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Evaluation of Water Absorption and Solubility of Digitally and Conventionally Produced Temporary Fixed Materials

SUMMARY

Background/Aim: *The study aims to evaluate water sorption and solubility of conventional and digitally produced temporary fixed materials.* ***Material and Methods***: *A total of 40 disc-shaped specimens were prepared from two conventionally produced temporary fixed materials: bis-acrylic composite resin (Protemp 4-PT) and acrylic resin (Dentalon plus-DP) and two digitally produced [3D printing (MACK4D Temp-MT) and CAD/CAM milling (On Dent-OD)]. The prepared disks were dried in a desiccator until they reached a constant mass. They were then kept in distilled water at 37°C for 1 week and weighed. The weights of the specimens, which were again subjected to conditions similar the initial drying procedure, were measured. Water absorption and solubility values were calculated by formula. The data obtained were analyzed using 1-way analysis of variance (ANOVA) and the Tamhane or Tukey post hoc test (α=.05).* ***Results:*** *Water absorption values of the PT group (24.16±8.1 μg/mm^3) were statistically higher than all other groups (p= 0.001). However, there was no significant difference in the pairwise comparisons of OD, MT, and DP groups (p>0.05). When the water solubility values were analyzed, DP group (0.49±2.01 μg/mm^3) showed no significant difference with the PT group (1.69±2.2 μg/mm^3) (p=0.402), while they were higher than OD (-3.96±0.84 μg/mm^3) and MT (-10.29±1.37 μg/mm^3) groups. In addition, a significant difference was observed in the water solubility values of CAD/CAM-3D groups (p<0.05).* ***Conclusions:*** *All of test groups were found to be within the values recommended by ISO standards. It can be inferred that the PT material may cause the most staining.*

Keywords: Temporary Fixed Prostheses, Water Sorption, Solubility, CAD/CAM, 3D Printing

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Introduction

Temporary crown which a well-made is essential to obtain a high-quality definitive prosthesis[1]. The use of temporary crown and bridge restorations in prosthodontic treatment accomplishes many goals, such as function restoration, preservation of the teeth and periodontal tissues, occlusion stabilization, and diagnostic assessment before definitive restoration fabrication[2].

Currently, there are two categories for custom temporary materials: monomethacrylates, which include polymethylmethacrylate (PMMA), polyethylene/butyl methacrylate (PEMA), and other methacrylate resins or a combination thereof, acrylic resins and dimethacrylates or bis-acryl composite resins [bisphenol A-glycidyl dimethacrylate (Bis-GMA) and urethane dimethacrylate (UDMA, visible light polymerized resins)][3]. Conventional methods and materials such as PMMA and bis-acryl resins are still routinely used in the construction of temporary prostheses[4]. The most widely used substance for creating interim restorations is conventional acrylic resin because of its low cost, ease of manipulation, strong mechanical qualities, and aesthetic appearance[5]. However, polymerization shrinkage, exothermic polymerization reaction, and monomer release are important negative properties of PMMA material. Bis-acryl-containing materials, on the other hand, exhibit lower polymerization shrinkage and less exothermic reaction[4].

The area of prosthodontics has experienced a revolution in patient treatment approaches with the arrival of digital technology, specifically computer-aided design/computer-aided manufacture (CAD/CAM)[1]. Prefabricated polymethyl methacrylate (PMMA), which is pre-polymerized under high pressure and temperature environment and is utilized in milling equipment, demonstrated good physical attributes like material density and strength. However, there is a substantial material and milling burr consumption because the prosthesis is constructed in a subtractive method[6]. The goal of additive manufacturing, also known as three-dimensional (3D) printing, is to create the required prosthesis by layering on small pieces of material. Because the 3D printing process utilizes less raw material and requires less manufacturing time, it can be an affordable choice for creating temporary crowns[1].

In cases involving full occlusal rehabilitation or oral implantation therapy, where the restorations may be subjected to prolonged functional stress, long-term interim restorations are required[7]. To prevent failures under sustained functional loads, temporary restorative materials should have high physical (such as color stability, water sorption, and solubility) and mechanical qualities[1]. Acrylic resins with high solubility might cause more unreacted monomers to be present, which can harm oral tissues; nevertheless, acrylic resins that absorb water can also compromise dimensional stability and lead to prosthesis failure[8]. Therefore, minimum water sorption and solubility are necessary for a material to be successful[9].

The purpose of this study was to assess water sorption and solubility of conventional and digitally produced temporary fixed materials. The null hypothesis of this study was that the water sorption and solubility of temporarily fixed materials produced by different methods would not differ from each other.

Material and Methods

Four different temporary fixed prosthetic materials were used in this study, two produced by the conventional method and two produced by the digital method. Material properties are summarized in Table 1.

Table 1 Materials and production methods used in the study

Trade name	Material type	Group abbreviations	Material composition	Manufacturer	Specimens' production methods
Dentalon plus	PMMA resin based	DP	Methacrylate, copolymer, peroxide, initiator, pigment	Heraeus Kulzer, Gmbh, Wehrheim, Germany	Conventional
Protemp 4	Bis-acryl resin based	PT	Ethanol,2,2'-[(1-methylethylidene) bis(4,1-phenyleneoxy)] bis-, diacetate, benzyl-phenyl-barbituric acid, silane treated silica, tert-butyl peroxy-3,5,5-trimethylhexanoate	3M ESPE, Seefeld, Germany	Conventional
Tempo CAD	Pre-polymerized PMMA resin	OD	PMMA, pigments	On Dent, Izmir, Turkey	CAD/CAM milling
MACK4D Temp	Acrylate ester resin- based	MT	UDMA, TEGDMA	GmbH, Neukiritzsch, Germany	3D printing

(CAD/CAM: computer-aided design/computer-aided manufacturing, 3D: Three-dimensional, PMMA: Polymethylmethacrylate, UDMA: Urethane dimethacrylate, TEGDMA: Triethylene glycol dimethacrylate

For the conventional method, Dentalon plus and Protemp 4 materials were mixed in accordance with the manufacturer's guidelines. Group DP and PT specimens were then obtained using Teflon molds.

For the digital method, test specimens of the specified size were prepared in the CAM software program (15 mm diameter and 1 mm thickness) and then converted to STL format. For the CAD/CAM milling method, pre-polymerized Tempo CAD blocks were milled on the milling device (CORiTEC 250i, imes-icore GmbH, Eiterfeld, Germany) according to the STL data. For the 3D printing method, the STL data were sent to the DLP printer (Anycubic Photon Ultra, Texas Instruments, USA) and the test specimens were printed from MACK4D Temp resin. The post-processing of the specimens obtained with the 3D printer was completed by the manufacturer's directives.

To ensure the standardization of the surfaces of a total of 40 specimens, all specimens obtained were sanded at 600, 800, and 1000 grits. After that, the specimens were arranged parallel and apart on a platform within a desiccator that contained fresh silica gel that had been dried for 300 minutes at 130°C. The oven was then set to 37°C for 23 h. After 60 min at 23°C the desiccator in the oven, the specimen was weighed using a digital precision balance. (Ohaus Corporation, Pine Brook, NJ). Except for handling specimens and exchanging dry silica gel, the desiccator was maintained closed. Following the specimens' weighting, the desiccator's silica gel was replaced, and the platform that had supported the supports was reinserted into the desiccator before it was transported back to the oven. This process was carried out daily until specimens with a consistent mass (M1) were acquired, which is to say that each specimen was deemed dry if its mass loss between successive weighing did not exceed 0.1 mg.

The water absorption assay was evaluated using the immersion technique. For a week, the specimens were submerged in distilled water at 37°C. (The International Organization for Standardization-ISO 10477:2020)[10]. The specimens were taken out of the water after, dried off on a paper towel, shaken in the air for fifteen seconds, and then weighed sixty seconds later to get the M2 value. The weight increase from the new specimen to the immersed specimen was used as the water absorption rate. The weight measurements of the specimens that were subjected to the initial conditions again were renewed. Similar to the drying and soaking in distilled water technique described for M1, the specimens were reconditioned at constant mass in a desiccator. This conditioned mass value of the specimen was recorded as M3.

The following formula was used to determine the values obtained for water absorption and solubility.

Water Absorption: M2–M3/V

Water Solubility Test: M1 –M3/V

M1: Dry weight (μg)

M2: First measurement weight after soaking (μg)

M3: Second measurement weight after dry (μg)

V: Volume of the specimen (mm^3) ($V=\pi r^2 h$)

The statistical analysis was carried out utilizing the IBM SPSS 22 package. The Kolmogorov-Smirnov and Shapiro-Wilk tests were utilized to determine whether the data conformed to a normal distribution. Since the water absorption and water solubility values showed normal distribution (p>0.05), one-way ANOVA was performed in independent groups to determine whether there was a significant difference between the test materials. Levene's test was used to assess whether the variances were homogeneous. The Tamhane test was employed as a post hoc test because the variances in the water absorption values were not homogeneous, and the Tukey test was employed because the variances in the water solubility values were homogeneous.

Results

A statistical comparison of water absorption and water solubility values of the test specimens between the groups is presented in Table 2.

Table 2 Statistical comparison of water sorption and water solubility values of the test specimens between the groups

Test materials	Water sorption ($\mu g/mm^3$)	Water Solubility ($\mu g/mm^3$)
DP	8.02 ± 0.67^a	$0.49\pm2.01^{A,B}$
PT	$24.16\pm8.1^{a,b,c}$	$1.69\pm2.2^{C,D}$
OD	8.09 ± 0.93^b	$-3.96\pm0.84^{A,C,E}$
MT	8.10 ± 0.96^c	$-10.29\pm1.37^{B,D,E}$
p	0.001	0.000

The same uppercase and lowercase letters in the same column indicate a significant difference between the test materials.
(DP: Dentalon plus, PT: Protemp 4, OD: Tempo CAD, MT: MACK4D Temp)

Water absorption values between the groups are ranked as PT >MT >OD >DP. Water absorption values of the PT group (24.16±8.1 $\mu g/mm^3$) were statistically higher than all other groups (p= 0.001). However, when comparing the other groups statistically, there was no significant difference (p>0.05).

The PT group had the highest value found when the water solubility data were investigated (1.69±2.2 $\mu g/mm^3$). In the pairwise comparison between groups, a significant difference was found between all groups except the PT-DP group (p<0.05).

Discussion

The materials used in the construction of temporary prostheses must meet the mechanical, physical, and biological requirements for use within the mouth[11]. In this research, water absorption and solubility parameters, which are one of the physical properties of temporary fixed materials produced by 3D printing and CAD/CAM milling methods, were analyzed and compared with those produced by the traditional method (bis-acrylic composite resin and acrylic resin based). The null hypothesis is partially rejected. PT group (bis-acrylic composite resin) exhibited higher water absorption values than the other test groups. The other groups showed similar water absorption values. In water solubility values, the conventionally produced groups showed similar values, while differences were found in all other pairwise comparisons. The water solubility values of traditionally produced temporary materials (PT, DP group) were higher than those of digitally produced (MT, OD group). The water solubility of the 3D printed test specimens (MT) was found to be lower than that of the CAD/CAM milling material (OD).

Water absorption and solubility in dental restorations are critical factors in determining the material's resistance to surrounding oral fluid because they prevent hydrolytic breakdown and expansion, which provides the material's clinical longevity[12]. Although the mass loss from the polymers defined the water solubility, the increase in mass per unit volume indicated water absorption[13].

The ability of dental materials to absorb liquids and alter their weight and volume is known as water absorption. It is stated in milligrams per centimeter (mg/cm^2) and is determined by weighing the greatest amount of liquid absorbed by a certain material in a unit area. The decrease in a material's volume and/or weight upon contact with liquids or solvents is known as solubility. It results in modifications to the dental components' volume, composition, and form inside the mouth. It has been seen in contact with gingival secretions, saliva, and fluid within dentinal tubules[14].

Shin *et al.*[6] compared the water absorption and solubility of temporary resins produced by 3D printing with those produced by CAD/CAM milling and conventional methods. According to reports, 3D-printed PMMA resins have a higher water absorption capacity than traditional polycarbonate resins and a lower water absorption capacity than conventional PMMA resins. In another study, when compared to bis-acrylic and CAD/CAM milled PMMA resins, 3D-printed photopolymer resins were reported to have a greater water absorption rate. But they have less water sorption than conventional PMMA resins[15]. Furthermore, they claimed that 3D-printed PMMA and photopolymer provisional resins were more water soluble than CAD/CAM milled PMMA and bis-acryl resins[6,15]. In the present study, the bis-acrylic composite resin-based (PT group) exhibited higher water absorption values than digitally produced (CAD/CAM-OD, 3D printing- MT) and conventional acrylic-based test materials (DP group). The other test groups (DP, MT, OD) showed similar water absorption values. The water solubility values of traditionally produced temporaries (PT, DP group) were higher than those of digitally produced temporaries (MT, OD group). Test specimens created by 3D printing (MT) were shown to have less water solubility than those produced using CAD/CAM milling (OD). This study differs from the aforementioned studies in that the water absorption rate of 3D printing resin can be affected by many parameters including material qualities and other output parameters.

Compared to PMMA polymers, generally bis-acrylic polymers are more polar. They are more attracted to polar substances like water[2]. In the present study, the higher water absorption values found in PT material compared to other materials may be connected to the polymerization process, higher residual monomer ratio, and larger porosity. This indicates that PT may cause more color changes in the test specimen than other specimens.

According to ISO 10477:2020 standards, water absorption of temporary restorations should not exceed 40 µg/mm^3 and water solubility values[10] should not exceed 7.5 µg/mm^3. Based on the results of this investigation, all test materials comply with the values specified in ISO. On the other hand, digitally produced test specimens show negative water solubility values. The weight gain of entangled water molecules causes a negative solubility. The negative water solubility values are similar to some studies[12,13,16].

The production of digitally produced temporary materials is more recent and has gained popularity compared to traditional methods. One of the limitations of this study was that short-term water absorption and solubility parameters were evaluated. More studies are needed to evaluate long-term water absorption and solubility parameters and to examine other physical properties. Thus, making inferences about the physical properties of these materials in clinical use, will also enable physicians to provide evidence-based data for material selection.

Conclusions

All test groups were found to be within the values recommended by ISO standards. However, PT material may be more susceptible to staining and should be considered in clinical use.

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