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Evaluation the effect of artificial aging on shear bond strengths of a subtractive and additive 3D printing extra coronal restorations

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ABSTRACT

Aims: to evaluate the effect of artificial aging of shear bond strength (SBS) value on extra coronal restoration that prepared by different techniques.

Methods: A total of 48 rectangular-shaped bar prepared in dimensions (18*7*1.5 mm) length, width, and height, respectively, were be fabricated from four different materials: IPS E.max Press, IPS E.max CAD/CAM, ZLS, and 3D printing nanoceramic (n=12 for each material). 24 samples (6 from each material) were undergone thermocycling, A tygon tube placed at the center of intaglio surface of each material with the aid of an orthodontic wax and cemented with resin cement and shear bond strength (SBS) testing performed for the samples.

Results: (SBS) test show that the thermocycling had a lowest impact value on the material (E.max Press) and the technique (conventional technique) than on other materials and techniques. Regarding the impact of materials on SBS, E.max CAD/CAM exhibited the highest bond strength values both before and after thermocycling. In terms of technique, the subtractive method had the highest SBS before thermocycling, whereas no significant differences were observed between the techniques after thermocycling.

Conclusion: Thermocycling had an effect on different materials and techniques; also, the difference in materials according to the working conditions has an effect before and after the thermocycling, and the difference in techniques according to the working conditions had an effect before thermocycling.

Keywords: *Zirconia reinforced lithium silicate, 3D printing, CAD-CAM, Shear bond strength..*

1. INTRODUCTION

In dentistry, 3D printing technology is now commonly utilized for a variety of purposes, including temporary restorations, splints, aligners, dental casts, and surgical guides [1]. Because of its environmental benefits and procedural efficiency versus subtractive production methods, it has become a growing trend across industries [2].

Accurate diagnosis and the fulfillment of dental professionals' needs have been made easier by the incorporation of supportive technologies such as oral and model scanners and advanced design software. However, these applications usually allow room for lab or chairside adjustments and require less precision than definitive restorations [3]. The benefits of 3D printing technology are being used by researchers to broaden its use to single crowns and long-span fixed prostheses, which require more dimensional accuracy and higher mechanical requirements under loading [4].

For dental restorations made with 3D printing to work well and last a long time, dental materials that are as strong as cast metal or milled restorations need to be created [5].

Achieving sturdy and long-lasting connections that link the dentin and extra coronal restoration is essential for the long-term success of restorations in the field of restorative dentistry [6]. Recurrent cavities, restorative failure, and eventually tooth loss can result from a weakened connection between the tooth and the restoration [7].

A strong bond that connects the tooth surface with restoration is consider necessary to resist many dislodging forces that occur in the oral cavity [8]. The definition of shear bond strength is the ability of restorative material to withstand stresses that allow it to move past tooth structure. The principal dislodging stresses at the tooth restoration contact have a shearing effect; hence the restorative material is quite important clinically. Increased shear bond strength hence implies improved material-to-tooth bonding [9].

Thermal cycling is commonly utilized in experimental research to assess the performance of materials since it is one of the most popular methods for simulating the physiological aging that biomaterials experience in clinical settings [10]. The null hypothesis of this study stated that neither the type of materials nor the techniques used for preparing the ceramic samples had any effect on the shear bond strength value with the underlying resin cement. The aim of this study was to evaluate the effect of artificial aging on the shear bond strength value of extra coronal restorations that were preparing either by subtractive and additive techniques.

2. MATERIALS AND METHODS:

2.1 Sample size:

Forty-eight rectangular-shaped bars will be prepared in dimensions (18*7*1.5 mm) length, width, and height, respectively, from the materials used in the study.

2.2 Preparation of the samples:

The samples were designed in a rectangular bar shape using the AutoCAD program. Then save the design as a standard tessellation language (STL) file, which is essential for 3D printing and milling system techniques. In the conventional technique (IPS e-max press), a wax template in the shape of a rectangular bar with dimensions (18*7*1.5) is created using a 3D printer (Phrozen Mighty 8K). The manufacturer's instructions guide the production of pressed lithium disilicate samples (IPS e-max press) using this template and the "lost-wax and press technique". A wax sprue (IPS Multi Wax Pattern Form A; Ivoclar Vivadent) was used to hold the wax templates in place before they were invested (IPS Press VEST Premium; Ivoclar Vivadent) and put in an oven (KaVo EWL 5645; KaVo, Kloten, Switzerland). The invested template was heated at 850 ◦C, with a holding time of 60 minutes, to create the mold. After that, lithium-disilicate ceramic (IPS e-max press; Ivoclar Vivadent) was poured into the mold. It was then put in a pressing furnace (Programat EP 5010 Ivoclar Vivadent) that was heated at a rate of 60 °C/min from 700 °C to 920 °C and held there for 25 minutes. As soon as the samples were cool, they were carefully devesting and cleaned of the investing material for three minutes using air abrasion particles (Germany/Renfert GmbH No. 15941305). The outer surface will undergo glazing with IPS e-max fluorescence glaze [11].

A dental CAD/CAM system (Yenadent) was used to make a rectangular bar sample from an initial (STL) file of the same size in order to get ceramic samples from the IPS e-max CAD group (LT A2, Ivoclar Vivadent, Schaan, Liechtenstein). Once the milling process was complete in the milling machine, the samples were meticulously separated and extracted from the e-max blanks. a football-shaped fine diamond bur (379-023 M-HP) was used to refine the margins of each sample and remove any excess material. After that, all the samples were put on a firing tray and sintering was done according to the manufacturer's instructions in the high-temperature Zetain Sintering Furnace at 400–860°C for 25 minutes. The outer contour surface of e-max CAD samples underwent fine grinding, polishing, cleaning, and drying, and concluded with a glazed firing [12].

A CAD/CAM system produced six ZLS samples. We conducted the sintering process for these samples in a Zetain sintering furnace at temperatures ranging from 0 to 1530°C.

An STL file with consistent dimensions for the 3D printing of nanoceramic samples. The samples were designed in the AutoCAD program before starting the process. The 3D printing process used a 3D printer (Phrozen Mighty 8K) and the vat photopolymerization technique. The resin is initially a liquid, but it undergoes chemical reactions and hardens when exposed to light, creating a solid object. The procedure begins by heating the resin bottle in a hot water jar. Using all the resin in the bottle and thoroughly mixing all nanoceramics into the product is crucial. Fill the water heater with 1L to 1.2L of water and bring it to a boil. Once the water reaches boiling point, the machine will automatically stop.

At that point, place the entire bottle inside the water heater. Allow a waiting period of 5 to 10 minutes, then shake vigorously for 30 seconds to 1 minute. Afterward, introduce the resin into the tank of the 3D printing machine and initiate the printing process. Post-printing, cleanse with a 96% ethanol solution utilizing an unheated ultrasonic bath for 3 minutes (ultrasonic cleaner power 30-35 watts). Resin residues may also be eliminated with a brush saturated in 96% ethanol. Following the alcohol cleaning, rinse with tap water for 5-10 seconds, then spray with alcohol for a final cleanse and promptly dry using compressed air. Use a cutting wheel to remove the support structure after the curing process. Then, use a glass bead blasting material with particles that are 50 μm in size and a maximum blasting pressure of 1.5 bar for three minutes to remove the white layer. Examine the objects thoroughly for both fit and finish. Use a carbide cutter or a diamond grinding stone (No. PH-1011) for finishing and contouring.

3.3 Fixation of the samples:

The samples were placed on a flat bench surface to maintain their parallelism during cement application. A Tygon tube with a central hole (1.5mm diameter, and 2 mm height) were placed at the center of the sample intaglio surface and fixed in its place by aid of an orthodontic wax.

2.4 Cementation of the samples:

Conditioning of the intaglo surface of materials:

1- (5%) hydrofluoric acid etching (IPS ceramic etching gel; Ivoclar Vivadent, Schaan, Liechtenstein) for 20 s, rinsed for 40 s under running water, then dried with oil-free air for 30 s.

2- acid-etched with 37.5% phosphoric acid (Gel Etchant, Kerr) for 30 s, rinsed with air–water spray for 60 s, and gently air-dried with oil-free air for 30 s.

3- primer (Monobond plus primer Ivoclar Vivadent) for sixty seconds and air-dried for five seconds according to the manufacturer instructions.

4- After conditioning, the samples were cemented using dual-cure resin cement (Variolink Esthetic DC Ivoclar Vivadent) and glass slide slap was placed onto the Tygon tube with a constant load of 50 g placed over the glass slide slap for 60 seconds, and all excess cement was removed with a small bond brush, and a light curing unit (Ivoclar Vivadent, Shaan) was used for polymerization on each surface for forty seconds [13].

The samples were saved in distilled water after cementation, and shear bond strength tests were done after 24 h of cementation to ensure complete polymerization of the cement.

Cementation protocol was completed for 24 samples before thermocycling and 24 samples after thermocycling.

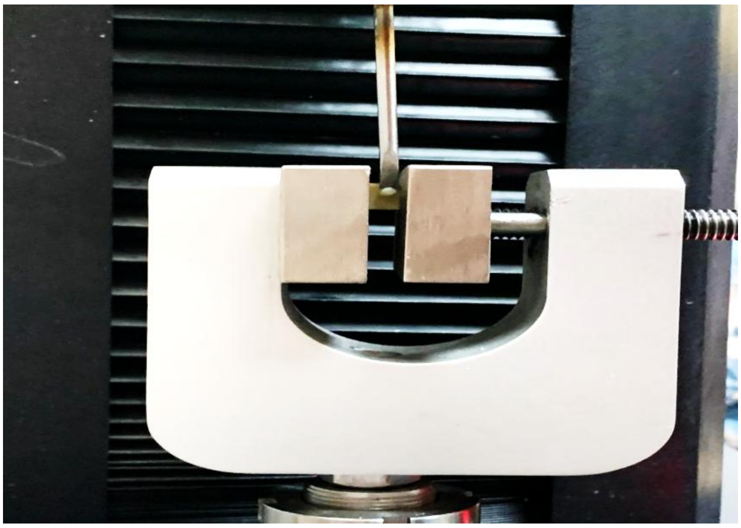
2.5 Thermocycling:

Only 24 samples were put through thermocycling (Vafaei Industrial, TC-300, Iran) with bath temperatures of 5 and 55 °C and a dwell time of 30s. This was done 5000 times, which is the same as putting the samples intraorally for a year [14].

2.6 Shear bond strength test:

A universal testing machine was used to apply shear force at a crosshead speed of 1 mm/min until all samples broke (before and after thermocycling). The ultimate load-to-failure was recorded in Newtons (N) and then calculated with a suitable mathematical method to express the bond strength in MPa. This process is illustrated in Figure (1).

Figure 1. show shear bond strength test.



3. RESULT

3.1 Shear Bond Strength Parameter:

To evaluate the shear bond strength value of the rectangular bars prepared from different materials (IPS e-max press, IPS e-max CAD/CAM, ZLS, and 3D printing nanoceramic) using different techniques before and after thermocycling, the data were collected, submitted to a normality test, and statistically analyzed.

The influence of thermocycling on shear bond strength value of ceramic samples:

The effect of thermocycling on the samples prapared by different materials and techniques (IPS e-max press, IPS e-max CAD/CAM, ZLS, 3D printing nanoceramic, subtractive and additive technique). The Wilcoxon Signed Ranks Test was used and showed that there was significant difference between ceramic materials and techniques at ($p \leq 0.05$) before and after thermocycling (Table 1).

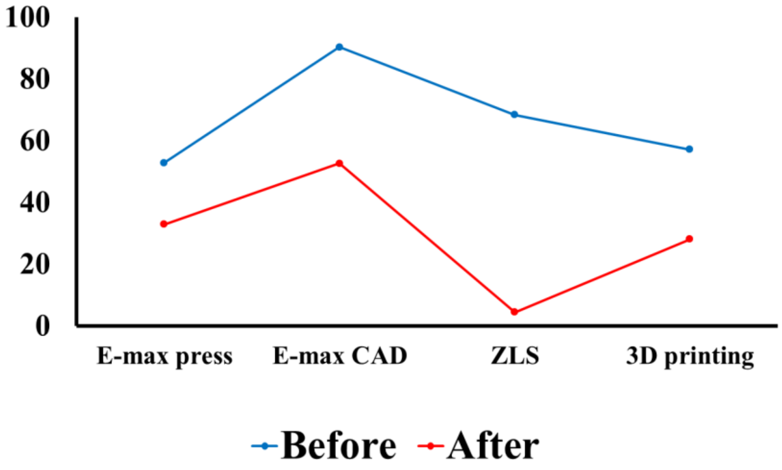
Table 1. Wilcoxon Signed Ranks Test of four types of samples prapared by different materials and techniques

before and after thermocycling.

Effect of thermocycling	Ceramic Material			N	Mean±SD	Test- value	P-value
On the material	E-max press		Before	6	52.7491±6.58480	-2.201	0.027*
			After	6	32.7795±5.54549		
	E-max CAD		Before	6	90.2852±5.97783	-2.201	0.027*
			After	6	52.5340±2.11464		
	ZLS		Before	6	68.3260±3.39761	-2.201	0.026*
			After	6	4.3850±2.86653		
	3D printing		Before	6	57.0822±4.63758	-2.201	0.028*
			After	6	28.0527±2.86653		
On the technique	Subtractive Tech	Conventional Tech	Before	6	52.7491±6.58480	-2.201	0.027*
			After	6	32.7795±5.54549		
		CAD/CAM Tech	Before	6	79.3050±4.68772	-3.059	0.002*
			After	6	28.4600±2.49058		
	Additive Tech		Before	6	57.0822±4.63758	-2.201	0.028*
			After	6	28.0527±2.86653		

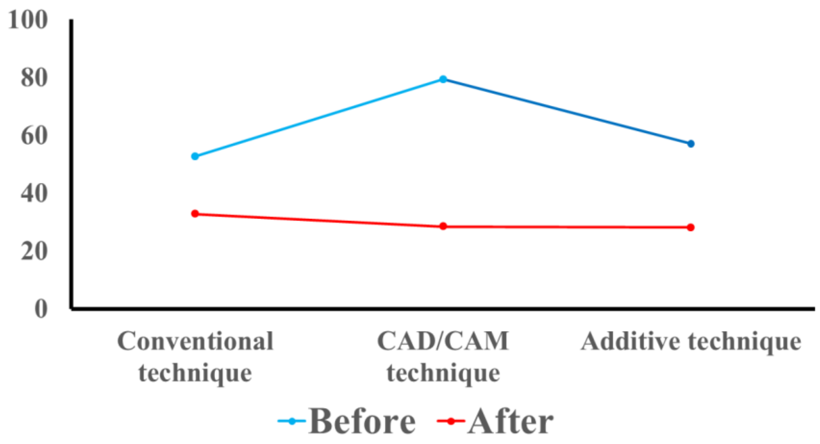
To determine the level of significance according to different materails, Figure (2) showed that the shear bond strength value of the IPS e.max press was the least affected by thermocycling in comparison to ZLS, which is highly affected.

Figure 2. Line graph for Wilcoxon Signed Ranks Test showing the results of SBS, including the effect of materials before and after thermocycling.



To determine the level of significance according to different techniques, Figure (3) showed that the shear bond strength value of the contentioanl technique was least affected while the shear bond strength value of the CAD/CAM technique was most affected.

Figure 3. Line graph for Wilcoxon Signed Ranks Test showing the results of SBS, including the effect of techniques before and after thermocycling.



The influence of materials type used on the shear bond strength values of ceramic samples :

To determine the effect of ceramic material type used and their shear bond strength value before and after thermocycling, the Kruskal Wallis test showed that there was a high significant difference between all materials at ($p \leq 0.05$) as shown in Table (2).

Table 2. Kruskal-Wallis Test of four types of samples prepared by different materials before and after thermocycling.

	Ceramic Material	Mean± SD	Test value	P- value	Compare (Dunn's Test)
Before	E-max press	52.7500 ± 6.58315	19.37	0.001*	C
	E-max CAD	90.2833 ± 7.42064			A
	ZLS	68.3267 ± 5.97794			B
	3D printing	57.0833 ± 3.39851			C
After	E-max press	32.7783 ± 4.63842	20.4	0.001*	B
	E-max CAD	52.5333 ± 5.54492			A
	ZLS	4.3867 ± 2.211301			C
	3D printing	28.0533 ± 2.86605			B

To identify the level of significance that was obtained before thermocycling, Dunn's multiple range test showed that the IPS e-max CAD/CAM had a higher shear bond strength value than other materials, while IPS e-max press had the lowest shear bond strength value.

While to identify the level of significance that was obtained after thermocycling, Dunn's multiple range test showed that the IPS e.max CAD/CAM had a higher shear bond strength value than other materials, while ZLS had the lowest shear bond strength value.

The influence of different techniques used on the shear bond streangth values of ceramic samples:

To determine the effect of different techniques used on the shear bond strength value of samples, the Kruskal-wallis test showed that there was a high significant difference between all techniques before thermocycling and no significant difference between all techniques after thermocycling at ($p \leq 0.05$) as shown in table (3).

Table 3. Kruskal-Wallis test of four types of samples prepared by different techniques before and after thermocycling.

Ceramic Technique			N	Mean±SD	Test-value	P-value	Compare Dunn's Test
Subtractive Tech	Conventional Tech	Before	6	52.7500 ± 6.58315	17.09	0.00*	B
	CAD/CAM Tech	Before	12	79.3050 ± 13.14359			A
Additive Tech		Before	6	57.0833 ± 3.39851			B
Subtractive Tech	Conventional Tech	After	6	32.7783 ± 4.63842	0.96	0.62	A
	CAD/CAM Tech	After	12	28.4600 ± 25.46006			A
Additive Tech		After	6	28.0533 ± 2.86605			A

To identify the level of significance that was obtained before thermocycling, Dunn's multiple range test showed that the shear bond strength of the CAD/CAM technique was a significantly higher value, while the conventional technique was the lowest shear bond strength value.

4. DISCUSSION

In dentistry, dental ceramics are used to replace lost tooth components because they provide the right qualities for building extra coronal restorations, which are essential to their success [15].

Ceramics must be properly bonded to the tooth structure using cement because they are fragile materials. Their clinical efficacy as dental restorations are contingent upon the strength of the resin cement and bond durability to both the ceramic material and the tooth structure [16].

Stewart et al. (2002) [17] and Fabianelli et al. (2010) [18] observed that when bonding ceramic material to tooth surface, the enamel or dentin/cement interfaces, along with the ceramic/cement interface, must be optimized, as the weaker interface will dictate the restoration's ultimate bond strength.

Generally speaking, the use of additive manufacturing (3D printing) in dentistry is growing in popularity since it enables practitioners to produce extremely precise and customized dental prostheses, including crowns, bridges, and implants. Patients who need customized solutions or who have unusual dental anatomy may find additive manufacturing especially helpful. Because additive manufacturing (3D printing) enables the production of complex and customized products on demand without the need for huge quantities of inventory or specialized equipment, it can also be more efficient and cost-effective than traditional manufacturing approaches. Despite its widespread popularity in various fields of technology and manufacturing, 3D printing in dentistry is still in its early stages of development [19].

The effect of thermocycling on the shear bond strength value of ceramic samples that were prepared by different materials, IPS e.max press, was least affected (52.7491 before and 32.7795 after). While ZLS value (68,3260 before and 4,3850 after) was the most affected due to IPS e.max press having a highly glassy structure that enhances chemical bonding adhesion with resin cement, showed less deterioration effect with thermocycling [20], While ZLS has a low percentage of glassy structure in comparison to e.max press, and it's not etchable and polycrystalline structure that shows less chemical bonding strength with underling resin cement [21].

For the effect of thermocycling on shear bond strength value of ceramic samples that prepared by different techniques, conventional technique was the least effected (52.7491 before and 32.7795 after) While CAD/CAM technique was the most affected (79.3050 before and 28.4600 after) due to conventional technique was prepared by pressing type and the material sentering under high temperature and pressure inside invesment mold with low air bubbles, which has high low porosity that lead to the percentage of deterioration effect become very low [20], While CAD/CAM technique was highly porous, partially stablize structure that sentering under high degree of temperature without pressure, so that the precentage of porosity will still high for this structure, so the thermocycling has high deteroration effect after for this techqinue [22].

Before thermocycling, the shear bond strength of ceramic samples that prepared by IPS e.max CAD/CAM was higher value (90.2833) and IPS e-max press was lowest value (52.7500) due to that e.max CAD/CAM which is a highly porous, actually there are two types of bonding (chemical and mechanical bonding). Therefore, high porosity will enhance physical properties and increase mechanical bonding and considered beneficial for higher shear bond strength[23], While IPS e-max press consider highly dense and smooth surface with low porosity. Therefore, less etchable in comparing to CAD/CAM material[24].

After thermocycling, the shear bond strength of ceramic samples that prepared by IPS e.max CAD/CAM was higher value (52.5333) and ZLS was lowest value (4.3867) due to IPS e.max CAD/CAM had highly glassy structure which enhance chemical bonding with underling resin cement and show less deterioration effect [24], While for ZLS has less glassy structure in comparing to e.max CAD and considered highly crystalline structure which is not etchable, so chemical bond strength was low and finally show more deterioration effect [25].

Before thermocycling, Shear bond strength of ceramic samples that prepared by CAD/CAM technique was higher value (79.3050) and conventional technique was lower value (52.7500) due to CAD/CAM technique prepared by milling technique which give porous structure that increase retention and increase shear bond strength [23]. While the samples prepared by conventional technique which give highly dense and smooth surface that decrease retention and decrease shear bond strength value [24].

After thermocycling, all samples prepared by different techniques had a deterioration effect, but there were no significant differences between them.

5. CONCLUSION

The study found that thermocycling had less impact on E.max Press material and conventional technique, while as a material, E.max CAD/CAM showing the highest SBS values and subtractive method had the highest SBS values before thermocycling. The results emphasize the importance of considering both material and technique when selecting restorative options, especially in long-term aging conditions.

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