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Original Article

Effect of soldering on bond strength of porcelain to metal in porcelain-fused-to-metal castings

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Abstract

Introduction: Soldering has several applications in prosthodontic treatments; however, the effect of soldering on porcelain to metal bond strength has not been adequately studied. This study was designed to assess the bond strength of porcelain to metal, and the mode of failure at the soldered and non-soldered areas of cubic specimens.

Materials & Methods: In this in vitro, experimental study, 40 porcelain-metal specimens were fabricated under similar conditions and divided into two groups (n=20). In the test group, a hole was created at the center of the frame and was then soldered and veneered with porcelain. The second group was considered as a control group. The bond strength was measured at the center of the specimen using the 3-point bending test in a universal testing machine with a crosshead speed of 0.5 mm/min. The mean force required for debonding was determined. Photographs of the specimens were digitalized by a scanner and magnified on a computer screen with x10.5 magnification. Next, each image was divided into 100 squares (1×1 mm). The mode of failure was determined for each specimen. The two groups were compared using independent t-test (p-value< 0.05).

Results: The mean porcelain-metal bond strength was 36.6±7.3 N for the soldered and 37.4±4.6 N for the non-soldered group with no significant difference between them (P>0.05). The mode of failure was cohesive in all specimens in both groups with no significant difference between them (P>0.05).

Conclusion: Within the limitations of this study, the soldered and non-soldered specimens showed no significant difference regarding the porcelain-metal bond strength.

Keywords: Dental bonding, Dental porcelain, Prosthodontics

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ارزیابی میزان استحکام باند بین چینی و فلز و نحوه‌ی شکست در نواحی لحیم شده و لحیم نشده از فریم های مکعبی شکل

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چکیده

مقدمه: لحیم‌کاری کاربردهای متفاوتی در پروتزهای دندانی دارد. اما اثرات لحیم کاری بر قدرت اتصال بین چینی و فلز کمتر بررسی شده است. تحقیق حاضر با هدف تعیین استحکام باند بین چینی و فلز و نحوه ی شکست در نواحی لحیم شده و لحیم نشده ی نمونه های ی مکعبی شکل طراحی شد.

مواد و روش ها: در این مطالعه، ۴۰ قطعه ی فریم چینی-فلز با شرایط یکسان ساخته شده و در دو گروه مساوی ۲۰تایی تقسیم شد. در نمونه های گروه تجربی، پس از ایجاد سوراخ در مرکز فریم لحیم کاری شده و سپس نمونه ها چینی گذاری شدند. استحکام باند نمونه ها در ناحیه ی وسط فریم با استفاده از روش آزمون خمش ۳ نقطه ای در دستگاه یونیورسال با سرعت ۰/۵ میلی‌متر در دقیقه ارزیابی و میانگین نیروی لازم برای شکست اتصال در هر نمونه اندازه گیری شد. تصویر نمونه ها توسط اسکنر و کامپیوتر دیجیتایز شده و تمام تصویرها با بزرگ‌نمایی ۱۰/۵ برابر روی صفحه ی کامپیوتر بزرگ‌نمایی شدند. سپس، هر تصویر به ۱۰۰ مربع ۱×۱ میلی‌متری تقسیم شده و درصد کل شکست کوهزیو و ادهزیو برای هر نمونه ثبت گردید. مقایسات آماری دو گروه با آزمون Independent t انجام شد. (p-value<0.05)

یافته ها: میانگین نیروی لازم برای شکستن اتصال چینی در اتصالات لحیم شده برابر ۳۶/۶±۷/۳ نیوتن و در اتصال لحیم نشده برابر ۳۷/۴±۴/۶ نیوتن به دست آمد (بدون تفاوت‌های معنی دار). نحوه‌ی شکست تمام نمونه های دو گروه هم کوهزیو بوده و بین دو گروه از نظر فراوانی شکست کوهزیو اختلاف معنی‌داری دیده نشد.

نتیجه گیری: : با در نظر گرفتن محدودیت ها ی این مطالعه ، نمونه های لحیم شده و لحیم نشده اختلاف معنی داری در استحکام باند چینی به فلز نداشته است.

واژگان کلیدی: باند دندانی ،پرسلن دندانی، پروتزهای دندانی

Introduction

At present, metal-ceramic restorations, used for the fabrication of fixed partial dentures (FPDs), are the most commonly used type of prosthetic crowns. These restorations benefit from a combination of strength and precision of the cast metal restorations and favorable esthetics of porcelain restorations. [1-3] However, debonding of porcelain from the metal is among the most common problems of these restorations, which can lead to treatment failure. [4] Use of metal-ceramic restorations has greatly increased in the past 40 years due to the technical advances in this field. [1] However, similar to most dental treatments, metal-ceramic restorations may have limitations and shortcomings such as insufficient precision due to the deformation of casting. [5-7] Soldering is extensively used to correct the defects in dental bridges. During the past decades,

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soldering has found new applications particularly in FPDs. Soldering is used to connect the multiple units of a FPD to achieve maximum adaptation to the tooth structure. It is also used to fill the voids present in the castings or add proximal contacts. [8] Evidence shows that soldered long bridges have higher marginal adaptation than bulk castings with the same length. [9, 10]

Porcelain is commonly used for the fabrication of esthetic restorations. However, its low strength against tensile and shear forces is a major drawback. Nonetheless, the bond strength of porcelain to metal base has been the highest compared with that of other available esthetic dental materials. [11] On the other hand, debonding at the porcelain-metal interface is a common problem encountered in metal-ceramic restorations, leading to treatment failure. Walton et al. in 1986 demonstrated that metal-ceramic bond failure was the second most common cause of metal-ceramic restoration replacement. [12] Bonding of porcelain to metal is mediated via four mechanisms. Chemical bonding as the most important mechanisms involves in this process. In chemical bonding, active oxides are formed on the outermost surface of casting and chemically bond to porcelain. Several alloys are used for the fabrication of porcelain-fused-to-metal restorations, and the process of chemical bonding is influenced by the type of alloy and its composition. [13,14]

Soldering has numerous applications for correction of frameworks of metal-ceramic restorations. Despite the advantages of soldering, it is important to ensure that soldering does not affect other properties of metal-ceramic restorations and does not compromise their long-term clinical service. The bond strength of porcelain to different alloys has been previously studied. [15] However, the bond strength of porcelain to base metal alloys at the soldered areas has been less commonly studied. Thus, to the aim of this study was to assess the bond strength of porcelain to a base metal alloy at the soldered and non-soldered areas. The mode of failure was also determined. To the best of the authors' knowledge, limited studies are available on this topic, and the existing ones have reported controversial results, which further highlights the need for further studies on this topic. For instance, Bajoghli et al. [4] reported higher bond strength in metal than in porcelain whereas Aladag et al. [16] and Mehdi et al. [17] reported lower bond strength in metal compared to porcelain at the soldered areas.

Materials & Methods

The protocol of this study was approved by the Research Committee of Islamic Azad University, School of Dentistry, Khorasgan Branch (23810201901005). In this in vitro, experimental study, 40 specimens measuring 20 × 6 × 0.5 mm were cut out of acrylic sheets (Fencia, Kyoto, Japan), used for the fabrication of occlusal splints by a surgical scalpel (Swann Morton, Ohio, USA). They were then divided into two groups of test and control (n=20). The specimens in the test group were perforated at the center using a carbide bur (Saimeng, Zhangjiagang, China) with a round cross-section and a handpiece (Saeshi, Daegu, Korea). The created hole had 2 mm diameter. To ensure the correct position of the hole at the center of specimen, two lines were drawn from the corners so that they crossed at the center, and the hole was created at the intersection.

The acrylic specimens were sprued and flasked in groups of 10 including five test and five control specimens using phosphate bonded investment (S.P.E, Bejing, China). After wax burnout in a furnace (Henan Sante, Luoyang, China), the specimens were cast by the same operator using a base metal alloy (Commend, Dentsply, USA) and a gas oxygen torch (Messer, Bangkok, Thailand). The irregularities of the casting were smoothened by a carbide bur (Saimeng, Zhangjiagang, China), and five specimens from each group were selected. The test group specimens were sandblasted around the created hole with 50 µm aluminum oxide particles under 75 psi for 15 seconds at a distance of approximately 10 mm (18) (Figure 1).

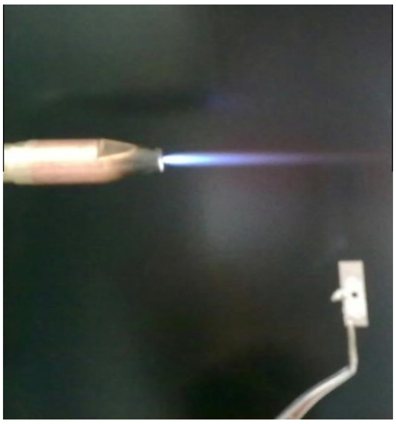

Figure 1. Soldering phase

Soldering was performed by adapting platinum foil (Cookson Dental, Birmingham, United Kingdom) to the bottom surface of the specimens in the test group and

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fixed with sticky wax (MDM Corp., Delhi, India). The specimens were then mounted on phosphate bonded investment. A black pencil was used to outline the soldering area and limit the solder flow around the hole. The casting was gradually heated up and a small amount of flux (AMTECH, Deep River, USA) was also placed in the hole. The solder was placed over the hole and the casting was heated until the solder started to flow. [1] After soldering, excess solder (Verasolder-Albadent, USA) was removed and the area was inspected under a light microscope (Omax, Denver, USA) at x10 magnification to ensure complete filling of the hole with the solder. The specimens in the two groups were then polished with aluminum oxide stone (YJSHARP, Poonay, India) and sandblasted with 50 µm aluminum oxide particles under 75 psi pressure from10 mm distance. A jig was used to standardize the distance of specimens from the sandblaster tip. Sandblasting continued until no trace of bur remained on the specimen.

This was ensured by inspecting the specimens under a light microscope (OMAX, Denver, USA) at x3.5 magnification. The thickness of specimens was measured at three points in the center with 1 mm distance from each other using a caliper (SOWDANE, China). The thickness of platinum foil (Cookson Dental, Birmingham, United Kingdom) was subtracted from the measured thickness in the test group. The specimens were then cleaned with water vapor and degassed according to the manufacturer's instructions.

In the next phase, two layers of opaque porcelain and two layers of A2 dentin porcelain (Ceramco 3, Dentsply, Wolfgang, Germany) with a total thickness of 1.5 mm were applied over the center of specimens with 10 mm length (Figure 2). The thickness of porcelain was controlled by fabricated silicon material (Speedex, Coltene Whaledent, USA). The porcelain was condensed by an electric condenser (TiOZ, Mumbai, India) and its excess water was removed by a paper strip. Glazing was performed according to the manufacturer's instructions, and the specimens were positioned in an Instron machine (Dartec, Turin, Italy) so that their porcelain-veneered surface was faced down. The specimens underwent three-point flexural strength test with a pin through a spherical tip designed for this purpose and load applied to the center of the sample. The cross-head speed was 0.5 mm/min and the load at porcelain fracture was recorded for each specimen.

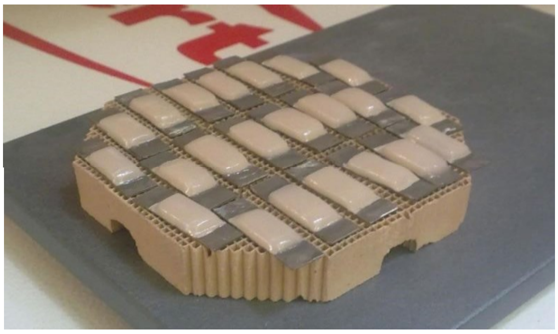

Figure 2. Porcelain application

The porcelain-metal bond failure was categorized as cohesive (fracture within the porcelain), adhesive (fracture at the porcelain-metal interface), and mixed (a combination of adhesive and cohesive) (Figure 3). For this purpose, the images of specimens in two groups were digitized by a scanner (3shape D750, New jersey, Usa) and magnified on a computer screen (Samsung, Tokyo, Japan) by ×10.5 magnification. Each image was divided into 100 squares measuring 1 x 1 mm. Coverage of at least half of the surface area of a square with opaque porcelain was indicative of cohesive failure while coverage of smaller areas indicated adhesive failure. Number of squares with more than 50% of their surface covered with opaque porcelain was then counted. Data were analyzed using the Kruskal-Wallis, Mann Whitney and independent t tests via SPSS version 24 at $p<0.05$ level of significance (Figures 4 and 5).

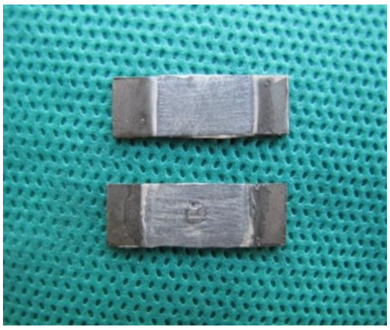

Figure 3. Broken specimens with/without soldering

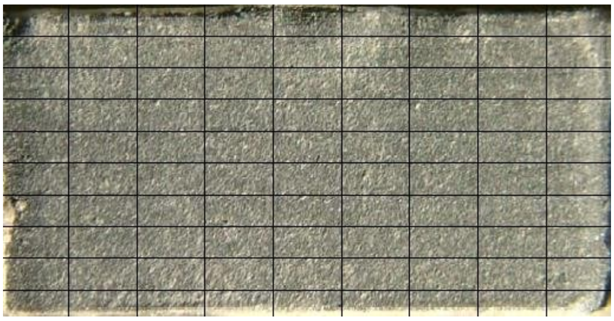

Figure 4. Broken specimen without soldering at x10.5 magnification

Figure 5. Broken specimen with soldering at x10.5 magnification

Results

The mean bond strength was 37.4 N in non-soldered and 36.6 N in soldered specimens (Table 1). Independent t-test revealed that the mean bond strength of porcelain to metal was not significantly different between two groups (P=0.689).

Table 1. Mean (± standard deviation) bond strength of porcelain to metal in soldered and non-soldered specimens

Bond Strength	Mean	Std. deviation	Minimum	Maximum
Non-soldered	37.4	4.6	31	47
Soldered	36.6	7.3	27	52

Assessment of the mode of failure revealed that the mode of failure was cohesive in all specimens in two groups. Thus, the frequency of cohesive failure was not significantly different between two groups (P=1.0).

Discussion

This in vitro study assessed the effect of soldering on bond strength of porcelain to metal. One shortcoming of metal-ceramic restorations is debonding at the porcelain-metal interface, which leads to treatment failure. Low strength of porcelain under tensile and shear loads is another shortcoming of porcelain. However, among the available esthetic dental materials, porcelain has shown maximum bond strength to metal base. [11] Soldering is extensively used to correct the defects of metal-ceramic restoration frameworks. However, further studies are required to ensure that soldering does not interfere with other properties of metal-ceramic restorations. Moreover, the effect of soldering on long-term clinical service of these restorations should be evaluated. [4]

According to the results of the current study, soldering did not significantly affect the bond strength of porcelain to metal compared with non-soldered areas. This finding was in contrast to the results of Mehdi et al., Kuluk et al. and Kang et al. [17-19] who showed that soldering decreased the bond strength of porcelain to meta. One reason for this difference can be the type of alloy used in two studies. Differences in the location of load application may also play a role in this respect. Besides, our results were inconsistent with those of Bajaghli et al. who reported that the bond strength of porcelain to metal in soldered areas was higher than that in non-soldered areas. [4] This may be due to the different shapes of the specimens. In the present study, the specimens were cubic while they were tooth-shaped in the study by Bajaghli et al. [4]

Our methodology was almost similar to that of Galindo et al. [20] who used cubic specimens for measurement of bond strength and their results indicated higher mean bond strength in the soldered group. Studies on the effect of soldering on bond strength of porcelain to metal are limited, and the available ones are widely variable in terms of study design, type of alloys used, load application method, type of porcelain, use of noble or non-noble alloys and technique of soldering. Our results were in agreement with those of Nikellis et al. who suggested equal bond strength in soldered and non-soldered groups. [21] Review of the available literature revealed that two studies expressed that soldering increased the bond strength [4, 20] while others [17-19] demonstrated that soldering decreased the bond strength values.

Form and shape of specimens are other important factors that can affect the results. Bajaghli et al. and Kang et al. used specimens similar to tooth crowns which were different from the cubic samples used in the ongoing study. [4,19] Kang et al. applied load to the buccal cusp of tooth 1.5 mm above the soldered area. [19] Bajaghli et al. used load to the center of pontic, which was the exact location of soldering. [4] The nature of applied load is also important since porcelain has lower strength under tensile and shear loads and this can affect the results. The loads applied to specimens in the study by Bajaghli et al. transferred less stress to the soldered area due to different nature of loads compared with the load applied to the buccal cusp by Kang et al. However, in the oral environment, tensile stresses are more

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commonly generated by flexural loads applied to occlusal surfaces of prosthetic restorations. [4,19] Thus, in the present study, we tried to use the same mechanism of load application as Galindo et al. [20]

Conduction of tests on cubic specimens eliminates the effect of some involved variables in the use of crown-shaped specimens. However, cubic specimens are not ideal either, and generalization of results to the clinical conditions and the result cannot be simply generalized to the clinical situations. Furthermore, the chemical bond strength between the porcelain and metal is influenced by a number of factors such as surface modification of alloy, degaussing and superficial oxidation, and composition of alloy. Hence, these factors should be carefully controlled and standardized. Moreover, the soldering technique affects the oxides produced on the metal surface and can affect the bond strength of porcelain to the metal. [4]

On the other hand, studies on the effect of soldering on mode of failure of porcelain are limited. The current study showed that soldering had no significant effect on the mode of failure of porcelain. The results of Galindo et al. represented higher percentage of cohesive failure in soldered specimens compared with non-soldered specimens. [20] However, Mehdi et al. reported that non-soldered group had higher frequency of cohesive failure than soldered group. [17] Therefore, the results of these three studies are completely controversial. However, the three-point flexural strength test was used in all three studies. It seems that controversy regarding the porcelain to metal bond strength and mode of failure of porcelain in soldered and non-soldered specimens may be due to the technical differences and high number of variables involved in the process of casting and soldering. In the ongoing study, magnified images of specimens were evaluated, but Mehdi et al. and Galindo et al. performed microscopic assessment of specimens, as well. [17, 20] Considering the controversial results, further studies are needed to be done.

Conclusion

The results showed that the soldered and non-soldered specimens had no significant difference regarding the porcelain-metal bond strength. Soldering had no significant effect on the mode of failure of porcelain in soldered and non-soldered specimens.

Limitations: This study had an in vitro design. Thus, generalization of results to the clinical setting must be done with caution. Another limitation of this study was difficult standardization of preparation conditions and the risk of lab technician errors, which could affect the results.

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Conflict of interest disclosure: The authors state that they have no conflict of interest.

Author's Contribution

Farzamfar, Mahabadi, Barekatain and Jamshidi developed the study concept and design Mahabadi, Barekatain as well as Jamshidi and Farzamfar performed the study supervision, analysis, interpretation of data and manuscript drafting. Jamshidi and Farzamfar collected data, recorded clinical indices and provided draft of study report.

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