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Ceramic Bond Strength of Various Metal Substrate Using Traditional and Digital Methods

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Abstract

Purpose: The aim of this study was to investigate the bond strength of cobalt-chromium (Co-Cr) metal frameworks prepared with three different production techniques with dental porcelain. Methods: In this study, a total of thirty disc samples divided to Three groups (n = 10/group) of metal cylinders (10 mm diameter x 4mm thickness with ring base (12 mm diameter x 1mm thickness) were fabricated by casting (Co–Cr), CAD CAM milling blank(Co–Cr) and by selective laser sintering SLM (Co–Cr) and abraded with airborne-particles then feldespathic porcelain was applied for all discs (10mm diameter x 2mm thickness), before the shear bond strength (SBS) test, the Surface characteristics of the dental alloys were observed by scanning electron microscopy (SEM) to determine the thickness of the oxide layer then surface roughness tester using TR220 portable roughness tester The average surface roughness (Ra) was determined for each group. SBS test-values and failure modes were recorded. Data were analyzed using ANOVA, Tukey's HSD (a = 0.05). Result: no statistically significant difference of the metal-ceramic bond strength of the test roughness used between casting, milling, and laser no statistically significant difference of the metal-ceramic bond strength of the SBS test between casting compare with milling, and laser groups SBS test statistically significant difference of the metal-ceramic bond strength of the test between milling, and laser technique. The mode of failure shows was mainly cohesive and mixed for all specimens. Conclusion: Within the scope of this research, the CAD/CAM milling Co-Cr alloy has a shear bond strength comparable to the castable alloy. For metal-ceramic restorations, the CAD/CAM milling Co-Cr alloy is an alternative to the castable alloy. Co-Cr restorations can benefit from CAD/CAM manufacture.

Introduction:

Replacing lost teeth with metal-supported ceramic restorations and prosthetic treatment is a prominent treatment option in dentistry. Metal-ceramic restorations have good function, cosmetic, and physical characteristics, and their costs are low, which is why they are still used successfully today. Recent material breakthroughs have also led to the development of metal-supported ceramic restorations (1, 2) .Recent research on the binding strength of ceramic restorations using Co-Cr metal substructures has centered on new metal infrastructure manufacturing processes(3). Metal-based restorations are often prepared using lost wax and classic casting procedures nowadays. However, faults made by technical employees in the laboratory, as well as challenges with measurement and dental stone models, can prohibit this procedure from producing optimum results in the creation of metal infrastructures. The use of computer-aided design manufacture (CAD/CAM) technology for the rapid creation of fixed restorations is becoming more widespread as technology advances(4) .The use of "Rapid Prototype Production Techniques" in prosthetic dental treatment has recently been emphasized for reasons such as excessive bur abrasion in milling technology, the failure of the system to provide the desired time savings, the excessive amount of residual material, and the difficulty of producing more than one complex restoration at the same time(5). It uses processes like Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS), and Selective Laser Melting to physically produce three-dimensional models produced in the CAD unit (SLM)(6). The shrinkage that occurs during casting processes is eliminated, objects with complex geometries can be produced easily, and great cost savings are achieved when compared to today's CAD/CAM systems, thanks to the ability of rapid prototype production techniques to layer the material instead of removing the material from the main part(7). The metal porcelain bonding has been the subject of the majority of recent investigations on the success of porcelain fused to metal restorations(8-10). Despite the fact that the majority of the literature comprises of studies examining the metal-ceramic bond strengths of Co-Cr metal substructures produced utilizing sophisticated manufacturing and traditional casting techniques (11-13). There are a few studies that incorporate in vitro testing that mimic intraoral temperature variations (14). The goal of this work was to analyze the bonding strength of Co-Cr metal infrastructures generated by different production procedures with a uniform low-temperature porcelain system in order to aid the development of metal-ceramic bonding.

Abbreviation and Acronyms

Co-Cr /cobalt chromium, SBS/ shear bond strength, Ra/ roughness ,SLM /selective laser melting

SEM/scanning electron microscopy.

Material and Methods

In this study, a total of 30 disc samples (10 mm diameter x 4mm thickness with ring base (12 mm diameter x 1mm thickness) were fabricated of Co-Cr alloy and divided into three groups (10 discs for each group) according to their fabrication technique:

Group **A**: fabricated by conventional casting.

Group **B**: fabricated by CAD/CAM soft milling machine.

Group **C**: fabricated by 3D Printer laser machine.

Then, porcelain build up for all discs (10mm diameter x 2mm thickness) was done using feldspathic Porcelain (15) , Fig. (1) .

2.1 Fabrication of metal substrates

Group A: Discs fabrication by lost wax casting technique, wax pattern preparation 10 discs (10 mm diameter x 4 mm thickness) and ring base (12 mm diameter x 1mm thickness) were prepared with the lost wax casting. In order to standardize their diameter and thickness, all wax discs were fabricated by the CAD/CAM technology. The wax discs were designed similar to the CAD/ CAM fabricated Co-Cr discs using the CAD software (Exocad Dental CAD, v.2016, GmbH, Darmstadt, Germany), wax patterns were milled from a casting wax blank for CAD/CAM (Huge, GmbH & Co. KG, Germany) using a 5-axis milling machine (Imes-Icore, 5 axis, COR TEC **350** iPRO, Germany). Using a Phosphate-bonded investment, the Co–Cr specimens were cast in a centrifugal casting equipment.; (Bego-Bellavest SH; Germany) The castings were finishing , and 110µm aluminum oxide powder was used to abrade for 15 seconds (Dentify GmbH, Scheffelstr.22, Germany) at 3 bar of pressure, at a 90 degree angle, and 2 cm away from the sand blast machine's nozzle. Discs fabrication by CAD/CAM technology .Group B subtractive group: Designing of the discs By the aid of the CAD software (Exocad Dental CAD,v.2016,GmbH, Darmstadt, Germany) Milling of the discs : A Co-Cr blank specific for the dry milling procedure (soft-Blank, GmbH& Co, Germany)samples10 discs were milled to the designed dimensions using a five-axis computerized numerically controlled milling machine (imes- icore competence in CNC&DENTAL –Solution), following milling protocol according to the manufacturer’s recommendations .Group C Sub additive group : The commercial SLM method Laser (EP-M150METAL DENTAL 3D PRENTER) was used to fabricate of metal cylinders, from Co–Cr the design file transferred to the SLM part (E Plus 3D control software) equipped with a 100W Yb-fiber laser. The specimens' longitudinal axes were positioned perpendicular to the building platform. The Co–Cr powders used have particle sizes of 10-45 m, respectively. Use SLM device with the proper laser. (e. g. Ytterbium Fiber Laser or Nd:YAG Laser (wavelength approx. 1060 – 1100 nm)) and enough laser power output (200 W) or power density at the surface (25 kW/mm2) to melt the granules selectively using a protective gas (e. g. Nitrogen). BEGO has the parameter settings for the EOS M270 SLM device, including the production parameters, and can install them on the client's equipment. To minimize residual stresses caused by the laser's localized heat input and to modify the microstructure for improved mechanical performance.

2.2. Surface characterization of dental alloys

Eight number of metal substrates, Surface roughness was determined using samples randomly chosen from each group. The surfaces were prepped in the same manner as if they were going to be covered in porcelain. They were first airborne-particle abraded110µm, cleaning with steam (15 sec) before the surface roughness test, all specimens were ultrasonically cleaned with distilled water for 8 min by using ultrasonic cleaning machine Their original surfaces were preserved untouched. The Ra for each of the substrates was measured, using TR220 portable roughness tester, Fig. (2). The location of roughness device in University of Technology.

Scanning Electron Microscope (SEM) evaluation. Three Further metal specimens, one for each group, were manufactured as previously reported to determine the surface oxide thicknesses of substrates fabricated using various processes, the metal substrates for all the specimens group placed immediately in a preheated furnace (oxidation firing) at 500°C Temperature was raised to 980°C; holding time 1 min to obtain a coating of oxide on the metal's surface,their as-built surfaces were left intact. SEM was performed on one sample from each group at random to test the sample’s. The specimens were coated with a gold alloy spray by using a vacuum sputter coater (YKY, USA), then were examined using an SEM Fig. (3).

2.3. Veneering porcelain application

The metal cylinder bases that were to be built-up by porcelain were airborne-particle abraded,a conventional low-fusing feldspathic ceramics (VITA VMK Master, VITA Zahnfabrik, Bad Säckingen, Germany) was placed on the Co–Cr substrates. Used plastic mould special design first, For the Co–Cr groups, a thin coating of opaque porcelain was placed manually and firing (0.5mm thickness), followed by two dentin porcelain layers – the second correcting for the first layer's shrinkage (2mm) thickness – and glaze firing (Vita Vacumat 6000 M furnace, VITA Zahnfabrik, Bad Säckingen, Germany) Fig. (4). The firing times were set according to the manufacturer's instructions. specification of groups and materials used in this study show in Table (1).

2.4. Shear bond strength testing and mode of failure

Shear bond strength (SBS) was determined for all groups using a universal testing machine (Instron universal testing machine (laryee WDW-50, China). The specimen mounting, as well as the custom-built testing apparatus, which consists of lower-stationary and upper-sliding stainless steel pieces, are shown in Fig. (5). At a crosshead speed of 0.5 mm/min, the upper component of the device slides down the grooves of the stationary part, loading the metal–ceramic interface until fracture occurs. The SBS values were written down. A digital microscope was used to examine the fracture specimens under samples. (Dinolite, Taiwan) at the magnification power of X100 to determine the type of failure. The failure modes were categorised as follows to characterize them: **(1)** adhesive failures, which occur between the metal and the metal oxide/ceramics; **(2)** cohesive failures, which occur totally within the ceramics; and **(3)** mixed failures, which are a mix of adhesion and cohesion failures (16).

Statistical methods were used to examine and evaluate the results include descriptive statistics (mean, standard deviation (SD), standard error (SE), minimum and maximum values of the SBS test, bar chart for mean values of SBS) and inferential statistics (One-way ANOVA (analysis of variances test followed by the Tukey honestly significant difference (HSD).

Shear stress is the most common stress in the SBS test, while tensile stress is the most common in the 3-point bending test. As a result, the SBS test was chosen for this investigation,which was in accordance with Della Bona and Van Noort(17), Valandro et al. (18), Joias et al. (19), and Haselton et al. (20), He stated that the SBS test has two advantages over other dental material testing procedures: it reduces operator participation in sample preparation and the failure of any sample is immediately apparent after testing (other tests need grinding or cutting first).

Results and Discussion

3.1. The surface properties of dental alloys

Fig. (6), showed the mean (Ra) values in microns (μm) and standard deviations (SD) for the three studied groups. The Ra values for each group of metal substrates abraded by airborne particles are shown in Table (2), showed the mean (Ra) values in microns (μm) and standard deviations (SD) for the three studied groups. The smallest Ra values (1.404±0.204) were found in GA while, the largest values (1.552±0.243) were in the GB, then GC was in the middle of the two values (1.540±0.256).

According to one-way ANOVA test Table (3), no significant difference was found between the group (A), the Ra of group (B) and group (C). The metal substrate has no effect on mean surface roughness, according to a one-way ANOVA analysis of the Ra data. There was no statistically significant difference. There were no significant changes in Ra values between the cast, machined, and laser substrates, regardless of alloy composition .The Ra test for whole specimens was measured in μm, the results of the study were statistically analyzed, a total of **8** measurements of surface roughness from each group (casting, milling. laser), with 24 readings for each subgroup.

The one-way ANOVA results are shown in the Table (3), indicate that the differences in surface treatment affected the final surface roughness of the tested material, and the same treatment will not effect on the difference between groups was a statistically non-significant P-value of (0.05) between (casting), (milling) and (laser) groups.

The Al2O3 air-particle abrasion procedure aided the metal-ceramic bond strength is harmed by the severe roughness of the metallic substrate, which produces stress accumulation at the interface. In addition, the sharp edges hinder the molten porcelain from adequately soaking the deep valleys on the metal surface, resulting in the formation of pores at the contact(21, 22). As a result, selecting the proper Al2O3 particle size is critical. The maximum bond strength was achieved following Al2O3 air-particle abrasion with a particle size of 110 µm, according to prior study(23) , which particle size was used in this research.

Metal substrates' SEM depth profiles are displayed, in Fig. (6). The surface oxide layer thickness appears to be larger for cast Co-Cr and CNC milled Co-Cr more than 19 µm. During the whole sputtering procedure, the oxide/substrate interface was not achieved for this specimen. On the other hand the quick oxygen drop in SLM specimens indicated the presence of significantly thinner surface oxide layers,12µm due to the excessive roughness of specimen as well as the resulting shadowing (24).

Chemical bonds create ionic, covalent, and metallic interactions with oxides in the ceramic opaque layer. The primary mechanism of metal and ceramic interaction is provided by the oxide layer on the metal framework. (25), As a result, an oxidation process is employed to generate an oxide layer on the porcelain-bearing surfaces and remove impurities.

Chemisorption via diffusion occurs at the metal-ceramic interface, resulting in chemical bonding (11). The oxide layer between the metal and the ceramic has an impact on this. The varying binding strengths among the groups in this investigation could be related to the oxide layer thickness. In comparison to milling and SLM, Wang et al. Casted substrates have a poorer metal-ceramic bond strength and a thicker oxide layer between the alloy and the ceramic, according to the study (26). According to Akova et al. and Serra-Prat et al., different production techniques result in different oxide layer thicknesses (14).

3.2. Shear bond strength

This study compared the SBS of PFM samples made with different Co-Cr alloy manufacturing processes, including CAD/CAM machining and traditional casting.

For each metal substrate–ceramic combination, the mean SBS values were obtained, comparing the three groups of ceramics' bond strength (n=30).

In Table (4) , the calculated percentage bond strength obtained for each porcelain used on specimens, Fig. (7) showed the mean distribution and standard deviations of (SBS) of the three tested groups. The group (B) recorded the highest average (SBS) mean values (9.126 ±0.932) followed by group (A) (8.288±0.474) while the lowest average (SBS) mean values were recorded for group (C) (8.133±0.943). According to the results of one-way ANOVA which were represented in Table (5), a statistically significant difference was shown between groups B and C with P-value (0.05) and no a statistically significant difference between traditional and digital groups.

In order to analyze the binding strength between metal and ceramics, researchers performed a variety of testing methodologies, including tension testing (27), SBS(2, 28), three-point bending and flexural However, there is still a scarcity of information in the literature about the best test for determining the bond strength of these two materials. However, several researchers discovered that the SBS test is the most accurate way to determine the binding strength between the two materials (2, 8, 29).

The influence of the opaque layer's firing temperature, as well as the thermal and mechanical aging technique, according to De Vasconcellos et al, It was explored the bond strength of a single type of dental ceramic supported by a Co-Cr metal substructure.They found that increasing the opaque layer's firing temperature boosted bond strength, but the thermal and mechanical aging procedures had no significant effect on bond strength (30).

stawarczyk et al., casting, milling, and laser sintering were used to create three distinct Co-Cr-Mo alloy infrastructures (Ceramill Sintron; Milling, Ceramill NP L; Laser, Girobond NB; Casting), which were then thermally cycled. Three different ceramics were used to test the binding strength (Creation, VITA VM 13, Reflex). According to the building procedures, the samples have equal bond strength values; nevertheless, when evaluating the link between ceramics and metal infrastructures, they noticed that Creation ceramics had a higher bond strength. than VITA VM 13 and Reflex brand ceramics (31). porcelain fracture in metal ceramic restorations can be caused by a number of factors, including the structure of the restoration, manufacturing techniques, and the connection between the core and veneering porcelains(32). Tolga Akova et al. show that laser-sintering the Co–Cr alloy powder instead of standard dental laboratory casting to produce the substructure for a metal–ceramic restoration does not significantly affect the metal–ceramic bond strength (2).

3.3. Mode of failure

In Table (7), this investigation, the failure mode analysis revealed that the majority of the disc samples had mixed failure, which included both adhesive and cohesive failure in the porcelain, with a porcelain fragment in contact with the metal. While some samples showed a lack of cohesiveness these outcomes were in line with expectations, those of Oliveira de Vasconcellos et al.(15, 30) , they looked into the influence of thermo-mechanical cycling on the bond strength of a ceramic fused to both Co-Cr and gold alloys, finding that both alloys had a high rate of mixed failure. Also, the mixed failure found in this investigation was the same as that found in Suliman and Styern's study (1) Additionally, according to Papazoglou and Brantley the mixed type of failure allow the existence of excellent bond strength between metal and ceramic.and agree with Maja Antanasovaa (24).

Conclusions:

Within the limitations of the present study the following conclusions can be drawn:

1. All the tested samples showed SBS values within the clinically acceptable levels.

2. CAD/CAM milled Co-Cr may be considered a promising alternative to the conventional cast Co-Cr for metal-ceramic prosthesis in terms of SBS.

3. It can be said that the reason why the milling group has a higher value compared to the other groups is due to the homogeneous structure of the infrastructure material used.

4. Roughness is not affected by the metal substrate

5. With a P-value of 0.05, a statistically significant difference was found between the CAD/CAM milling and SLM groups, but not between the traditional (casting) and digital groups.

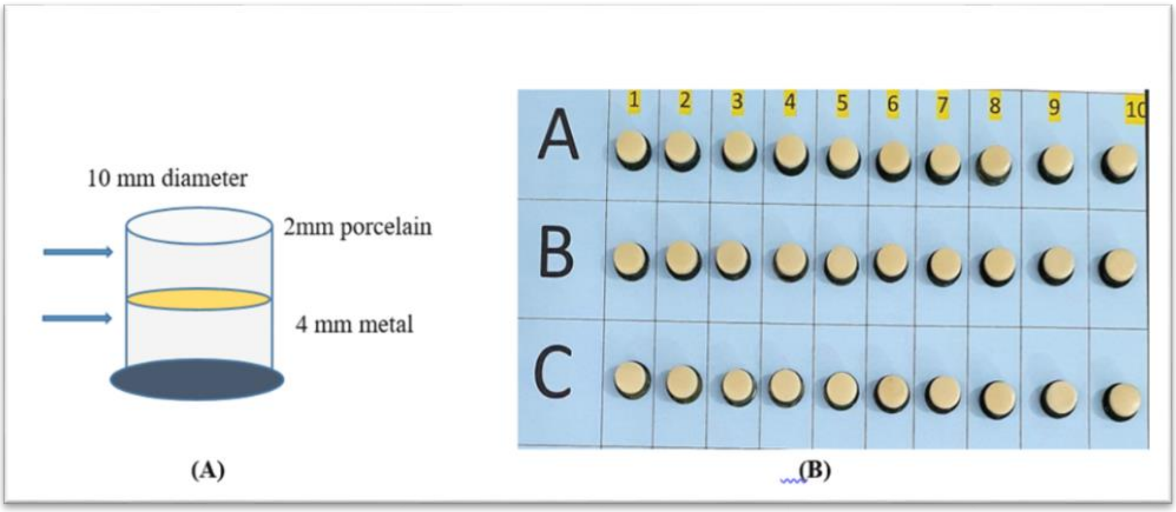

Fig. (1): Drawing of the metal–ceramic test specimens (A) and real appearance of the test specimens (B).

Fig. (2): TR220 portable Roughness tester

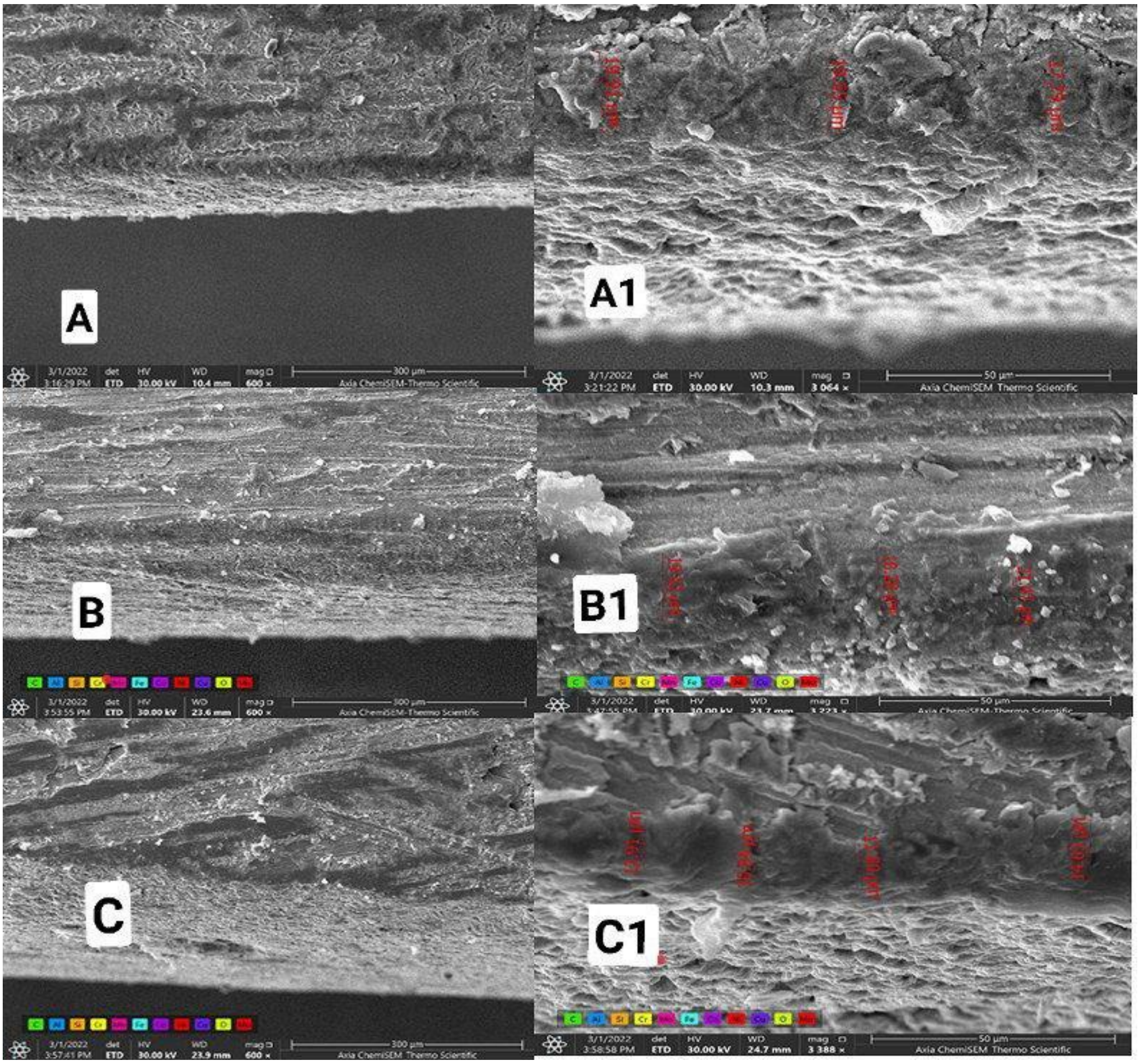

Fig. (3): SEM images (Aand A1) (Co–Cr) dental casting alloy at a magnification, A of (600 x) and A1(3064 x), SEM images (B and B1) Milling alloy at a magnification, B of (600 x) and B1(3223x).
SEM images(C) 3d printer alloy at a magnification, C of (600 x) and C1(3388 x).

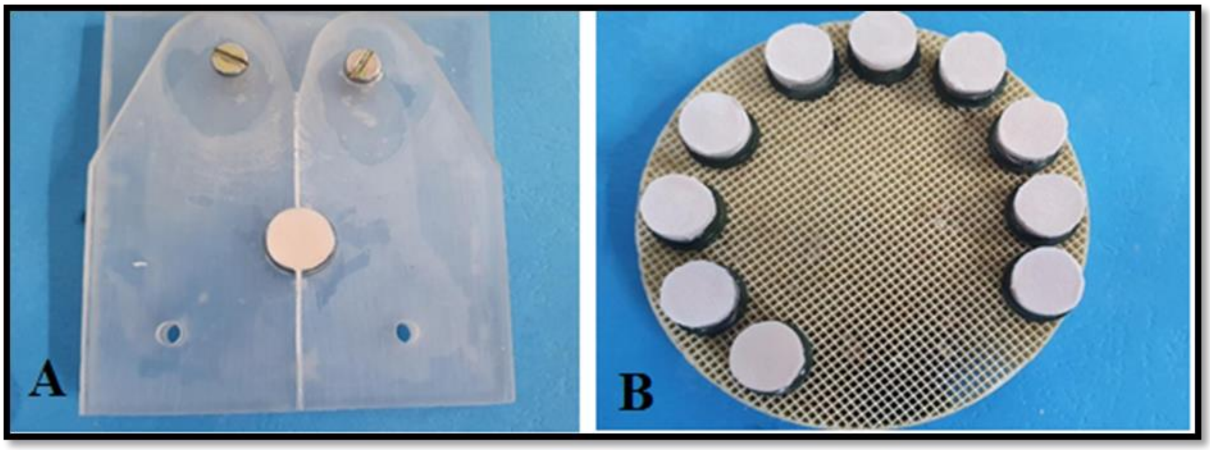

Fig. (4): porcelain build up on the specimens A: specimens placed inside special mould B: complete building porcelain fused to metal.

Fig. (5): Instron universal testing machine.

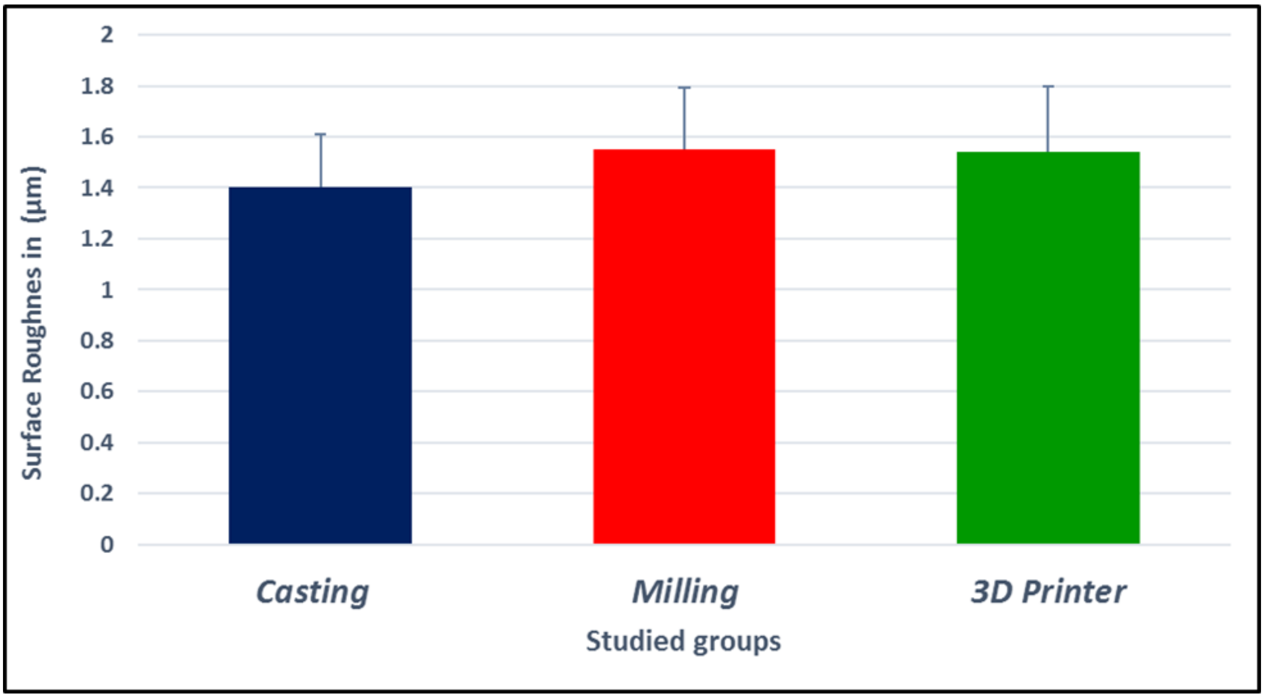

Fig. (6): Bar chart showing the mean distribution of surface roughness (Ra) in µm for the studied groups.

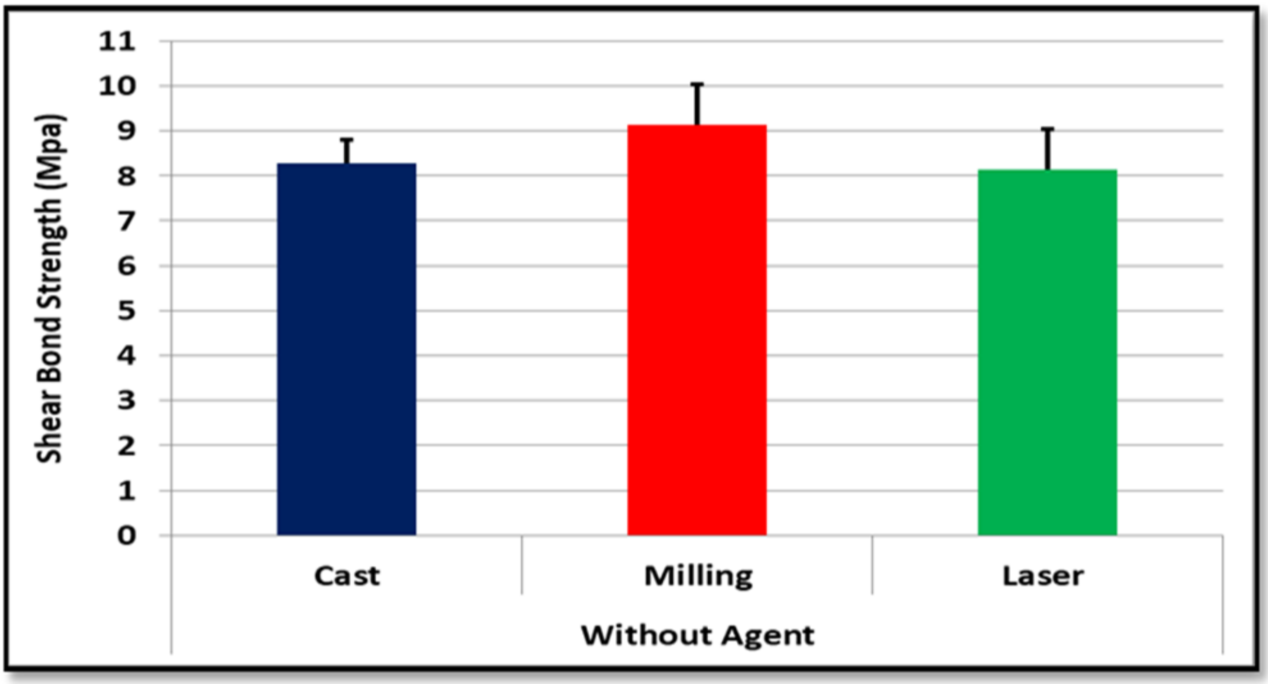

Fig. (7): Bar chart showing the mean distribution and standard deviations of shear bond strength (SBS) of the studied groups.

Table (1): Groups and materials used in this research were specified

Methods	Material	Manufacture	Composition	Process
Cast	Cobalt based dental casting bonding alloy ,type 4	Adentatec System,MG GmbH,Germany	Co 61.8%, Cr 29.5%, , Mo 5.7%, Fe 0.75 %, Si 0.95 % ,C 0,6% ,Mn 0.55% Others ≥ 0.1)	Lost wax casting
Milling	Soft milling co,cr disc type 4	Eisenbacher Dental waren ED GmbH Germany	Co 61.7 %, Cr 27.8 %, W 8. 5 %, Mn 0.3 %, Si 1.6%, Fe 0.2%, others<0.1	imes icore milling machine
Laser sintering	DentalCo- based metal ceramic alloy type5	BEGO Bremer,Herbst GmbH&Co Germany	Co 63.9%, Cr 24.7%, W5.4 %, MO5.0%, Si 1.0 others<0.1	EP-M150 METAL DANTAL 3D PRINTER
Ceramic Used	VITA VMK Master	VITA Zahnfabrik, Bad Säckingen, Germany	Glass (silica) based ceramics	(Vita Vacumat 6000 M furnace)

Table (2): Descriptive statistic of the surface roughness (in µm) for three different groups

Groups	Mean	Std. Deviation	N
Cast	1.4048	0.20415	8
Milling	1.5520	0.24379	8
Laser	1.5401	0.25627	8

Table (3): Statistical analysis (ANOVA and LSD) to compare the difference in average surface roughness values between different groups.

I Groups	(J) Groups	Mean Difference (I-J)	Std. Error	P-Value	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Cast	Milling	-0.1473	0.11789	0.225	NS	-0.3924	0.0979
	Laser	-0.1354	0.11789	0.264	NS	-0.3805	0.1098
Milling	Cast	0.1473	0.11789	0.225	NS	-0.0979	0.3924
	Laser	0.0119	0.11789	0.921	NS	-0.2333	0.2570
Laser	Cast	0.1354	0.11789	0.264	NS	-0.1098	0.3805
	Milling	-0.0119	0.11789	0.921	NS	-0.2570	0.2333

* At the 0.05 level, the mean difference is significant.

Table (4): Descriptive statistic of the shear bond strength for three different process techniques of studied groups.

Groups	N	Mean	Std. Deviation	Max.	Min.
Cast	**10**	**8.288**	**0.47403**	**9.100**	**7.700**
Milling	**10**	**9.126**	**0.93291**	**11.009**	**7.636**
Laser	**10**	**8.133**	**0.94338**	**9.800**	**7.127**

Table (5): Statistical analysis (ANOVA, post hoc- Tukey test) to compare the difference in shear bond strength (SBS) values between different groups.

(I) Groups Without	(J) Groups Without	Mean Difference (I-J)	Std. Error	P-Value	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Cast	**Milling**	**-0.8380**	**0.3637**	**0.072**	**NS**	**-1.7399**	**0.0639**
	Laser	**0.1550**	**0.3637**	**0.905**	**NS**	**-0.7469**	**1.0569**
Milling	**Laser**	**0.9930***	**0.3637**	**0.029**	**S**	**0.0911**	**1.8949**

Table (6): Test of homogeneity of variances (Levene's Test) of studied groups.

F	df1	df2	Sig.
2.959	2	27	0.06

Table (7): Failure mode distribution throughout the groups.

Groups	Mixed failure		Cohesive failure		Adhesive failure	
	No.	%	No.	%	No.	%
Group A	6	60	4	40	0	0
Group B	6	60	4	40	0	0
Group C	5	50	5	50	0	0

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