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Effect of Different Flaw Sizes and Surface Treatment on Biaxial Flexural Strength of Feldspathic Porcelain

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Authors' contributions

This work was carried out in collaboration between all authors. Author HK designed the study, wrote the protocol and wrote the first draft of the manuscript. Author NA managed the literature searches, analyses of the study and performed the spectroscopy analysis. Author SG managed the experimental process. Author FS identified the species of plant. All authors read and approved the final manuscript.

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ABSTRACT

Background and Objectives: Porcelain restorations are often ground for recontouring and occlusal adjustments. This removes the surface glaze layer and causes flaws that can grow in wet environments due to stress corrosion cracking and decrease the strength of porcelain and subsequently the longevity and clinical service of restoration. The aim of this study was to assess the effect of flaw size and surface treatments on biaxial flexural strength of feldspathic porcelain.
Materials and Methods: Eighty feldspathic porcelain discs were fabricated, polished (P2000) and divided into two series (n=40) each with four subgroups (n=10); three subgroups in each series

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were centrally indented by means of a Vickers hardness tester under a load of either 9.8 N (A series) or 29.4 N (B series) and were then subjected to no surface treatment (subgroups 2 and 6), polishing (subgroups 3 and 7) or polishing plus silane plus resin (subgroups 4 and 8). Ten specimens in each series were not indented as controls (subgroups 1 and 5). Biaxial flexural strength of the discs was tested after water storage for 48 hours and the data were analyzed by two-way ANOVA and Tukey's HSD test.

Results: Both control subgroups revealed significantly higher strength than other subgroups ($P<0.05$) but there was no significant difference among other subgroups ($P>0.05$). The mean flexural strength of indented subgroups in B series was significantly lower than that in the same subgroups in A series ($P<0.05$).

Conclusion: Presence and size of flaws affect the flexural strength of porcelain. Within the limitations of this study, none of the surface treatments could strengthen the cracked ceramic.

Keywords: Feldspathic porcelain; flaws; polish; silane; resin; biaxial flexural strength.

1. INTRODUCTION

Dental ceramic restorations are extensively used due to their favorable esthetics, durability and excellent biocompatibility. However, ceramics are brittle and prone to premature failure, especially in wet environments and under cyclic loading [1]. Most failures originate from flaws in the surface or subsurface of ceramics [2]. Due to the fragility of ceramics, a critical size flaw can initiate fracture [3]. According to Thompson et al. [4] fracture strength of dental ceramics is determined by flaw distribution in their structure.

Although occlusal adjustment of porcelain restorations with diamond bur and high speed hand piece may be necessary for accurate occlusal and marginal fit, such procedures may traumatize the ceramic surface and subsurface and cause flaws, which can decrease the fracture strength and result in clinical failure of restoration [1]. Due to high brittleness of ceramic restorations, occlusal adjustment cannot be done before cementation. Thus, intraoral occlusal adjustment and polishing of ceramic surface are often required [5,6]. It has been confirmed that ceramic restoration fractures are often due to the presence of surface flaws [7,1]. The surface roughness and critical flaw size of ceramic surfaces have a direct correlation with ceramic strength. Such a correlation indicates that reduction in the size of surface flaws and surface roughness may increase the flexural strength [5].

In contrast to glazing, chair-side polishing of ceramic restorations after cementation is easy to perform and time-saving for both patients and clinicians [2,8,9,10]. However, controversy exists on the effects of surface treatments on the strength of ceramics. Some studies found no difference in flexural and fracture strength of glazed and polished ceramics [2,8,10,11,12,13], while some others showed that polished porcelain had higher fracture strength than glazed porcelain [3,12,13,14]. Several chair-side polishing techniques have been evaluated as possible alternatives to glazing especially in terms of causing enamel wear in the opposing teeth [9,6,14,15,16,15].

Ceramic strength decreases in wet environments. This is mainly because of the chemical reaction of water with porcelain at the crack initiation point, which leads to crack propagation. O'Brien [16] reported 30% reduction in strength of broken ceramic in water; some others focused on the effect of stress corrosion cracking on the clinical service of ceramic restorations [17]. Thus, since silane is hydrophobic, it may prevent stress corrosion cracking by preventing the penetration of water molecules into the crack initiation point [18]. Resin can also increase the ceramic strength. Several studies have confirmed the efficacy of resin cements for increasing the flexural strength of ceramics [19,20]. Several mechanisms have been described for ceramic strengthening by resin application including crack closure by applying crack closure stresses, full or partial healing of superficial cracks, benefitting from the Poisson constraint effects and minimizing water content at the ceramic/bonding agent interface [4,19,20]. Resin can enhance the strength of ceramic crowns when used for cementation. However, a dominant mechanism to improve the strength of resin-bonded crowns has yet to be found.

In previous studies, the effect of resin was mainly assessed when it was used as resin cement on the internal surface of ceramic restorations [19,21-23] to control internal surface flaws.

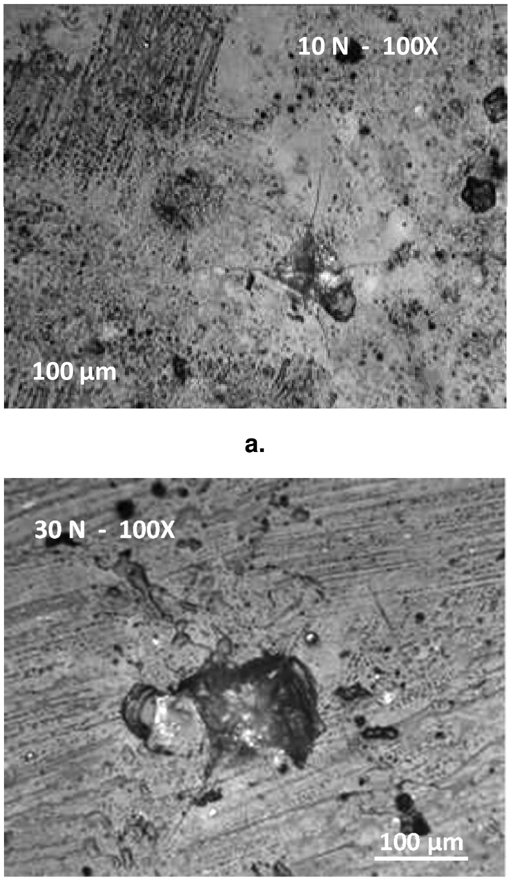
Studies on methods to limit external surface cracks caused by occlusal adjustment have only focused on the efficacy of polishing and re-heating for this purpose [21,24,25]. Moreover, studies on the efficacy of silane for limiting crack expansion due to its hydrophobic nature are scarce [20,26].

Thus, this study sought to assess the effect of polishing alone or followed by applying low viscosity resin on flexural strength of feldspathic porcelain with controlled flaws. The null hypothesis was that polishing alone or in combination with resin coating would not cause a significant change in flexural strength of indented ceramics.

2. MATERIALS AND METHODS

Eighty disc-shaped specimens measuring 14±2 mm in diameter and 1.2±0.2 mm in thickness measured with a digital caliper (Mitutoyo Manufacturing Company Ltd.,) were fabricated of feldspathic porcelain (Vita VMK68, VITA Zahnfabrik, Bad Säckingen, Germany). The ceramic powder (A2 shade, LOT1553: Vita, Bad Säckingen, Germany) and the modeling liquid (Vita modeling fluid, Vita, Bad Säckingen, Germany) were mixed and transferred (under vibration) to a metal ring mold (16.0 mm in diameter and 1.5 mm in thickness) 12% larger than the desired final specimens to compensate for ceramic contraction. The mixture was condensed and the excess liquid was removed with absorbent paper. The discs were sintered in a vacuum furnace (Vita Vacumat 200, Vita, Bad Säckingen, Germany) and the firing cycles were adjusted according to the manufacturer's instructions. After air cooling, the discs were polished with SiC 120, 400, 600, 800 and 1200 grit abrasive discs (Struers), under coolant, at 300 rpm.

The specimens were randomly divided into eight subgroups of 10 (subgroups 1 to 8). Subgroups 1, 2, 3 and 4 belonged to A series and subgroups 5, 6, 7 and 8 belonged to B series. Specimens in subgroups 1 and 5 were considered as negative controls. The polished surfaces of the remaining 60 specimens (the remaining 6 subgroups) were centrally indented by a Vickers hardness tester (Nexsus, 4000/60, INNOVATEST, Netherlands, Europe) under a load of either 9.8 N for A series specimens (subgroups 2, 3 and 4) or 29.4 N for B series specimens (subgroups 6, 7 and 8) for 15 seconds (Fig. 1). The indenter-induced cracks were inspected to ensure equivalent dominant flaws in all specimens of the same subgroup. The indenter-induced cracks were stabilized in air for one hour.



a.

b.

Fig. 1. Indents caused by 10 N(a) and 30 N(b) indentation loads on the ceramic surface

As seen in Fig. 1, by increasing the indentation load, the size of the indent and length of crack increased.

After the stabilization process, one subgroup of each series served as the positive control (2 and 6) and the remaining indented subgroups (3, 4, 7 and 8) were wet polished with silicon carbide abrasive papers (P2000) on a grinding and polishing machine (IMPTECH 10V grinder-polisher, Iran) at 150 rpm for 120 seconds (subgroups 3 and 7 represented the polished groups) [27-29].

After polishing the indented surfaces of the specimens in subgroups 4 and 8, they were coated with a thin layer of Bis-Silane ceramic primer (Bis-Silane, Bisco, Schaumburg, USA) and allowed to air dry (30 seconds of dwelling) and then the surface was coated with a thin layer of low viscosity resin (Biscover LV liquid polish, Bisco, Schaumburg, USA) and light cured for 30 seconds using a LED light curing unit (VALO, Ultradent, Products, South Jordan, UT, USA) with a light intensity of 500 mW/cm^2, at close range (0-2 mm).

All specimens were immersed in distilled water and incubated at 37±1ºC for 48 hours (Kavosh Mega, Tehran, Iran). Then, the specimens were air-dried.

Biaxial flexural strength test was then performed. Each disc was supported by 3 steel balls (1.5 mm in diameter, positioned 120º apart, 10 mm support circle) and the center of the top surface was loaded with a 1.0 mm diameter flat punch. The specimens were loaded with a servo hydraulic load frame (Model 5565; Instron) equipped with a 1-kN load cell at a crosshead speed of 0.5 mm/min. The biaxial flexural strength (MPa) was calculated based on the load (N) at failure using the ISO 6872 equation:

$$S = -0.2387P(X-Y)/d2 \text{ [ISQ 6872:2015]} \quad (1)$$

Where S is the maximum stress in MPa, P is the total load causing fracture in Newton, and d is the disk thickness at fracture origin in millimeters. X and Y were determined as follows:

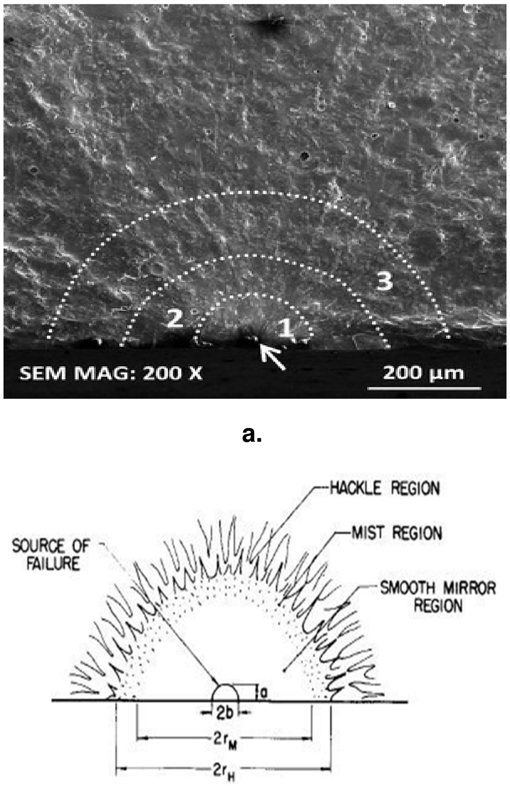
$$X= (1+\upsilon)\ln(r2/r3)2+[(1-\upsilon)/2](r2/r3)2 \quad (2)$$

$$Y= (1+\upsilon)[1+\ln(r1/r3)2]+(1-\upsilon)\ (r1/r3)2 \quad (3)$$

Where, υ is the Poisson's ratio (=0.2521); r1 is the radius of support circle in mm (5.6), r2 is the radius of loaded area in mm (0.625); r3 is the radius of specimen in mm and d is the disk thickness at fracture origin in mm measured by a screw-gauge caliper (Mitutoyo, Kawasaki-shi, Japan) with an accuracy of 10 µm.

Flexural strength was recorded, three randomly selected specimens in each subgroup were gold coated and evaluated under a scanning electron microscope (SEM, S-4800; Hitachi Ltd., Tokyo, Japan) with 15 kV (Figs. 2-5) for inspection of the cracked surface.

T-test was used to compare non-indented control subgroups. Two-way ANOVA was applied to assess the effect of two independent variables of indentation load and indentation/treatment. The interaction effect of the two was not significant. Thus, no further Univariate analysis was performed. Tukey's post hoc test was applied for pairwise comparison of different combinations of indentation/treatment.



a.

b.

Fig. 2. SEM micrograph (a) and schematic view (b) of hackle region

Arrow in Fig. 2 shows crack initiation point. Dotted lines differentiate the estimated outlines of the cracked surface regions (1) Smooth mirror region (2) Mist region (3) Hackle region.

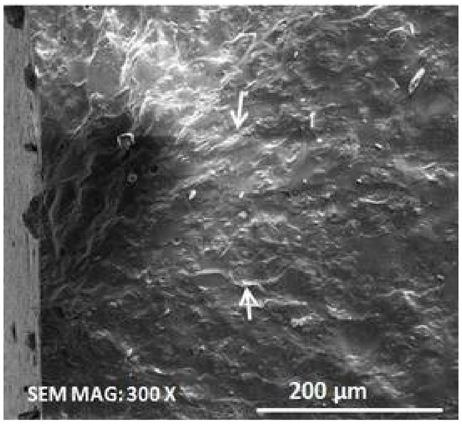


Fig. 3. Fracture surface of a negative control specimen (subgroup 1). Hackle crack lines are marked

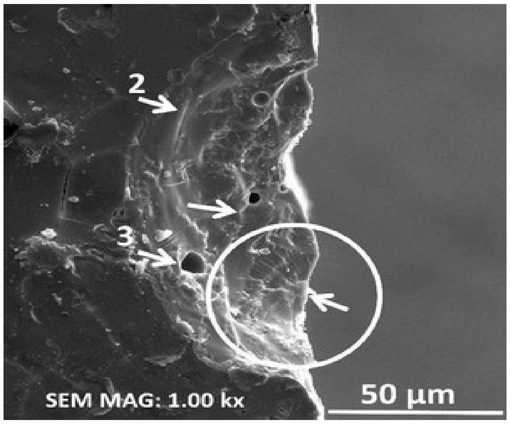


Fig. 4. The encircled area shows density of crack lines initiating from the crack initiation site (number 1). Number 2 shows lines perpendicular to the path of crack propagation (Wallner lines). Some voids in the ceramic mass can be seen (number 3)

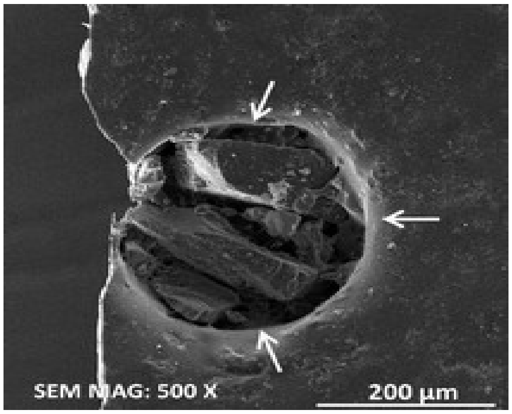


Fig. 5. An internal ceramic defect can be seen

3. RESULTS

Analysis of the data by two-way ANOVA revealed no significant interaction effect of the two independent variables namely polishing and resin coating (P=0.376).

Fig. 6 shows changes after completion of polishing and resin coating of ceramic surface. As seen in Fig. 6, it appears that crack length decreased after polishing. No sign of crack can be seen after coating the surface with resin.

In the current study, resin was separated from the surface of some specimens during their immersion in water and also during flexural strength testing (Fig. 7).

Short polishing time can be another possible factor explaining the insignificant effect of polishing on the strength of indented ceramics in this study. As seen, length of cracks decreased by an increase in polishing time (Fig. 8a-d).

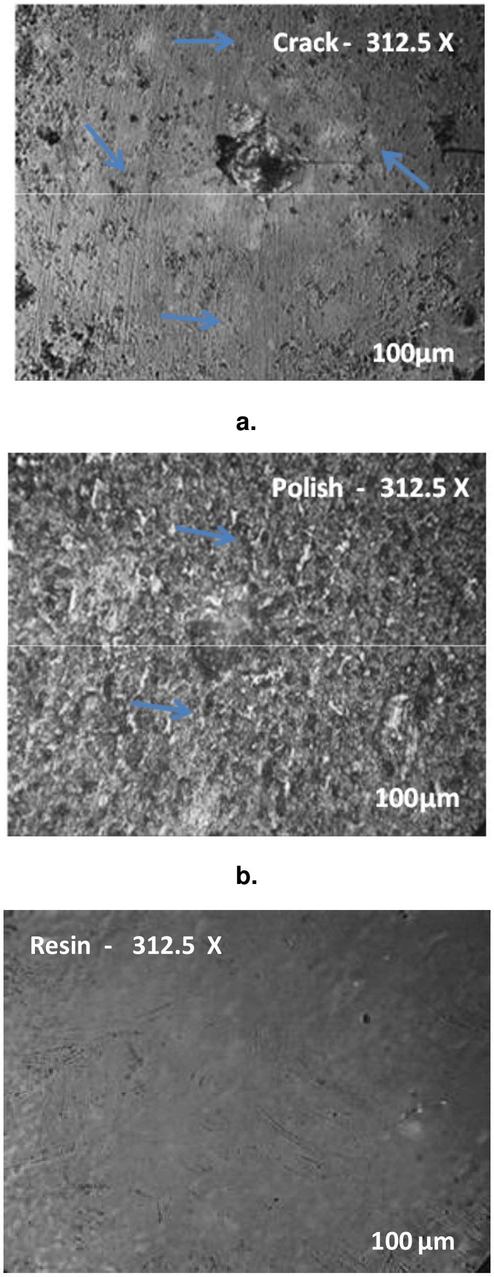


Fig. 6. Comparison of indented ceramics (a) with no surface treatment (b) after being polished (c) and after resin application (estimated end points of crack lines are marked with arrows)

The mean flexural strength of the specimens that were indented by 9.8 N load (subgroups 2, 3 and 4) was greater than the same subgroups indented with 29.4 N load (5, 6 and 7; P=0.018). There was a significant difference between the subgroups of the two series in flexural strength (P<0.001). A summary of the results is given in Table 1.

Post hoc Tukey's HSD test (table 2) indicated that the mean flexural strength of non-indented negative control subgroups (1 and 5) was significantly greater than that of other subgroups in both series (P<0.05); which means that indentation with 9.8 or 29.4 N load decreased the strength of feldspathic porcelain. But there was no significant difference among other subgroups of each series (P>0.05) namely indented, indented-polished and indented-polished-resin coated subgroups (neither among subgroups 2, 3 and 4 nor among subgroups 6, 7 and 8).

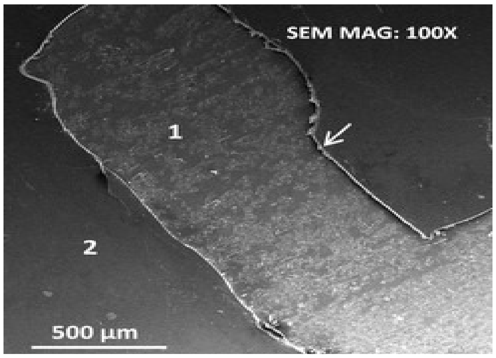
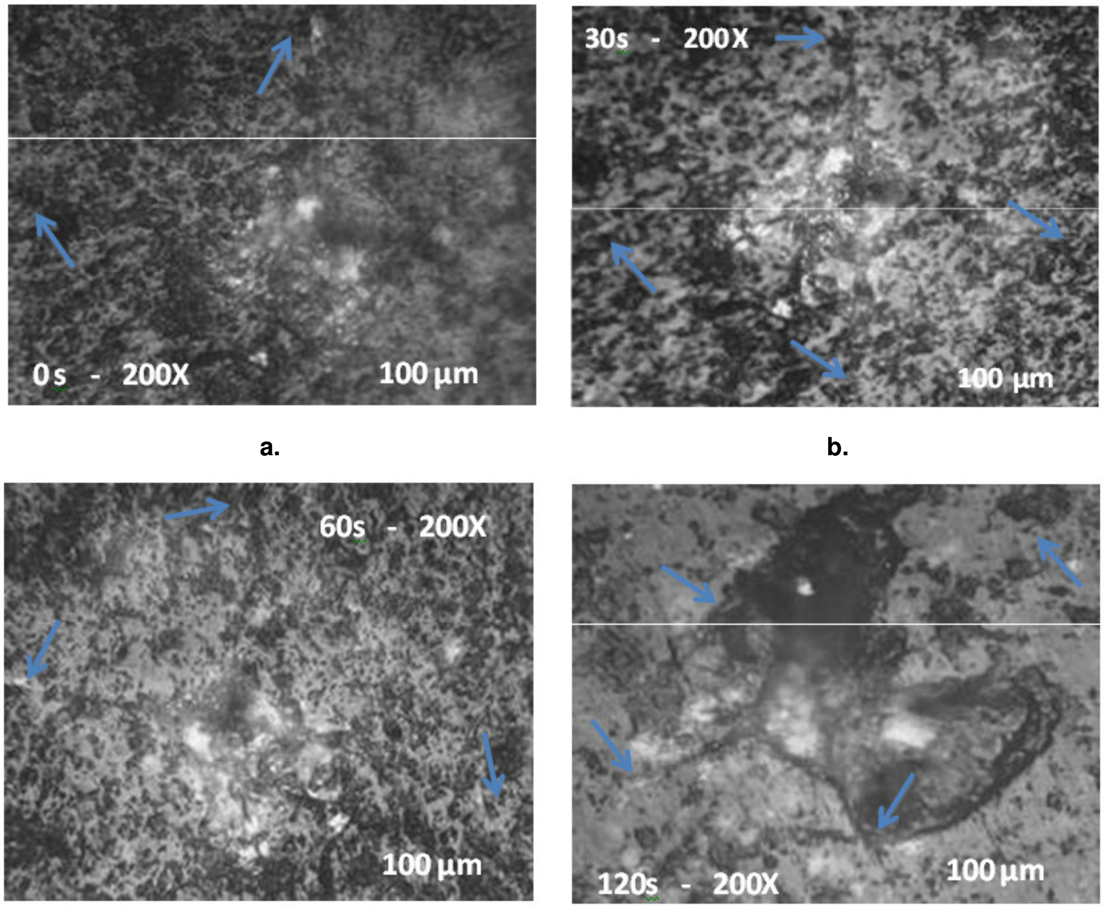


Fig. 7. Separation of resin from the ceramic surface. The resin-ceramic interface (arrow); ceramic surface (1); resin-coated surface (2)



a.

b.

c.

d.

Fig. 8. Comparison of cracked surface after polishing for different time periods. Arrows point to the estimated end of crack lines

Table 1. The mean flexural strength values (σf) with 95% confidence interval

Group	Surface treatment (groups)	Mean strength (Mpa)	Minimum (Mpa)	Maximum (Mpa)	Standard deviation	Confidence interval
A series (indentation load=9.8N)	Not indented (1)	124.71	107.15	158.12	14.99	5.45
	Indented (2)	110.57	91.58	133.04	22.15	6.98
	Indented- polished (3)	109.92	49.49	128.35	25.41	8.47
	Indented- polished-resin (4)	87.23	45.39	127.56	29.33	9.94
B series (indentation load=29.4N)	Not indented (5)	134.49	105.42	149.57	12.60	4.20
	Indented (6)	94.71	66.15	119.65	15.41	5.13
	Indented- polished (7)	89.20	67.79	112.53	16.22	5.40
	Indented- polished-resin (8)	80.67	65.86	97.34	12.01	4.00

Table 2. Inter group comparisons using Tukey HSD test

Compared groups	Mean difference	P value
1 vs. 2	22.3248	0.004*
1 vs. 3	25.5860	0.001*
1 vs. 4	40.8290	< 0.001*
2 vs. 3	3.2611	0.954
2 vs. 4	18.5041	0.072
3 vs. 4	15.2430	0.079

1: Not indented, 2: Indented, 3: Indented-polished and 4: Indented-polished-resin.
**Statistically significant difference for P<0.05*

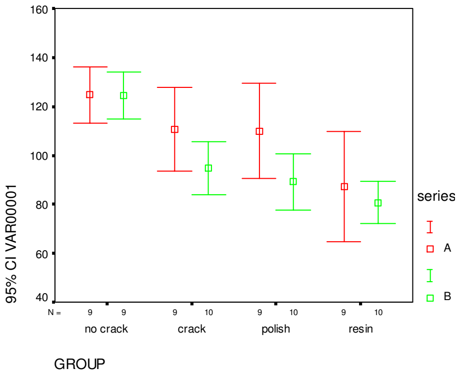


Diagram 1. Error bar of the mean and 95% confidence interval of flexural strength in subgroups of A and B series (polished with P2000) based on indentation/treatment combinations; the indentation load was 9.8N in a series (red) and 29.4N in B series (green)

4. DISCUSSION

Based on the results of this study, the mean flexural strength of non-indented specimens (subgroups 1 and 4) was significantly greater than that of indented specimens with either 9.8 or 29.4 N load; it means that in this study, cracks caused a significant reduction in flexural strength of ceramic. This result is in line with the findings of Fleming et al. [28]; they revealed that cracks made by means of 50 N indentation load on the surface of aluminous porcelain and 9.8 N load on feldspathic porcelain decreased the strength of ceramics.

Statistical data analysis showed that the mean flexural strength of specimens indented with 29.4 N load was significantly lower than that of specimens indented with 9.8 N load; thus, the larger the flaw size, the greater the reduction in strength. The same results were obtained by Thompson et al. [4] who compared 9.8 N and 19.7 N indentation loads. However, our finding was in contrast to that of Griggs et al. [30]; they evaluated the effect of different indentation loads (3.9, 7.8, 11.8, 15.7 and 19.6 N) on the flexural strength of ceramics and found no difference among them; they attributed this result to the presence of other confounding factors such as internal porosities and stresses which, dominate the strength behavior and conceal the effects of flaw modification.

The SEM micrographs in the current study showed that crack length decreased after polishing. Another important point is the created surface roughness after polishing of ceramic. After resin coating, no sign of crack was seen.

In the current study, there was no significant difference in the mean flexural strength of indented specimens with and without polishing in both series (with the indentation load of 9.8 or

29.4 N; subgroups 2-3 and 6-7). This finding is in agreement with the results of Guazzato et al. [31], but in contrast to those of Giordano et al. [32] and Albakry et al. [12]. In the afore-mentioned studies, reduction or increase of ceramic strength was related to increase or reduction of surface roughness and depended on the method of polishing, respectively. Regardless of the results of the afore mentioned studies, the method of assessing the effect of polishing on porcelain strength in the current study was different from that in previous studies; in previous studies, grinding of the surface of porcelain with coarse abrasive papers or burs (instead of indentation) was done to simulate damages and cracks caused by occlusal adjustment of ceramics in the clinical setting.

The SEM micrographs in the current study showed the size of crack decreased during polishing and it is possible that further polishing for a longer duration of time could have increased the strength of ceramic.

However, after polishing the cracked surface for 120 seconds, crack lines and indents were still visible and were not completely eliminated. Created defects on the ceramic surface could be seen.

Analysis of the data revealed no significant difference in the mean flexural strength of indented- polished- resin coated subgroups (4-8) and indented (2-6) or indented- polished subgroups (3-7) in both series; it means that coating the surface of indented ceramic after polishing with low viscosity resin did not increase the strength. This finding is in contrast to the results of Addison et al. [19], and Fleming et al [28]. In most studies on the effect of resin on the strength of ceramic, a filled resin was used for cementation; because the aim of those studies was to assess the effect of resin when applied on the internal surface of restorations. But the aim of the present study was to evaluate the effect of resin when used to eliminate external surface flaws; thus, low viscosity resin was used in the current study to minimize occlusal interferences after applying.

Previous studies suggested strategies for resin coating to strengthen dental ceramics. Addison et al. [29] discussed the resin thickness, type of resin, filler content, modulus of elasticity of resin, formation of a good hybrid layer and surface texture (depending on the surface treatment method) to be effective factors in this respect. As mentioned earlier, low viscosity resin (Biscover) was used for the reasons discussed earlier; it contains low filler content and has low film thickness and modulus of elasticity; these properties may explain why resin was not effective in this study. On the other hand, achieving a suitable hybrid layer and a strong bond require ceramic surface treatments such as acid etching and sandblasting prior to resin coating. In the current study, since it was assumed that etching or sandblasting would affect ceramic strength [25,26], these surface treatments were not performed. In the study by Addison et al. in 2008 [29], separation of resin from the ceramic surface affected the ceramic strength. The SEM micrographs in the current study showed that resin was separated from the surface of some specimens during their immersion in water and also during flexural strength testing. This can be due to inappropriate ceramic surface preparation and ineffective bond of silane and resin to ceramic.

Addison et al. [33] in 2008 evaluated the effect of water storage on resin-coated ceramic strength and reported that water was responsible for degradation of ceramic strength. However, Rosenthal et al. [34] in 1993 reported that short-time water storage did not cause a reduction in strength of resin-coated ceramics. Many previous studies evaluated the bond strength of ceramics in dry environment [20,29,35]. In general, a combination of the above mentioned factors might explain the inefficacy of resin coating in the current study.

Considering the fact that a specific protocol has not been explained for increasing the ceramic strength by resin coating, prevention of water penetration and stress corrosion cracking may also be effective in this respect. Thus, to assess the efficacy of application of low-viscosity resin on the external surface of ceramic restorations, study of crack propagation behavior during water storage may be helpful. Also, further studies are required to evaluate the process of slow crack propagation. Cyclic loading in presence of water is also recommended to further assess the efficacy of resin coating.

Based on the current results, cracks created by a Vickers indenter using 29.4N load decreased the ceramic strength. Within the limitations of this study, it appears that polishing or coating of such surfaces with low viscosity resin does not increase the bond strength.

5. CONCLUSION

The strength of porcelain is affected by the presence and size of surface flaws. Within the limitations of this study, neither polishing nor surface coating with low viscosity resin could increase the biaxial flexural strength of cracked ceramic.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Song XF, Yin L. Subsurface damage induced in dental resurfacing of a feldspar porcelain with coarse diamond burs. J Biomech. 2009;42(3):355-60.
2. Venturini AB, Prochnow C, May LG, Bottino MC, Felipe Valandro L. Influence of hydrofluoric acid concentra- tion on the flexural strength of a feldspathic ceramic. J Mech Behav Biomed Mater. 2015;48:241-8.
3. Yen T, Blackman RB, Baez RJ. Effect of acid etching on the flexural strength of a feldspathic porcelain and castable glass ceramic. J Prosthet Dent. 1993;70:224-233.
4. Thompson JY, Anusavice KJ. Effect of surface etching on the flexure strength and fracture toughness of dicor disks containing controlled flaws. J Dent Res. 1994;73:505-510.
5. Oliveira-Junior OB, Buso L, Fujiy FH, Lombardo GH, Campos F, Sarmento HR, Souza RO. Influence of polishing procedures on the surface roughness of dental ceramics made by different techniques. Gen Dent. 2013;61:e4-8.
6. Tholt de vasconcellos B, Miranda-Junior WG, Prioli R, Thompson J, Oda M. Surface roughness in ceramics with different finishing techniques using atomic force microscope and profilometer. Oper Dent. 2006;31:442-449.
7. Han GJ, Kim JH, Lee MA, Chae SY, Lee YH, Cho BH. Performance of a novel polishing rubber wheel in improving surface roughness of feldspathic porcelain. Dent Mater J. 2014;33(6):739-748.
8. Chu FC, Frankel N, Smales RJ. Surface roughness and flexural strength of self-glazed, polished, and reglazed in-ceram/vitadur alpha porcelain laminates. Int J Prosthodont. 2000;13:66-71.
9. Yilmaz K, Özkan P. The methods for the generation of smoothness in dental ceramics. Comp Cont Educ Dent. 2010; 31:30-41.
10. Aboushelib MN, Wang H. Effect of surface treatment on flexural strength of zirconia bars. J Prosthet Dent. 2010;104:98-104.
11. Fahmy NZ, El Guindy J, Zamzam M. Effect of artificial saliva storage on microhardness and fracture toughness of a hydrothermal glass-ceramic. J Prosthodont. 2009;18:324-331.
12. Albakry M, Guazzato M, Swain MV. Effect of sandblasting, grinding, polishing and glazing on the flexural strength of two pressable all-ceramic dental materials. J Dent. 2004;32:91-99.
13. Fairhurst CW, Lockwood PE, Ringle RD, Thompson WO. The effect of glaze on porcelain strength. Dent Mater. 1992;8: 203-207.
14. Preis V, Behr M, Handel G, Schneider-Feyrer S, Hahnel S, Rosentritt M. Wear performance of dental ceramics after grinding and polishing treatments. J Mech Behav Biomed Mater. 2012;10:13-22.
15. Jagger DC, Harrison A. An *in-vitro* investigation into the wear effects of unglazed, glazed and polished porcelain on human enamel. J Prosthet Dent. 1994; 72:320-323.
16. O'Brien WJ. Dental materials and their selection. 3rd ed. Berlin: Quintessence Publishing; 2002.
17. Kawakami Y, Takeshige F, Hayashi M, Ebisu S. Fatigue of tooth-colored restoratives in aqueous enviroment. Dent Mater J. 2007;26(1):1-6.
18. Rosenstiel SF, Denry IL, Zhu W, Gupta PK, Van der Sluys RA. Fluoroalkylethylsilane coating as a moisture barrier for dental ceramics. J Biomed Mater Res. 1993;27(3):415-7.
19. Addison O, Marquis PM, Fleming GJ. Resin elasticity and the strengthening of all-ceramic restorations. J Dent Res. 2007; 86(6):519-23.

20. Addison O, Marquis PM, Fleming GJ. Resin strengthening of dental ceramics-the impact of surface texture and silane. J Dent. 2007;35(5):416-24.
21. Brentel AS, O¨zcan M, Valandro LF, Alarc¸a LG, Amaral R, Bottino MA. Microtensile bond strength of a resin cement to feldpathic ceramic after different etching and silanization regimens in dry and aged conditions. Dent Mater. 2007; 23(11):1323-31.
22. Hooi P, Addison O, Fleming GJ. Testing rate and cementation seating load effects on resin-strengthening of a dental porcelain analogue. J Dent. 2013;41(6): 514-20.
23. Fleming GJ, Hooi P, Addison O. The influence of resin flexural modulus on the magnitude of ceramic strengthening. Dent Mater. 2012;28(7):769-76.
24. Neis CA, Albuquerque NL, Albuquerque Ide S, Gomes EA, Souza-Filho CB, Feitosa VP, Spazzin AO, Bacchi A. Surface treatments for repair of feldspathic, leucite- and lithium disilicate-reinforced glass ceramics using composite resin. Braz Dent J. 2015;26(2):152-55.
25. Venturini AB, Prochnow C, Rambo D, Gundel A, Valandro LF. Effect of hydrofluoric acid concentration on resin adhesion to a feldspathic ceramic. J Adhe as Dent. 2015;17(4):313-20.
26. Mohammadi N, Shakur Shahabi M, Kimyai S, Pournagi Azar F, Ebrahimi Chaharom ME. Shear bond strengths of methacrylate- and silorane-based composite resins to feldspathic porcelain using different adhesive systems. J Dent Res Dent Clin Dent Prospect. 2015Summer;9(3):181-7.
27. Song XF, Yin L, Han YG, Wang H. Micro-fine finishing of a feldspar porcelain for dental prostheses. Med Eng Phys. 2008; 30(7):856-64.
28. Fleming GJ, Maguire FR, Bhamra G, Burke FM, Marquis PM. The strengthening mechanism of resin cements on porcelain surfaces. J Dent Res. 2006;85(3):272-6.
29. Addison O, Marquis PM, Fleming GJ. Quantifying the strength of a resin-coated dental ceramic. J Dent Res. 2008;87(6): 542-7.
30. Griggs JA, Thompson JY, Anusavice KJ. Effects of flaw size and auto- glaze treatment on porcelain strength. J Dent Res. 1996;75(6):1414-7.
31. Guazzato M, Albakry M, Ringer S. Strength, fracture toughness and microstructure of a selection of all ceramic materials. Part I. Pressable and alumina glass-infiltrated ceramics. Dental Materials. 2004;20:441-445.
32. Giordano R, Cima M, Pober R. Effect of surface finish on the flexural strength of feldspathic and aluminous dental ceramics. Int J Prosthodont. 1995;8(4):311-9.
33. Addison O, Marquis PM, Fleming GJ. Adhesive luting of all-ceramic restorations-the impact of cementation variables and short-term water storage on the strength of a feldspathic dental ceramic. J Adhes Dent. 2008;10(4):285-93.
34. Rosenstiel SF, Gupta PK, Van der Sluys RA, Zimmerman MH. Strength of a dental glass-ceramic after surface coating. Dent Mater. 1993;9(4):274-9.
35. Salazar Marocho SM, de Melo RM, Macedo LG, Valandro LF, Bottino MA. Strength of a feldspar ceramic according to the thickness and polymerization mode of the resin cement coating. Dent Mater J. 2011;30(3):323-9.

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