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Evaluation of Color Stability of Provisional Restoration Manufactured by Conventional and Digital Workflow

Mahmoud shams [1], Mohamed Ghazy [2], Manal Abo Madina [3] , Mahy Hassouna [4]
1,2,3,4Fixed prosthodontic department, Faculty of dentistry, Mansoura university, Mansoura, Egypt

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ABSTRACT: This research paper is about to assess the influence of impression technique and manufacturing technique used on the color stability of PMMA provisional restorations. All printed master models were divided into two main groups according to type of impression making:Group(C): Conventional impression using polyvinyl siloxane impression material and Group (D): Digital impression using intra oral dental scanner.
All printed master models of group (C and D) were divided into two subgroups according to restoration manufacturing technique. Subgroup (CS): Provisional FDPs were fabricated using CAD-CAM manufacturing technique (Subtractive manufacturing). Subgroup (CA): Provisional FDPs were fabricated using 3D printing manufacturing technique (Additive manufacturing). Subgroup (DS): Provisional FDPs were fabricated using CAD-CAM manufacturing technique (Subtractive manufacturing). Subgroup (DA): Provisional FDPs were fabricated using 3D printing manufacturing technique (Additive manufacturing). The specimens were immersed in coffee for 28 days. Color measurements of the specimens were recorded by a spectrophotometer at baseline, and after 28 days. there were statistically significant higher mean ΔE among CA than CS followed by CS and the least detected for DS. Milled PMMA restorations showed better color stability compared to 3D printed PMMA restorations and is recommended for eshatic provisional restorations.
KEYWORDS: IOS, Physical impression, Additive manufacturing , Subtractive manufacturing, Color stability

I. INTRODUCTION

The goal of provisional treatment is to protect the pulp and periodontium from bacterial, chemical, and thermal insults. For teeth subjected to endodontic therapy, a well-made provisional restoration helps prevent coronal microleakage, thus protecting the root canal system. (1) Digitally fabricated Provisionals can be fabricated using subtractive method (CAD-CAM milling method) or additive method (3D printing) (2). **Recent researchers** (3-5) investigated the use of CAD/CAM technologies for the fabrication of PMMA dental prostheses and compared the materials' properties and various aspects of the conventional and CAD/CAM PMMA materials. Although the chemistry of CAD/CAM PMMA is similar to that of conventional heat cured PMMA, CAD/CAM PMMA shows superiority in terms of many properties, including its hardness, flexural strength, flexural modulus, and impact strength.Recent dental technological advancement uses the PMMA as liquid photosensitive resin form in additive manufacturing technique of 3D printing technology to fabricate many dental restorations. (6)

In fixed prosthodontics, the accuracy of the impression technique and the definitive casts is essential for proper fabrication of restorations, thus preventing subsequent biological and prosthetic complications. Discrepancies between the intraoral condition and the definitive cast can lead to restoration misfit and compromising the treatment outcome. (7) The gold standard impression technique is the conventional physical impression with elastomeric impression material and stock trays.(8) In spite of the low-wear resistance and minimal setting expansion, the resultant stone casts that obtained from elastomeric impression materials are considered a benchmark for accurate fixed dental prostheses.(9) However, the conventional workflow for obtaining gypsum casts is time-consuming and labor-intensive. (10) Nowadays, Computer-aided design and computer-aided manufacturing (CAD-CAM) systems can replace gypsum casts by printed resin model using intraoral scanners (IOSs) and additive manufacturing technique (11)

Rafael Siqueira et al. (4) stated that the IOS technology can improve the patient experience measured by overall preference and comfort and is able to provide reliable prosthodontic outcomes. In addition, **other study** has shown that digital impressions are time efficient, as they enable reduction of the working times (and therefore costs) when compared to conventional impressions.

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Recent technological advancements in IOS, with the latest devices introduced in the market enabling the capture of a full-arch scan in less than 3 min. [12]

The advent of CAD/CAM has enabled the dentists and laboratories to harness the power of computers to design and fabricate esthetic and durable restorations. Computer-aided manufacturing (CAM) consider as the third and final stage of CAD/CAM technology that categorized into two groups according to the manufacturing technique. In subtractive manufacturing technique (SM) the milling is done with computerized electrically driven diamond disks or burs which cut the restoration from dental blanks or blocks. [13] While the Additive manufacturing technique (AM) is defined by the American Society of Testing and Materials (ASTM) as the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. [14] Even though SM has been routinely used for the better part of at least the past two decades for the fabrication of dental restorations, innate drawbacks of this technology include raw material waste, untenable wear of the milling tools, limited geometric reproducibility, and introduction of microcracks in the restoration. AM however is a relatively novel technology that has begun to sideline SM as the final step in digital workflow by virtue of its versatility and customization possibility in manufacturing complex geometries. [15]

The International Organization for Standardization has classified AM into many categories: vat-polymerization (VP), material jetting (MJ), material extrusion (ME), binder jetting (BJ), powder-based fusion (PBF), sheet lamination (SL), and direct energy deposition (DEP). Four different vat-polymerization (VP) technologies can be differentiated based on the light source employed for polymerization: stereolithography (SLA), digital light processing (DLP), liquid crystal display (LCD) based, also called daylight polymer printing (DPP), and continuous liquid interface production (CLIP).[16] **Wonjoon Moon et al.** [17] suggested that the 3D printing manufacturing is most accurate method with less deviation and shrinkage when a DLP printer was used for short unit restorations.

One of the most important aspects that must be addressed carefully in dental prosthodontic manufacturing is the color**.** It is defined as the quality of an object or substance with respect to light reflected or transmitted by it. The color is usually determined visually by measurement of hue, saturation, and luminous reflectance of the reflected light. [18] From the beginning of the 20th century to the present, many different color systems developed to measure colors mathematically as Munsell Color System and CIE Lab Color System [19]

The CIE color system represents a uniform color space, with equal distances corresponding to equal perceived color variances. In this three-dimensional color space, the three-axis are L*, a*, and b*. The L* represents the value which is a lightness measurement of an object and is quantified on a scale as a 100 L* of value for a perfect black. While the a* value is a quantity of greenness (negative a*) or redness (positive a*). Whereas the b* value is a quantity of blueness (negative b*) or yellowness (positive b*). The a* and b* coordinates approach zero for natural colors and increase in degree for more intense or saturated colors. [20] Spectrophotometry is a one of available methods that measures that measures L* a* b* color values. It measures the amount of light energy reflected or transmitted from an object’s surface at 1-25 nm intervals along the visual light spectrum “380-780 nm”. For color matching in dental practice, the spectrophotometer can be the most accurate instrument [21]

Joshi et al (2019) [22]**.** compare the physical and optical properties of provisional crown and bridge materials fabricated using CAD/CAM or 3D printing technology. printed resin showed significantly better translucency and gloss when compared to milled PMMA or acrylic resin. **Shin et al (2020)** [23]. evaluate the discoloration resistance and color stability of CAD/CAM block and 3D printing materials by evaluating color changes upon exposure to staining foods. The color stability of 3D printing resins was much lower than that of CAD/CAM block materials.

This in vitro study was performed to assess the influence of impression technique and manufacturing technique used on the color stability of PMMA provisional restorations. The null hypothesis assumed that color stability of provisional restoration fabricated using additive manufacturing would not differ from those fabricated with the subtractive manufacturing.

II. EXPERIMENTATION

The acrylic maxillary left first premolar was removed from the study model and Its socket space was blocked out by pink wax (Dental modelling wax, Cavex, The Netherlands). A putty index was made for the study model before preparation using polyvinyl siloxane impression material (HD elite plus VPS Impression Material – putty material, Fast Set, Germany) to assess the amount of reduction. The index material was adapted on the model then each tooth was embedded and left till complete setting. Horizontal preparations on the maxillary left canine and second premolar simulating preparations for a 3-unit fixed partial denture were made on the study model following the biomechanical principles of tooth preparation using 5x dental loups (Univet, Italy). The final amount of reduction was checked for uniformity by corresponding putty index and graduated periodontal prob. Range of insertion was evaluated by direct inspection from the occlusal and incisal view. Then it was confirmed digitally by lab desktop scanner (Shinning 3D, AutoScan-DS-EX Pro, Hangzhou, Zhejiang, China) to avoid presence area of undercuts **.**

A double-mix, two-step impression technique was used. The putty base and catalyst pastes of a polyvinyl siloxane impression material (HD elite plus VPS Impression Material Fast Set , Germany) were proportioned and mixed according to the manufacturer's instructions . Recorded impression was poured by mixing Type IV extra hard dental stone (SHERA PREMIUM, REF, SHERA Werkstoff Technologie GmbH & Co. KG, Germany) with water under vibration to avoid air inclusion in the mix. A saw frame and blade were used to cut through the stone cast mesially to the canine abutment and distally to the premolar abutment to obtain stone cast model for prepared abutments only. The stone cast model was mounted on stone base containing special guiding grooves. After Waxing up the gingival part of the ridge by blue wax (Renfert, Germany) for simulating the natural gingival contour of edentulous area between two abutments, the stone cast model was scanned using lab desktop scanner (Shinning 3D, AutoScan-DS-EX Pro, Hangzhou, Zhejiang, China).

The stone cast model was fixed on an adhesive special plate that was screwed to the base plate of the scanner. Then the scanned model images were arranged uniformly on 3d printer platform (AccuFab-D1Dental 3D Printer, Hangzhou, Zhejiang, China) and printed 40 times for getting 40-dimensional standardized printed master models with layer thicknesses of 50µm [(24)] using PMMA resin (Shinning 3D DM12). After printing, each model was soaked in 90% isopropyl alcohol for 20 mins to remove the residual monomers, followed by drying with compressed air. Subsequently, the printed master models were cured with the help of UV light for 30 mins in a curing chamber (Shining 3D FabCure UV Post-curing Machine Hangzhou, Zhejiang, China). [(25)] Finally, all cured printed master models were completely formed **(Figure 1).**

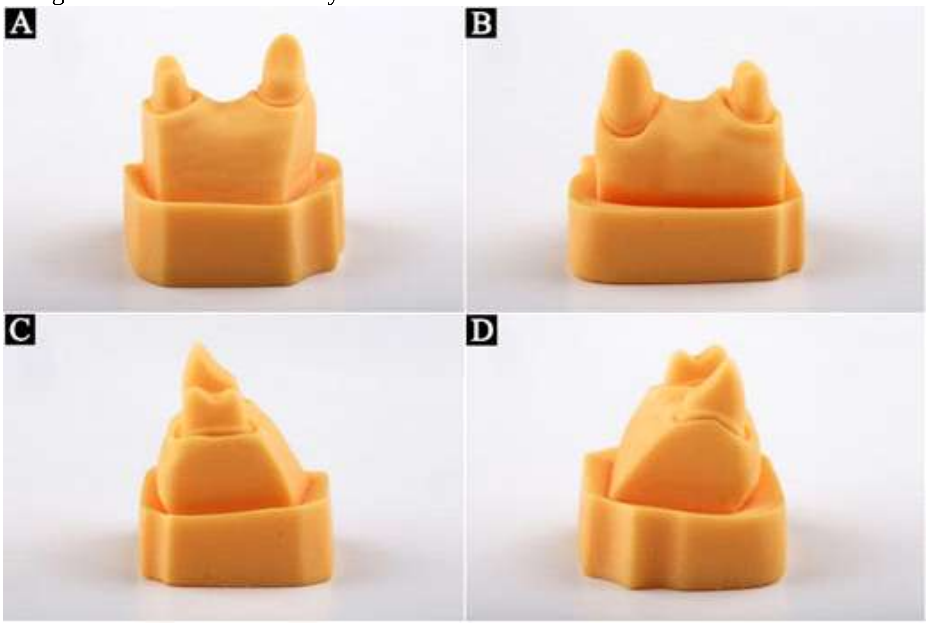

Figure (1): Finally cured printed master model; Palatal view (A), Buccal view (B), Distal view (C) and Mesial view (D).

Twenty silicone putty impressions (HD elite plus VPS Impression Material Fast Set, Germany) were taken individually for 20 printed master models by custom acrylic trays according to the manufacturer's instructions. Each impression was poured by mixing Type IV extra hard dental stone (SHERA PREMIUM, REF, SHERA Werkstoff-Technologie GmbH & Co. KG, Germany). When the stone master models become hard and dry, a saw frame and blade were used to cut through the stone to obtain separate removable dies for prepared abutments. Then ditching of the dies 0.5mm below the level of the finish line was done. scanned using a lab desktop scanner (Shinning 3D, AutoScan-DS-EX Pro) 20 intraoral scans of 20 printed model were performed individually under extraoral conditions using a dental intraoral scanner (CS 3600®, Carestream, Rochester, NY, USA). The corresponding exported STL files (digital virtual casts) were used to fabricate 3D-printed casts with separated movable dies. 3-unit fixed dental prosthesis were designed for each scan by means of a dedicated CAD software (Exocad Dental CAD, Exocad GmbH, Darmstadt, Germany). The following configuration of the restorations was used: margin line defining, cement gap thickness (0.05mm/50µm) and its distance from margin (1mm), range of insertion and minimal thickness 1 mm were determined until the finished full anatomical design was obtained. In order to obtain a standardized restoration contour for all provisional FDPs, the same design of 3-unit fixed dental prosthesis from the software library was applied for all provisional FDPs of conventional impression group (C group) and digital impression group (D group).

Subtractive manufacturing: The provisional FDPs of the milled provisional restoration subgroups (CS & DS) were milled from the CAD/CAM PMMA blank (Ceramill A-temp, Amann Girrbach AG, Austria A2 98x14mm) using a 5-axis (wet) milling machine (Ceramill motion 2 Amann Girrbach, Austria), 6.0 mm shaft tool; 60,000 rpm spindle.

Additive manufacturing: The provisional FDPs of 3D printed provisional restoration subgroups (CA & DA) were fabricated using a 3D printer (AccuFab-D1Dental 3D Printer, Xiangbin Road, Wenyan, Xiaoshan, Hangzhou, Zhejiang, China) using PMMA resin (Mammoth 3D printing resin material) with 405- nm ultraviolet light. The provisional FDPs were 3D printed at a build angle of 180 degree, [26] The thickness of each printing layer was set to 50 µm, and the supporting structures were attached to the bottom of the printed provisional FDPs.

No further adjustment or finishing was done on the milled and printed provisional FDPs, except for the removal of the supporting structures. All milled and printed provisional FDPs were examined for the presence of any defects or cracks and polished by a single dental technician to minimize any experimental error with aluminium oxide polishers (Enhance PoGo, Dentsply Sirona, York, PA) for 20 seconds under intermittent pressure. and this was followed by washing with distilled water. The fitness and margin adaptation of each fabricated milled and printed provisional FDP was checked with its corresponding movable dies.

All provisional FDPs were cemented by temporary cement (NETC Non Eugenol temporary cement) on their respective printed master model under 50 N constant pressure from a metal pendulum of loading device for six minutes [27] . After complete setting, the excess cement on each surface was removed with dental explorer . All specimens were stored in distilled water for 24 h at 37 C. All specimens of 4 subgroups (DA, DS, CA, CS) were dried with gauze and the baseline color was measured (T0) with the spectrophotometer (Cary 5000 UV-Vis-NIR spectrophotometer). Measurements were performed on the middle of the facial surface of canine tooth, using adhesive glue pads (Patafix yellow, UHU GmbH & Co. KG, Bühl, Germany) securing the specimen in its well-adapted precise target position. the spectrophotometer was calibrated according to the manufacturer's instructions, by using the calibration supply and during measurements of each specimen. The color was measured in a black room using black and white backgrounds to minimize the influence of external light on the borders of each specimen. The L*, a*, and b* values of each specimen were recorded 3 times and the average was recorded using the CIELAB color space.

Staining solution was prepared by mixing 5 g of coffee powder (Coffee Gold, LuLu CO, Vietnam) with 300ml of boiling water and then filtered using filter paper after 1 min. Four transparent containers were classified and named according to the tested subgroups. Each one filled with the prepared staining solution for receiving tested specimens. After baseline readings were taken, specimens were stored on the solutions for 4 weeks at 37°C **(Figure 2)**. The solutions were changed every 3 days and stirred once a day manually. The pH of the solution was measured during each solution replacement to verify its quality.

Figure (2): Storage of specimens on staining solution.

After aging, all specimens were rinsed with water, brushed with a soft toothbrush, and dried with absorbent paper towels after which the final color assessment was performed.[28] Triple readings were taken for each specimen after staining solution aging using same procedure and under same conditions as previously mentioned for the initial measurements, the color coordinates for all specimens were expressed in CIE L*a*b* values and represented by their means, were obtained, and recorded. The color differences of all specimens between color coordinates before and after staining solution aging were calculated using CIELAB (ΔE-lab) color difference formula: $(\Delta E^*) = [(\Delta L^*)2 + (\Delta a^*)2 + (\Delta b^*)2]\ 1/2$, where: ΔE* is the total color difference, while ΔL*, Δa* and Δb* represent the differences in L* (lightness-darkness), a* (redness-greenness) and b* (yellowness-blueness) coordinates, respectively, before and after staining solution aging

III. OBESERVATIONS FROM THE TESTS

Table (1) shows that there is statistically significant higher mean ΔE among CA than CS followed by CS and the least detected for DS (4.69, 4.13, 2.69 & 2.45, respectively). Post Hoc Tukey test shows within group significant and illustrates statistically significant difference between subgroups.

Table (1) comparison of ΔE between studied groups.

	GROUPS				test of significance
	DA n=10	CA n=10	DS n=10	CS n=10	
ΔE	4.13±0.23	4.69±0.38	2.45±0.13	2.69±0.11	F=209.82 P<0.001*

F: One Way ANOVA test, *statistically significant.

Two-way ANOVA, (Table 2) was used to assess the effect of different impression techniques and different manufacturing technique on the color changes ΔL*, Δa*, Δb*, and ΔE* after aging. It was found that the impression technique had a significant effect on ΔE* value (p = <.001*), Also the manufacturing technique had a significant effect on ΔE* value (p = <.001*). The interaction between the impression technique and manufacturing technique showed significant effect on ΔE* value (p = .040*) and illustrates that 94.1% of ΔE is affected by combined change in main and subgroups. That means the ΔE* value varied significantly depending on both the impression technique and manufacturing technique.

Table (2): Two way ANOVA test for color stability among studied subgroups.

Dependent Variable: ΔE					
Source	Type III Sum of Squares	df	Mean Square	F	P value
Subgroups	33.911	1	33.911	596.956	<.001*
main groups	1.588	1	1.588	27.955	<.001*
Subgroups * main groups combined effect	.258	1	.258	4.535	.040*

Main groups (Impression technique): Digital impression/Conventional impression, Subgroups (Manufacturing technique): Additive manufacturing / Subtractive manufacturing.

IV. DISCUSSION

The recent development of CAD/CAM and 3D printing technology has led to the increased use of related materials, and the proportion of restorations made using materials with tooth shades is increasing. Although provisional restorations are intended for a limited period of use, color stability in these materials is a concern especially in the aesthetic zone, so it is essential to evaluate the color consistency and stability of tooth-colored resin materials based on various environmental changes in the oral cavity. In this study, milled and 3D printed PMMA provisional restorations were immersed in coloring agent for one month to quantitatively assess the degree of discoloration according to the Impression technique and manufacturing technique used. In this study, coffee coloring agent solution was prepared due to its smaller molecular size along with water absorption characteristic of the tested materials. [28]

As a result, it was observed that the provisional restorations made by conventional impression had lower color stability than those made by digital impression and all 3D printed PMMA provisional restorations (Additive manufacturing) had lower color stability than all milled PMMA restorations provisional (Subtractive manufacturing). Therefore, based on data from the present study, all null hypotheses were rejected. the color stability of resin based restorations is influenced by material dependant factors including the degree of conversion, polarity of monomers, amount of cross linking, initiator system, particle size and distribution, water sorption, monomer conversion and pigment stability. [29] Also, material independent factors as discoloration of underlying cement background, Surface smoothness, and thickness of the specimen surface can affect too. In this study, the thickness of provisional restorative material was standardized to 2 mm. [28]

Regarding the DLP technique, a digital micromirror device was used to project a single light-mask image for each layer across the entire print area. It allows the entire layer illuminated by this single light-mask image at once and shortens production time. The characteristics of 3D printed provisional restorations from a DLP printer are further influenced by the depth of polymerization, light projection intensity and the position of the part in the build platform. The ΔE * values indicate the color changes of the interim prostheses after simulated aging. When ΔE * is less than 1, it is considered visually imperceptible. When the ΔE * is between the range of 1 to 3.3, it is considered that the color change is clinically acceptable and can only be detected by skilled individuals. When the ΔE * is larger than 3.3, the color change is considered clinically unacceptable and can be easily observed by laypeople. [30] In the present study, ΔE * values of all provisional restorations were between the clinically acceptable range of 1 to 3.3, except for the DA (4.13±0.23) and CA (4.69±0.38) subgroups.

The low polymerization rate of 3D printed PMMA materials compared to other materials is another causative factor of low color stability. Milled PMMA materials are made by polymerizing in a high-temperature and high-pressure environment. Therefore, the polymerization rates in these materials are high, and their structures are compact. In contrast, although 3D printed PMMA materials undergo post-curing processes after printing, their polymerization rates are relatively low. A low polymerization rate may affect mechanical strength and biological processes as well as increase the possibility of discoloration due to poor surface integrity and affect surface deterioration due to the presence of residual monomers. In addition, water sorption may also affect the discoloration characteristics. (31) **Berli et al**. (32) had indicated that the water sorption of 3D printed resin was generally higher than that of prefabricated PMMA. In our study, the water sorption of 3D printed resin tended to be higher than milled PMMA resin restorations.

Furthermore, the inherent material composition of light-polymerizing resin including initiator, pigment, accelerator, matrix, and inorganic fillers can all affect surface smoothness and polishability of the restorations material. The lack of inorganic filler particles might contribute to the lower surface smoothness of 3D printed resin restorations. (30)In this study, the color stability of the 3D printing resins was lower than that of the CAD/CAM resins., most companies that produce 3D printing resins have patents to protect detailed ingredient combinations. Because it is difficult for general researchers to access such detailed information, a detailed analysis of these elements was not performed in this study. If detailed information is provided in the future, detailed analysis of the color stability of 3D printing resins may be feasible. Furthermore, the 3D printing resins used in this study were manufactured using dedicated 3D printers compatible with the resins. Setting parameters for 3D printing could also affect the surface quality during specimen fabrication.

Rayyan et al. (33) stated that the improvement of marginal fit of dental restorations can affect the color stability. In this study the digital impression subgroups (DA, DS) exhibited rational higher color stability in compare with conventional impression subgroups (CA, CS). Therefore, marginal microleakage from interim restorations was commonly observed after the use of temporary cements. **Almohareb et al.** (28) compared the color stability of computeraided design/computeraided manufacturing (CAD/CAM) fabricated provisional restorations with those of conventional restorations. He reported that the CAD/ CAM provisional material showed better color stability compared to conventional materials.

Measuring specimen color was accomplished by holding the probe tip at 90 degrees to the specimen surface. However, minor angulations of the probe may have caused an edge-loss effect. In this effect, the illuminating beam scatters within the specimen and beyond the edge of the probe tip, especially when measuring a translucent specimen. The edge-loss effect could contribute to inaccurate color measurement. The present study had limitations, including the in vitro conditions for color measurements, the neutral gray background instead of a natural oral environment, the spectrophotometer selected and a geometric specimen instead of a natural tooth, these factors could all amplify or reduce the color differences found. Further studies are recommended to assess the color-matching capabilities of these new AM materials. (34)

V. CONCLUSION

Within the limitations of this study, milled PMMA restorations showed better color stability compared to 3D printed PMMA restorations and is recommended for eshatic provisional restorations.

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