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Comparative shear bond study of dental porcelain to cobalt chromium discs obtained by conventional lost wax technique and methods based on CAD/CAM system.

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Abstract:
Background: *Porcelain fused to metal crown prosthesis has a combined effect of fracture resistance of metal substructure and esthetic property of porcelain. The bonding ability of porcelain to metal affects the long-term reliability of porcelain fused to metal restorations. New technologies have led to introduction of new materials, so an evaluation of the adhesion of porcelain to these material is needed.*
Materials and Methods: *Total 30 discs 10 discs each of cobalt chromium were fabricated by conventional lost wax technique (casting) and two CAD/CAM systems by subtraction (direct milling) and addition (laser sintering) which were later fired with a popular commercial porcelain system. The finished samples were thermocycled 500 times at a temperature range of 5^0 C to 55^0 C and then tested for shear bond strength by "Universal Testing Machine". The type of failures were visualized and analysed by stereomicroscope.*
Results: *In this study shear bond strength of samples fabricated by milling with pre-sintered blank (Ceramill Sintron) showed higher values of mean (76.76MPa) compared to DMLS (48.19MPa) and conventional lost-wax technique (33.67 MPa). There was a significant difference seen in the fabrication technique of milling and casting (p=0.043*).*
Conclusion: *Within the inherent limitations of this in-vitro study, the shear bond strength between dental porcelain and cobalt chromium alloys fabricated by three different methods can be surmised by considering the novel pre-sintered millable (Ceramill Sintron) material for milling as an alternative for DMLS as it showed better shear bond strength values. According to the present study milling can be considered superior to casting as it showed significant shear bond strength difference.*
Keyword: *CAD/CAM, shear bond strength, DMLS, direct milling, lost wax technique, porcelain, pre-sintered blank.*

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I. Introduction

As ceramo-metal crown prostheses combine the cosmetic qualities of porcelain with the fracture resistance of a metal substructure, they are widely and extensively utilised in fixed prosthodontics.[1] But as there are quite a frequent cases of chipping fractures of porcelain from metal and as the aetiology is not known, so the preventive measures such as framework design changes, fabrication damage reduction, and thermal processing methods, which will help reduce the probability of chipping fractures and will increase survival probabilities for ceramic crown and ceramic bridge restorations must be used.[2] The metal used to make the substructure for metal-ceramic restorations is an important consideration for these restorations.

Recently, casting technology is undergoing a radical shift and a process of industrialization is taking place in dentistry. Computer-assisted design/computer assisted manufacturing (CAD/CAM) technology has revolutionized prosthodontics by enhancing new manufacturing methods and materials.

Direct metal laser sintering (DMLS) being one such additive process, is a CAD/CAM based rapid manufacturing technique fabricating base metal alloy restorations, was introduced by EOS (Krailing/Munich). It is a novel, additive manufacturing technique which offers processing versatility, improved material properties, and short product development cycles.[3] DMLS crowns and bridge restorations are made of a particle size of 3–14 µm. This, combined with a very fine point laser (0.1 mm), results in a density of 99.9%, resulting in stronger metal substrate copings. There are virtually no voids in the densely sintered crown restorations. The procedure yields highly accurate, detailed restorations. For the dental practitioner, chair side time is reduced and time required in the dental laboratory is enormously less. A high-powered laser beam is focused onto a bed of powered metal, fusing the areas together to form a thin solid layer. After that, another layer of powder is applied, and the next slice of the framework is created and fused with the first layer, resulting in the formation of the designed prostheses. Author Tara MA, Eshbach S, Bohlsen F, Kern M according to their findings regarding metal copings and their bond to veneering porcelain, laser sintering was a viable alternative to traditional casting methods.[4]

The subtractive technique is CNC hard milling technique which requires processing of metal substructure for base metal alloys at the milling centre for a very high cost. Milling burs must be changed on a regular basis because they cut hard metal alloys like cobalt chromium.[4]Thus, the wax-like pre-sintered alloy powder blank was introduced, which provided an advantage to milled substructure in the green stage of powder pre-sintered blank and then sintered to achieve the final substructure. This method reduces both the time and the cost of fabricating metal substructures. It was demonstrated that sintered alloy had mechanical properties comparable to hard milling alloy.[5] Fabrication of restorations with sinterable alloy and CAD/CAM includes less stages compared with casting alloy restorations, which reduces the probability of error. These restorations are also superior due to the consistency of their composition throughout the process. Accordingly, it can be concluded that the sintering process along with CAD/CAM milling used for Ceramill Sintron has many advantages over the conventional casting method. Ceramill Sintron is also superior to casting Co-Cr because of its less hardness, which facilitates polishing. Generally, mechanical properties of Ceramill Sintron are comparable, and in some cases, superior to casting alloys.[6]

The bonding ability of ceramic to metal affects the long-term reliability of porcelain fused to metal restorations.[7]As to achieve clinical longevity of metal-ceramic bonded crowns, it is important to have adequate bond strength between the metal substrate and veneering porcelain.[8]

Therefore, the goal of this study was to assess shear bond strength of CAD/CAM direct pre-sintered millable and direct laser sintered cobalt chromium base metal alloy with casting (conventional lost-wax technique).

II. Materials And Methods

This study was carried out in the Department of Prosthodontics in 2020–2022. Ethics was granted by the Institutional Ethical Committee and research board approval. The study conducted according to the ethical standards given in the 1964 Declaration of Helsinki, as revised in 2013.

The sample size was calculated using the references of related articles, studies, reviews and sample size formula. The sample was divided into three groups, namely Group 1,2 and 3. Each group was assigned 10 samples each.The technique used for sampling was purposive sampling in which, the sample size was estimated by using G power 3.1.9.2. Software with effect size 0.25, power of study 80%, alpha error 5%, beta error 20%, confidence interval 95% and significance level set at 5%.The sample size came out to be minimum 10 by using the formula: The total sample size for the study was taken as 30.

The present study was an experimental in vitro study to evaluate and compare the shear bond strength of 30 cobalt chromium base metal alloy discs fabricated 10 discs each by CAD/CAM subtractive pre-sintered milling, CAD/CAM additive direct metal laser sintering and casting lost wax technique with commercially available veneering porcelain.

Inclusion criteria:

- Samples without any evident visual flaws
- Samples without flaws in ceramic build-up

Exclusion criteria:

- Samples with bubbles
- Sample with crack
- Samples with incomplete coping fabrication
- Perforated discs

Procedure methodology

Fabrication of sample disc- A circular disc of 10 mm diameter and 4mm thickness dimensions fabricated by pattern resin was casted conventionally by lost-wax technique (Fig 1). A circular disc of 10 mm diameter and 4mm thickness dimensions was created by CAD/CAM software (exocad). The job file was transferred to milling machine (Fig 2) and pre-sintered cobalt chromium base metal alloy blank (Ceramill Sintron) was milled in the form of a disc, then the disc was placed in sintering furnace for 12hrs at 1400ºC to 1500ºC temperature. The same job file was transferred with all details for subsequent fabrication of laser sintered samples. The unit had a compartment where a high power laser beam was focused onto a bed of powdered metal and those areas fuse into a thin solid layer (Fig 3). The metal powder was of very fine particles of around 20 microns. Another layer of powder was then laid down and the next slice of the framework was produced and was fused with first. The cycle was repeated until the fabrication of the discs of desired dimensions were made.

Figure 1: casting machine

Figure 2: milling machine

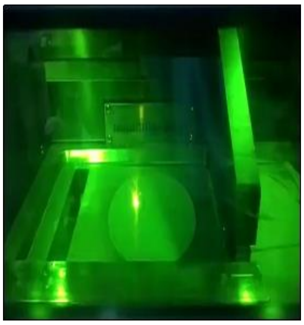

Figure 3: DMLS machine

Finishing of the discs- Once the discs were fabricated they were sandblasted with 50 microns of aluminium oxide powder and then was finished with finishing burs.

Porcelain build-up- After sandblasting and creating a rough surface on the samples, they were placed in ceramic furnace for degassing. The discs were then ready for ceramic build-up. The commercially available veneering porcelain Ivoclar Vivadent was used. Group1, Group2 and Group3 samples were built with Ivoclar Vivadent porcelain. A layer of wash opaque was applied to the discs (Fig 4) with a brush and the discs were then subjected to firing cycle as per manufacturer's instructions. Similarly first and second dentin layer was followed by enamel layer applied with a brush following manufacturer's instructions. A ceramic layer of 2mm thickness and 10mm diameter was built. Finally, glazed porcelain was then applied and subjected to firing to get final completed samples (Fig 5).

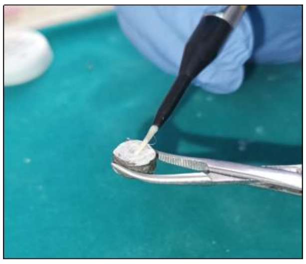

Figure 4: porcelain application

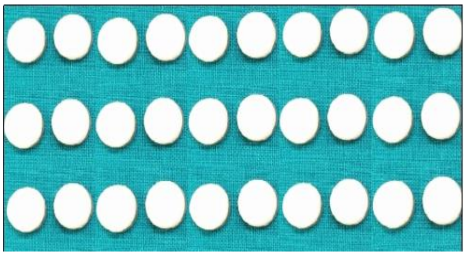

Figure 5: PFM study samples

Thermocycling of the samples- samples were processed at 5-55^{0}C (Fig 6) for 500 cycles for 20 seconds for each cycle.

Figure 6: thermocycling

Shear bond strength testing - To hold the specimens for shear bond testing, by circular interface test method a customized stainless steel jig assembly will be fabricated (Fig 7). The assembly will consist of two cylindrical rods and two plates. One of the plates will have a cylindrical hole with internal diameter of 10mm and 4 mm depth which will facilitate stabilizing and holding of the specimen during shear bond testing .The first plate will have a sliding mechanism. It will have a hole which would engage the ceramic portion of the specimen whereas the cylinder will engage the metal portion of the specimen. The shear bond strength will be measured using universal testing machine (Fig 8). The test sample will be placed into the cylinder such that, the metal-ceramic interface lies exactly between the two plates and the metal ceramic portion will engage into the holes of the two plates. A shear load will be applied at a crosshead speed of 1mm/minute till the ceramic debonded completely (Fig 9).

Figure 7: jig assembly **Figure 8:** universal testing machine

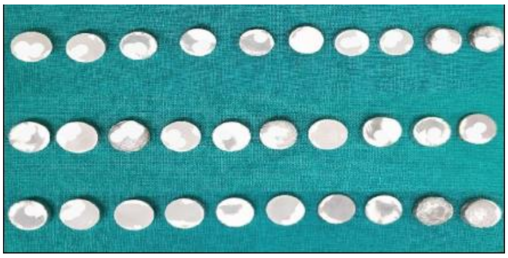

Figure 9: debonded study samples

Analysis of fractured surfaces- All the debonded samples were cleaned in an ultrasonic cleaner and were kept ready for observation under stereomicroscope (Fig 10). The metal surface was examined to determine whether the fracture occurred in the porcelain layer or at the metal-porcelain interface. Accordingly, the type of fracture, adhesive, cohesive or mixed was determined. The fractured surface were evaluated and scored using Adhesive Remnant Index (ARI).

Group 1 **Group 2** **Group 3**

Figure 10: debonded study sample under stereomicroscope (40 X magnification)

Group 1: Test samples obtained by DMLS system.
Group 2: Test samples obtained by pre-sintered milling system.
Group 3: Test samples obtained by casting.

Statistical analysis
It was been performed using Statistical Product and Service Solution (SPSS) version 21 for windows (SPSS Inc, Chicago, IL).
•Mean and Standard Deviation (SD) were calculated
•Statistical tests employed for the obtained data in the study were:
1. One way Analysis Of Variance (ANOVA) test was used for multiple group comparisons.
2. Tukeys post hoc for group wise comparisons.

In the statistical evaluation, the following levels of significance are used:
P>0.05-no significant difference
*P<0.05-significant difference

III. Results

Data comparison was done by applying specific statistical tests to find out the statistical tests to find out the statistical significance of the results. Since the data were continuous type, parametric tests were used for analysis. Mean and Standard Deviation (SD) were calculated (Table 1). One way ANOVA was used to do the inter group comparison between group 1, group 2, and group 3 which showed 'F'value as 8.641 (Table 1). Statistically significant difference was found for pair wise comparison using tukey's post hoc test for shear bond strength amongst the two groups viz. group 2 and group 3 (p= 0.043*) (Table 2).

Table 1: Comparative statistics of shear bond strength

	Mean	SD	One way Anova 'F' test value	P value, Significance
Group 1 (DMLS)	48.19	5.22	F = 8.641	p = 0.043*
Group 2 (Sintron)	76.76	17.44		
Group 3 (Casting)	33.67	1.46		

Table 2: Comparative statistics of shear bond strength pairwise comparison

Tukey's post hoc test to find pairwise comparisons			
Group	Comparison group	Mean Difference	p value, Significance
Group 1 (DMLS) vs	Group 2 (Sintron)	28.57	p = 0.142
	Group 3 (Casting)	14.52	p = 0.454
Group 2 (Sintron) vs	Group 3 (Casting)	43.09	p = 0.043*
p> 0.05 – no significant difference	*p<0.05 – significant difference		

IV. Discussion

Clinicians and patients have always sought restorations that closely resemble natural teeth. A look at the current dental market situations, might possibly lead to conclude encountering zirconium oxide present quite literally in every mouth. Particularly as the "white gold" dominates the current discussions on dental restoration materials. Whereby, cobalt-chromium alloys (Co-Cr) still remain highly relevant as a material of dentistry. Due to its mechanical properties, its processing, bio-compatibility, modulus of elasticity and its structural stability, cobalt-chromium has been proved to be a reliable material for a broad range of indications until today. As aesthetic demand has risen over the years, it is often achieved by veneering the metal base of a restoration with porcelain.[9] The success of any porcelain veneered to metal restorations is determined by variety of factors. One such primary requirement for a successful metal-ceramic restoration is the growth of a lasting bond between the porcelain used for veneering and metal alloy.[10,11]

According to dental literature, Dr. Swasey (1890) was the first to develop a technique for making solid gold inlay. Dr Martin (1891) was the first to use wax to make gold inlays. Dr. Philbrook (1896) popularised the pressure casting method for making gold inlays. A decade later, Dr. William Taggart (1907) presented a paper to the New York Odontological Group in which he discussed his casting technique and machine.[4] But, conventional lost-wax technique make it more prone to errors, prompting an alternative predictable technique that could be a panacea to the dentist and the dental technician. Casting technology is undergoing a radical shift and a process of industrialization is taking place in dentistry like all other industries. Recent advances in technology revolutionized the designing and fabrication of dental restorations by the computer-aided design/computer-aided manufacturing (CAD/CAM) systems. Several alloys and materials are used for the fabrication of restorations using the CAD/CAM systems, and their quality and variability continuously improve with advances in science and technology.[12] The advancements in additive or subtractive techniques from computer-aided design and computer-aided manufacturing can be used in digital dentistry to fabricate the metal substructure for metal ceramic restorations (CAD-CAM).[5]

DMLS is a novel, additive manufacturing process offering enhanced processing versatility, improved material properties, and shortened product development cycles.[15]It is based on CAD/CAM technology. The other commonly used CAD/CAM technique is subtractive technique in which milling is performed. Due to the hardness of Cr-Co-based alloys, the milling process of fully-sintered blocks is difficult and results in excessive wear of the milling tools and the machine. The equipment required is still expensive and technique sensitive, restricting production availability to only large CAD-CAM centres. Hard metal milling of Co-Cr blocks has the advantage of minimizing the formation of casting defects. However, it poses considerable disadvantages compared with casting, including fast tool wear caused by the hardness of the solid blank and high maintenance costs.[13] Soft metal milling (SMM) is a recent advancement in the production of Co-Cr dental restorations, with fabrication steps similar to those of pre-sintered zirconia.

The results of this study are very much in agreement with the reports published in contemporary scientific literature from reputed journals. The findings here are in reflection to study conducted by **Mitra Farzin et al** and **Alireza Izadi et al** where too a difference was obtained between the subtractive pre-sintered milling technique and conventional lost wax technique, with subtractive technique having higher SBS.[14,12] The findings of this study is further corroborated by the work of **Recep Kara,** where also the milled Co-Cr samples had a higher SBS value than casting and laser sintering samples.[15] Also, in a recent study conducted by **Elie E. Daou** it has been confirmed that although the results of pre-sintered and cast Co-Cr were not statistically different, but the SLM group showed SBS values significantly lower than those of both the cast and Ceramill Sintron milled groups. [16] Thus the superiority of Ceramill Sintron is clearly established over the the two most common techniques of obtaining the metal substrate in the contemporary dental laboratory set up, viz. lost wax technique and DMLS technique. **Zahra M et al** also reported that bond strength of pre-sintered Co-Cr alloy was better than that of lost wax technique, which fall in line with the findings of the present study that pre-sintered milling technique results in a higher bond strength.[6]

In the present study although there was a difference in the shear bond strength values among the three test groups, the values of all the test specimens exceeded the minimum requirement of 25 MPa as SBS between ceramic and Co-Cr alloys. (ADA specification no. 38 and ISO standard 9693).[17]

Notwithstanding the fact that in this study pre-sintered milling has shown a very promising result, the concurrent dental literature do have references revealing the superiority of DMLS as far as the bond strength of ceramic to metal is concerned. **Hongmei Wang et al** concluded that metal ceramic bond strength for metal substrate obtained by DMLS technique was superior to those obtained by conventional casting and CNC milling. [18] Whereas **Josep Serra-Prat et al** found that no significant adhesion differences were observed between cast milled and laser sintered specimen. [19]

In this study no statistical difference was seen in between the veneering porcelain across both the methods of manufacturing the metal substrate. This finding is substantiated by the study done by **Eun-Jeong Bae et al**, which says that the ceramic powder do not affect the SBS but the method of fabrication of metal substrate do matter.[20]

Among the mechanisms determining porcelain fused to metal interaction, chemical bonding is the predominant factor. Chemical bonding is known to be influenced by the elemental composition of metal alloys and the formation of an oxide layer on the metal surface. The metal oxide layer has been studied extensively and shown to play an important role during metal-ceramic bonding. If the oxide layer is thin, it would be completely eliminated during ceramic firing. However, an extensively thick oxide layer may also weaken bonding strength since it has poor cohesive strength. Bond strength may also be improved by increasing the surface roughness of the alloy. Airborne-particle abrasion can not only increase the metal surface energy but also improve the wettability of porcelain.[8] Therefore, the samples in this study were all sandblasted with 50 µm Al_2O_3 particles to increase surface roughness. The probable reason for greater bond strength of pre-sintered milled Co-Cr alloys has been described by **Akova et al.** and **Serra Prat et al**, different production techniques result in different oxide layer thicknesses and affects the bond strength. [21,19] Another reason as stated by **Xingting Han et al** is mechanical interlocking is another parameter for bond strength.[22] A general consideration is that higher roughness would lead to increased metal-ceramic bond strength due to the improved contact area and mechanical interlocking on the porcelain fused to metal interface. This could explain why the milled samples had a higher bond strength than the casting group. The SLM powder particles are loosely attached to the metal substrate on the laser fusion borderline, resulting in a rough surface. However, manufacturing parameters such as powder particle size, material composition, layer thickness, object geometry, building direction, and so on influence the surface roughness of SLM substrates.[22]

According to **Serra-Prat et al** it was also stated that there is no difference in connection failure types between samples with and without thermal cycling. However, thermocycling application was still included in the present study as applying it is not a disadvantage, as also temperature variation simulates a clinical condition or reality. [19]

After the shear bond strength testing, the debonded samples were examined to determine the type of fracture under stereomicroscope viz. Adhesive, cohesive or mixed and were scored using Adhesive Remnant Index (ARI). In the present study, a mixed mode of failure was obtained for the three groups, with more adherence of porcelain to metal substrate for group 2 samples (pre-sintered milling) compared to group 1 samples (DMLS) and group 3 (casting).

In the present study employing circular interface test design for evaluating the metal-ceramic shear bond strength between just three methods of obtaining the metal substrate, and only one veneering porcelain was studied. A study design employing more no of methods of obtaining metal substrate may elicit a broader picture of shear bond strength. Also, involving different types of veneering porcelains could have revealed additional information about SBS or types of bond failure. The alloy used for the three methods of obtaining the metal substrate differed in composition, hence there was difference in SBS. Here, just five cycles of ceramic firings were employed, studies can be planned with a varied range of ceramic firing cycles. Therefore, it may be suggested that future study designs employing more number of test samples, more number of metal alloys, use of different techniques of obtaining metal substrate, and incorporating different interfaces like metal conditioners or metal ceramic bonding agents could be envisioned.

V. Conclusion

Among the three techniques of obtaining the metal substrate, the subtractive technique (Ceramill Sintron pre-sintered Co-Cr) revealed stronger shear bond strength. No statistically significant difference in shear bond strength was found in the veneering porcelain, irrespective of technique of obtaining metal substrate. Almost all the test samples showed mixed mode of bond failure.

References

[1]. Yurdanur Ucar, Zafer Aksahin and Cem Kurtoglu. Metal ceramic bond after multiple castings of base metal alloy. J Prosthet Dent 2009; 102:165-171.
[2]. Anusavice,K.J. Standardizing failure, success, and survival decisions. In clinical studies of ceramic and metal–ceramic fixed dental prostheses. Dental Materials 2012; 28(1):102–111.
[3]. Traini T, Mangano C, Sammons RL, Mangano F, Macchi A, Piattelli A. Direct laser metal sintering as a new approach to fabrication of an isoelastic functionally graded material for manufacture of porous titanium dental implants. Dental materials. 2008 Nov 1; 24 (11):1525-33.
[4]. Venkatesh KV, Nandini VV. Direct metal laser sintering: a digitised metal casting technology. The Journal of Indian Prosthodontic Society. 2013 Dec; 13(4):389-92.
[5]. Juntavee N, Oeng SE. Shear bond strength of ceramic fused to CAD-CAM milled alloys. Journal of Clinical and Experimental Dentistry. 2018 Jan;10 (1): 32.
[6]. Mohammadi Z, Mahabadi M, Tabbakhian G, Talaakoob M. Bond strength of porcelain to milled sintered and casting base metal alloys. Journal of Dentistry. 2021 Mar; 22(1):21.
[7]. Vanessa Zulema Ccahuana Vasquez, Mutlu Ozcanb, Estevao Tomomitsu Kimparaa. Evaluation of interface characterization and adhesion of glass 14 ceramics to commercially pure titanium and gold alloy after thermal- and mechanical-loading. Dental materials 2009; 25 :221–231.
[8]. Xiang N, Xin XZ, Chen J, Wei B. Metal–ceramic bond strength of Co–Cr alloy fabricated by selective laser melting. Journal of dentistry. 2012 Jun 1; 40 (6):453-7.
[9]. Petridis H, Hirayama H, Kugel G, Habib C, Garefis P. Shear bond strength of techniques for bonding esthetic veneers to metal. The Journal of prosthetic dentistry. 1999 Nov 1; 82(5):608-14.
[10]. Lombardo GH, Nishioka RS, Souza RO, Michida SM, Kojima AN, Mesquita AM, Buso L. Influence of surface treatment on the shear bond strength of ceramics fused to cobalt–chromium. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2010 Feb; 19(2):103-11.
[11]. Roberts HW, Berzins DW, Moore BK, Charlton DG. Metal-ceramic alloys in dentistry: a review. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2009 Feb;18(2):188-94.
[12]. Izadi A, Vafaee F, Shishehian A, Roshanaei G, Afkari BF. Evaluation of dimensional accuracy of dental bridges manufactured with conventional casting technique and CAD/CAM system with Ceramill Sintron blocks using CMM. Journal of Dental Research, Dental Clinics, Dental Prospects. 2018; 12(4):264.
[13]. Hong MH, Lee DH, Hanawa T, Kwon TY. Comparison of microstructures and mechanical properties of 3 cobalt-chromium alloys fabricated with soft metal milling technology. The Journal of Prosthetic Dentistry. 2022 Mar 1; 127(3):489-96.
[14]. Farzin M, Giti R, Asalforush-Rezaiye A. The effect of multiple firings on the shear bond strength of porcelain to a new millable alloy and a conventional casting alloy. Materials. 2018 Mar 22; 11(4):478.
[15]. Kara R. Evaluation of Shear Bond Strength of Porcelain to Cobalt-Chromium Alloy Fabricated with Different Methods after Thermocycling. South Asian Research Journal of Oral and Dental Sciences. 2021 Jan 3(1) ; 6-11
[16]. Daou EE, Özcan M. Evaluation of ceramic adherence to cobalt-chromium alloys fabricated by different manufacturing techniques. The Journal of Prosthetic Dentistry. 2022 Dec 1; 128(6):1364-e1.
[17]. The International Organization for Standardization. Metal-ceramic systems. Third edition, ISO 9693-2019.
[18]. Wang H, Feng Q, Li N, Xu S. Evaluation of metal-ceramic bond characteristics of three dental Co-Cr alloys prepared with different fabrication techniques. The Journal of prosthetic dentistry. 2016 Dec 1; 116(6):916-23.
[19]. Josep Serra-Prat, Jordi Cano-Batalla, Josep Cabratosa-Termes, and Oscar Figueras-Alvarez. Adhesion of dental porcelain to cast, milled, and laser sintered cobalt-chromium alloys: Shear bond strength and sensitivity to thermocycling. The Journal of Prosthetic Dentistry 2014; 112(3):600-605.

[20]. Bae EJ, Kim HY, Kim WC, Kim JH. In vitro evaluation of the bond strength between various ceramics and cobalt-chromium alloy fabricated by selective laser sintering. The journal of advanced prosthodontics. 2015 Aug 1; 7(4):312-6.
[21]. Akova T, Ucar Y, Tukay A, Balkaya MC, Brantley WA. Comparison of the bond strength of laser-sintered and cast base metal dental alloys to porcelain. Dental materials. 2008 Oct 1; 24 (10):1400-4.
[22]. Han X, Sawada T, Schille C, Schweizer E, Scheideler L, Geis-Gerstorfer J, Rupp F, Spintzyk S. Comparative analysis of mechanical properties and metal-ceramic bond strength of Co-Cr dental alloy fabricated by different manufacturing processes. Materials. 2018 Sep 22; 11(10):1801.

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