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The effect of Surface Finishing Protocoland ThermocyclingOnthe Surface Roughness of Two CAD/CAM Provisional Restorations.

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Abstract:
Purpose:*This study was designed to examine the effect of the fabrication method (milling versus 3D printing) and surface finishing protocol on the surface roughness of provisional restoration before and after thermocycling.*
Materials and methods: *Poly-methyl-methacrylate (PMMA) blocks for the fabrication of 21 specimens using Computer Aided Design/Computer Aided Milling and 21 specimens were fabricated from MMA liquidusing 3D printing. Each specimen was 2 mm thick and 10 mm in diameter. Then each group was subdivided according to the surface finishing protocol used into:* subgroup 1; unfinished "control", subgroup 2;conventional abrasive polishing, and subgroup 3; Finishingand glazing*(n=7 in each subgroup). Surface roughness was assessed for all specimens with a digital surface profilometer before thermocycling. Then, thesurface roughness measurements were repeated after 5000 thermal cycles. For statistical analysis, a three-way mixed model ANOVA and post hoc Tukey's test were utilized.*
Results: *3D-printed polished specimens showed the highest statistically significant surface roughness values before thermocycling. The surface roughness values measured before thermocycling were higher than thatmeasured after thermocycling in unfinished milled and 3D printed specimens and there was no statistically significant difference. However, within the different surface finishing protocols, both the milled and 3D printed specimens showed significantly higher surface roughness values before thermocycling than after thermocycling.*
Conclusion: *The surface roughness of the CAD-CAM provisional restorations is influenced by the method of manufacturing, finishing protocol, and thermocycling.*
Keywords: *CAD/CAM, Finishing Protocols, Provisional restorations, Surface Roughness, Thermo cycling*

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I. Introduction

To meet the functional and aesthetic demands of the patient while the final restorations are being prepared, provisional restorations are frequently employed in dentistry[1,2]. They shield the prepared teeth from thermal and chemical influences, stop the supporting teeth from shifting, and maintain the stability of occlusal relationships and occlusion[2].

Provisional restorations are made using a variety of acrylic resins, including methacrylate resins (conventional PMMA resin, polyethyl methacrylate (PEMA) resin, and polyvinyl methacrylate (PVMA) resin), bis-resins such as chemically cured bis-acryl composite resin, or urethane dimethacrylates (UDMA) visible light-cured resin[3,4].Traditional provisional restorations have an imperfect, fractured, and porous structure because they were fabricated under non-standardized circumstances [2,5]. As a result, these prostheses exhibit long-term degradation and early discoloring [2,6].

Today, a provisional restorationis frequently fabricated using CAD/CAM technology [7,8].Many manufacturers have developed high-density polymers with significant amounts of crosslinked PMMA resinto mill 3D-designed items out of bulk materials with high precision[9,10]. Due to their prior polymerization, the blocks and discs employed in these systems have a stronger and more uniform structure[6,7]. The CAD/CAM technique has recently been used to fabricate interim restorations using thermoplastic materials. These materials have been employed with fast prototyping, including both liquid-based stereolithography and powder-based 3D printing.They call for specialized tools and are technique-sensitive[10].

During the finishing of the provisional restorations, traditional polishing with abrasives can cause the creation of microcracks and small defects [11].Due to the development of these micro cracks on the material surface, surface roughness can negatively impact the fracture resistance of the provisional restorative materials[12]. However, the application of glazing as the last step in the creation of CAD/CAM restorations has been suggested as a way to reinforce restorative materials, improve their surface qualities, and boost stain resistance [13,14].

Due to its ability to replicate the oral environment, thermocycling is a common technique for artificially accelerating the aging of dental materials [15]. This approach uses repeated cycles of conventional thermal settings with baths between 5 and 55 °C [16].The thermocycling technique may have an impact on the restoration's long-term success because it makes it possible to simulate how a material would behave in a mouth environment[2].

The purpose of this study was to examine whether CAD/CAM provisional materials and surface finishing protocol would affect the surface roughness before and after thermocycling. The null hypothesis was that different CAD/CAM provisional materials with different finishing protocols would not affect the surface roughness of provisional restorations before and after thermocycling.

II. Materials And Methods

Specimens preparation and grouping:

A total of 42-disc-shaped specimens (2 mm in thickness and 10 mm in diameter) were fabricated using *Computer Aided Design/Computer-Aided Manufacture*.Half of the specimens were milled (n=21) and the other half were 3-dimensionally (3D) printed.

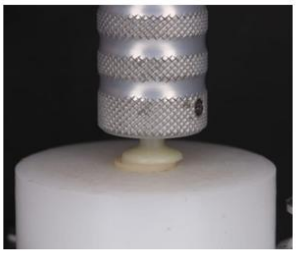
A Polymethylmethacrylate (YAMAHACHI, Aichi, Japan) disc with dimensions of (98.5 mm diameter x 16 mm thickness) was milled by CAD/CAM milling machine (Dentsply Sirona in Lab MC X5, Germany) into cylindrical blocks with 10 mm diameter. Then each cylindrical block was sectioned using an Isomet saw (Isomet saw, Buehler, Lake Bluff, IL, USA), to obtain 21 discs, each of 2 mm thickness and 10 mm diameter. Finally, each specimen's dimensions were verified with a digital caliper

However, for 3D printing,a standard tessellation language (STL) file software (3Shape Cambridge, Copenhagen K Denmark)application was used to produce disc-shaped specimens with dimensions of 10 mm diameter and 2 mm thickness and supporting structures on the lateral side of the disc to enable the removal of specimens after construction was complete[17].Then, the created disc design was uploaded as an STL file to the software (3Shape, Cambridge) atthe 3D printer (EPAX 3D, North Carolina, USA). The liquid resin PMMA from Next Dent C&B in Zetterberg, the Netherlands, was used to create 3D-printed disc specimens. The printer was instructed to begin printing vertically with successive layers that were approximately 50μm thick. The platform was lowered a few microns and the subsequent layer is cured once the first layer has polymerized. An incomplete 3D-printed disc was produced after roughly 30 minutes of this technique being repeated. The 3D-printed discs were then taken out of the printer andcleanedusing an ethanol solution (99.9% isopropyl alcohol, ultra-pure, Sigma-Aldrich, USA).Then they were put in an UV lightbox (Bredent, Bre. Lux power unit 2, Germany) for an additional 30 minutes of post-processing curing. [17,18].Finally, using 4X HD magnifying loupes at a 4X magnification, the created specimens were checked for voids, and any defective specimens were eliminated. After manufacturing, the specimen dimensions of both groups were verified with a digital caliper (ACCUD company., Egypt).

Finishing protocols:

A specifically made Teflon mold was created with an interior diameter of 10 mm and a height of 1 mm to retain the specimens and expose one mm of the resin throughout the finishing procedures. The finishing-polishing process was carried out by the same operator using a dental surveyor and adhering to the manufacturer's instructions to reducevariability and establish standardization.According to the surface finishing methodology, eachgroup was subdivided into 3 subgroups (n=7 in each); subgroup 1; unfinished "control" specimens, subgroup 2;conventional abrasive polishing, and subgroup 3; Finishingand glazing.

For abrasive finishing protocol; the Enhance finishing and polishing kit from Dentsply Caulk in Milford, USA, was used. The specimens of both groups were finished, with the last steps being completed with aluminum oxide discs (figure 1)using a low-speed handpiece running at 5000 rev/min for 30 seconds in a circular motion with light to moderate intermittent pressure. Then polishing was carried out for 15 seconds using a polishing cup (one cup per specimen) and polishing paste (Prisma Gloss, 1μm Fine). Then, 15 seconds of fine polishing using polishing paste (Prisma Gloss, 0.3μm Extra Fine particles) were applied (figure 2). The specimens were cleaned with water for 10 seconds and allowed to air dry for 5 seconds before and after applying the polishing paste [19].



Figure(1): finishing with aluminum oxide disk.

Figure(2): Thepolishing is done using a polishing cup with pastes.

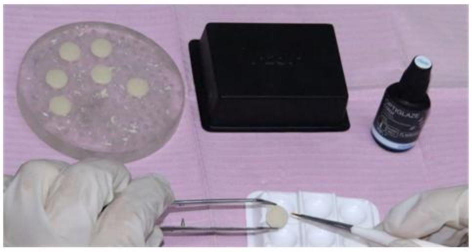


Figure (3):application a thin layer of (Optiglaze).

For finishing and glazing protocol; thefinishing was primarily completed with aluminum oxide discs, as previously described, and then further two clear glaze coatings (Optiglaze, GC tricorporate, Tokyo, Japan) were applied (figure 3). To remove air bubbles, a thin layer of light-polymerizing glaze was applied with a brush in one direction (Figure 8). After 20 seconds of supplication, each layer of Optiglaze sealant coating waslight-polymerized for 90 secondsin a UV box[20].

Thermocycling:
All specimens were thermocycling (Robota thermocycler,Alexandria, Egypt). The specimens were subjected to thermocycling for 5000 cycles between 5 ±2^{o}C and 55 ± 2^{o}C with a dwell time of 30 seconds in each bath and 20sec intervals between baths at ambient air [2].

Surface roughness measurements:
Surface roughness was assessed for all specimens in each subgroup with a digital surface profilometer before and after thermocycling. The average surface roughness (Ra) was measured with a USB digital surface profile gauge profilometer (Elcometer 224/2, Elcometer Instruments, Great Britain), and data were recorded using the computer software (Elcomaster 2, Elcometer Instruments) of the roughness tester supplier. Each surface was read three times, always with the needle scanning the geometric center of the specimen, starting from three different points. The mean value of the three readings yielded the mean value of the roughness of each specimen.

Statistical analysis:
In the form of mean and standard deviation (SD) values, numerical data were given. By examining the data distribution and applying the Shapiro-Wilk test, they were examined for normality. Data had a parametric distribution; therefore, surface roughness analysis was done using a three-way mixed model ANOVA. At P equal to or less than 0.05, the significance level was established. R statistical analysis software for Windows, version 4.1.3, was used to conduct the statistical analysis.

III. Results:

Regarding the effect of fabrication method: 3D printed samples had a significantly higher value than milled samples. (as shown in table1)

Surface roughness (Ra) (mean± SD)		**p-value**
Milled	**3D printed**	
0.2898±0.0026	0.2915±0.0031	**<0.001***

While regarding the effect of the finishing protocol: There was a significant difference between different groups (p<0.001). Thehighest surface roughness value was found in polished samples, followed bycontrol group, while the lowest value was found in glazedsamples (as shown in table 2).

Surface roughness (Ra) (mean±SD)			**p-value**
Control	**Polished**	**Glazed**	
0.2909±0.0028^{A}	0.2913±0.0030^{A}	0.2899±0.0028^{B}	**<0.001***

While the effect of thermocycling demonstrated that: surface roughness values measured before thermocycling was significantly higher than the values measured after it (as shown in table 3).

Surface roughness (Ra) (mean±SD)		**p-value**
Before aging	**After aging**	
0.2919±0.0029	0.2895±0.0024	**<0.001***

The effect of fabrication methods on other variables revealed that:the 3D-printed unfinished and polishedspecimens hadsignificantly higher surface roughness values thanmilled specimens from same subgroups before and after thermocycling. However, the milled and 3D-printedglazed specimens showed non-statistically significant (P>0.05) surface roughness values before and after thermocycling.

Additionally, **the effect of the finishing protocolon the other variablesshowed**:thatin milled specimens before the thermocycling,there was a significant difference between different groups (P<0.001), and the Post hoc pairwise comparisons showed the unfinished control subgrouphad a significantly lower surface roughness value than other group specimens (P<0.001). However, after the thermocycling, there was no significant difference between the different subgroups (P>0.05).Moreover, the effect of the finishing protocol on the 3D printed specimens showed that before and after the thermocyclingthere was a significant difference between different groups (P<0.05), and the Post-hoc pairwise comparisons showed polished group specimens had a significantly higher value than other group specimens (P<0.001) before the thermocycling. However, after the thermocycling, the Post-hoc pairwise comparisons showed unfinished control group specimens had a significantly higher surface roughness value than other subgroups specimens (P<0.001).

The effect of thermocycling on other variables showed that:the surface roughness values measured before thermocycling were higher than the values measured after thermocycling in unfinished milled and 3D printed specimens and there was no statistically significant difference. However, after the different surface finishing protocols, both the milled and 3D printed specimens showed significantly higher surface roughness values before thermocycling than after thermocycling. (Table 3)

Table (2): Mean, Standard deviation (SD) values of interactions of different subgroups.

Fabrication method	Thermocycling	Unfinished (control)	Abrasive polished	Finishing and glazing	P-value
Milled	Before	$0.2894{\pm}0.0014^{B}$	$0.2928{\pm}0.0020^{A}$	$0.2913{\pm}0.0028^{A}$	<0.001*
	After	$0.2884{\pm}0.0019^{A}$	$0.2885{\pm}0.0019^{A}$	$0.2886{\pm}0.0017^{A}$	0.919ns
3D printed	Before	$0.2926{\pm}0.0023^{AB}$	$0.2943{\pm}0.0024^{A}$	$0.2909{\pm}0.0036^{B}$	0.001*
	After	$0.2932{\pm}0.0023^{A}$	$0.2895{\pm}8e\text{-}04^{B}$	$0.2887{\pm}0.0018^{B}$	<0.001*

Different superscript letters indicate a statistically significant difference within the same horizontal row *; significant (p ≤ 0.05) ns; non-significant (p>0.05).

IV. Discussion:

In the current study, the effect of the manufacturing technique and finishing protocol on the surface roughness of CAD-CAM provisional restorative materials were examined before and after thermocycling. The null hypothesis was rejected.

In the current investigation, the interim material's surface roughness was chosen as a test attribute since it was thought to be a risk factor for bacterial accumulation and surface staining[11,21]. A variety of factors, including the production process, the composition of the material, and the degree of polymerization, could have an impact on the provisional materials' surface roughness[2,18]. So, for the present investigation, two distinct CAD/CAM materials with various fabrication techniques (milling and 3D printing)were chosen.

The acrylic resins have historically been polished with water and pumice or with typical resin polishing kits. Recently, resin-based materials have also been treated with surface sealants to get rid of surface flaws and improve wear and stain resistance[21]. Therefore, in the current study, the alteration in the surface roughness was tested after the two different finishing protocols.

Thermocycling regimens are frequently used to simulate hydrothermal aging on the specimens [15]. In this investigation, water and temperature fluctuations between 5 and 55 °C played a role in the aging of CAD/CAM provisional restoration. The use of 5000 thermal cycles between 5 and 55 degrees Celsius is regarded by ISO 11405 as being appropriate to model the short-term aging of dental materials [15]. Also, it was suggested that 10,000 cycles would roughly equal 1 year of in vivo functioning, with 20 to 50 cycles being similar to one day[2,15]. Therefore, the decision was made to keep thermal cycling till 5,000 cycles to evaluate the long-term outcomes of the provisional restorations.

The findings of this investigation showed that the surface roughness values of the tested provisional materials were significantly influenced by the manufacturingtechnique. This study is in agreement with earlier research findings that the manufacturing process can impact the surface roughness of restorative materials[18,22]. In addition, the study's findings demonstrated that CAD/CAM milled specimens demonstrated lower surface roughness values thanthe 3D-printedones. This finding is consistent with recent research by Aldahian et al. 2021 [23] and Al-Qahtani et al. 2021 [22]which found that 3D printed specimens had a higher surface roughness than milled specimens. The 3D-printed specimens' increased surface roughness results may be attributed to the liquid MMA material utilized, the UV light employed as a curing light during polymerization, and the roughness measurement settings[22]. As it was noted that the monomer evaporation caused surface roughness as a result of the printed PMMA's incomplete polymerization[24]. However, the lower surface roughness of the specimens produced with milling in the current study is produced in a highly dense state with negligible shrinkage porosity or free monomers with minimal flaws and small intermolecular distances[20,25].

The highest surface roughness value was found in polished samples, followed by unfinished control group, while the lowest value was found in glazed samples. This may be due to the use of glaze, which can improve the surface properties of temporary materials by filling any micro defects and porosities in 3D printed specimens by capillary action. However, the milled specimens have no porosities with minimal flaws and small intermolecular distances [11,20,25].

Additionally, **the effect of the finishing protocol on the other variables showed**:that in milled specimens before the thermocycling, the unfinished control subgroup had a significantly lower surface roughness value followed by polished then glazed specimens. However, after the thermocycling, there was no significant difference between the different subgroups. This may be due to the microdefects caused by the abrasives used in both techniques. Also, the results can be attributed to the surface topography created by Isomet saw where the surface may be grooved and improperly sealed by the glaze that resulted in higher surface roughness values to the glazed specimens. In relation to unfinished ones before thermocyclying, this needs further investigations by scanning electron microscope.

Furthermore, the results of the present study revealed that the surface roughness of the unfinished specimens was insignificantly decreased after thermocycling. The results of the current investigation is in agreement with those of Atalay et al. 2021 [21], who found no significant changes in the surface roughness values of CAD/CAM restorations subsequent to thermocycling.

However, the results of the present study revealed that the surface roughness of the finished specimens was significantly decreased after thermocycling. This might be explained by the entry of water molecules into the resin, which results in resin expansion and, consequently, a degradation of the polymeric matrix through hydroxylation, which can increase the likelihood of unreacted monomers and surface polymers leaching and result in a reduction in surface roughness values[21,26]

V. Conclusions

3D printed polished specimens had the highest surface roughness before thermocycling. The use of glaze enhanced the surface properties of milled and 3D-printed provisional specimens. Thermocycling greatly decreased the surface roughness values of CAD/CAM provisional specimens finished by the two protocols used in this study.

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