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RESEARCH ARTICLE

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Effect of micro blasting process parameters on 3D surface topography and surface properties of zirconia (Y-TZP) ceramics

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Abstract

The present study aims to examine the effects of operational parameters on the surface topography and wear mechanisms of monolithic and conventional yttria-stabilized zirconia (Y-TZP) ceramics in the micro blasting process, performed under various acceleration pressures (1.5–3 bar), particle impact angles (30°–90°), and erodent particle sizes (50–460 μm). Three-dimensional (3D) surface topography, surface roughness, and surface morphology of micro-blasted specimens were analyzed by using non-contact optical profilometry and SEM-EDS. The micro blasting characteristics of both Y-TZP were similar that increased blasting pressure and erodent particle size increased surface roughness. Erosion rate increased with increasing blasting pressure, whereas it decreased with increasing erodent particle size. Particle size was the most effective parameter on changing surface topography, while the particle impact angle had no distinct effect on the erosion rate, surface roughness, and surface topography of Y-TZP ceramics. SEM-EDS analyses showed that the primary wear mechanism during micro blasting was micro-cutting with a substantial amount of embedded particles on the material's surface.

KEYWORDS

grit blasting, prosthetic dentistry, surface morphology, yttria-stabilized zirconia

1 | INTRODUCTION

Zirconia ceramic is a unique engineering material with excellent mechanical properties such as high elasticity modulus, hardness, wear-resistance, and high toughness compared to traditional ceramics along with good corrosion resistance, significant biocompatibility, and excellent aesthetic features.[1-12] Ceramic prostheses are a distinct prosthesis type as a natural appearance, one of the essential aesthetic concerns of dental prosthesis, cannot be achieved by metal prosthesis.[8]

Although ceramic prostheses are good in aesthetics and adequate in biocompatibility, they underperform in mechanical behavior. Thus, zirconia ceramics have been standing out due to their superior properties and toughness in dental restorations since the 1990s.[7,13] Zirconia ceramics have become popular in prosthetic dentistry due to their prospering results in in-vivo and in-vitro studies as a result of advanced manufacturing.[2,5,6,9,14,15]

The most widely used zirconia in prosthetic dentistry is yttria-stabilized zirconia (Y-TZP), which has a tetragonal structure of yttrium oxide (Y_2O_3)[1,11,15] and is classified as conventional and monolithic zirconia. Conventional zirconia has remarkable mechanical properties required in prosthetic dentistry, yet they may not entirely satisfy demanding aesthetic requirements such as translucency and natural appearance. Thus, they are used with feldspathic porcelain veneering material. However, the veneering material is one of the most fundamental issues that adversely affect the service life of substrate material due to fracturing and delamination.[5,7] Monolithic Y-TZP ceramics eradicate the aesthetic drawbacks of conventional zirconia and can be used without porcelain veneering due to their high translucency.[1,5,16]

The bonding strength between the veneering material and the zirconia ceramic is an essential factor that limits the service life of Y-TZP ceramics with feldspathic porcelain veneering processes carried out.[13,17,18] It is also vital to improve the bonding strength between the ceramic restoration and the substrate in order to have long-lasting prosthetic restorations.[6,7,11,18,19] A good bonding strength not only depends on chemical bonding but also on micromechanical bonding.[7,13,15,19,20] The micromechanical bonding is precisely related to the roughness and topography of surfaces[3,14,19] as increasing surface roughness means a higher surface area between the ceramic surface and the cement[3,15] and surface energy.[3,19] Consequently, optimizing surface treatments to improve bonding strength is of great importance.[21]

Micro blasting is one of the most preferred surface treatment methods, which has been widely used for zirconia in prosthetic applications due to its applicability and *low cost*.[2,6-9,11,13,17,22-24]

It is a mechanical surface roughening treatment where erodent particles are accelerated with pressured air and sent to the material surface under a defined distance, angle, duration, and pressure.[2,9,24,25] During the process, high-speed erodent particles impact the material's surface and remove micro-chips from the surface.[1,2,22] It removes redundant contaminants on the surface of the material and improves surface energy, wetting angle, surface roughness, and topography[1,7,15,18,22] and enhances the micromechanical bonding between the resin cement-restoration and zirconia ceramic-veneering porcelain.[1,2,7-9,23] The development of micromechanical bonding is recently studied in prosthetic dentistry. During micro blasting process, operation parameters (erodent type, erodent size and geometry, blasting time, acceleration pressure, impingement angle) affect the surface properties of Y-TZP ceramics such as surface roughness and surface topography.[24,26,27] Furthermore, changes in surface and subsurface properties affect the mechanical properties of the ceramic, such as fracture resistance, toughness, and crack growth rate.[2,9,19] Therefore, optimizing micro blasting parameters is crucial regarding the micromechanical bonding strength of Y-TZP restorations,[8] its performance, and service life.[11,19,20] Also, the tetragonal phase to monoclinic phase transformation occurs on the Y-TZP ceramics' surfaces by the end of the micro blasting process.[8,11,22,23]

Moon et al.[7] investigated the effects of blasting parameters (particle size, acceleration pressure, blasting time and impact angle) on bending strength and shear bond strength of monolithic Y-TZP ceramics. They concluded that the strength significantly depended on particle size, acceleration pressure, and blasting time, while the impact angle was insignificant. Chintapalli et al.[2] showed that it was essential to control the process parameters so that the blasting process could be beneficial in the blasting process of Y-TZP ceramics. Eduardo et al.[19] compared flexural strength performance of polished and grit blasted Y-TZP ceramics and concluded that grit blasting led to higher surface roughness but negatively affected flexural strength. Queiroz et al.[28] reported that particle type, blasting time, and acceleration pressure were effective sandblasting parameters, which changed the surface topography of Y-TZP ceramics. Hallmann et al.[8] carried out studies on micro blasting of Y-TZP ceramics and reported that alumina particles led to higher surface roughness on Y-TZP ceramics than zirconia particles due to their sharp corners. Particle size and acceleration pressure affected the surface roughness, surface morphology, and phase transfer of Y-TZP ceramics,[3] and also there were embedded particles, cracks, and plastic deformations on the material surface after blasting.[3,8,29] According to the existing literature, sandblasting and grit blasting are effective methods to improve the bonding strength and mechanical properties of Y-TZP ceramics. However, they may cause undesired surface effects unless the process parameters are appropriately selected, which could also detrimentally affect bonding strength and the mechanical properties of Y-TZP ceramics. Thus, most of the studies in this field have focused on understanding the influences of micro blasting on bonding strength and mechanical properties of ceramics; however, the effects of blasting parameters on surface topography, roughness, and morphology have not yet been fully investigated. Moreover, the studies have not included a sufficient discussion related to the solid particle erosion phenomenon that occurs during the micro blasting of Y-TZP ceramics.

TABLE 1 Properties of zirconia ceramics obtained from different suppliers

Sample code	Materials	Manufacturer (batch number)	Composition	Heating time	Holding time
CZ	Cercon ht Pre-sintered full-contour Y-TZP	Degudent, Hanau, Germany (1803778)	ZrO_2, 5%Y_2O_3, <3% HfO_2, <1% Al_2O_3, <1% SiO_2	22°C/min to 900°C, 11°C/min to 1500°C	2 h and 25 min (1500°C)
ZZ	Prettau Pre-sintered full-contour Y-TZP	Zirkonzahn, Bruneck, Italy (ZB1180D)	ZrO_2, 4–6%Y_2O_3, <1% Al_2O_3, max. 0.02% SiO_2, max. 0.01% Fe_2O_3, max. 0.04% Na_2O	5.5° C/min to 1600°C	2 h (1600°C)
NA	Alliance Pre-sintered conventional Y-TZP	Noritake Dental Supply, Nagoya, Japan. (DCEWK)	94.4% ZrO_2, 5.4% Y_2O_3	10°C/min to 1100 °C, 5 °C/min to 1375°C	2 h (1375 °C)
ICE	Ice Zirkon Pre-sintered conventional Y-TZP	Zirkonzahn, Italy. (ZA9246A)	ZrO_2, 4–6% Y_2O_3, <1% Al_2O_3, max. 0.02% SiO_2, max. 0.01% Fe_2O_3, max. 0.04% Na_2O	5°C/min to 1500 °C	2 h (1500°C)
LP	Lava Frame Pre-sintered conventional Y-TZP	3M ESPE St. Paul, MN, USA. (394475)	ZrO_2 (92.27), Y_2O_3 (4.98) Al_2O_3 (0.43), SiO_2 (O.21), HfO_2 (1.58)	25°C/min to 1500 °C	11 h (1500°C)

The present study aims to investigate the effects of micro blasting process parameters on the 3D surface topography, surface roughness values, and erosion behavior of conventional and monolithic Y-TZP ceramics. Furthermore, it aims to provide a practical methodology on the surface roughening of zirconia ceramics for clinical applications by clarifying the dominant wear and deformation mechanisms in micro blasting through morphological, topographical, and erosion studies.

2 | MATERIALS AND METHODS

2.1 | Materials

The properties of Y-ZTP samples used in the experimental studies are given in Table 1. The samples were supplied as pre-sintered blocks and designed using computer-aided design program (DWOS; Dental Wings, Montreal, Canada), fabricated at dimensions Ø10 mm × 0.40 ± 0.01 mm via computer-aided manufacturing machinery (Yenadent D40; Turkuaz Dental, Izmir, Turkey). Afterward, they were sintered according to the manufacturer's instructions (Table 1). The detailed manufacturing process for Y-TZP specimens has been previously explained.[5] Before micro blasting treatment, the surfaces of the specimens were ground with 800- and 1200-grit silicon carbide (SiC) abrasive paper. Prepared samples were cleaned in an ultrasonic bath for 5 minutes in pure water.

Al_2O_3 abrasive particles with two particle sizes (50 and 460 μm; President Dental, Germany), which are broadly preferred in prosthetic procedures due to their high abrasive character, high hardness and high biocompatibility, were used as abrasive particles during micro blasting because of their suitability for surface preparation procedures and their use in commercial applications. Particle size distributions of the abrasive particles were analyzed with a Microtrac S3500 laser diffraction particle size analyzer (Table 2).

TABLE 2 Particle size distributions of Al_2O_3 abrasive particles

	Particle size distribution										
Particle type	Percentile	10	20	30	40	50	60	70	80	90	95
50 μm	Size (μm)	37.54	43.30	47.60	51.52	55.42	59.58	64.58	71.28	83.25	97.48
460 μm		334.6	369.9	398.7	428.0	460.1	497.1	544.5	611.3	725.8	834.4

2.2 | METHODS

2.2.1 | MICRO BLASTING

The surfaces of Y-TZP ceramics were blasted by Zhermack S-24R (Zhermack S.p.A., Badia Polesine (RO), Italy) micro blasting device, which is frequently used in commercial prosthetic dentistry procedures. Zhermack S-24R micro blasting device is a compressed-air blasting model, which allows sending air/shot mixture onto the workpiece at a constant speed, and the designed fixture enables to adjust particle impact angle and stand-off distance (Figure 1). The experimental studies were carried out under controlled parameters by a custom-designed test fixture (Figure 1). The system is composed of an air compressor for providing pressured air, an air dryer, an air regulator, and a blasting nozzle for blasting abrasive particles at different sizes (Ø0.8 mm for 50 μm abrasive particles and Ø1.7 mm for 460 μm abrasive particles).

The micro blasting was carried out for 10 seconds at 10 mm stand-off distance at acceleration pressures of 1.5 and 3 bar, particle impact angles of 30° and 90°, and with Al_2O_3 abrasive particles of 50 and 460 μm (Table 3). Each test has been conducted in triplicates. Commonly preferred particle type, particle size, and acceleration pressures in prosthetic dentistry applications were considered to determine the blasting parameters.

2.2.2 | Erosion rate

The evaluation of erosion rate is a necessary step to understand the wear effects of micro blasting. The erosion rate of a material is the ratio of the weight loss of the samples (Δm) to the total amount of the used erodent particles (m_e). In the present study, the erosion rate of the ceramic samples (mg/g × 100) was calculated by using the following formula:

$$erosion\ rate = \frac{\Delta m}{m_e} x100 \tag{1}$$

where Δm is the weight loss of the samples (mg), and m_e is the amount of the used erodent particles (g). Δm was measured via a Shimadzu ATX224 balance (0.1 mg precision), and m_e was measured via a Shimadzu UW6200H balance (0.1 g precision).

2.2.3 | Surface analysis

Topography analysis was performed with a Nanovea 50 PS 3D optical profilometer. A 2 mm × 2 mm area for each sample was selected from the centre of the wear trace and scanned three times with a 10 μm × 10 μm scanning precision. The

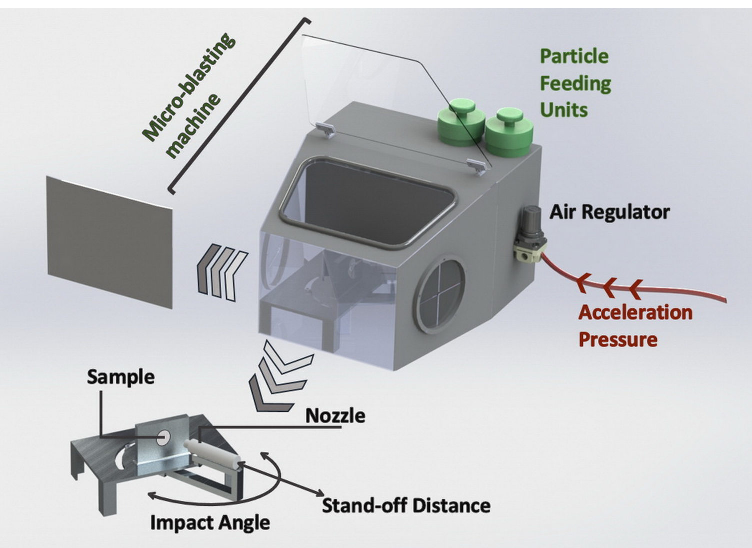

FIGURE 1 Schematic view of micro blasting test rig

TABLE 3 Micro blasting process parameters and specimen codes

Sample I.D.	Material	Micro blasting operation parameters				
		Particle size (µm)	Acceleration pressure (bar)	Particle impingement angle (°)	Stand-off distance (mm)	Blasting time (s)
CZ.1	Cercon ht (CZ)	50	1.5	90		
ZZ.1	Prettau (ZZ)					
ICE.1	Ice Zirkon (ICE)					
LP.1	Lava Pre-Sintered					
NA.1	Alliance					
CZ.2	Cercon ht (CZ)	50	3	90	10	10
ZZ.2	Prettau (ZZ)					
ICE.2	Ice Zirkon (ICE)					
LP.2	Lava Pre-Sintered					
NA.2	Alliance					
CZ.3	Cercon ht (CZ)	50	1.5	30		
CZ.4	Cercon ht (CZ)	50	3	30		
ICE.3	Ice Zirkon (ICE)	460	1.5	90		
ICE.4	Ice Zirkon (ICE)	460	3	90		

obtained data were processed with Mountains® surface imaging and metrology software, and average surface roughness (Sa), maximum peak height (Sp), and maximum valley depth (Sv) values of the samples were determined in accordance with ISO 25178-2:2012 standard. Three-dimensional surface topography analyses were performed over an area of $500 \times 500\ \mu m^2$ from the center of the wear trace of each sample, which was scrutinized through the program for 3D and 2D surface topography analysis. Sa, Sp, and Sv measurements were performed by Gaussian Filter and 80,000 µm of cut-off length from the centre of the wear trace, where the scanning area was limited as a flat area, $300 \times 300\ \mu m^2$, using the program. Thus, the undesirable effect of the created crater by blasting on the surface roughness measurement was minimalized. The methodology used for surface topography and roughness analysis is summarized in Figure 2.

The post-micro blasting surface morphology of Y-TZP specimens was investigated using Tescan Vega 2 brand scanning electron microscope (SEM) and the attached Bruker Quantax EDS detector. The images of the specimens were examined using the backscatter electron (BSE) mode at HV: 20.00 kV, WD:15.00 mm.

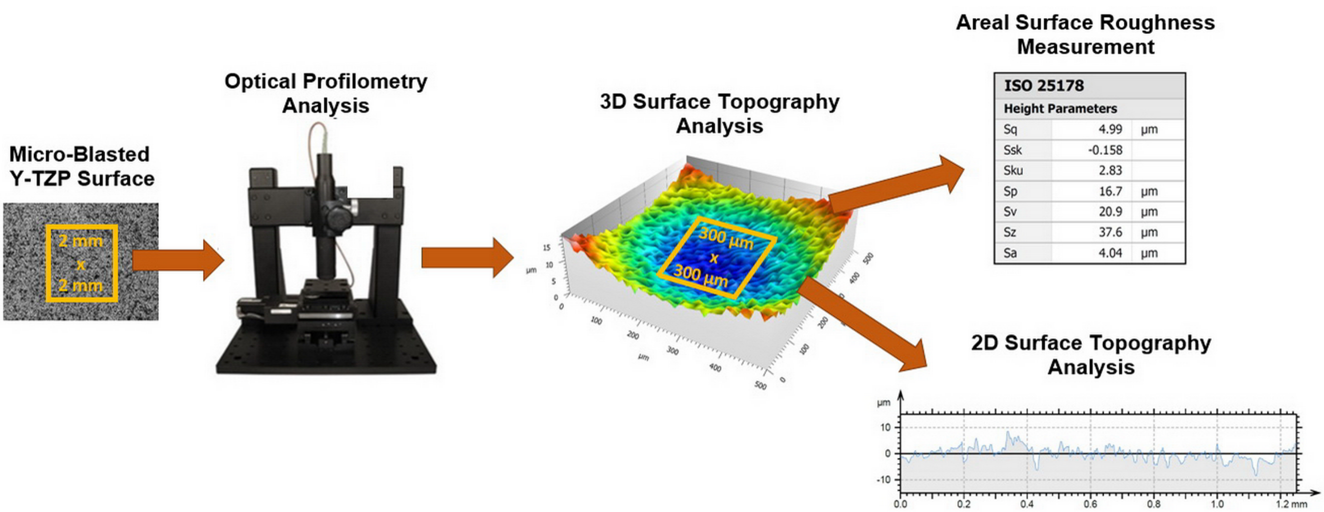

FIGURE 2 3D surface topography and roughness analysis flow chart

3 | RESULTS AND DISCUSSION

3.1 | Erosion rate

The erosion rates for micro blasted conventional and monolithic Y-TZP ceramics are presented in Figure 3, where two different subgroups (the group of conventional zirconia and the group of monolithic zirconia) are compared (Figure 3(A,B)). Since the differences between samples were not significant, a general trend could be mentioned between the subgroups. The erosion rates were higher for the monolithic zirconia samples with respect to conventional samples (averages: 12.05 ± 1.2 vs. 7.63 ± 1.5 at 1.5 bar, 29.72 ± 0.52 vs 24.33 ± 2.14 at 3 bar). The differences observed in the Y-TZP subgroups could be due to the manufacturing procedures of the ceramics, grain size characteristics, and sintering conditions.[30,31] Cercon ht (CZ) from the monolithic zirconia group and Ice Zircon (ICE) from the conventional zirconia subgroup was selected as representatives for the further characterization studies.

The effect of particle impingement angle on the erosion rate (Figure 3(C), the average erosion rate of monolithic Y-TZP samples blasted with 50 μm Al_2O_3 abrasive particles) was limited as the erosion rates at high (90°) and low (30°) impact angles were almost similar, with slightly higher values at 90°. Several reports have shown that brittle materials are worn at higher ratios in micro blasting performed at normal angles[7,25,30,32]; however, this effect was less pronounced in the present study. The primary wear mechanism in brittle materials is that chips are removed from the surface of the

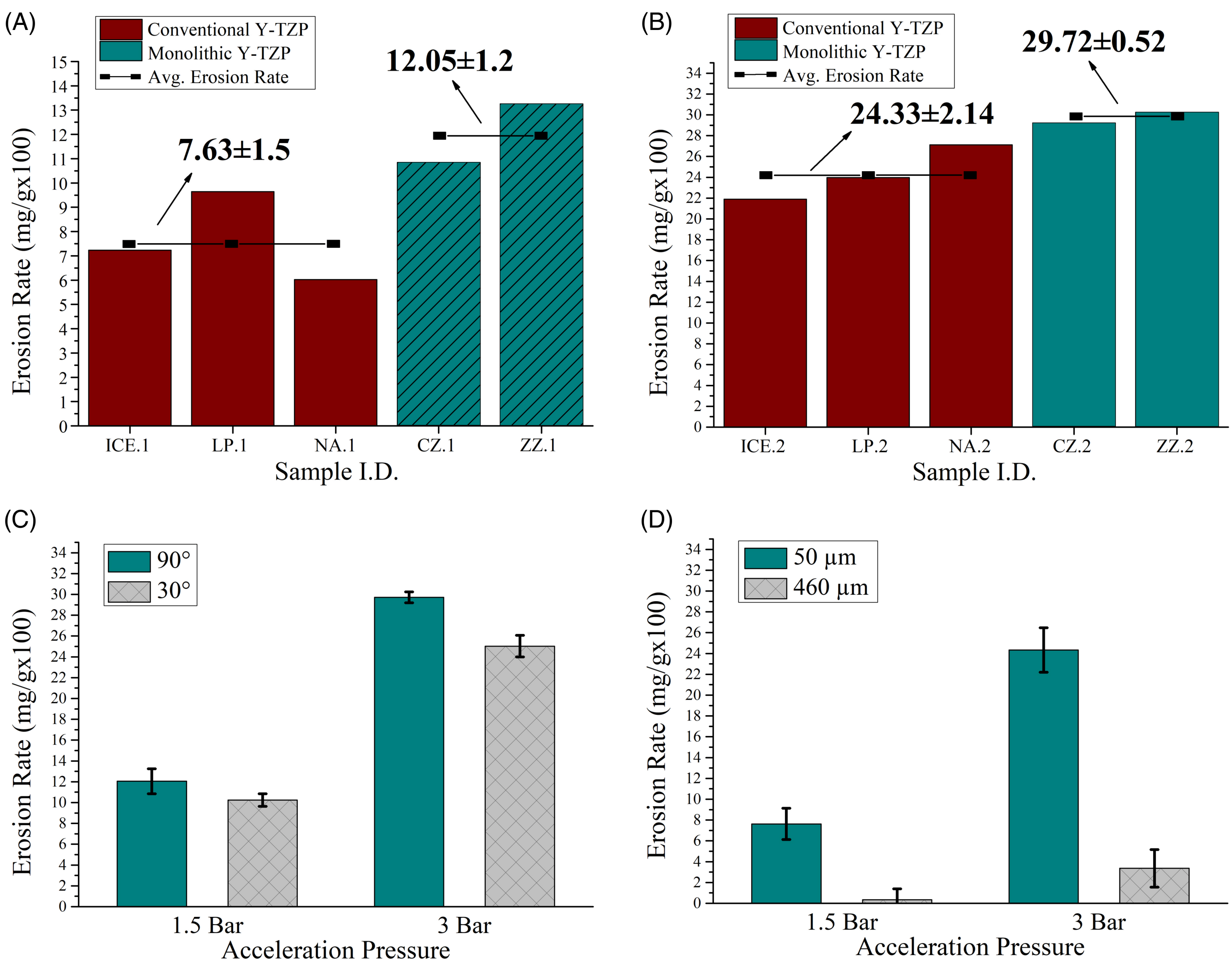

FIGURE 3 Erosion rates of zirconia samples: (A) all conventional and monolithic zirconia's at 1.5 bar 90°–50 μm, (B) all conventional and monolithic Y-TZP samples at 3 bar 90°–50 μm, (C) the effect of impact angles on the erosion rate, (D) the effect of particle size on the erosion rate

material, which mainly occurs at grain boundaries through the crack formation by the impact of erodent particles.[32,33] The particles have constant average impact velocities in an absolute acceleration pressure; thus, particles can transfer on the ceramic surface higher energy at normal impact angle (90) than lower impact angles. Therefore, the higher erosion rate is expected at more perpendicular impact angles since erodent particles sent to the material surface at a normal angle hit the surface with higher kinetic energy.[30] The results showed a lower change in the erosion rate depending on impact angle comparing to acceleration pressure.

Considering the effect of acceleration pressure on the erosion rate (Figure 3(C,D)), the erosion rate increased with higher acceleration pressure in all-ceramic groups. Micro blasting led to solid particle erosion,[25,34] where particles with high energies impacting to the surface of the target material led to the removal of micro-chips from the material surface and/or to plastic deformation.[25,27,32,35] The abrasive particles impacting the surface of the ceramic with higher kinetic energy caused larger and/or more micro-chips that are to be removed from the surface.[36] Therefore, both the kinetic energy of the abrasive particles[2,7,26,27,36] and the erosion rate increased at higher acceleration pressures.[7,27,36]

Regarding the effect of particle size on erosion rate (Figure 3(D), the average erosion rate of conventional Y-TZP samples blasted at 90°), increasing particle size decreased the erosion rate. Avcu et al.[27] indicated that particle size is a key parameter on erosion rate. Erosion rate could vary with an increasing particle size which might lead to higher kinetic energy based on the selected acceleration pressure. However, the effect of abrasive particle sizes on the erosion rate could not be evaluated alone by this parameter as kinetic energy might be dependent on both particle size and acceleration pressure. Zhou et al.[33] reported that increasing particle size decreased abrasive particle velocity so that erosion rate decreased. Oka et al.[30] studied the effect of various erodent particles with different particle sizes and stated that erosion rate was affected by abrasive particle size, which induced to change in particle impact velocity. Oka et al.[30] and Hallmann et al.[8] reported that particle angularity had a strong effect on erosion rate, which relied on particle size and type. In conclusion, the effect of particle size on erosion rate is a complicated phenomenon due to its relationship with kinetic energy and particle angularity according to the existing studies.

3.2 | Roughness and 3D topography

Surface topography and roughness are significant indicators of the bonding strength of micro-blasted ceramics. The existing literature on the analysis of surface roughness and topography has usually been carried out via 2D surface roughness measurement techniques such as linear profilometer.[2,3,8,10,12,28,31,37] However, obtained linear surface roughness values, such as Ra, Rv, and Rq as well as 2D topography analysis by utilizing those methods derive a limited amount of information (compared to 3D analyses) on changing surface roughness and topography, and those results do not fully represent the characteristics of the whole surface of the material. A detailed investigation of the surfaces with 3D analysis techniques is desirable for a better investigation surface topography and roughness.

Sa, Sp, and Sv values for CZ (monolithic) and ICE (conventional) zirconia (Figure 4A, blasted at 90°) indicated that both Y-TZP ceramics had similar surface roughness following blasting under the same blasting parameters. Increased acceleration pressure led to the higher Sa values of Y-TZP ceramics (Figure 4A). An increase in acceleration pressure led to the higher kinetic energy of abrasive particles.[37] Afterward, the particles impacted the surface at high velocities could remove more material from the surface[9] (Figure 3). Increasing acceleration pressure also caused higher plastic deformation on the surface; thus, an increase in roughness values with increasing pressure could be expected. Larger particle sizes also resulted in higher surface roughness (Figure 4B, conventional (ICE) Y-TZP samples blasted at 90°), where the effect of blasting pressure was more pronounced for 50 μm particles. The variation of roughness depending on the blasting parameters may be linked to the material removal through solid particle erosion of the samples during the blasting. For instance, larger chips could be removed from the material surface with increasing particle size,[21] which led to the formation of deeper pits on the surface[7,31] and resulted in higher surface roughness. The increase in abrasive particle size altered the surface roughness more at low pressures.

The roughness values remained at the same level in both impingement angles (Figure 4(C), monolithic (CZ) Y-TZP samples blasted with 50 μm Al_2O_3 abrasive particles) although the erosion rate showed a dramatic increase at 90° impingement angle compared to that of 30°. Beatrice et al.[38] investigated the effect of impingement angle and stand-off distance on the roughening of zirconium dental ceramics at 3.5 bar acceleration pressure with 110 μm by using silica-coated alumina particles. Contrary to the results of the present study (Figure 4(C)), they claimed that an impingement angle of 75° caused the higher surface roughness. In theory, it is expected that the higher surface roughness can be achieved by higher impingement angles such as 75° or 90° due to the higher impingement kinetic energy. However, the roughening

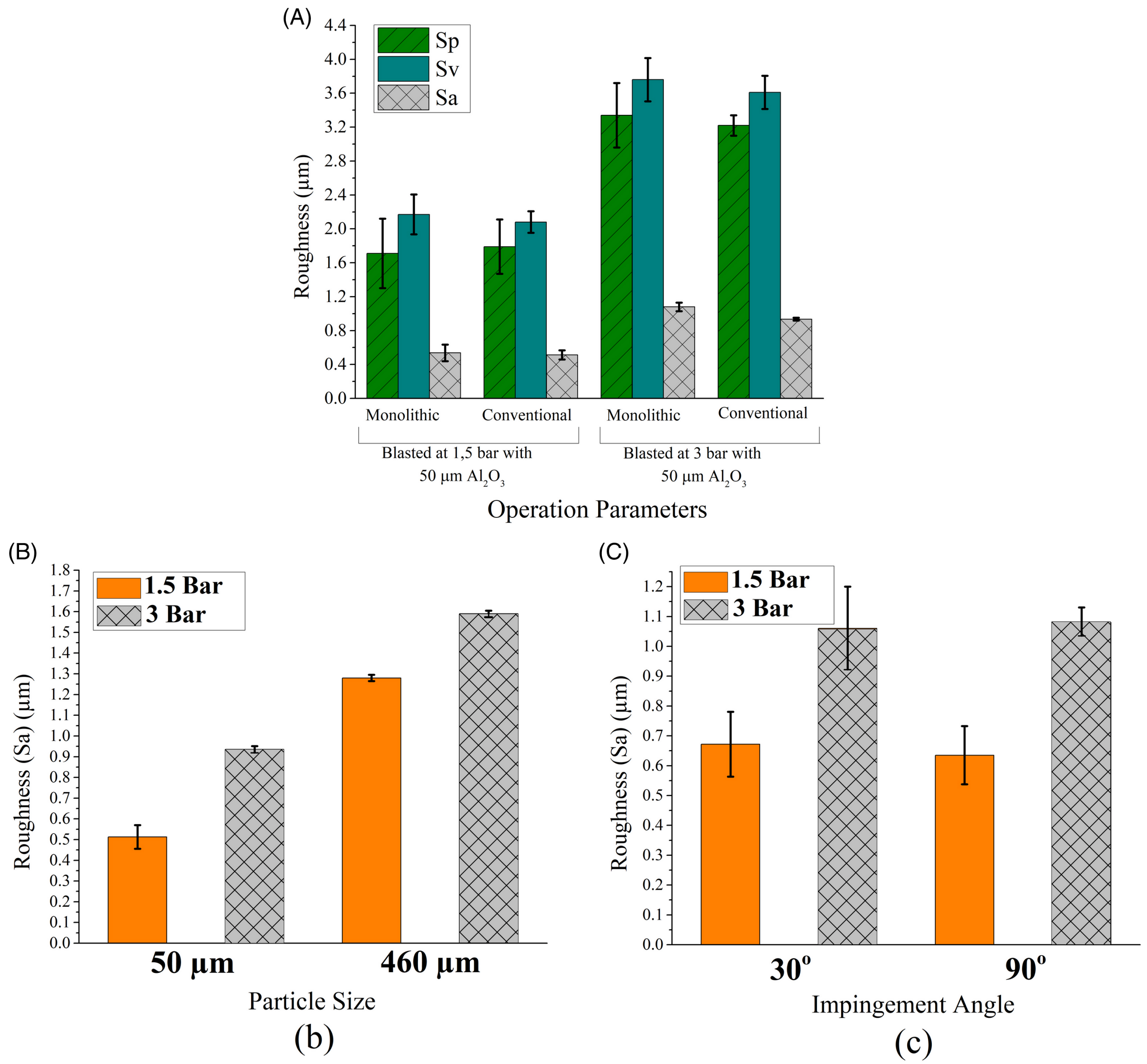

FIGURE 4 Areal surface roughness values of conventional and monolithic zirconia blasted at different parameters: (A) conventional (ICE) and monolithic (CZ) zirconia's at 90°, (B) the effect of particle size on Sa, (C) the effect of impact angles on Sa

behavior of materials can be varied depending on many other parameters, such as media sizes and acceleration pressure. Therefore, the different roughening results of dental zirconia at the same impingement angle could be explained by the characteristic of the erodent particles depending on the particle size. In conclusion, the present study showed that larger erodent particles (460 μm) had higher roughening characteristics than smaller erodent particles.

The relationship between the erosion rate and surface roughness of Y-TZP ceramics (Figure 5) showed that 50 μm abrasive particles eroded the surface (0.7 mg/g × 100 at 1.5 bar and 1.6 mg/g × 100 at 3 bar) more than roughening (~0.5 μm at 1.5 bar and ~ 1.1 at 3 bar) them in the blasting process in comparison to 460 μm abrasive particles (erosion rate: 0.1 mg/g × 100 at 1.5 bar and 0.3 mg/g × 100 at 3 bar, roughness: ~1.3 μm at 1.5 bar and ~ 1.6 μm at 3 bar). With 460 μm particles, the erosion rate was low, whereas higher roughness values were obtained. The micro blasting of Y-TZP ceramic surfaces with small-sized abrasive particles seemed to be more suitable for the surface cleaning, whereas the micro blasting with large particles was more effective to modify the surface topography for roughening. During the micro blasting, abrasive particles with different shapes impacted randomly to the surface to form peaks and pits, which

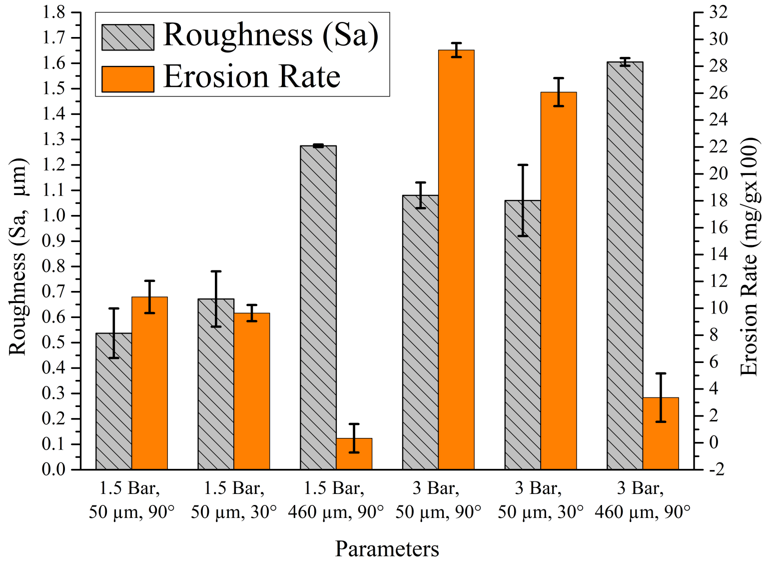

FIGURE 5 Relationship between erosion rate and surface roughness corresponding to acceleration pressure, particle size, and impingement angle

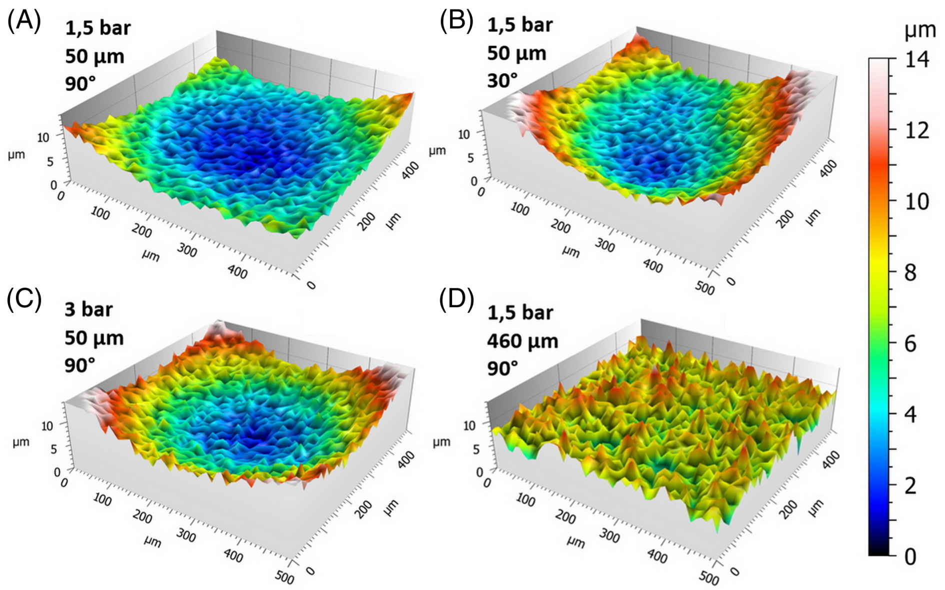

FIGURE 6 3D surface topography analysis after the micro blasting process

significantly changed the topography.[28,31] Multiple parameters affected the surface topography simultaneously during micro blasting, including particle shape, type, size, acceleration pressure, and impact angle,[25,27,39] which made 2D and 3D characterization techniques valuable to understand the changes in surface topography better. The effects of the acceleration pressure on the surface topography as shown in Figure 6(AB) indicated that the increase of the pressure deepened the peaks and pits, but there was no significant change in the peak and pit morphologies (baseline width). The increase in the acceleration pressure led to higher particle kinetic energy, causing the particles with the higher impact energy to penetrate deeper beneath the surface resulting in deeper and more extensive material removal.[18,33,37] As a result, there was no significant change in the surface morphology (base width of the material removal), since the increase in the pressure only increased the depth of the peaks and pits (Figure 7(A,B)).

As shown in Figure 6(A,C), particle impact angle did not cause significant differences in the surface topography of Y-TZP ceramics. The depths and morphologies of peaks and pits formed on the surface exhibited similarities at different particle impact angles (Figure 7(A,C)). The surface topography changed considerably with the increase of abrasive particle size (Figure 6(A,D)). As the particle size increased, the depths of the peaks and pits formed on the Y-TZP ceramic surface were more pronounced, and the abrasive particles (due to the larger particle size) removed larger chips from the surface. Three-dimensional surface topographies of the zirconia specimens obtained using two different size particles at the same acceleration pressure and particle impact angle are given in Figure 8 for a 2 mm × 2 mm area. The abrasive particles of

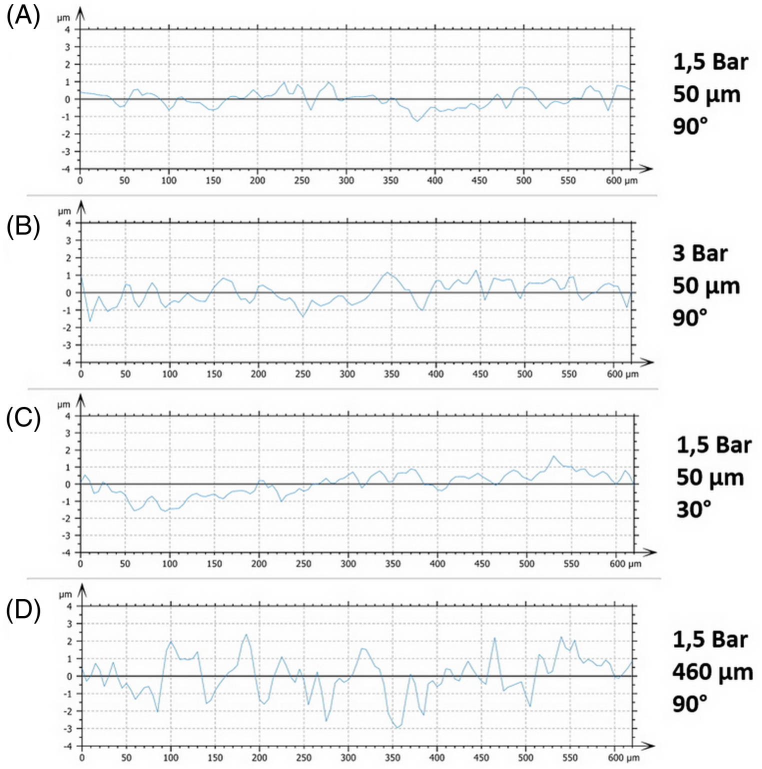

FIGURE 7 2D surface topography analysis after the micro blasting process

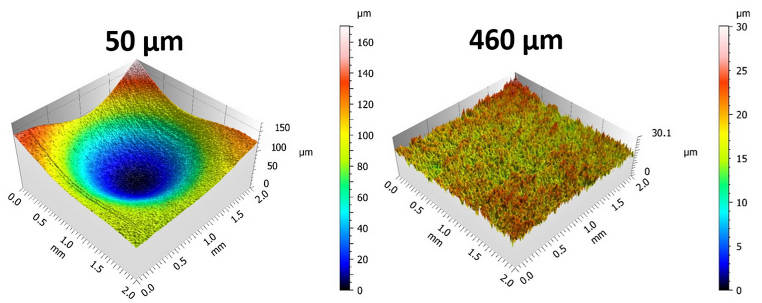

FIGURE 8 Effects of abrasive particle size on surface texture in micro blasting (conventional zirconia, 3 bar, 90°)

50 µm size formed a deep pit due to erosion of the surface, whereas 460 µm particles formed a rougher surface topography due to the homogeneous abrasion of the surface.

3.3 | Surface morphology

The surface morphologies of the samples were mainly affected by plastic deformation, microcracks, and micro-cutting mechanisms, which occurred by the repeated impacts of sharp-edged alumina particles (Figure 9).[40,41]

The depth, size, and width of the micro-cutting observed on the surface (Figure 9) increased when 460 µm abrasive particles were used instead of 50 µm, and the plastically deformed areas were also expanded. The angularity of abrasive particles was different at varying abrasive particle sizes.[8] Sharper corners and more rigid particles tended to cause more significant damage to the surface.[32] The depths of the micro-cutting pits observed in the eroded area were larger at higher particle acceleration pressures, which increased the kinetic energy of impacting particles.[9] There was not an apparent change in wear mechanisms as a function of the impingement angle. SEM analyses indicated dark contrasted regions on the Y-TZP ceramics due to micro blasting as the gray colored regions identified as the primary matrix representing zirconium-rich regions and the black colored regions identified as the aluminum-rich regions according to EDS analysis (Figure 9). The aluminum-rich regions revealed that abrasive particles embedded on the surface during the micro blasting. The existing studies on micro blasting has indicated that particle embedment on the surfaces of Y-TZP ceramics might

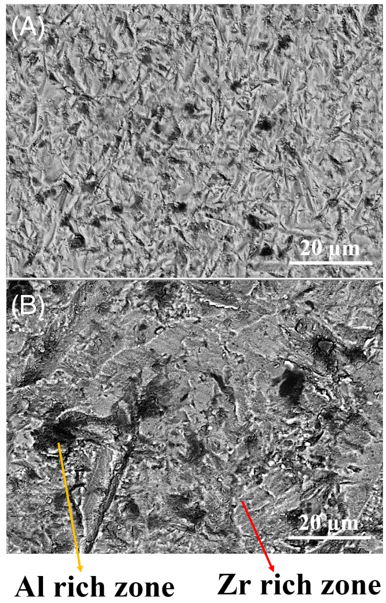

FIGURE 9 SEM images of zirconia ceramics sandblasting at different parameters: (A) acceleration pressure 3 bar, particle size 50 µm, impact angle 90°, (B) acceleration pressure 3 bar, particle size 460 µm, impact angle 90°

reduce the bond strength between the resin cement and the ceramic in application.[3,29] Therefore, decreasing the number of abrasive particles embedded in the surface of the material might be essential to enhance the performance of Y-TZP ceramics in prosthetic dentistry applications.

4 | CONCLUSION

The present study aimed to investigate and compare the surface roughening process and erosion behavior of monolithic and conventional yttria-stabilized zirconia (Y-TZP) ceramics in a micro blasting procedure used for dental applications. The studies carried out would help the researchers to understand the surface roughening of Y-TZP ceramics and be a guide for achieving the targeted surface topography during the surface modifications of zirconia ceramics.

The dominant parameters affecting the surface topography and roughness were acceleration pressure and particle size. The particle size significantly changed the character of the surface topography, and the pressure modified the height and depth peak and valley, respectively. The detailed 3D surface topographies revealed that the use of high pressure and small size particles during the micro blasting eroded the surface of Y-TZP ceramics. Thus, these parameters would be used for surface cleaning purposes. By contrast, the use of large particles was more effective for modifying the surface topography. Thus, the solid particle erosion behavior of these ceramics needs to be carefully considered in the micro blasting applications prosthetic dentistry since the excessive erosion occurs during the blasting may detrimentally affect the mechanical performance and also the aesthetic features of the ceramics during service life. We recommend that further studies, specifically on the solid particle erosion behavior of these ceramics under various parameters, are required to be performed, which have not yet been detailed in the existing literature.

The present study showed that the particle size was the main parameter on the surface modification of Y-TZP ceramics. Large size particles (460 µm) could be recommended to achieve a homogenously roughening of the surface. By contrast, small size particles (50 µm) would be more useful for cleaning Y-TZP ceramics in dental applications. The understanding of the microstructural features and mechanical properties of these ceramics (such as grain sizes, the distribution of phases, hardness, etc.) could be useful to discuss better the underlying reasons for the erosion behavior of Y-TZP ceramics. Furthermore, the adhesion strength and T > M phase transformation after micro blasting should be investigated in order to provide a complete understanding of the effect of surface modification on the microstructural features and mechanical performance of Y-TZP.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

Okan Yetik: Conceptualization; investigation; methodology; validation; visualization; writing-original draft. **Berzah Yavuzyegit:** Investigation; methodology; visualization; writing-original draft. **Yasemin Yıldıran Avcu:** Conceptualization; investigation; methodology; validation; visualization; writing-original draft. **Hürol Koçoğlu:** Investigation; methodology. **Gürel Pekkan:** Resources. **Serkan Sarıdağ:** Investigation; methodology; resources; visualization; writing-original draft. **Mert Guney:** Validation; visualization; writing-original draft; writing-review and editing. **Egemen Avcu:** Conceptualization; investigation; methodology; project administration; resources; supervision; validation; visualization; writing-original draft; writing-review and editing.

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