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Surface roughness and color stability of 3D printed temporary crown material in different oral media (*In vitro* study)

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Abstract
Aim: To evaluate the effect of different oral media (artificial saliva, carbonated orange juice and coffee) on the surface roughness and color stability of 3D printed temporary material.
Methodology: twenty one discs samples were designed using additive manufacturing technique (SLA) were divided into 3 groups and stored in artificial saliva, coffee and carbonated orange juice at 37 ℃. Surface roughness was measured before and after immersion using non-contact USB Digital microscope. Color measurements were made before and after immersions using CIE L*a*b*. Data was analyzed by ANOVA followed by Tukey's pair-wise tests.
Results: After two, three and twelve weeks of immersion period there was statistically significant difference between the three tested oral media groups regarding the surface roughness. The highest ΔE values were observed in the coffee (3.58, 4.40 and 10.35 ΔE) followed by Carbonated orange juice mean values (3.29, 3.84 and 7.18 ΔE) while the lowest color changes mean values were for A. Saliva immersed group (1.91, 2.29 and 2.98 ΔE) respectively.
Conclusions:
1. All different oral media (except A.saliva) used in the present study affected the surface roughness and the color stability of Interim discs constructed using 3-D printing technique.
2. Manufacturing of interim crowns using 3-D printing technique could be used for short-term provisional restoration.
3. This study has shown a strong positive correlation between color change and surface roughness of provisional restorative material.

Keywords: 3D technology, Rapid prototyping, Temporary material, Surface rougness, Color stability.

Introduction
The principle of using temporary restorations is to meet requisites such as pulp protection, marginal integrity, wear resistance, esthetics and to reestablish masticatory function for a limited period, until it is possible to insert the definitive dental prosthesis. It is important to select a temporary material with greater color stability and resistance to different pigmenting liquids to which they are subjected, with the purpose of optimizing the esthetics of the restorations made. Even during the time when temporary restorations are being present in the mouth, esthetics is important [1]. Discoloration of temporary materials for fixed prosthodontics ay result in patient dissatisfaction and additional expense for replacement. This is particularly problematic when temporary restorations are subjected to colorants during lengthy treatment. Hence, color stability is a significant criterion in the selection of a particular temporary material for use in esthetically critical area [2].
Three-dimensional (3D) printing is a manufacturing method in which objects are made by fusing or depositing materials such as plastic, metal, ceramics, powders, liquids, or even living cells in layers to produce a 3D object. The 3D printing methods include Stereolithography (SLA), Digital light processing (DLP), Selective Laser Sintering (SLS) and Fused Deposition Modeling (FDM) [3].

Materials and methods

Samples Grouping

A total of 21 samples (seven in each group) were used in the present study:

Group (A): included 7 discs samples immersed in artificial saliva (control group). Group (B): included 7 discs samples immersed in Carbonated Orange juice. Group (C) included 7 discs samples immersed in coffee.

Samples preparation.

Designing of samples (Computer aided designing)

Sample design was carried out using STL file software program to design a disc with a 10 mm diameter and 2 mm thickness**.** Ten supporting structures were placed on the outer surface of the disc**.**

3D printing process

When the design was finished, it was sent to 3Shape Cambridge software as STL file. This software was used for preparing the file for printing and for transferring the information about the printer and the material that was used to modify the STL file accordingly. The 3D- model is modified and distributed in a proper position and angle on the virtual platform. Building support was inserted and adjusted. After choosing the correct build style and calibrating of the stereolithography machine (The layer thickness was about 50 µm and the numbers of layers was 296 with 10 supporting structures. detecting the printing direction of the disc in vertical orientation was performed. Adjusting the printing process parameters also was carried out (Build height: 10 mm, layer count: 296). The STL file was sent to the Rapidshape D30 printer figure (1).

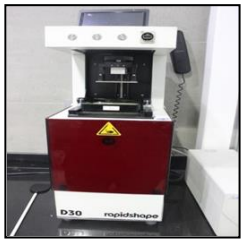

Fig 1: Rapid-shape D30 printer

For construction of 3D printed interim disc samples, the polymer material selected was Next Dent C&B for the provisional crowns. The resin liquid was poured in a special container & then placed in the rapid shape printer**.** The printer was given the order to start printing. The printing cycle has taken about 30 minutes for partial curing of each interim disc. After the completion of the printing process; the 3D printed discs attached to the upper compartment of the printer with 10 supports figure (2) were removed from the printer to start the post processing curing.

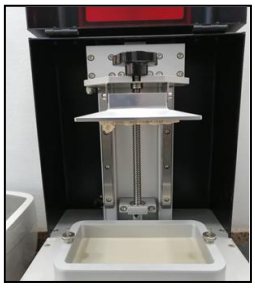

Fig 2: 3D printed discs attached to upper compartment of the 3D printer with 10 supports

Post processing

It is an important step where the final object was carried out to complete the polymerization process. Each printer has post-processing recommendations provided by the manufacturer. The LC-3DPrint Box is an Ultraviolet light box suitable for post curing 3D printing resin materials

Twelve ultraviolet light bulbs are presented inside the box to ensure that a product is illuminated from all sides, which results in a quick and uniform curing cycle. Post-curing is an UV light treatment to ensure that NextDent materials obtain full polymer conversion, through this the residual monomer is reduced to a minimum and the highest mechanical properties are obtained. The post curing cycle last for 30 minutes.

After fabrication of the temporary discs, all supporting structures of the final end product of 3D printed provisional discs were removed with Jota Arkansas stone 649 then samples were finished and polished with soft-lex disks according to Alharbi *et al.* [4] to get perfect smooth surface. Ethanol solution was used for cleaning and disinfection of the restoration.

The final thickness was measured using a digital caliper Digimatric at different points to assure all discs are 2mm in thickness with an accuracy of ±0.01 mm figure (3)

Fig 3: Disc measurements after polishing using a digital caliper

Intervention for each group Preparation of different oral media

Artificial Saliva prepared at (faculty of pharmacy, Cairo University, Egypt) and was used as the 1st immersion medium.

Carbonated orange juice (Mirinda) ready-made was used.

To prepare the coffee solution 3.6 g of coffee (Nescafe Classic, Nestle Egypt) was poured into 300 ml of boiled distilled water. The solution was stirred and then filtered through a filter paper.

After preparation of the different oral media, the pH of the solutions were measured using a pH meter 3 times and determined to (7.5, 2.9, 5.4) for the artificial saliva, Carbonated Orange juice and coffee respectively.

Each samples group was placed in a tightly sealed container for storage in the immersion media and stored in an incubator at 37ºC to stimulate the temperature in the oral cavity and prevent any alteration. The solutions were freshened daily to avoid yeast or bacterial contamination. To reduce the precipitation of particles in the staining solutions, the solutions were stirred twice a day. By the end of the immersion period, specimens were rinsed with distilled water and wiped with gauze.

All samples were immersed for three time interval 12 hours, 18 hours and 72 hours which is equivalent to 2 weeks, 3 weeks and 12 weeks respectively of consumption of beverages according to the protocol followed by Guler *et al.* [5], the average consumption time for one cup of coffee is 15

minutes (according to the manufacturer of the coffee), and among coffee drinkers the average consumption quantity is 3.2 cups per day.

Baseline Color Assessment

The specimens' color was measured using a Reflective spectrophotometer**.** The aperture size was set to 4 mm and the specimens were positioned in the center of the measuring port. A white background (CIE L*= 88.81, a*= -4.98, b*= 6.09) was selected and measurements were made according to the CIE L*a*b* color space relative to the Commission Internationale de l'Eclairage (CIE) standard illuminant D65, where L* refers to the degree of lightness (0-100), a* to the color on the red/green axis and b* to the color yellow/blue axis. The spectrophotometer was calibrated before each measurement. Three measurements were taken for each specimen and the average was recorded.

Color Change (ΔE) Assessment

Specimens' color was assessed after the different staining protocols as described for baseline measurements. In accordance to Cevik *et al.* [6] Color change (ΔE) of each specimen was calculated using the following formula:

$$\Delta E = [(L^* \text{ after staining} - L^* \text{ baseline})^2 + (a^* \text{ after staining} - a^* \text{ baseline})^2 + (b^* \text{ after staining} - b^* \text{ baseline})^2]^{1/2}$$

Roughness testing

The optical methods tend to fulfill the need for quantitative characterization of surface topography without contact. Specimens were photographed using USB Digital microscope with a built-in camera connected with an IBM compatible personal computer using a fixed magnification of 120X.The images were recorded with a resolution of 1280 × 1024 pixels per image. Digital microscope images were cropped to 350 x 400 pixels using Microsoft office picture manager to specify/standardize area of roughness measurement. The cropped images were analyzed using WSxM software. Within the WSxM software, all limits, sizes, frames and measured parameters are expressed in pixels. Therefore, system calibration was done to convert the pixels into absolute real world units. Calibration was made by comparing an object of known size (a ruler in this study) with a scale generated by the software.

Subsequently, a 3D image of the surface profile of the specimens was created. Five 3D images were collected for each specimen, in the central area and in the sides at area of 10 µm × 10 µm. This area was chosen on the basis of the dimension of the typical bacteria expected to adhere to restoration surface in vivo.

WSxM software was used to calculate average of heights (Ra) expressed in µm, which can be assumed as a reliable indices of surface roughness

Results

Results of surface roughness measured at different time intervals in the three tested groups.

In saliva group, the mean values of roughness measured at baseline, after 2, 3 and 12 weeks were 0.215µm ± 0.001, 0.223µm ± 0.004, 0.225µm ± 0.005 and 0.231µm ± 0.003, respectively. There was a statistical significant difference between the four phases (F= 41.021; p= 0.001), Where the mean value of roughness measured after 2, 3 and 12 weeks were significantly increased when compared with its corresponding value measured at baseline (p= 0.028, 0.015 and 0.001, respectively).

On the other hand, there was no statistical significant difference between 2 and 3 weeks (p= 0.282) while the roughness was significantly increased in 12 weeks when compared to its corresponding values measured at both two weeks (p= 0.001) and three weeks (p= 0.049) table (1), Figure (4).

Table 1: Statistical analysis of surface roughness of artificial saliva immersed group measured at different immersion times.

	Baseline	Two weeks	Three weeks	Twelve weeks	F test	p value
Mean ± SD	0.215 ± 0.001	0.223 ± 0.004	0.225 ± 0.005	0.231 ± 0.003	41.021	0.001 (S)
P value vs baseline	---	0.028 (S)	0.015 (S)	0.001 (S)		
P value vs 2 weeks	---	---	0.282 (NS)	0.001 (S)		
P value vs 3 weeks	---	---	---	0.049 (S)		

S= p≤ 0.05= significant.
NS= *p*> 0.05= not significant.

In Carbonated orange juice group, the mean values of roughness measured at baseline, after 2, 3 and 12 weeks were 0.215µm ± 0.001, 0.267µm ± 0.011, 0.325µm ± 0.012 and 0.395µm ± 0.012, respectively. There was a statistical significant difference between the four phases (F= 343.888; p= 0.001), Where the mean value of roughness measured after 2, 3 and 12 weeks were significantly increased when compared with its corresponding value measured at baseline (p= 0.001, 0.001 and 0.001, respectively).

Also, the roughness mean value was significantly increased in both 3 and 12 weeks when compared to its corresponding values measured at two weeks (p=
0.002 and 0.001, respectively). The roughness mean value was significantly increased in 12 weeks when compared to its corresponding values measured at 3 weeks (p= 0.001) (table (2), Figure (4).

Table 2: Statistical analysis of surface roughness of carbonated orange juice immersed group measured at different times.

	Baseline	Two weeks	Three weeks	Twelve weeks	F test	p value
Mean ± SD	0.215 ± 0.001	0.267 ± 0.011	0.325 ± 0.012	0.395 ± 0.012	343.888	0.001 (S)
P value vs baseline	---	0.001 (S)	0.001 (S)	0.001 (S)		
P value vs 2 weeks	---	---	0.002 (S)	0.001 (S)		
P value vs 3 weeks	---	---	---	0.001 (S)		

S= p≤ 0.05= significant.
NS= *p*> 0.05= not significant.

In coffee group, the mean values of roughness measured at baseline, after 2, 3 and 12 weeks were 0.215µm ± 0.001, 0.239µm ± 0.013, 0.282µm ± 0.011 and 0.327µm ± 0.014, respectively. There was a statistical significant difference between the four phases (F= 124.370; p= 0.001), Where the mean value of roughness measured after 2, 3 and 12 weeks were significantly increased when compared with its corresponding value measured at baseline (p= 0.023, 0.001 and 0.001, respectively).

Also, the roughness mean value was significantly increased in both 3 and 12 weeks when compared to its corresponding values measured at two weeks (p= 0.012 and 0.001, respectively). The roughness mean value was significantly increased in 12 weeks when compared to its corresponding values measured at 3 weeks (p= 0.002) table (3), Figure (4).

Table 3: Statistical analysis of surface roughness of coffee immersed group measured at different times.

	Baseline	Two weeks	Three weeks	Twelve weeks	F test	p value
Mean ± SD	0.215 ± 0.001	0.239 ± 0.013	0.282 ± 0.011	0.327 ± 0.014	124.370	0.001 (S)
P value vs baseline	---	0.023 (S)	0.001 (S)	0.001 (S)		
P value vs 2 weeks	---	---	0.012 (S)	0.001 (S)		
P value vs 3 weeks	---	---	---	0.005 (S)		

S= p≤ 0.05= significant.

The surface roughness values between all samples at four time intervals of the three tested groups as shown in figure (4)

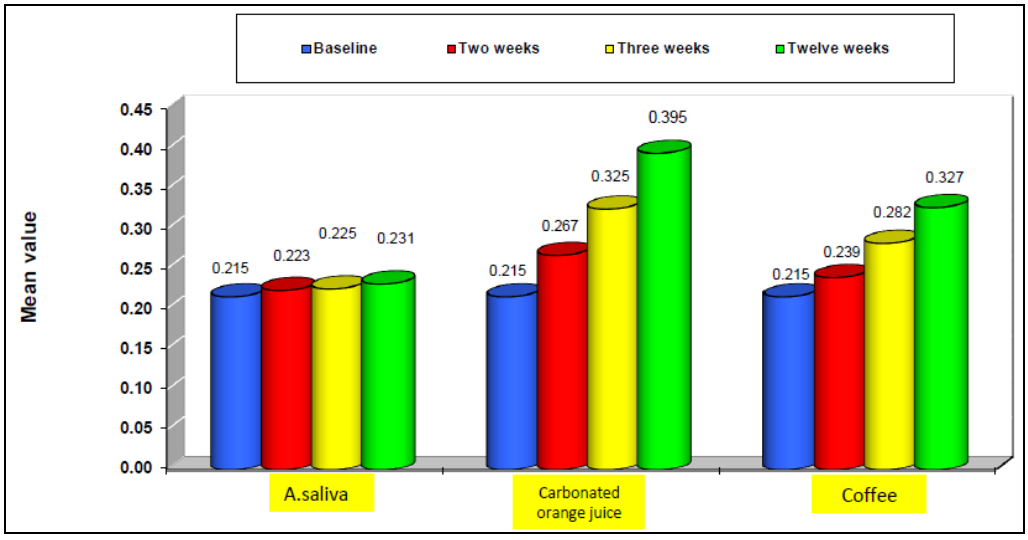

Fig 4: Mean values of roughness measured at different times of measurements in the three studied groups.

Results of color change measured at different time intervals in the three tested groups.

In saliva group, the mean values of change in color measured after 2, 3 and 12 weeks were 1.91 ± 0.341, 2.29 ± 0.502 and 2.98 ± 0.246, respectively. There was a statistical significant difference between the three phases (F= 15.219; p= 0.001), Where there was no significant difference in the mean value of change in teeth colour between 2 weeks and 3 weeks (p= 0.074). In contrary, the change was significantly increased after 12 weeks when compared to 2 weeks (p= 0.002). Again, no significant difference between 3 weeks and 12 weeks (p= 0.120) table (4) figure (5).

Table 4: Statistical analysis of change in color in (saliva) group measured after 2, 3 and 12 weeks.

	Two weeks	Three weeks	Twelve weeks	F value	p value
Mean ± SD	1.91 ± 0.341	2.29 ± 0.502	2.98 ± 0.246	15.219	0.001 (S)
P value vs 2 wks	---	0.074 (NS)	0.002 (S)		
P value vs 3 wks	---	---	0.120 (NS)		

S= p≤ 0.05= significant.
NS= *p*> 0.05= not significant.

In Carbonated orange juice group, the mean values of change in color measured after 2, 3 and 12 weeks were 3.29 ± 0.294, 3.84 ± 0.274 and 7.18 ± 0.436, respectively. There was a statistical significant difference between the three phases (F= 323.265; p= 0.001), Where there was a significant increase in the mean value of change in teeth colour after 3 weeks (p=0.001) and 12 weeks (p= 0.001) when compared with its corresponding value after 2 weeks. Also, the change was significantly increased after 12 weeks when compared to 3 weeks (p= 0.001) table (5) figure (5).

Table 5: Statistical analysis of change in color in carbonated orange juice group measured after 2, 3 and 12 weeks.

	Two weeks	Three weeks	Twelve weeks	F value	p value
Mean ± SD	3.29 ± 0.294	3.84 ± 0.274	7.18 ± 0.436	323.265	0.001 (S)
P value vs 2 wks	---	0.001 (S)	0.001 (S)		
P value vs 3 wks	---	---	0.001 (S)		

S= p≤ 0.05= significant.

In coffee group, the mean values of change in color measured after 2, 3 and 12 weeks were 3.58 ± 0.393, 4.40 ± 0.740 and 10.35 ± 0.690, respectively. There was a statistical significant difference between the three phases (F= 234.852; p= 0.001), Where there was no significant difference in the mean value of change in teeth color between 2 weeks and 3 weeks (p= 0.091). In contrary, the change was significantly increased after 12 weeks when compared to both 2 weeks (p= 0.001) and 3 weeks (p= 0.001) table (6) figure (5).

Table 6: Statistical analysis of change in color in coffee group measured after 2, 3 and 12 weeks.

	Two weeks	Three weeks	Twelve weeks	F value	p value
Mean ± SD	3.58 ± 0.393	4.40 ± 0.740	10.35 ± 0.690		
P value vs 2 wks	---	0.091 (NS)	0.001 (S)	234.852	0.001 (S)
P value vs 3 wks	---	---	0.001 (S)		

S= p≤ 0.05= significant.
NS= *p*> 0.05= not significant.

The color change values between all samples at three time intervals of the three tested groups as shown in figure (5)

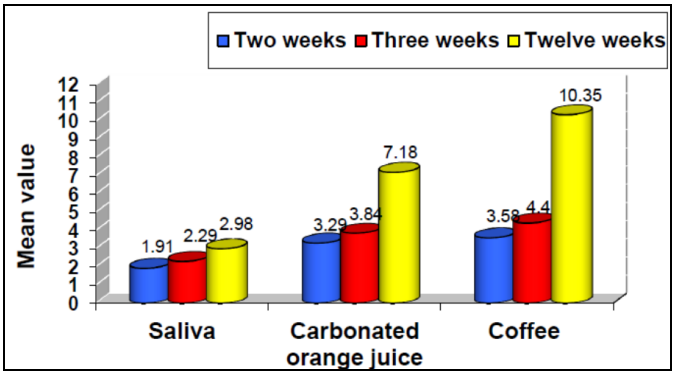

Fig 5: Comparison between values of change in color in the three tested groups measured after 2, 3 and 12 weeks.

Correlation between the effect of roughness (Ra) on color change (ΔE)

There was a statistically significant positive (direct) correlation between surface roughness and color change. An increase in surface roughness is associated with an increase in color change and vice versa as revealed by Pearson correlation (r=0.4548, r2=0.2068, *p*>0.05). This correlation is presented numerically in table (7) and graphically in figure (6).

Table 7: Correlation between the effects of roughness on color change

Parameter	Correlation coefficient (r)	(r2)
Color change	0.4548	0.2068
Roughness		

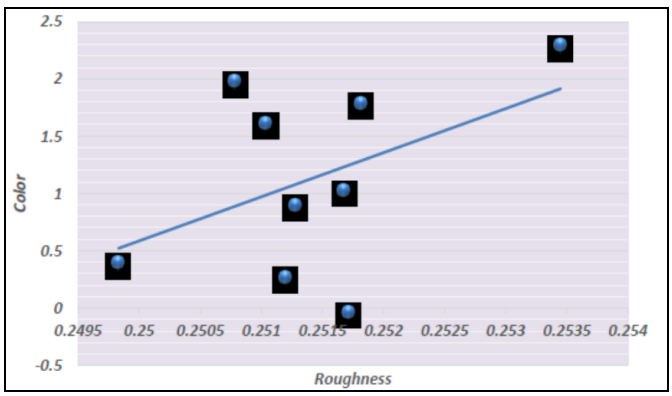

Fig 6: A linear chart of correlation between total color change and roughness 4.

Discussion

Color stability is an important criterion when selecting an interim crown material. Color alteration is multifactorial and generally related to incomplete polymerization, water sorption, oral hygiene, and the surface smoothness of the restoration. Pigmented beverages such as coffee and tea also promote discoloration7.The degree of color change can be influenced by a number of factors like chemical reactivity, diet, colorants, oral hygiene and surface smoothness of the restoration. The type of immersion solution and the amount of time the materials are exposed to the staining solution can also affect the degree of color change and surface topography [8]**.** Therefore, the current in vitro study was carried out to evaluate the effect of different oral media on the surface roughness and color stability of 3D printed temporary material.

Recently, the three dimensional (3D) printing have been widely used in fabricating provisional restoration. It has many advantages over subtractive milling technique as it's an additive technique, where the material was deposited layer by layer so less material was wasted and therefore, decreasing expenses. It is called rapid prototyping as it is a faster manufacturing technique. Furthermore, cracks introduced due to milling were eliminated so mechanical properties were improved [9].

The additive manufacturing technology "Sterolithography" technique was selected in this study due to its high resolution and rapid prototyping. It was also used due to its accuracy compared to other additive manufacturing technologies with the ability to print complex structures with fine details. It can achieve a restoration of 5mm in x\y axis and 10 mm in z axis. The liquid resin used in the study was Nextdent C&B which is a biocompatible material that can

be used intra-orally without fear from toxicity of acrylic material. Li *et al.* [10] used sterolithography technique to print provisional restoration using photo-curable dental resin.

For purpose of standardization in the present study, maximum facial or occlusal thickness of provisional crown approximately 2mm so the thickness of the discs used in this study were 2mm, which is recommended by several studies [6, 7]. Meanwhile the diameter of the discs used in this study were 10 mm to provide adequate area for color measurement by spectrophotometer according to the dimension of the window (measuring area).

In the present study finishing of the samples were carried out with soft-lex disks to remove possible residues left on the surface in accordance to Alharbi *et al.* [4] and Mickeviciute *et al.* [11].

Artificial saliva was chosen in the present study instead of human whole saliva in order to minimize the influence of inter individual variations in salivary protein content and composition and was accurately prepared according to Wongkhantee *et al.* [12].

The selected immersion media were of the commonly consumed beverages such as carbonated orange juice orange due to its low pH value as in accordance with Hamouda [13] while coffee was used because of its high staining potential [14, 15].

All samples were immersed for 12 hours, 18 hours and 72 hours and it is equivalent to 2 weeks 3 weeks and 12 weeks respectively of consumption of beverages according to the protocol followed by Guler *et al.* [5], the average consumption time for one cup of coffee is 15 minutes (according to the manufacturer of the coffee), and among coffee drinkers the average consumption quantity is 3.2 cups per day. All tightly sealed containers were stored in an incubator at 37°C to stimulate the temperature in the oral cavity and prevent any alteration. After preparation of the different oral media, the pH of the solutions were measured using a PH meter.

Throughout this study, the null hypothesis were rejected as both surface roughness and color stability of the 3-D printed provisional restoration material (NextDent) were significantly affected by different oral media as artificial saliva, coffee and Carbonated orange juice beverages.

In the present study, the change in the surface roughness was tested as it has been reported that, the surface roughness may affect esthetic by changing the texture of esthetic restoration, increasing scattering of incident light and consequently affecting the color stability. Contact and non-contact methods are currently used for surface roughness measurement. One of the disadvantages of contact method using profilometer is that the stylus may damage or alter the surfaces tested **[16].** Therefore, non-contact USB digital microscope with a built in camera were used in the present study.

Color changes can be assessed by visual and instrumental mechanisms. Instrumental techniques eliminate the subjective interpretation of visual color comparison. Many devices are used for color measurements. Such as the digital devices, the colorimeters and spectrophotometer. Moreover, spectrophotometer shown to be more accurate when compared with the colorimeter. Thus, even slight color changes in dental materials can be detected using Spectrophotometers [17]. Therefore, spectrophotometer was used in the present study.

With regard to the effect of immersion media on the surface roughness of the tested materials, results of the present study demonstrated a statistically significant increase in surface roughness of the tested samples after immersion in different oral media.

The Ra value of disc samples immersed in different oral media revealed increased surface roughness this may be due to hydrolytic degradation of the resin surface in aqueous environment and deterioration of its surface by the acidity of the selected beverages. This finding was in agreement with Lussi *et al.* [18] who reported that, the erosive activity of citric and other acids as ingredients of beverages. Moreover liberman *et al.* [19], found that, an aqueous environment can interfere with the characteristics of the resin and even lead to hydrolytic degradation over time. Results of the current study are also consistent with the findings of Fay *et al.* [20] and Hamouda [13] they reported that increased consumption of low PH beverage, caused deterioration of the resin materials.

In contrast to the present results, other studies reported decrease in surface roughness after immersion in beverages, one of them was for Sores *et al.* [16] stated that the decrease in the surface roughness of the material and attributed this to the long period of immersion, and also Baretto *et al.* [21] reported that the decrease in surface roughness was claimed to the brushing of the samples which decrease the surface roughness by removing the stains and the peaks and valleys of the material itself which make it smoother.

Depending on the composition of the interim material and the type and degree of polymerization, staining may vary. The chemical properties of materials such as the size and distribution of the polymethylmethacrylate particles, stability of pigments, polarity of monomers, effectiveness of the initiator system, filler content, and cross-linking amount are important factors in the degree of polymerization, water sorption, and color stability [22]. Furthermore, Rutkunas *et al.* [23] who concluded that color stability was significantly influenced by the material type and staining of dental materials is the result of both extrinsic (surface roughness and material wear) and intrinsic factors (filler, monomer composition and polymerization degree), it was found it is vulnerable to test this new material with 3 D printing construction technique to elucidate its color stability under different coloring beverages.

Regarding the effect of different oral media on the color change of the tested material. Results of the current study after 2 weeks revealed there is statistically significant difference in color change (ΔE) with different oral media but was clinically acceptable and this may be related to the short period of immersion of the samples in all media in which surface roughness doesn't increase to the level that affect deposition of coloring agent that alter the color stability 11.

Furthermore, the results of the current study was in accordance with those of Bitencourt *et al.* [24] who found that artificial saliva showed the statistically significantly lowest mean $\Delta E \leq 2$ and this may be due to that saliva does not contain colorant particles.

As regard to the effect of carbonated orange juice on the results of color change, although the carbonated orange juice which reported the lowest PH value (2.9) and provided the highest roughness values compared with coffee and artificial saliva, carbonated orange juice did not produce the highest color change values compared to other tested groups. This was in accordance with Alghamdi *et al.* [8] who stated that despite of the low PH of Carbonated orange juice and increasing the surface roughness of the temporary material it doesn't contain coloring agent enough to deposit on the material which affect the color stability.

After period of 3 weeks of immersion there was statistically significant increase in color change in the tested samples of carbonated orange juice and coffee groups. Disc samples immersed in coffee recorded the highest ΔE (4.4) followed by Carbonated orange juice (3.8) and artificial saliva (2.2).

After period of 12 weeks of immersion there was statistically significant increase in color change in the tested samples of carbonated orange juice and coffee groups. Disc samples immersed in coffee recorded the highest ΔE (10.3) followed by Carbonated orange juice (7.1) and artificial saliva (2.9).

In the current study artificial saliva showed slight increase in color change ΔE (2.2) this may be due to that the immersion of resin in saliva for a prolonged period may irreversibly affect their color. Also, resins can absorb water at a higher rate because of a high diffusion coefficient25.These properties may explain the cause of the color changes observed with the resin based material. But this was not in agreement with

Cevik *et al.* [6], Alghamdi *et al.* [8] and Bitencourt *et al.* [24] who found that artificial saliva showed the statistically significantly lowest mean $\Delta E \leq 2$ and this may be due to that water does not contain colorant particles.

In the present study coffee was found to cause the highest discoloration effect. The reason for this may be that coffee is possible absorbable solution which also has different chemical and physical properties behind it. Discoloration with coffee may have occurred through the absorption and adsorption of polar colorants into/onto the organic phase of resin materials. Furthermore, yellow colorants of coffee are much more than the other solution types and this in agreement with Mickeviciute *et al.* [11] and ERGUN *et al.* [14] who found that highest color change observed in coffee group.

In the current study, carbonated orange juice did not produce as much discoloration as coffee, although it is assumed that carbonated orange juice is degradable due to its low PH. It could be defined as due to its lack of yellow colorant and high acid rate, carbonated orange juice did not exhibit more color change than coffee group. These results is in agreement with Bitencourt *et al.* [24] and guler *et al.* [5] who found that color change in group of cola was significant higher than the color change in group of artificial saliva, time was found to be a critical factor for color stability of provisional restorative materials.

As immersion time increases, color changes became more intense. This could be because of the increased interaction between the chemicals and the resin as well as better penetration of staining substances into the resin26. In addition, it was clear that there is a correlation between the surface roughness and the color stability. The rougher surface indicates that it stains more rapidly than smooth surface because of the presence of surface topographical irregularities, which retains the colorants and plaque8.

Clinical perceptibility of color differences has been the subject of numerous investigations [23, 16]. In this study all tested groups showed significant color change within the clinical acceptability which is ($\Delta E = 3.7$) except for the carbonated orange juice and coffee after 3 weeks, dictating limiting the use of 3D printed PMMA provisional restoration material up to 3 weeks only. Although the protocol of this study proposing the extending of the immersion time up to 12 days which is equivalent to one year based on other material properties and manufacturer's recommendation, it was found unrealistic to extend the study to such a period due to unacceptable color change resulted after 3 weeks for the two tested beverages.

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