



## Effect of Sandblasting Angle and Distance on Biaxial Flexural Strength of Zirconia-based Ceramics

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### ABSTRACT

**Aim:** Surface treatment is necessarily required for bonding of zirconia to the veneering porcelain and luting cements. Sandblasting is the most common and probably the most efficient surface treatment method. Sandblasting roughens the surface and may affect the flexural strength of zirconia. Different sandblasting protocols may yield variable results. This study sought to assess the effect of sandblasting angle and distance on the biaxial flexural strength of zirconia-based ceramics.

**Materials and methods:** This *in vitro* experimental study was conducted on 50 zirconia discs measuring  $1.2 \pm 0.2$  mm in thickness and  $15 \pm 0.2$  mm in diameter, which were randomly divided into five groups ( $n = 10$ ) of one control and four experimental groups subjected to sandblasting with  $110 \mu\text{m}$  aluminum oxide particles under 2 bar pressure for 10 seconds at 15 and 25 mm distances and 45 and 90° angles (between the nozzle head and zirconia surface). Surface roughness was measured by a roughness tester and samples were subjected to thermocycling followed by biaxial flexural strength testing according to ISO6872. The data were analyzed using one-way analysis of variance ( $p < 0.05$ ).

**Results:** No statistically significant difference was noted in the mean biaxial flexural strength of the five groups ( $p = 0.40$ ). Different sandblasting protocols yielded significantly different surface roughness values ( $p < 0.001$ ). The highest and the lowest mean surface roughness belonged to 15 mm/90° ( $0.51 \mu\text{m}$ ) and control ( $0.001 \mu\text{m}$ ) groups respectively.

**Conclusion:** Change in sandblasting angle and distance had no significant effect on the biaxial flexural strength of zirconia-based ceramic, but surface roughness was significantly different in the study groups.

**Clinical significances:** Regardless of sandblasting angle, increasing distance to 25 mm significantly decreases surface roughness that may negatively affect zirconia bond strength.

**Keywords:** Fracture, Laboratory research, Sandblast, Strength, Zirconia.

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**Conflict of interest:** None

### INTRODUCTION

Metal-ceramic restorations are still commonly used for reconstruction of tooth crowns,<sup>1</sup> but patient demands for more esthetic and durable restorations led to the fabrication of all-ceramic restorations.<sup>2</sup> Advances were made in the fabrication of these restorations following the introduction of novel materials and techniques.<sup>3</sup>

Zirconia ceramics have gained the spotlight but selection of optimal surface treatment methods and luting cements to enhance the bond strength of zirconia or highly crystalline ceramics in general remains a challenge in dentistry.<sup>4</sup> These ceramics have a small crystalline phase compared with the older types (silica-based ceramics); as a result, the commonly used methods to enhance the bond strength, such as hydrofluoric acid etching are not effective for roughening of surface, increasing the wettability and increasing the required surface for mechanical interlocking and use of silane before the application of resin cement due to the absence of silica are not much effective.<sup>5,6</sup> Moreover, since zirconia has a neutral surface,<sup>7</sup> it has a low potential for forming a chemical bond, and this compromises the union of zirconia substrate with cement.<sup>8</sup> In other words,

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it appears that both micromechanical interlocking and chemical bond between the zirconia core and resin cement are hard to achieve. Resultantly, the common methods of bonding cannot provide the adequate bond strength of zirconia substrate to tooth structure or restorative materials and is a challenging issue.<sup>9</sup> A previous study revealed that the bond of 7% of single crowns placed in the posterior areas was lost by the end of a 3-year observation period.<sup>10</sup>

On the contrary, high-strength ceramics are more opaque than the older types. Thus, to achieve optimal esthetics and favorable morphology, high-strength ceramics must be veneered with feldspathic porcelain.<sup>11,12</sup> However, the mechanical properties and behavior of zirconia core and the veneering porcelain are different.<sup>4</sup> Chipping and delamination of the veneering feldspathic porcelain are among the most common complications of these restorations, which lead to exposure of the underlying zirconia core.<sup>13,14</sup> Such a high rate of fracture may be related to the loss of bond between the veneering porcelain and the underlying zirconia structure.<sup>15</sup>

Zirconia crowns are often subjected to surface treatment to enhance their wettability and bond strength of ceramic core to cement and also the bond of the external surface of core to the veneering porcelain.<sup>16,17</sup> Zirconia surface treatment increases the surface roughness to obtain mechanical interlocking and chemically activates the surface to obtain a chemically strong bond.<sup>18</sup> Sandblasting is among the most common and most efficient surface treatment methods,<sup>19</sup> which enhance the bond of zirconia to the veneering ceramic and luting cement via mechanical interlocking.<sup>3</sup>

However, it should be noted that during the process of sandblasting, microcracks might form in the zirconia surface due to the impact of particles. These cracks may compromise the stability and durability of ceramics in the long term<sup>20</sup> and degrade its strength.<sup>21-23</sup> Impact of particles at high speed creates a rough surface, damages some superficial areas, and creates a residual compressive stress due to tetragonal to monoclinic phase transition.<sup>2,20,24</sup> The sandblasting protocol determines the severity of damage, and variability in the results is due to differences in the type and size of particles, pressure, nozzle size, impact angle, and other parameters, such as microstructure of the substrate.<sup>19</sup>

Some researchers including Sato et al,<sup>2</sup> Ban,<sup>25</sup> Souza et al,<sup>26</sup> Kosmac et al<sup>20,27,28</sup> showed that biaxial flexural strength of zirconia after sandblasting was higher than that of the control group. In contrast, some others including Wang et al<sup>29</sup> reported a reduction in biaxial flexural strength of zirconia after sandblasting. El-Naga et al<sup>30</sup> demonstrated that sandblasting did not cause any significant change in the strength of zirconia.

Since the results are controversial and there is no definitive protocol for sandblasting, this study aimed to assess the effect of sandblasting angle and distance on the biaxial flexural strength of zirconia-based ceramic.

## MATERIALS AND METHODS

### Fabrication of Samples

Fifty yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) zirconia discs (Cercon, Dentsply, Germany) were fabricated by milling of semi-sintered zirconia blocks using Cercon Expert milling machine (Cercon, Dentsply, Germany). The samples were then sintered in Cercon Heat Plus furnace (Cercon, Dentsply, Germany) at 1,350°C. Discs were then polished with 600, 800, and 1,000 grit silicon carbide papers under running water to match their thickness and surface roughness. The samples (measuring  $1.2 \pm 0.2$  mm in thickness and  $15 \pm 0.2$  mm in diameter) were then randomly divided into five groups ( $n = 10$ ). A no-sandblasting control group was also included in the study.

### Sandblasting

The four experimental groups were subjected to sandblasting (Mestra galaxy sandblaster, Argibond, England) by 110  $\mu$ m aluminum oxide particles (Aluminium Oxide, Edelkorund, Germany) under 2 bar pressure for 10 seconds. The experimental groups were as follows:

- Sandblasting at 45° impact angle and 15 mm distance
- Sandblasting at 45° impact angle and 25 mm distance
- Sandblasting at 90° impact angle and 15 mm distance
- Sandblasting at 90° impact angle and 25 mm distance.

### Assessment of Surface Roughness by Profilometry

Before the assessment of surface roughness (Ra), the samples were placed in an ultrasonic bath (Eurosonic 4D, Euronda, Italy) containing 20°C distilled water for 5 minutes to eliminate impurities. The samples were then air-dried with air spray, and their surface roughness was measured by a portable surface roughness tester (Qualitest TR200, USA).

### Biaxial Flexural Strength Testing

To simulate the oral environment in terms of moisture, thermal changes, and aging of restorations, the samples were subjected to thermocycling (TC-300, Vafaei Industrial, Iran) before flexural strength testing. For this purpose, the samples were subjected to 5,000 thermal cycles (corresponding to 6 months of clinical service) between 5 and 55°C with a dwell time of 15 seconds and transfer time of 10 seconds. Biaxial flexural strength test was then

performed using a universal testing machine (Zwick Roell, Ulm, Germany) according to ISO6872 standard.

### Statistical Analysis

One-way analysis of variance was used to compare the mean surface roughness and biaxial flexural strength values of the five groups. Pairwise comparison of the groups was carried out using Tukey's test or Games-Howell test. Level of significance was set at  $p < 0.05$ .

## RESULTS

### Biaxial Flexural Strength

The mean and standard deviation (SD) of biaxial flexural strength values in the five groups are presented in Table 1. Statistically, no significant difference was found among the five groups in the mean biaxial flexural strength ( $p = 0.40$ ).

### Surface Roughness

Data regarding the mean and SD of surface roughness values in the five groups and their comparisons are presented in Tables 1 and 2. Based on the results, different sandblasting protocols caused significant differences in surface roughness of the five groups ( $p < 0.001$ ).

## DISCUSSION

This study aimed to assess the effect of different sandblasting protocols on the biaxial flexural strength of zirconia.

**Table 1:** Mean and SD of biaxial flexural strength and surface roughness in the five groups (n = 10)

Group	Mean biaxial flexural strength (MPa)	SD
15 mm/45°	1070.83 ± 203.76	0.33 ± 0.24
25 mm/45°	1015.57 ± 104.09	0.002 ± 0.0007
15 mm/90°	976.60 ± 152.24	0.51 ± 0.13
25 mm/90°	983.63 ± 129.38	0.13 ± 0.19
Control	930.33 ± 108.92	0.001 ± 0.0005

SD: Standard Deviation

**Table 2:** Pairwise comparisons of mean and standard error of surface roughness values in the five groups

Group	Group	Mean difference	Standard error	p-value
15 mm/45°	25 mm/45°	0.32	0.084	0.03*
	15 mm/90°	-0.18	0.09	0.37
	25 mm/90°	0.19	0.10	0.40
	Control	0.32	0.08	0.03*
25 mm/45°	15 mm/90°	-0.51	0.05	0.001 <*
	25 mm/90°	-0.13	0.06	0.38
	Control	0.00	0.00	0.74
15 mm/90°	25 mm/90°	0.38	0.08	0.005*
	Control	0.51	0.05	0.001 <*
25 mm/90°	Control	0.13	0.06	0.38

\*Statistically significant ( $p < 0.05$ )

Simultaneous effects of angle and distance between the nozzle and surface on bond strength of zirconia have been less commonly evaluated. The reason may be that accurate adjustment of angle and distance simultaneously is more difficult compared with other factors and is less feasible in conventional sandblasters. In studies, which did not intend to assess the effect of impact angle, sandblasting was done vertical to the surface. Chintapalli et al<sup>19</sup> evaluated the effect of sandblasting with 30 and 90° angles and Moon et al<sup>31</sup> compared 45 and 90° angles. No previous study was found on the effect of changing the distance of sandblasting on the flexural strength. However, the distance from the sandblaster to the surface in different studies has been variable ranging from 10 to 30 mm. These studies have suggested some protocols to achieve the best results in terms of surface roughness and highest bond strength. In 2013, Chintapalli et al<sup>32</sup> recommended mild sandblasting with 110 µm particles under 2 bar pressure due to insignificant damage to the surface. In contrast, intense sandblasting with 250 µm particles under 4 bar pressure can cause significant damage not tolerable by the layer with concentrated compressive stress.<sup>32</sup> Moon et al<sup>31</sup> recommended sandblasting with 50 µm alumina particles under 4 bar pressure for 20 seconds at 45° or 90° angle to achieve maximum bond strength to resin cement.

Aurélio et al,<sup>33</sup> in their review study in 2016, concluded that in general, sandblasting improved the flexural strength of Y-TZP ceramics irrespective of the size of particles, sandblasting pressure and its duration. Slikkerveer et al<sup>34</sup> discussed that since particles have less energy in lower pressures, damage would be limited to plastic deformation around the impact site. In higher velocities, higher kinetic energy of particles may create tensile stresses around the impact site and cause cracks.

Chintapalli et al<sup>19</sup> observed that the strength of zirconia further increased in low pressures because the defects created by sandblasting were less or slightly higher than the initial natural critical defects that are primarily present in the zirconia surface. In both conditions, the positive effect of the created compressive stress is high enough to overcome the created damage. Chintapalli et al<sup>19</sup> believed that the interaction effect of the residual compressive stress and the created damage would determine the increase or decrease in the strength of zirconia, and their interaction effect at a certain pressure and particle size depends on the impact angle.

In this study, changing the distance and impact angle of sandblasting with 110 µm alumina particles under 2 bar pressure for 10 seconds did not cause a significant change in the biaxial flexural strength of Y-TZP ceramic. However, the mean flexural strength of the four sandblasted groups showed a slight increase compared with the control group. These findings confirmed those of



previous studies and revealed that sandblasting increased the flexural strength of zirconia. Furthermore, our findings showed that changing the distance and impact angle of sandblasting did not cause a significant change in the flexural strength of zirconia. Increase in flexural bond strength after sandblasting is attributed to the tetragonal to monoclinic phase transformation, which creates residual compressive stress. In fact, stresses created and concentrated at the tip of the cracks (present on the surface before sandblasting or later created by sandblasting) prevent crack propagation and consequently increase the strength of substrate.<sup>2,20,25</sup>

The results of the current study revealed that sandblasting increased the surface roughness. This increase in surface roughness of sandblasted samples at 15 mm distance was significantly higher than that of the control group. The samples sandblasted at 25 mm distance showed a slight increase in surface roughness. In contrast to sandblasting at 15 mm distance, sandblasting at 25 mm distance could not provide adequate surface roughness for bonding. The results of the current study showed that irrespective of the angle of impact, reduction in distance significantly increased the surface roughness. This result may be due to higher energy of particles impacting the zirconia surface at a closer distance, which may result in fracture or delamination of the surface. Most previous studies concluded that different sandblasting protocols increased the surface roughness<sup>35,36</sup> and enhanced the bond to zirconia.<sup>37,38</sup> Moon et al<sup>31</sup> revealed that increase in surface roughness was proportionate to the size of particles, duration of sandblasting, and angle of impact.

Future studies are required to simultaneously assess the effect of parameters involved in changes in mechanical structure and surface topography caused by sandblasting. Moreover, clinical studies are necessary to test the efficacy of methods and protocols suggested in experimental studies.

## CONCLUSION

Within the limitations of this *in vitro* study (which could not perfectly simulate the oral clinical setting), the following results were obtained:

- Change in distance and impact angle of sandblasting had no significant effect on biaxial flexural strength of zirconia-based ceramic.
- Changing the distance of sandblasting caused a significant change in surface roughness of zirconia-based ceramic.
- Sandblasting with 110  $\mu\text{m}$  alumina particles under 2 bar pressure for 10 seconds at 15 mm distance, irrespective of the angle of impact, slightly increased the biaxial flexural strength of zirconia and yielded the highest surface roughness (Ra) value.

## CLINICAL SIGNIFICANCE

Regardless of sandblasting angle, increasing distance to 25 mm significantly decreased surface roughness that may negatively affect zirconia bond strength.

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