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Characterization of Temporary Dental Crown Materials Prepared by Different Digital Technologies

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Abstract **-** Temporary fixed dental restorations are an essential part of prosthodontics treatment to restore aesthetics and function as well as to protect teeth from damage until treatment completion. Various digital technologies have recently been introduced for the fabrication of temporary crowns that need to be evaluated physically and mechanically. The objective of this study was to evaluate the physical and mechanical properties of temporary crown materials fabricated using various digital fabrication techniques and 3D printing systems. Methods: Four groups of temporary dental crown materials (N=8) were prepared using conventional methods and three digital systems. Groups A, manual method, B, a digital subtractive method, C, additive method with the NextDent system, and D, additive method with the Asiga system. Surface roughness (Ra), three-point bending, and Vickers microhardness tests were performed. One-way analysis of variance (ANOVA) and Fisher's multiple tests were used to compare outcomes between the groups. Results: Group B was statistically smoother ($P < .05$) than other groups. The flexural strength values for groups B and C were significantly higher than groups A and D. The microhardness values for groups A, B, and C were higher than that of group D. Conclusion: Both additive and subtractive methods for manufacturing temporary crowns tend to have stronger flexural strengths and smoother surfaces than those prepared by the conventional method. Additive methods vary according to the type of printer and materials and system used. Based on the test materials and 3D printer type, subtractive temporary resin and additives from NextDent printing showed superior flexural strength.

Keywords**:** Temporary crown, Interim crown, Fixed prostheses, Prosthodontic, 3D printing, Additive manufacturing, Subtractive manufacturing

1. Introduction

Temporary or interim crowns are an element of dental prosthodontic treatment intended to preserve natural teeth and restore oral structures' function and aesthetics [1, 2]. Temporary crowns are used for a short period of time until the fitting of a definitive crown [2, 3]. Temporary crowns can be made directly in the dental clinic on the tooth or indirectly in the dental laboratory on the dental cast by using an impression or a digital scan of the patient's teeth [3]. The fabrication of temporary crowns using conventional, traditional methods is a long, labor-intensive process that may result in time-consuming and low-quality dental prostheses [2, 4].

Digital technologies such as dental scanning and CAD/CAM (computer-aided design and computer-aided manufacturing) technology have revolutionized the process of manufacturing temporary crowns [2]. They can improve the quality of temporary crowns and reduce patient chair time by making fabrication times faster and lowering the risk of human errors with manual processes [2, 3]. CAD/CAM systems can be subtractive or additive manufacturing methods [2, 5]. The subtractive (milling) method processes an object by trimming a block or disc of material into the desired shape [2, 5]. The additive (3D printing) method builds the object layer-by-layer [2, 5]. The additive method has gained popularity because it uses fewer materials and processes objects more quickly, and processes complex shapes than the subtractive (milling) method [6]. Different 3D printers are currently available in the market for manufacturing temporary crowns [6]. These printers are based on either digital light processing (DLP) or stereolithography (SLA) technologies [2, 5, 6].

The mechanical and physical properties of temporary crowns can be influenced by the materials used, and manufacturing methods applied [5]. In the 3D printing methods, it is also affected by printers' capability and printing parameters [2, 6]. There is a lack of scientific studies that evaluate and compare the physical and mechanical properties of temporary crown materials made using various digital fabrication techniques and 3D printing systems. Therefore, the objective of this study was to evaluate the physical and mechanical properties of temporary crown materials fabricated using various digital

fabrication techniques and 3D printing systems. The null hypothesis was that there would be no significant differences in the mechanical and physical properties of temporary crown materials fabricated using various digital fabrication techniques and 3D printing systems.

2. Materials and Methods

2.1. Sample preparation

Four groups of temporary crown materials were made using different manufacturing methods: A, traditional manual method; B, subtractive digital method; and C, additive method using NextDent system, and D, additive method using Asiga system. For each group, eight rectangular specimens (25×2×2 mm) were fabricated according to the ISO10477 standard [2]. The chemical compositions for the materials used in each group are listed in Table 1 and the flowchart of the study process is showing in Figure 2.

The specimens for group A were made with a self-cured resin (Bosworth Trim Plus; Bosworth, Skokie, USA) in a custom mold from specimens of groups C and D by utilizing duplicate silicon materials (Adisil; Siladent, Munich, Germany) in accordance with the manufacturer's instructions. The specimens for group B were made from prefabricated resin discs (Ceramill temp; Amann Girrbach AG, Kobach, Austria) and were cut to the specimen dimensions using a cutting disc (IsoMet 5000 Linear Precision Saw, Buehler Ltd., IL). The specimens for groups C and D were first designed via CAD software (FreeCAD v.18) and then 3D printed using two DLP printers; for group C the printer was NextDent 5100 (3D Systems Soesterberg, The Netherlands) using the printer materials Crown & Bridge NextDent ®; (3D Systems Soesterberg, The Netherlands); for group D the printer was Asiga MAX (Asiga, Alexandria NSW, Australia) using the printer materials with Asiga DentaTooth (Asiga, Alexandria NSW, Australia). The printing parameters for groups C and D were 50 m layer thickness and a 0° printing angle. The printed specimens have been removed from their supporting frames and cleaned with isopropyl alcohol. Finally, post-processing polymerization was carried out for 30 min in accordance with the manufacturer's specifications through a post-curing device (LC-3D Print Box; 3D Systems). All specimens were ground and polished under water cooling using a polishing machine (EcoMet/AutoMet 250, Buehler, Lake Bluff, IL, USA) using three types of silicon carbide papers (800, 1000, and 1500 grit), and a final polishing cloth with polishing paste is used after that. (Abraso-Starglanz asg; Bredent, Senden, Germany).

Table 1: The chemical composition of temporary crown materials of all groups.

Group	Resin type	Chemical composition	Manufactures
A	Acrylic resin set (Powder and Liquid)	Powder: Polymethylmethacrylate (PMMA) and Benzoyl peroxide Liquid: Methylmethacrylate (MMA) and N, N-Dimethylp-toluidine	Bosworth Company, Skokie, USA
B	Milling Disc (solid)	Polymethylmethacrylate (PMMA) and cross-linked polymers based on methacrylic acid esters, colorants, dibenzoyl peroxide, and Methylmethacrylate (MMA)	Amann Girrbach AG, Koblach, Austria
C	Methacrylate-based photopolymer resin (liquid)	Methacrylic oligomers, methacrylate monomer, phosphine oxides, pigment	Crown & Bridge NextDent ®; Nextdent, Soesterburg, The Netherlands
D	Methacrylate-based photopolymer resin (liquid)	Trimethyl-4,13-dioxo3,14-dioxa-5,12-diazahexadecane-1,16- diyl bismethacrylate, Tetrahydrofurfuryl methacrylate, and Diphenyl phosphine oxide	DentaTooth; Asiga, Alexandria NSW, Australia

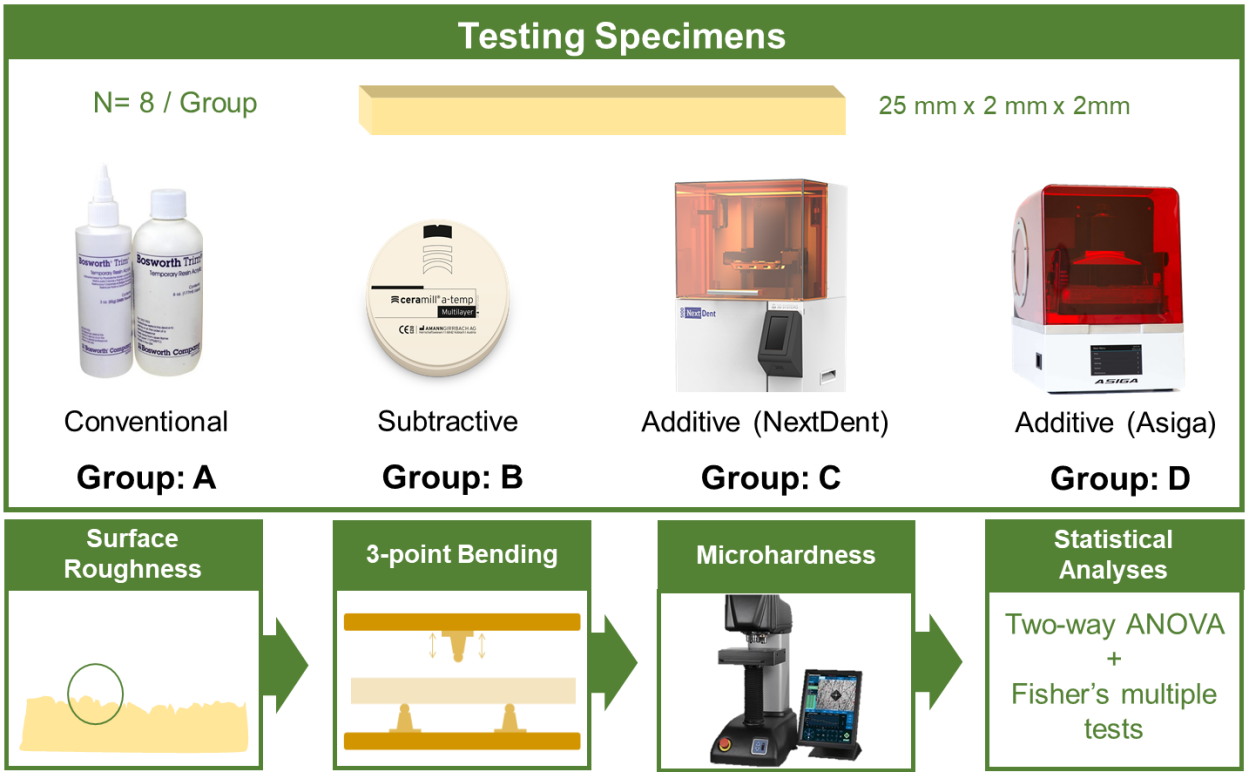

Figure 1: Drawing shows the flowchart of the study process.

2.2. Surface roughness

A non-contact optical profilometer (Contour GT; Bruker, Tuscon, AZ) working on the concept of vertical scan interferometry was used to quantify the surface roughness of the specimens for each group (N=8). With a threshold of 4%, length of 90 m, speed of x2, and VSL measurement type. Three specimens from each group were selected randomly. Three different measurements at various locations were taken for each specimen, and the average Ra was calculated in micrometres (µm).

2.3. Flexural strength

Three-point bending tests were performed at room temperature on an Instron Universal Testing Machine (Instron Corp., Canton, MA) with a 500 N load cell and a constant speed of 1 mm/min. The N=8 specimens from each group were individually mounted on two pins 18 mm apart. Bluehill software (v.2; Instron Corp.) was used to obtain force-deflection curves for each test. The flexural strength (F) was calculated using this equation:

$$F = 3 F_{max} L / 2 b d^2 \quad (1)$$

Where Fmax is the maximum applied force, L is the distance between the supports, b is the width of the tested specimen, and d is the height of the observed specimen.

2.4. Microhardness assessments

The microhardness of all groups was measured using a Vickers microhardness indenter (Nova 130; Innovatest Europe BV, Maastricht, The Netherlands) under a 50 g indentation load with a 10 sec dwell time. Three specimens from each group were selected randomly and indented three times at different points. The mean microhardness values were calculated from images captured by a built-in camera at the indentation site.

2.5. Statistical analyses

The mean and standard deviation (SD) were measured, and the data are presented as the mean ± SD. The groups statistically analyzed and compared with a one-way analysis of variance (ANOVA) and Fisher's multiple comparison The software Origin program (v.9.0; Origin Lab, Northampton, MA, USA) was used for the statistical analyses, and the results were considered statistically significant when P<.05.

3. Results

The mean and standard deviations of surface roughness (Ra ± SD) of conventional (A), B: subtractive (B), additive by NextDent printer (C), and additive by Asiga printer (D) temporary crown materials are presented in Figure 2. The mean Ra value of the A group was significantly (P < .05) higher (.547±.22 µm) than group B (.133±.05 µm), group C (.22±.01 µm), and group D (.21±.02 µm). Group B was statistically smoother (P < .05) than other groups.

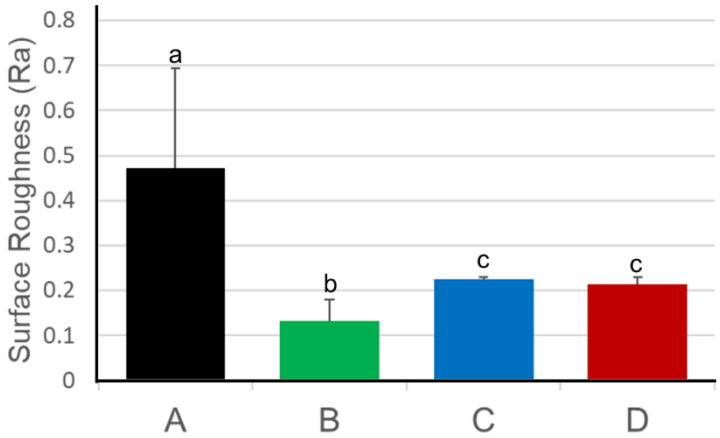

Figure 2. Chart showing the surface roughness (Ra) of the temporary crown materials for all groups. Group A: Conventional, B: subtractive, C: additive by NextDent printer, and D: additive by Asiga printer. The same letter indicates no significant differences between the groups.

The mean and standard deviation values of the flexural strengths of conventional (A), B: subtractive (B), additive by NextDent printer (C), and additive by Asiga printer (D) temporary crown materials are presented in Figure 3. The flexural strength values for groups B and C (125.6±9.5 and 119.9±5.6 MPa, respectively) were significantly higher (P < .05) than those for groups A and D (84.6±12.6 and 86.0±7.3 MPa, respectively).

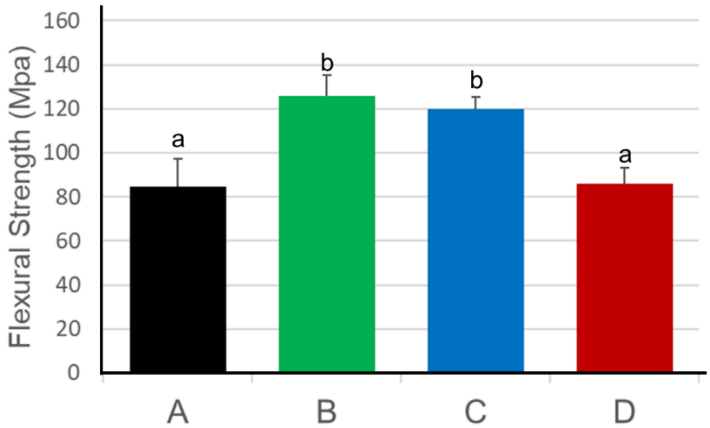

Figure 3: Charts showing the flexural strength (MPa) of all tested groups temporary crown materials for all groups. Group A: Conventional, B: subtractive, C: additive by NextDent printer, and D: additive by Asiga printer. The same letter indicates no significant differences between the groups.

Figure 4 shows the results of the microhardness test for all groups. The microhardness values for groups A (25.1±.2 HV), B (25.1±.3 HV), and C (24.09±.8 HV) was higher (P < .01) than that of group D (23.5±.3 HV) group.

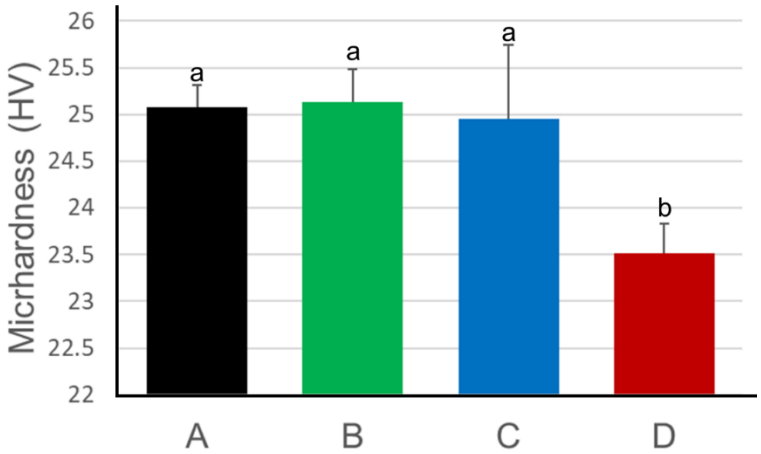

Figure 4: Chart showing the microhardness values (HV) of the temporary crown materials for all groups. Group A: Conventional, B: subtractive, C: additive by NextDent printer, and D: additive by Asiga printer. The same letter indicates no significant differences between the groups.

4. Discussion

The null hypothesis was rejected based on the statistical analysis of the results, indicating that temporary crown materials fabricated using digital technologies can exhibit superior mechanical and physical properties compared to the conventional method. However, the results might relate to the type of printers and material used in the additive methods.

Both digital methods (additive and subtractive) can present smoother surfaces than conventional methods. As part of the conventional way of fabricating and polymerizing acrylic resins, an uncontrolled environment can produce air bubbles, defects, and surface irregularities [7]. While all digital methods (additive and subtractive) groups were polymerized in controlled environments. Group B (subtractive) was made by cutting the disc that processes in a controlled manufacturing process. The 3D printed (additive) in groups C and D was processed using 3D printing technology, which can present smooth surface depending on the printer type [2,7].

The flexural strengths of groups B and C were higher than those of A and D groups. This could be because of the organized microstructure of the additive and subtractive structures. Conversely, the lower flexural strength of the A group is perhaps due to defects and irregularities on the surface. This is a result of uncontrolled polymerization of acrylic resin [5]. The differences between additive methods (groups C and D) might be related to the chemical composition of materials used in 3D printing methods. Group D showed a significantly lower Vickers microhardness than other groups. This also might be related to the materials used in group D. These materials may have different mechanical properties, contributing to the observed differences between C and D [6]. Moreover, the differences in microhardness may be attributed to the difference in the porosity of the materials used in each group. Porosity affects the mechanical properties of the printed components, which may explain why group D showed lower microhardness values than the other groups.

This study had some limitations because it was carried out in vitro on flat specimens. This didn't really replicate the in vivo trials that used actual dental crowns. Future studies are needed to assess the aging process, color stability, porosity, and additional mechanical measurements of temporary crown materials. In addition, further characteristic studies could be conducted on different parameters of 3D printing technology for temporary crowns. These parameters include building orientation, post-processing, and layer thickness. Finally, clinical studies should be conducted to investigate the clinical performance of 3D-printed temporary crowns.

5. Conclusion

Within the limitations of this study, the following conclusions were drawn: both additive and subtractive methods manufacturing temporary crowns tend to have higher flexural strengths and smoother surfaces than those prepared by conventional method. The additive methods vary according to the type of printer and materials used. Based on the test materials and 3D printer type, subtractive temporary resin and additives from NextDent printing showed greater flexural strength.

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