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Evaluation Of Bond Strength of Dental Ceramic Materials With Co-Cr Copings Fabricated Using Different DMLS Machines - A Systematic Review

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ABSTRACT

Background: New invention made dentistry to a next level . Metal ceramic bonding can be dependent on the technology. Hence the aim of the review is to assess the bond strength of ceramic with cobalt chromium copings fabricated on various DMLS machines.

Materials and Methods: The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were applied. A systematic search was conducted by an electronic search in PubMed, Sciencedirect, European PMC, Google Scholar and Cochrane databases. Several others were complemented by a manual search.

Results : A total of 151 papers were screened, with 5 deemed appropriate and the rest failing to meet the Systematic Review's requirements. Majority of them were in vitro trials.The SLM and conventional cast sample groups did not significantly differ in terms of mean bond strength, according to a student t-test conducted within the groups. A mixed fracture pattern was detected by SEM/EDS analysis on the debonding interface of both the SLM and in comparison to the control group in the cast groups, the SLM group showed significantly more porcelain adhesion.

Conclusion: To determine the bonding strength of ceramic to DMLS manufactured co-cr copings, more clinical studies with longer follow-up are needed.

Keywords: *DMLS, direct metal laser sintering, debonding, ceramic bonding, adhesion, SLA*

INTRODUCTION

Traditional technique relies on lost wax technique for fabricating the metal copings of porcelain fused metal crowns (1) Base metal alloys and mostly co-cr based alloys are widely used for fabrication of these metal copings(2).

The procedure of casting itself is tedious presenting various difficulties in trimming and finishing of these copings, which is a time consuming procedure (2,3). Owing to these inherent difficulties, bonding of porcelain to the metal substrate is still a challenging aspect, especially with the metal fused ceramic restorations(4). Various techniques and technologies have been introduced, tried and improved in this field, to achieve an optimal bonding (5).

To overcome all these negative outcomes, a newer CAD/CAM based technology has been introduced (6).Among the various CAD/CAM based technologies for fabricating the metal coping, the newly developed DMLS, an additive metal fabrication technology has been introduced and being improved in recent days. Based on information received from three-dimensional (3D) computer-aided design and using a data file, metal powder is shot selectively and fused with a laser to laminate approximately a 20–60 μm thick layer with each shooting to complete a metal structure.

SLM (Selective Laser Melting) and DMLS are the two major technologies for CAD/CAM based additive manufacturing of metal copings. Metal powders are subjected to higher temperatures to fuse, but not to melt together, to form a solid component in the DMLS process (7). SLM, on the other hand, melts the metal powder entirely, resulting in a homogeneous element with a universal melting point and the same mechanical properties. Although the processes are similar, DMLS is used to make alloys for metal substructures, while SLM is used to make single element metals like titanium or aluminium. On the other hand, DMLS and EBM use the same technologies, with the exception in heating and solidifying the metal powder (8).

DMLS (selective laser melting) is a novel additive manufacturing method that improves production versatility, material properties, and product development cycles(9,10,11). DMLS allows powder to be fully melted without retaining much porosity, resulting in near-full density objects with complex geometries. The high efficiency, good aesthetics, and high density of DMLS products suggest that DMLS may have a significant capacity for dental restoration fabrication. In the preparation of DMLS prostheses for dental applications, the choice of metallic powders is critical. Characterization Studies, evaluating various metallic powders, elicited Co-Cr powders to be suitable in additive technologies (12,13). Co-Cr was most widely used metal as compared to Ti based alloys due to its inherent advantages of superior biocompatibility as compared to nickel chromium alloys and low cost as compared to titanium based metal alloys (12).

According to allergy studies(14), intraoral exposure to certain elements found in base metal alloys (such as nickel and beryllium) is dangerous to human health. Recently, a new Co–Cr alloy based on DMLS technology was launched for the production of a new type of base metal copings. The immediate benefit of this DMLS Co–Cr alloy is that its efficiency is comparable to that of other base metal alloys, but without an allergic nickel component. It is important for porcelain-fused-to-metal (PFM) crowns to have sufficient bond strength in order to achieve clinical durability. Between the metal substrate and the porcelain veneering In both the clinic and the laboratory, any form of metal–ceramic fracture failure can become a costly and time-consuming problem. The failure rate of porcelain-fused-to-metal crowns is high. The percentage varies from 2.3 percent to 8% (15–17). As a result, the ceramic bonding capability of the Co–Cr DMLS alloy is crucial to its suitability for dental applications. While a variety of mechanical tests can be used to assess the debonding strength of a metal–ceramic interface, the Schwickerath crack initiation test (three-point bending test), first proposed by Lenz et al(18), is the most widely used to check the debonding strength of a metal–ceramic system. Ringle was the first to use the SEM/EDS system for measuring porcelain adhesion to metal, and it has since been widely used (19,20,21). Literature shows varied results on the bond strength obtained in porcelain fused metal substrates, fabricated especially with the usage of DMLS or SLM based additive technology. While few support its superiority(14,22), others showed a poor bonding (23)on using this technology.

Our team has extensive knowledge and research experience that has translated into high quality publications(24–33)(34–39). Hence, the aim of this systematic review is to compare a Co–Cr alloy fabricated using the DMLS technique to a standard cast Co–Cr alloy sample in terms of metal–ceramic bonding strength and porcelain adherence. The review also aimed at determining the best system to offer optimal ceramic bond strength on coping fabricated using various DMLS machines.

Structured Question

The aim of this literature review was to assess the bond strength of ceramic with co-cr copings fabricated on various DMLS machines. The researchers followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

P - Porcelain fused to metal restorations
I - DMLS printing machines
C - bond strength

MATERIALS AND METHODS

This review was done in accordance with guidelines of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)(40).

The keywords were defined based on one PICO (population [P], intervention [I], comparison [C], and outcome [O])

Search strategy and Sources

Two authors after preliminary review of literature created the search strategy (Table 1) using Controlled vocabulary (Medical Subject Headings) and freetext. An electronic search in PubMed, Science Direct, Cochrane Library, European PMC, and Google Scholar databases was used to perform the search strategy. No search restriction on date or language was set. Speciality journal, grey literature and reference of potentially eligible articles were hand searched to find additional paper. Conference paper, short communication, letter to editors, case report/series, review were excluded (Table 2).

Searched Databases:

- PubMed
- Cochrane
- Google scholar
- European PMC
- Science direct

No limitation regarding publication type and publication date was set.

Hand Searching

The following journals were hand searched for articles on the subjects of interest to complete the review:

- The Journal of Prosthetic Dentistry
- Journal of Oral Rehabilitation
- Journal of Advanced Technologies and Techniques
- Journal of Medical Sciences
- Journal of Prosthetic and Restorative Dentistry
- Journal of Indian Prosthodontic Society
- European Journal of Prosthetic and Restorative Dentistry
- Journal of Advanced Prosthodontics

Screening and Selection studies

Initially, two independent reviewers scanned the titles and abstracts to find relevant articles based on prespecified inclusion and exclusion criteria . The full texts of potentially eligible articles were retrieved to determine their eligibility for present review. Any disagreements were resolved by consensus or by a third reviewer.

Eligibility Criteria

Inclusion criteria

1. In vitro studies
2. Studies on metal ceramic crown bonding
3. Articles discussing ceramic debonding
4. Studies on ceramic bonding to metal

Exclusion criteria

Case reports

Review articles

Search Strategy

The following search strategy was performed based on the search terms from PICO (Table 1).

RESULTS

Search

The selection process from Pubmed, Science Direct, EMBASE, Cochrane and additional sources subjected to manual search yielded 151 articles, as reported in the flowchart (Fig. 1). A total of 20 studies were included after abstract screening, and 19 reports were evaluated for eligibility, finally only five studies accomplished the inclusion criteria. The four classified studies considered

Extraction of data

Using structured abstraction tables, the data from the selected studies was extracted. Type for data extraction The papers were gathered together, and the most important information was collected (Table 3). The following were extracted from each sample and mentioned in one table as general characteristics of the study: 1) Author and year 2) Study design 3) Sample size 4) Groups 5) Types of statistical methods used 6) Outcome measures 7) Inference (Table 4).

Before ceramic veneering, all of the findings in this review were CoCr restorations. One study featured patients and was clinical, whereas the other employed master models made of human teeth. Six of the studies evaluated the bond strength of multi-unit FDPs, whereas the other twelve covered single crowns. The review produced 36 test groups with single crowns, four test groups with 4-unit FDPs, and 10 test groups with 3-unit FDPs because the majority of the studies published results from more than one test group. The groups ranged in size from three to 110, but the majority of them contained ten patients or specimens. Five studies examined traditional and digital impression techniques, while 13 studies solely published data from conventional impression techniques. In the experiments, the abutment teeth included incisors, canines, premolars and molars. Eight test groups were manufactured using CAD design with subtractive or additive produced wax patterns for the lost wax technique (CLW), nine test groups were manufactured using the lost wax technique (LW), three test groups were manufactured using soft milling (SMill), sixteen test groups were manufactured using hard milling (HM), and fourteen test groups were manufactured using additive manufacturing (AM).

The SLM and conventional cast sample groups did not significantly differ in terms of mean bond strength, according to a student t-test conducted within the groups. A mixed fracture pattern was detected on the debonding interface of both the SLM and in comparison to the control group in the cast groups, the SLM group showed significantly more porcelain adhesion.

DISCUSSION

Bond strength of dental ceramic materials with cobalt chromium copings fabricated using different DMLS machines prompted this updated analysis due to conflicting findings in previous publications. Five studies were chosen from the total number of studies analysed for this systematic review. Many of the experiments that were included were performed in the eastern hemisphere. In the west, there was a dearth of facts (14,41).

Metal Ceramic Bond Strength

The metal–ceramic bond strength and fracture mode of an DMLS prepared Co–Cr alloy are compared to a cast Co–Cr base metal alloy for the first time in this review. Dental prosthesis fracture is a multifaceted issue that is both serious and expensive (8). Ceramometal failure can be caused by a combination of incompatible thermal expansion coefficients between metal and porcelain, microcrack formation inside the porcelain during the condensation and sintering process, and occlusal forces or trauma(42).

To date, there have been 5 published articles comparing the bond strength of dental ceramic to Co-Cr copings fabricated using different DMLS machines (43,44,45). The use of DMLS to fabricate Co-Cr copings (5) have shown promising results; however, further studies need to be done to conclude something substantially. The included studies were majorly concentrated and analysed the superiority of bond strength of fabricated restorations. But various other issues such as marginal fit, surface roughness, and aesthetics need to be addressed in future studies.

Dmls Vs Laser Sintered Vs Cad Cam

The porcelain bond strength of cobalt-chromium (Co-Cr) metal frameworks prepared using the traditional lost-wax technique was compared to milling, direct metal laser sintering (DMLS), and laser sintering (46). Except for laser sintering, DMLS and CAD CAM experienced adhesive and mixed form bond failure. CAD/CAM however had higher bond strength in comparison with DMLS and laser sintering (46),(47). There is literature that states the strength of Co-Cr crowns made using various production methods, such as casting, milling, or laser-sintering, is the same (45). The results of these in vitro studies however may be influenced by numerous factors pertaining to the oral cavity which may alter the metal ceramic bond strength.

Laser-sintered Co-Cr crown copings showed increased surface roughness and better internal and marginal fit than copings produced by milling or milled wax/lost wax technique (48).

Against this background, studies showed promising accurate results for the use of DMLS to fabricate Co-Cr copings (5,41,48) however, the clinically decisive bond strength has not yet been evaluated for which further studies have to be done.

Thermal Ageing V/S No Thermal Ageing

The bond strength of various types of cobalt-chromium (Co-Cr) metal frameworks to a single form of low-temperature porcelain system varied after the thermal ageing process (43). Among the included studies, one study compared Traditional casting, CAD/CAM, and two commercially available lasers to create 120 Co-Cr alloy specimens and a single type of ceramic (Kuraray Noritake Dental Inc., Tokyo, Japan was layered over them. Half of the specimens were subjected to a thermal ageing process after the subgroups were determined. A 3-point bending test was used to determine the bond strength of the specimens. SEM under 1000 magnifications was used to analyse the metal-porcelain bonding region of samples chosen at random from eight classes.

The bond strength values of all samples, with and without thermal ageing, were found to be higher than the minimum acceptable value.

Thus, the metal-ceramic bond strength varies depending on the manufacturing process used, but is unaffected by thermal ageing (43).

Co-Cr vs Gold Alloy : Fracture Resistance

Metal ceramic crowns with copings made of a high-gold alloy have a numerically higher fracture strength than crowns with copings made of Co-Cr alloys(45,49)). There was a substantial difference in fracture intensity between the gold alloy copings and Co-Cr laser-sintered copings. The difference in fracture surfaces is confirmed but low (45,49). Thus, even though gold alloy gives superior fracture toughness, the use of Co-Cr to fabricate copings show greater promise (41). The available literature however isn't enough to come to solid conclusions, and thus the need for further detailed studies arises.

SEM/EDS study of Si ka X-rays was created as an additional assessment of the bonding strength between metal and ceramic in addition to the three-point bending test. To ascertain whether debonding had taken place at one end of the metal-ceramic contact, where a crack would have extended towards the other intact end, visual inspection was used. A combination of cohesive and adhesive fracture modes were seen during a SEM/EDS inspection of the debonding surface of both groups. Additionally, the cast Co-Cr metal-ceramic interface experienced higher metal exposure (adhesive fracture) than the SLM specimen, which was supported by the EDS findings. Cohesive failure (the crack totally within the porcelain) would be the perfect circumstance if the metal-ceramic link were to fracture. It is always predicted that the cohesive strength within the porcelain layer will be weaker than the interfacial binding strength between metal and ceramic. As a result, the SLM specimen in our investigation behaved better by maintaining greater porcelain adhesion during the destructive three-point bending test.

There was no correlation between the porcelain adherence values and the force-to-failure values, according to Papazoglou and Brantley. In addition, Zinelis et al. found that, as compared to specimens with an adhesive fracture mode, specimens with primarily cohesive fractures produced the highest and lowest bond strengths during the mechanical test. 12 The three-point bending test revealed no appreciable difference between the SLM and the cast group, whereas the SLM demonstrated the disparity between fracture modes and the force-to-failure values.

Thus in our opinion, despite the possibility that the three-point bending test utilised in this study might not accurately reflect the actual environment, and that despite having a common flaw shared by all metal-ceramic mechanical testing techniques, this test can still be used to assess the bonding strength between metal and ceramic. A more suitable mix of SLM metal and ceramic may also be created in the near future due to the ongoing development of new ceramic systems.

Limitations

Assessment of quality of the included studies was limited due to heterogeneity in type of material and the type of preparation design. The high heterogeneity of the included studies prevented quantitative analyses of the data. This systematic review advocates more research to be conducted in this field for better clinical outcomes of prosthetic dentistry.

Hence, there is a need for more high quality research to evaluate the bond strength of dental ceramic to Co-Cr copings fabricated using different DMLS machines as well as updating the current existing literature for a better understanding and clinical judgement of the same.

Therefore, any general conclusions need to be drawn cautiously.

Future Scope

Most of the studies available on this topic are invitro, of which only a few were relevant to the discussed topic. The literature available isn't enough to draw solid conclusions, and thus there is a need for further detailed studies on the same.

Also there is a need for heterogeneity as most of the literature available is published in and around the eastern hemisphere. Thus leading to a possible demographic bias.

CONCLUSION

Within the constraints of the current analysis, the following conclusions can be drawn:

There was no significant difference in the metal ceramic bond strength in copings fabricated by casting, milling, or laser sintering.

Metal ceramic crowns with copings made of a high-precious gold alloy have a higher numerical fracture resistance than crowns with copings made of Co-Cr alloys.

When examining the fracture surfaces between copings made by dmls, conventional and CADCAM techniques, the difference is verified, but was statistically not significant.

However, the high heterogeneity of the included studies prevented quantitative analyses of the data. Therefore, any general conclusions need to be drawn cautiously. As a result, the clinical significance of the discrepancy cannot be confirmed and must be explained by further research

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TABLE 1: Table search strategy

P (search by inclusion (or)	((((((((DMLS) OR (DML*)) OR (directly milled laser sintered crowns)) OR (directly milled laser sin***))) OR (rapid prototyping)) OR (selective laser sintering)) OR (metal printing)) OR (3d printed metal)
I (search by inclusion OR)	(((((dmls printing machines) OR (dmls printers)) OR (metal laser sintering machines)) OR (metal 3d printers)) OR (3d printers)) OR (metal printing)
C (search by inclusion OR)	(((((((((((bond strength) OR (ceramic bonding)) OR (ceramic bond strength)) OR (ceramic debonding)) OR (ceramic adherence)) OR (bonding strength)) OR (debonding)) OR (bonding)) OR (ceramic failures)) OR (dmls failures)) OR (ceramic failures in dmls)) OR (ceramic failures in metal ceramic)

TABLE 2: Table showing excluded studies

S No.	Author	Reason For Exclusion
1	M Vojdani	Title and abstract not relevant
2	Aaron B. Harding	Title and abstract not relevant
3	Guliz Aktas	Title and abstract not relevant
4	Philipp KohorsT	Title and abstract not relevant
5	Francesco Mangano	Title and abstract not relevant
6	Luis Gustavo	Title and abstract not relevant
7	Giovanni de A. P	Title and abstract not relevant
8	Giovanni A. Di Giacomo	Title and abstract not relevant
9	Philipp Kohorst	Title and abstract not relevant
10	Carlo Mangano.	Title and abstract not relevant
11	Emily R. Batson	Title and abstract not relevant
12	J.-P. Kruth	Title and abstract not relevant
13	Bandar AlMangour	Title and abstract not relevant
14	J.R. McDonough	Title and abstract not relevant
15	Elif Ece Yoldan	Title and abstract not relevant
16	T.Ibn-Mohammed	Title and abstract not relevant
17	Christel Larsson	Title and abstract not relevant

TABLE 3: Table showing included studies and their details

Author and Year	Study Setting	Sample size	Group 1	Group 2	Group 3 and 4	Type of statistics used	Outcome Measures
1.Elif Ece Yoldan, 2020	InVitro	n=120	CAD CAM	CONVEN TIONAL CASTING	DMLS	ANOVA	Bond strength
2.Necati Kaleli, 2017	Invitro	n=96	Conventio nal lost-wax	MILLING	DMLS	1 WAY ANOVA and Tukey honest significant difference tests	Bond strength
3.Sozan Hama Suleiman 2013	InVitro	n=50	CAST Co-Cr	MILLED Co-Cr	LASER SINTERE D Co-Cr	Not mentioned	BOND STRENGTH
4.Edeinburg,Zalsman, Elliot 2017	Invitro	N= 78	SLM	MILLED Co-Cr	LASER SINTERE D Co-Cr	Casted Co-Cr copings	Bond Strength
5.Chang et al 2019	Invitro	N =64	Laser sintered	CAD CAM		Not mentioned	Bond strength

TABLE 4: Table showing included studies result and their performance

Characteristics	Sozan Suleaman et al (2013)	Necati Kaleli et al (2017)	Edinburg Elliot et al (2017)	Chang et al (2019)	Elif Yoldan et al (2020)
Primary casting method used	DMLS	Conventional	Laser sintered	SLM	CAD CAM
Study design , setting & details	Clinical study setting, Invivo Sample size of 32 Used 3-4 unit fpds Compared the findings with a control group of SLM fabricated copings	Retrospective study design Sample size of 78 including both single crowns and 3 unit fpds Used single crowns Compared the findings with a control group of DMLS fabricated copings	Prospective Study Sample size of 49 Compared the findings with a control group of conventionally casted copings	RCT Sample size of 90 single crowns Compared the findings with a control group of conventional fabricated copings	Prospective study design Invitro setting. \3shape D700 software used, using BEGO Wirobond 280 alloy. Sample size of 120. Compared the findings with a control group of conventionally casted copings
Result	SLM fabricated Co-Cr copings had better bond strength with ceramic	Cadcam fabricated Co-Cr copings had better accuracy and also bond strength with ceramic	Laser sintered Co-Cr crown copings showed increased surface roughness and better internal and marginal fit produced by milling or milled wax/lost wax technique.	SLM fabricated Co-Cr copings had better bond strength with ceramic	Cadcam fabricated Co-Cr copings had better accuracy and also bond strength with ceramic

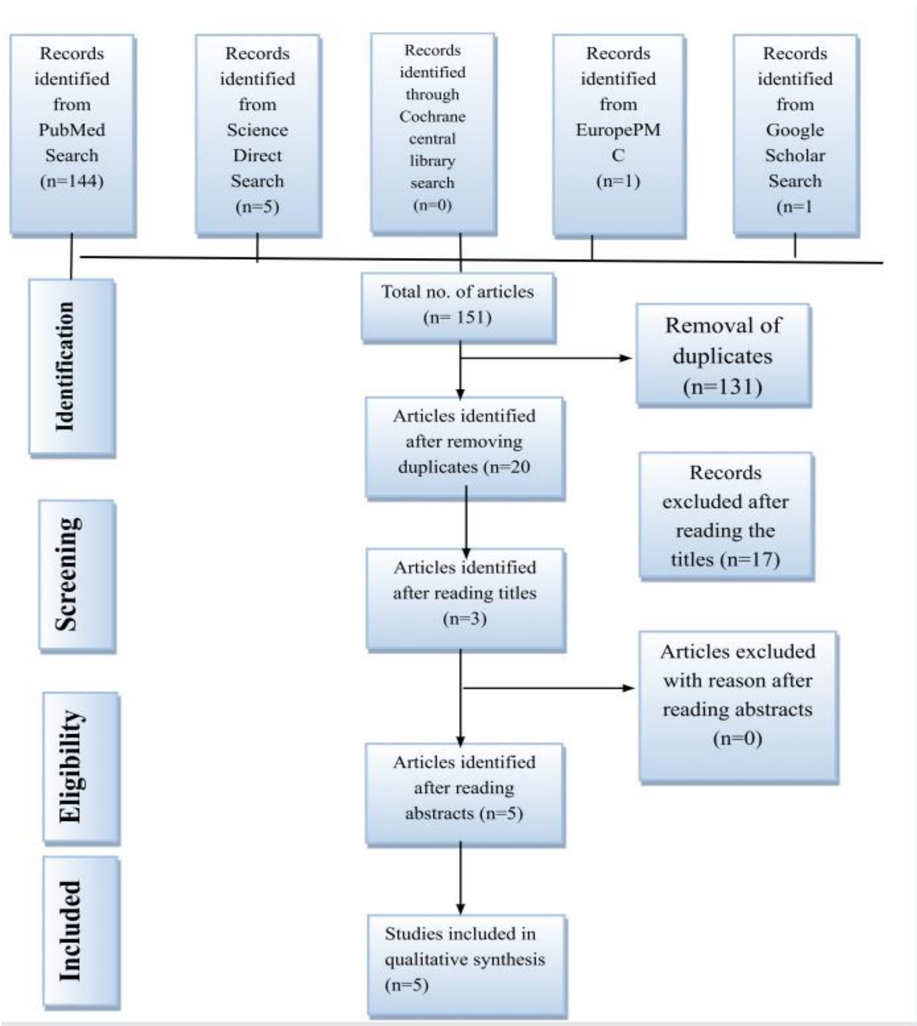

FIGURE 1: Flow chart of the study selection