitation [2]. The mock-up is an intraoral resin template that replicates the planned prosthetic design. It serves as a commonly employed clinical technique to ensure effective esthetic and functional outcomes. Creating mock-ups adheres to the principle of conserving tooth structure, allowing both the dentist and the patient to visualize the anticipated results and gain

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approval before proceeding with any irreversible procedures [3]. Several methods have been described to fabricate the mock-up, either directly in the mouth or indirectly using a silicone index or through computer-aided design/computer-aided manufacturing (CAD/CAM) options [2].

Success in esthetic dentistry mainly depends on understanding the patient's chief complaint and expectations in seeking dental treatment to correct an esthetic concern and to address them as fully as possible, which demands achieving both white and pink esthetics [4].

Patient's requirements and expectations regarding esthetic dentistry are increasing, and they may have expectations that differ from what can be achieved. Moreover, esthetics, being subjective, may not be based on the same criteria for both the patient and the dentist [5]. Therefore, it is strongly recommended that before any elective esthetic treatment, patients are enabled to visualize the projected result with its limitations to help them understand what can realistically be achieved [6].

Using a mock-up approach provides a preview of esthetic rehabilitation; however, the mock-up must align closely with the anticipated esthetic results. Familiarity with the advantages and limitations of materials in modern CAD/CAM technology enables dentists to create mock-ups based on a digitally planned smile design, ensuring reliable accuracy and efficiency [7]. For these reasons, mock-ups have become essential in treatments involving esthetic restorations in both the proposition stages as well as the preparation and temporization steps, and their accuracy is of prime importance [8,9]. Although mock-ups have been widely used in dental esthetic rehabilitation, their accuracy has not been quantitatively evaluated. Also, despite the importance of the mock-up, there are not extended studies concerning different types of mock-ups and their correlation to marginal accuracy affecting the oral tissues.

This study was performed to evaluate the marginal accuracy of three types of mock-ups [conventionally constructed, milled using CAD/CAM, and three-dimensional (3D) printed] used in esthetic regions that require simple (cases with defects in color or texture) or moderate intervention (cases with defect in size or spacing or alignment). The periodontal tolerance of the three mock-ups was also evaluated and compared with the final restoration. The null hypothesis of the present study was that different types of mock-ups will not affect the marginal accuracy and periodontal tolerance compared with the final restoration in the anterior esthetic region.

2. Patients and methods

2.1. Sample size calculation

The sample size was calculated depending on a previous study [10]. According to this study, the minimally accepted sample size was four per group when the mean ± SD of group 1 was 0.0468 ± 0.0204 while in group 2 the mean ± SD was 0.0103 ± 0.004, with 2.48 effect size when the power was 80 % and type I error probability was 0.05. The total sample size increased to five per group to compensate for the 20 % dropout. The *t* test was performed by using G. power3.1.9.7.

2.2. Classification of patients

Thirty patients with anterior esthetic restorations were selected from the Crown and Bridge Department clinics in the Faculty of Dental Medicine for Girls at Al-Azhar University. The procedures were explained to each patient, and written informed consent was obtained. The possible discomforts, risks, and benefits were fully explained to the patients. Approval from the Research Ethics Committee (REC) of the Faculty of Dental Medicine for Girls, Al-Azhar University, was obtained (code: P-CR-21-14).

The criteria of the selection included patients who had good oral hygiene, complete set up of anterior teeth, and their ages ranged from 25 to 40 years, and their teeth needed to be restored by veneers [11], while exclusion criteria were included: patients who had missed one or more maxillary anterior teeth, those with a history of prior orthodontic treatment, individuals presenting with periodontal issues in the maxillary anterior region, patients exhibiting habits such as bruxism or clenching, and individuals with uncontrolled systemic diseases [12]. The selected patients were divided into two groups: group 1 ($n = 15$ patients) included cases with defects in color or texture, where no changes to the size or shape of the teeth were needed. Group 2 ($n = 15$ patients) comprised cases with defects in size, spacing, or alignment, requiring modifications to the size and/or shape of the teeth. Each group was further subdivided into three subgroups based on the method used for mock-up construction: subgroup A (1A and 2A), where mock-ups were manually constructed on a CAD waxed-up cast; subgroup B (1B and 2B), where mock-ups were milled using a CAD/CAM system; and subgroup C (1C and 2C), where mock-ups were constructed on a 3D-printed cast (Table 1).

Table 1. Groups, subgroups, and number of subjects in the study.

	Group 1	Group 2	Number
Subgroup A (conventional mock-up)	IA	IIA	10
Subgroup B (CAD/CAM-milled mock-up)	IB	IIB	10
Subgroup C (mock-up on 3D-printed cast)	IC	IIC	10
Total	15	15	30

3D, three-dimensional; CAD/CAM, computer-aided design/computer-aided manufacturing.

2.3. Research workflow

For subgroups (1A and 2A): CAD wax-up (RMH3 Dental; Rhein'83 Medical & Health, Italy) was done according to the digital smile design for each case, and then a conventional silicone index was fabricated using Zeta plus rubber base silicon impression material (Zhermack, Italy) to perform the mock-up where fast-setting temporary BIS-Acrylic material (Structure 2 SC temporary resin material; Voco, Germany) was used. For subgroups (1B and 2B): PMMA CAD blocks (A2, OD 98 × 14 mm, LOT NO 20230915) were milled using a dental milling machine (DGSHAPE, Roland DG Corporation, Japan) according to the digital smile design for each case. The last subgroups (1C and 2C): 3D-printed models were constructed using a 3D printer (Elegoo Inc., Shenzhen, China) and photopolymer resin (Norton 8K series; Saint-Gobain, Courbevoie, France) according to the suggested smile design, and then a transparent silicone index was fabricated with vacuum forming splint thermoforming material hard crystal plate (Sheet, Bioart, Brazil) to perform the mock-up as the former (IA and IIA) subgroup.

All the fabricated mock-ups, irrespective of their materials, were scanned using an extraoral scanner (T310 lab scanner; Medit, Seoul, South Korea) to develop an standard tessellation language (STL) file for each patient. Another scanning was done using the same laboratory scanner for the final restorations on the same plaster models.

Each STL file of the mock-up was superimposed with its corresponding final restoration STL file. After an initial alignment, a best-fit alignment was performed, followed by a 3D comparison using Geomagic Control X metrology software for surface matching analysis (Geomagic Inc., Morrisville, North Carolina, USA) (Fig. 1). This process quantified the actual volumetric differences between the two models. Lastly, the images were compared to assess which mock-up exhibited greater deviations and which was more closely aligned with the final restoration.

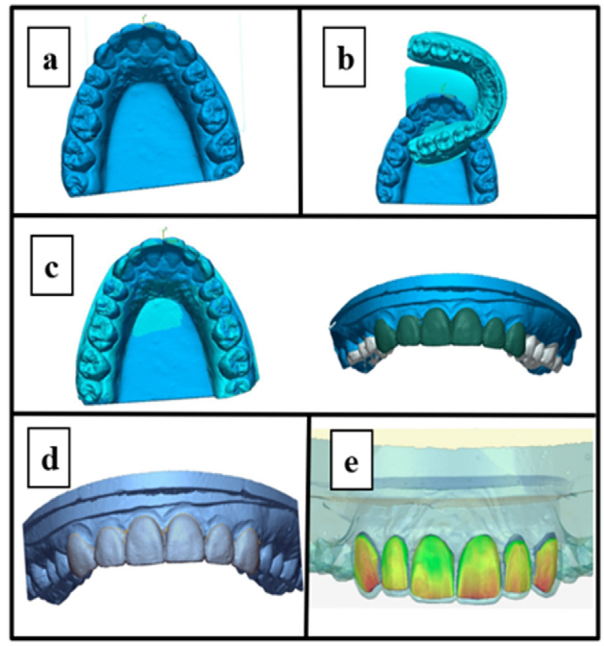

Fig. 1. Geomagic superimposition software steps (a) importing baseline STL file to Geomagic software; (b) initial alignment; (c) best-fit alignment; (d) 3D compare; and (e) the final result. 3D, three-dimensional; STL, standard tessellation language.

2.4. Treatment planning

Every one of the patients discussed with the researcher doctor his own tailored treatment plan. All the patients were aware of his treatment plan, and then a medical consent was signed before starting the plan. Patients of both groups underwent the following procedure: clinical photographs and impressions recording the dental arches were taken, impressions were scanned by a digital scanner, digital smile design program (Exocad Dental CAD, Darmstadt, Germany) was used to design the smile and accordingly the restorations. Then, another mock-up was fabricated (each subgroup according to its meant type).

A periodontal assessment for the mock-up was held at the baseline and after 2 weeks using a standardized periodontal probe (Williams with Markings, Hu-Friedy, United States) with the same operator performing all assessments to minimize variability. Subsequently, teeth preparation was done to be susceptible to receiving fixed dental restorations. Followed by the fabrication of interim restorations, then try in and cementation for the final restorations (IPS e. max Press, Ivoclar

Vivadent, Liechtenstein). A final periodontal assessment was performed at baseline and 2 weeks after cementation of the final restorations.

2.5. Statistical analysis

Exploration of the given data was performed using the Shapiro–Wilk test and Kolmogorov–Smirnov test for normality, which revealed that the significant level (*P* value) was shown to be insignificant as *P* value more than 0.05, which indicated that data originated from normal data. One-way analysis of variance (ANOVA) test compares all groups in marginal accuracy. The independent *t* test compares group 1 and group 2 in periodontal ligament (PDL) tolerance. Repeated measures ANOVA to compare between different mock-ups, and between A, B, and C subgroups.

3. Results

3.1. Marginal accuracy

Marginal accuracy across three parameters (A, B, and C) for two groups (group 1 and group 2) was compared using a one-way ANOVA, followed by Tukey's post hoc test for pairwise comparisons. The analysis revealed statistically significant differences between the parameters ($P < 0.0001$). For both group 1 and group 2, parameter B exhibited the highest mean values (1.02 ± 0.01 and 1.06 ± 0.02, respectively), followed by parameter C (0.96 ± 0.02 and 0.99 ± 0.03), while parameter A showed the lowest values (0.81 ± 0.04 and 0.84 ± 0.03) (Table 2).

3.2. Periodontal ligament tolerance

3.2.1. Comparison between different intervals

Present data comparing different intervals across two groups (G1 and G2), each with three subgroups (A, B, and C) using the repeated measures ANOVA test. The measurements were taken at four-time points: a mock-up, after 2 weeks, at final restoration, and after another 2 weeks. There was an insignificant difference between different readings in both groups regarding A, B, and C (Table 3).

Table 2. Comparison of marginal accuracy between different mock-ups.

Marginal accuracy	Mean	SD	*P* value
G1A	0.81^{a}	0.04	<0.0001*
G1B	1.02^{b}	0.01	
G1C	0.96^{c}	0.02	
G2A	0.84^{a}	0.03	
G2B	1.06^{b}	0.02	
G2C	0.99^{c}	0.03	

Means with different superscript letters were significantly different as *P* value less than 0.05.

Means with the same superscript letters were insignificantly different as *P* value more than 0.05.

*Significant difference as *P* value less than 0.05.

3.3. Comparison between groups

A comparison between two groups (G1 and G2) across three parameters (A, B, and C) at four different time points was conducted using an independent *t* test. Each parameter was measured at four intervals: baseline (mock-up), 2 weeks post-mock-up, at final restoration, and 2 weeks postrestoration. The analysis showed no statistically significant differences between the groups ($P > 0.05$) (Table 4).

3.4. Comparison between different mock-ups

A comparison of three parameters (A, B, and C) across four-time points for two groups (G1 and G2), potentially related to PDL tolerance, was conducted using repeated measures ANOVA. The results indicated that, in G1, differences between parameters were not statistically significant, with *P* values of 0.16, 0.23, 0.27, and 0.09 for the first (mock-up), second (2 weeks post-mock-up), third (final restoration), and fourth (2 weeks postrestoration) time points, respectively. Similarly, in G2, the differences between parameters were also not statistically significant, with *P* values of 0.06, 0.06, 0.06, and 0.11 for the respective time points (Table 5).

4. Discussion

Modern prosthodontic dentistry prioritizes esthetics to meet patient expectations. Failures can arise not only from technical issues but also from poor communication with the patient. Using a mock-up can be beneficial to prevent scenarios that might require starting the restoration from scratch. This technique helps control the function of the final result even before starting the actual work and allows for minimally invasive tooth preparation. Broadly speaking, in prosthodontics, it assures us that the work will be functionally and esthetically successful [13].

This study aimed to determine whether the different techniques of fabrications of the mock-ups would stay faithful to their final restorations or not and to correlate if there are any marginal misfits with the periodontal health.

Digital smile design is crucial for optimizing treatment management in anterior esthetic restorations [14]. In this study, Exocad software was used to design mock-ups for patients. Its selection was

Table 3. *Comparison of periodontal tolerance between different intervals.*

		1st (mock-up)		2nd (after 2 weeks)		3rd (final rest)		4th (after 2 weeks)		*P* value
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
G1	A	1.782	0.185	1.756	0.250	1.722	0.312	1.722	0.312	0.39
	B	1.682	0.206	1.733	0.182	1.756	0.183	1.756	0.183	0.07
	C	1.772	0.188	1.904	0.081	1.908	0.064	2.038	0.345	0.21
G2	A	1.625	0.173	1.655	0.190	1.660	0.184	1.678	0.182	0.06
	B	1.871	0.111	1.929	0.086	1.940	0.092	1.940	0.092	0.06
	C	1.882	0.078	1.935	0.103	1.946	0.083	2.080	0.368	0.29

Table 4. *Comparison of periodontal tolerance between groups.*

		G1		G2		Mean difference	SE difference	95 % confidence interval of the difference		*P* value
		Mean	SD	Mean	SD			Lower	Upper	
A	1st (mock-up)	1.782	0.185	1.625	0.173	0.150	0.100	−0.410	0.014	0.20
	2nd (after 2 weeks)	1.756	0.250	1.655	0.190	0.101	0.140	−0.420	0.200	0.85
	3rd (final rest)	1.722	0.312	1.660	0.184	0.060	0.160	−0.430	0.311	0.71
	4th (after 2 weeks)	1.722	0.312	1.678	0.182	0.044	0.160	−0.420	0.330	0.79
B	1st (mock-up)	1.682	0.206	1.871	0.111	−0.189	0.105	−0.430	0.052	0.11
	2nd (after 2 weeks)	1.733	0.182	1.929	0.086	−0.195	0.090	−0.403	0.012	0.06
	3rd (final rest)	1.756	0.183	1.940	0.092	−0.184	0.091	−0.395	0.026	0.08
	4th (after 2 weeks)	1.756	0.183	1.940	0.092	−0.184	0.091	−0.395	0.026	0.08
C	1st (mock-up)	1.772	0.188	1.882	0.078	−0.110	0.091	−0.320	0.100	0.26
	2nd (after 2 weeks)	1.904	0.081	1.935	0.103	−0.031	0.059	−0.166	0.104	0.61
	3rd (final rest)	1.908	0.064	1.946	0.083	−0.038	0.047	−0.146	0.069	0.44
	4th (after 2 weeks)	2.038	0.345	2.080	0.368	−0.042	0.226	−0.562	0.479	0.86

Table 5. *Comparison of periodontal tolerance between different mock-ups.*

PDL tolerance		A		B		C		*P* value
		Mean	SD	Mean	SD	Mean	SD	
G1	1st (mock-up)	1.782	0.185	1.682	0.206	1.772	0.188	0.16
	2nd (after 2 weeks)	1.756	0.250	1.733	0.182	1.904	0.081	0.23
	3rd (final rest)	1.722	0.312	1.756	0.183	1.908	0.064	0.27
	4th (after 2 weeks)	1.722	0.312	1.756	0.183	2.038	0.345	0.09
G2	1st (mock-up)	1.625	0.173	1.871	0.111	1.882	0.078	0.06
	2nd (after 2 weeks)	1.655	0.190	1.929	0.086	1.935	0.103	0.06
	3rd (final rest)	1.660	0.184	1.940	0.092	1.946	0.083	0.06
	4th (after 2 weeks)	1.678	0.182	1.940	0.092	2.080	0.368	0.11

based on the ability to provide precise, efficient, and customizable results, thereby enhancing restorative outcomes and patient satisfaction. Exocad's high accuracy, user-friendly interface, and versatility enable the creation of accurate restoration contours, optimizing fit, function, and esthetics. Regular software updates integrate the latest advancements, supporting immediate chairside adjustments and streamlining the overall workflow [15,16].

In the current study, extraoral scanning was utilized based on evidence that suggests extraoral and model-based scanning methods generally provide superior accuracy compared to intraoral scanning techniques. Research indicates that intraoral conditions, such as saliva and limited space, can adversely affect the accuracy of intraoral scans, further supporting the choice of extraoral methods for enhanced precision [17,18].

Marginal accuracy was evaluated in this study through the superimposition of STL files utilizing Geomagic Control X (3D Systems) software, which is recognized as a reliable tool for assessing accuracy and precision. The software's ability to analyze digital scans and compare them to reference models has been widely recognized as a valuable resource in dental research, as evidenced by numerous previous studies [19–21].

According to the results of the carried study, the null hypothesis of different fabrication techniques having no effects on the marginal accuracy was rejected, while it agreed with the hypothesis of not affecting the periodontal tolerance.

These findings were in agreement with others [22] who declared that printed trial restorations exhibited greater accuracy compared to milled trial restorations. Furthermore, it was observed that the dimensions of milled trial restorations were larger than those specified in the 3D designs. Notably, 80 % of participants deemed the trial restorations produced via CAD/CAM technology as unacceptable, likely due to the inherent limitations of the milling system.

Moreover, a previous study stated that several techniques for fabricating mock-ups have been introduced in recent years, such as 3D printing and milling of composite resin, which have shown promising outcomes in terms of predictability. However, the author's own research has yielded suboptimal esthetic results with these techniques, as well as challenges in placement when undercuts are present. Although advancements in CAD/CAM materials were expected to enhance these methods in the future, the indirect molding technique using bis-acryl resin currently remains the gold standard [2].

Several studies [23–27] were in agreement with the findings of the present study, which reported the lower marginal discrepancies for methacrylate-based 3D-printed provisional resins compared to CAD/CAM-milled PMMA resins. Also, it was reported that higher marginal discrepancies were observed when 3D-printed provisional resins were compared to conventional methacrylate resins [28].

The findings of the current study were also in agreement with the previous study [29], which reported that there were no significant differences in probing depth when utilizing various temporary crown fabrication techniques. However, the results of the current study contradict another study that found conventional temporary crown material Luxatemp and the additive material 3Delta temp significantly compromised cell viability when in direct contact with PDL cells. In contrast, other tested materials within the new category of additive resins, as well as the subtractive material Grandio, caused only minor alterations in cell viability [30]. These discrepancies might be attributed to differences in the materials used and the direct contact of these materials with PDL cells during the ageing process, a condition that does not typically occur in a clinical setting.

The findings of this study disagreed with a previous investigation that reported molded mock-ups were less accurate than milled ones, which made it more challenging for patients to visualize the final result [10], and the study [31] concluded that milled mock-ups offered greater accuracy, while molded mock-ups exhibited significant deviations. However, it is important to note that these studies compared the accuracy of mock-ups to wax-ups rather than to the final restorations.

Another study [32] disagreed with the findings of the current research, which indicated that 3D-printed provisional resins exhibited higher marginal discrepancies compared to CAD/CAM-milled PMMA resins. Additionally, another study [33] that compared two different brands of 3D-printed methacrylate resins reported lower marginal discrepancies in comparison to conventional bis-acrylic provisional resins. The variations in results might be attributed to factors such as differences in calibration and measurement techniques, as well as inconsistencies in the types, positions of teeth, and variance of the materials used.

The present study faced limitations inherent to in-vivo research, as variability among patients results in a lack of standardization. Additionally, the study's limitations included a small sample size. Furthermore, only a single milling machine and 3D printer were utilized for the investigation.

4.1. Conclusions

Under the limitation of the current study, the following could be concluded:

Variations in mock-up types significantly impacted the marginal accuracy when compared to the final restoration in the anterior esthetic region.

Notably, the milled PMMA mock-up displayed the lowest accuracy compared to the final restoration, whereas the conventionally constructed mock-up based on a CAD wax-up exhibited superior accuracy in comparison.

The accuracy of the mock-up constructed on a 3D-printed cast fell between that of the milled PMMA and the conventional CAD wax mock-up.

None of the mock-up fabrication techniques utilized in this study had a significant impact on periodontal probing depth.

4.2. Recommendation

Further research involving larger sample sizes and incorporating various materials, milling machines, and 3D printers is necessary to validate and strengthen the findings.

Ethics information

Approval from the Research Ethics Committee (REC) of the Faculty of Dental Medicine for Girls,

ORIGINAL STUDY

Al-Azhar University, was obtained (code: PCR-21-14).

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Biographical information

At the Crown and Bridge Department clinics in the Faculty of Dental Medicine for Girls at Al-Azhar University.

Conflict of interest

There are no conflicts of interest.

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