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Distinctive analysis of the shear bond strength of Porcelain Fused Metal substructure fabricated by conventional Casting, Direct Metal Laser Sintering and CAD-CAM Processing Techniques

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Abstract

Background: The use of metal-ceramic restorations began in the late 1950's allowing the development of prosthetic rehabilitation with better cosmetic results replacing previously in-demand precious metals. These restorations are commonly prepared using conventional casting, Direct Metal Laser Sintering and CAD-CAM processing techniques. The present study has been attempted to perform a distinctive analysis of the shear bond strength of porcelain fused metal substructure fabricated by conventional casting, Direct Metal Laser Sintering and CAD-CAM processing techniques.
Materials and Methods: The present study follows an in-vitro study design. A total of 45 samples were prepared and divided into 3 groups (n=15 in each group): conventional casting, Direct Metal Laser Sintering and CAD-CAM groups. The shear bond strength of all the specimens was measured using Universal Testing Machine. The specimens were subjected to shear load at the metal-porcelain interface with increasing load and the crosshead speed of 2 mm/sec till the disc debonded completely. The debonded samples were observed under Scanning Electron Microscope to assess the kind of failure.
Results: The obtained data of three experimental group samples were analysed using the student's t-test, One-way ANOVA test and Tukey's Post-hoc test. Results of t-test showed that, of all the three techniques, Casting technique shows highest mean of force and shear bond strength, and this mean difference was significant. The same results were shown in One-way ANOVA test and Tukey's Post-hoc test.
Conclusion: From the observations of the present study, it can be stated that Casting technique showed highest mean of load and shear bond strength followed by the CAD/CAM method and DMLS technique, respectively. The results of this study ranged from 69-87MPa which is within the safety borders. Therefore, it can be concluded that all three methods can be used to fabricate the metal substructure in metal-ceramic restoration.
Keywords: CAD-CAM, Casting, Direct Metal Laser Sintering, Shear bond strength.

1. Introduction

The use of metal ceramic restorations began in the late 1950's allowing the development of prosthetic rehabilitation with better cosmetic results replacing previously in demand precious metals [1]. However, to achieve these results the bonding between the metal coping and veneering porcelain is crucial, which depends on parameters such as chemical bonding, mechanical interlocking and coefficient of thermal expansion [2]. Metal oxides produced at the surface of the metal framework alloys enable a chemical bond with the porcelain whereas mechanical bonding is created by sandblasting which provides retention on the surface for the porcelain [3]. These restorations are commonly prepared using conventional casting, Direct Metal Laser Sintering and CAD-CAM processing techniques.

CAD-CAM technology with its constant improvements has been challenging conventional methods in fabricating various dental prostheses. These techniques are being considered for the fabrication of metal ceramic restorations routinely in every clinical situation. The outcomes on using this technology show more precision than traditional fabrication techniques [4]. Frameworks produced using CAD-CAM technology are based upon the principle of prefabricated solid hard blanks which are milled in a 5-axis computerized numerically controlled machine based upon the CAD data. This technique claims to produce consistent excellent marginal fit, and greater mechanical properties as the blanks are made by hot rolled process by which the material is more homogenous [5]. An absolute adjustment that avoids alterations in the connection geometry with the underlying natural tooth during the production process of a prosthesis is well assured by this technique [4].
On the other hand, Direct metal laser sintering (DMLS), also called as 3D printing, is also being considered in preparing such restorations. This technique works by a machine that

reads in CAD software and lays down successive layers of alloy powder which is fused into a solid part by focused laser beam. Advantages include its high accuracy, easy usage, simplified post processing procedures, minimum human error and superior mechanical characteristics [6-8].

Numerous studies that evaluated the bond strength of ceramic to metal core fabricated through different techniques. However, an accurate comparison of bonding of ceramic to Ni-Cr metal core fabricated using the techniques: conventional casting, DMLS and CAD-CAM has not been analysed previously. With this background knowledge, the present study has been attempted to perform a distinctive analysis of the shear bond strength of porcelain fused metal substructure fabricated by conventional casting, Direct Metal Laser Sintering and CAD-CAM processing techniques.

2. Materials and methods

The present in-vitro study was conducted in the Department of Prosthodontics, Sri Sai College of Dental Sciences, Hyderabad, Telangana, India. Approval to conduct the study was obtained from the Institutional Review Board of the institution prior to the start of the study. A total of 45 samples were prepared and divided into 3 groups (n=15 in each group). Preparation of the samples in each group was done in the following procedures

2.1 Group A- Conventional Casting Method

Firstly, an acrylic block of dimensions 20mmx10mmx4mm was designed using the software Corel Draw Graphics Suite Version22 (Figure 1). On this block, the specimens to be casted were sprued (Figure 2) using sprue wax of 2.5mm diameter followed by investing using the standard water powder ratio with a ring liner (Figure 3a and b). This was followed by a wax burnout step carried out in a burnout furnace at the temperature of 980 degree Celsius for 60 minutes (Figure 4). For fabrication of the specimens, fresh pellets of nickel chromium alloy were used (Figure 5). Casting was done and the mould was placed into centrifugal casting machine into which the molten nickel chromium alloy metal was flown. Once the molten metal was flown into the mould completely, it was taken out of the machine and allowed to cool gradually. The investment material was removed with 250μ aluminium oxide particles in recycling sand blaster at 4-5 bar pressure at 45-degree angle and then the casting was retrieved. The sprues were then cut using carborundum disc and the samples were finished using metal finishing points.

2.2 Group B-DMLS

In this group, the software Autodesk Mesh Mixer Software Version 3.5 was used to design the specimens. Desired dimensions were entered into the system (EOS M100) and the data was stored as STL FILE which was transferred into the machine for the fabrication of specimens (Figure 6). Metal powder of very fine particles (20 microns) was used for fabrication which was moved over the machine platform and spread evenly so that the laser beam (0.1 microns) on top melts the metal locally and the powder gets fused. This procedure was repeated until the samples were fabricated in accordance with the virtual design. Finally, the samples were retrieved and finished (Figure 7).

2.3 Group C- CAD-CAM

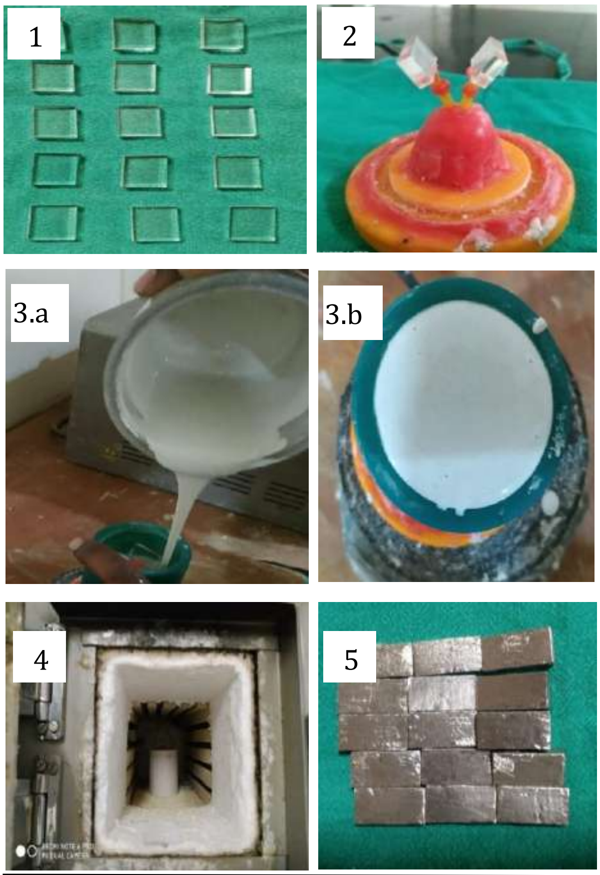

Figure 1 - 5: 1. Acrylic blocks, 2. Spruing, 3.a. Investing, 3.b After investing, 4. Wax burnout, and 5. Nickel-Chromium alloy.


Figure 6. DMLS Machine
Figure 7. Final DMLS samples

Fabrication of the samples in this group was done using the CAD software Autodesk Mesh Mixer Software Version 3.5. Firstly, a 3D virtual model of the metal specimens was prepared using the CAD software. Secondly, to fabricate the 3D model, it was exported to the CAM unit of the system in STL format (Figure 8). Round universal blanks (ARUM) with a thickness of 10 to 40 mm and 98.5 mm diameter were taken for milling using a 5-axis computerized numerically controlled milling machine following the wet milling protocol at 65,000 rpm. Finally, the milled specimens were separated using a cutting disk and sandblasted with 125μ aluminium oxide particles at 3 bar pressures (Figure 9).

Figure 8. CADCAM Unit
Figure 9. Final CADCAM samples

Figure 10. Final samples from the three groups

2.4 Application of dental porcelain

Porcelain was applied to all the samples, according to the manufacturer's instructions, by layering technique using feldspathic porcelain (SHOFU-VINTAGE HALO) that involved applications of opaque and dentin layers. A layer of paste opaque porcelain was first applied to the metal after mixing and fired in a porcelain furnace. To avoid shrinkage, another layer of paste opaque porcelain was mixed and applied over the metal specimens and were fired. Later 1st layer of dentin porcelain application and firing was done followed by 2nd firing and auto glaze firing. A ceramic layer of thickness 2 mm was achieved and measured using digital vernier callipers.

2.5 Evaluation of shear bond strength

The shear bond strength of all the specimens (Figure 10) was measured using Universal Testing Machine. Each specimen was placed in the machine such that the metal porcelain interface lied exactly at the point of application of force. The specimens were subjected to shear load at the metal-porcelain interface with increasing load and the crosshead speed of 2 mm/sec till the disc debonded completely. The force (N) that caused a bond failure on the metal-ceramic interface was recorded in the units of Megapascals (Mpa). The debonded samples were observed under Scanning Electron Microscope to assess the kind of failure (Figure 16). Values from Universal Testing Machine and Scanning Electron Microscope were noted and subjected for statistical analysis.

3. Results

The obtained data were subjected to statistical analysis using IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp. Descriptive statistics were performed on excel sheet data (Table 1). These include mean and standard deviations of force and shear bond strength of samples belonging to three experimental groups. For inferential analyses, IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp. software was used. These include comparison of means of force and shear bond strength of three experimental group samples using student's t-test, One way ANOVA test and Tukey's Post hoc test. Results of t-test showed that, of all the three techniques, Casting technique showed the highest mean of force and shear bond strength, and this mean difference was significant (Table 2). The same results were shown in One way ANOVA test and Tukey's Post hoc test, but the difference was not significant (Table 3-5). However, the 95% Confidence interval included 1 and therefore the results of *p* value of these tests should be ignored, and results of means compared using t test should be considered. To further find out the statistically significant difference among the three different groups, Cohen's D effect size test was performed. The effect size of three different groups was: Casting vs. DMLS- 1.44, Casting vs. CAD-CAM- 0.3 and DMLS vs. CAD-CAM- 1.13. It was observed that the overall effect size of three groups was greater than 0.8, which is considered as statistically significant. Therefore, it can be interpreted that the mean difference in the values of force and shear bond strength between the three experimental groups was statistically significant with Casting technique showing highest values (Figures 11 and 12). SEM analysis of failures of samples from all the three groups was performed. Majority of the failures that occurred (80%) were of a mixed type (cohesive and adhesive) in Ni-Cr. A SEM image of the base metal alloys under high magnification (original magnification X250) showed many small pores in the veneering porcelain from which the fractures originated and propagated into the veneering ceramics. A careful examination found a thin layer of veneering porcelain covering the fracture surface (Figures 13 a-c).

Table 1. Descriptive of the study parameters

Variable	Mean	SD	Range	Minimum	Maximum
Casting technique force	1757.13	590.829	1863	1174	3037
Casting technique shear bond strength	87.8567	29.54143	93.15	58.70	151.85
DMLS technique force	1390.07	483.311	1928	555	2483
DMLS technique shear bond strength	69.5033	24.16556	96.40	27.75	124.15
CAD-CAM technique force	1677.53	541.486	1746	638	2384
CAD-CAM technique shear bond strength	83.8733	27.07294	87.30	31.90	119.20

Table 2. Mean comparison of load and shear bond strength of 3 techniques using t test

Variable	t value	p value	95% Confidence Interval	
			Lower bound	Lower bound
Casting technique	11.518		71.4972	71.4972
DMLS technique	11.139	**<0.001***	56.1209	56.1209
CAD-CAM technique	11.999		68.8808	68.8808

*Significant at 5% level of significance

Table 3 Mean comparison of load and shear bond strength of 3 techniques using One way ANOVA

Variable	F value	P value
Force	1.916	0.16
Shear bond strength	1.812	0.12

Table 4. Mean comparison using of loads in 3 techniques Tukey's Post hoc test

Dependent variable	Standard Error	p value	95% Confidence Interval	
			Lower bound	Lower bound
Casting Vs. DMLS		0.163	112.28	112.28
Casing Vs. CAD-CAM	197.301	0.914	558.94	558.94
DMLS Vs. CAD-CAM		0.322	766.81	766.81

Table 5. Mean comparison using of shear bond strength in 3 techniques Tukey's Post hoc test

Dependent variable	Standard Error	p value	95% Confidence Interval	
			Lower bound	Lower bound
Casting vs. DMLS	9.865	0.163	-5.6134	-5.6134
Casing vs. CAD-CAM		0.914	-27.9500	-27.9500
DMLS vs. CAD-CAM		0.322	-38.3367	-38.3367

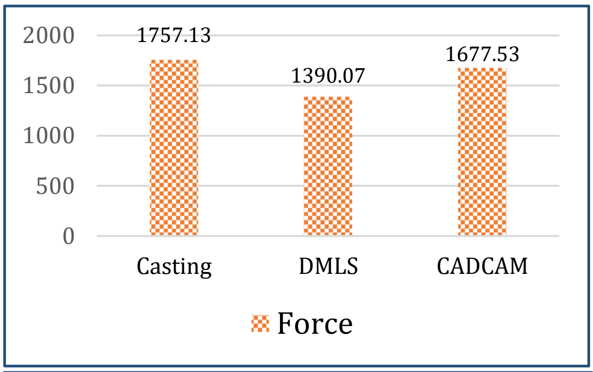

Figure 11. Means of force of three experimental groups

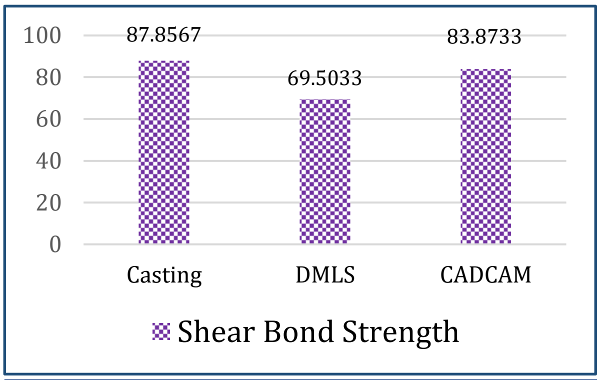

Figure 12. Means of shear bond strength of three experimental groups

4. Discussion

Till date numerous methods have been attempted to quantify adhesion of porcelain-metal bond. However, none of the methods are error-free due to the complexity of the porcelain - metal bonding. Thermal stresses are superimposed on C load stresses in metal-porcelain restorations for clinical application. For the majority of bond experiments described in the literature, stress concentration is present at the site near the load application shear tests.

The present study was an attempt to perform a comparative evaluation of the shear bond strength of porcelain fused metal substructure fabricated by conventional casting, Direct Metal Laser Sintering and

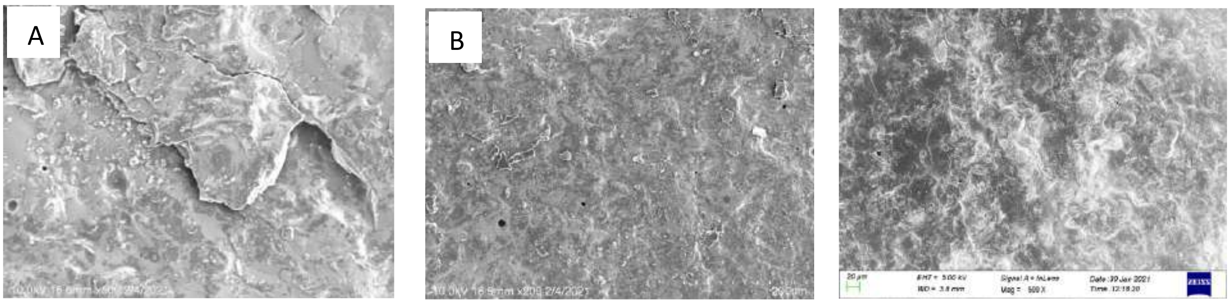

Figure 13 a-c. Scanning Electron Microscope images of a. Group-A (Casting), Group-B (DMLS), and Group-C (CAD-CAM)

CAD-CAM processing techniques. The results showed that Casting technique presented highest mean of force and shear bond strength.

Chong MP *et al.* [9] reported that persistent bond at the metal ceramic junction leads to success of metal ceramic restoration[9]. Several tests are capable of evaluating the metal-ceramic bond strength, such as flexural mode, twist, shear, tension or the combination of flexural and twist modes, all presenting advantages and disadvantages. The shear test is considered by some authors as the most adequate to measure bond between two materials as reported by Dias AHM *et al.* [10]. Lombardo GHL, Moslehifard E *et al*. and Deepak K *et al*. reported that the shear test is exceptionally dependable, because it relies on the least experimental variables and constitutes less residual stress at the metal–ceramic junction and also oblique forces are decreased. Therefore, the Shear bond strength test was used in the present study [11-13].
Hammad IA, Daftary F, Malhotra ML and O'Connor RP reported that mean shear bond strength greater than 10MPa indicate clinically satisfactory results [14-17]. The results of this study ranged from 69- 87MPa which is within the safety borders. In a study conducted by Mhaske Prasad *et al*. (2014) [18] the mean of shear bond strength of the casting group was 23.88 MPa and the mean of shear bond strength for the DMLS group was 23.70 MPa. Similarly, in a study conducted by Zhou *et al.* [19], the bond strength values were compared in the samples produced with the casting method and Concept Laser, and it was reported that the bond strength values were higher in the samples produced with the casting method. In contrast with the present study, Xiang and Ren *et al*. [20] found no significant difference in bond strength of the DMLS and casting groups. Serra-Prat *et al*. [21] in their study showed that despite higher bond strength of the casting group, the difference between the casting and DMLS techniques did not reach statistical significance. The results of the SEM analysis of the present study revealed that the majority of the failures that occurred (80%) were of a mixed type (cohesive and adhesive) in Ni-Cr. Similar results were shown in the study done by Shilpa *et al.* [22].

The present *in vitro* study presents some limitations. Firstly, it could not reproduce all clinical parameters such as compressive strength, colour stability, marginal fit and adaptation. Secondly, the different manufacturing methods might have influenced the mechanical properties and microstructural characteristics of fractured surfaces which has not been studied to its fullest extent in the present study. Therefore, further studies are recommended to be conducted which address the mentioned limitations.

5. Conclusion

From the observations of the present study, it can be stated that Casting technique showed highest mean of load and shear bond strength. Next best was CAD/CAM method followed by DMLS technique. The results of this study ranged from 69- 87MPa which is within the safety borders. Therefore, it can be concluded that all the three methods can be used to fabricate the metal substructure in metal ceramic restoration.

Conflicts of interest: Authors declared no conflicts of interest.

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