Original Article

Effect of simulated chairside grinding procedures using commercially available abrasive agents on the surface properties of zirconia

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Abstract

Aim: The aim of the present study was to assess the change in physical properties (surface roughness, surface hardness and phase transformation) after surface grinding of zirconia by using three commercially available abrasives.

Materials and Methods: Thirty sintered zirconia specimens were prepared and divided into three groups namely Group M (grinded using Mani Dia diamond bur standard grit), Group T (grinded using Tri Hawk diamond bur coarse grit) and Group P (grinded using Predator carbide bur). A customised assembly was used to follow a standardised protocol for surface grinding. The surface roughness, surface hardness and phase transformation was recorded before and after the grinding procedure.

Statistical Analysis Used: ANOVA and Bonferroni post hoc test were used to assess the values obtained after the testing the surface roughness and surface hardness.

Results: The results of the present study revealed the average values of change in surface roughness as Group M (0.44 μm) and Group T (1.235 μm) and Group P (-0.88 μm). The average values of change in surface hardness were Group T (19.578 HV), Group M (46.722 HV) and Group P (36.429 HV). The change in surface hardness was not statistically significant. There was no phase transformation seen after the grinding procedure.

Clinical Significance: Carbide burs along with copious water irrigation when used to grind zirconia intra-orally produces has a polishing effect, minimal change in hardness & no phase transformation. The present study advocates the use of carbides for chair-side grinding of zirconia.

Key Words: Carbides, chairside grinding, zirconia

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INTRODUCTION

The increasing demand for esthetics has led to metal-free restorations becoming the material of choice for fixed dental prostheses.[1-3] Metal-ceramic restorations, though the gold standard for restoration of teeth have known drawbacks such as compromised esthetics and the possibility of delamination of the ceramic overlying the metal.[4] One of the most recent additions to the family of all ceramic materials is zirconia.

Zirconia is a polycrystalline ceramic material. This polymorph exists in three phases-monoclinic phase (M), tetragonal phase (T), and the cubic phase (C). The tetragonal phase shows the most optimum physical and mechanical properties.[5] However, in the presence of stresses, the tetragonal crystals undergo a phasic transformation to the weaker monoclinic phase. This martensitic phase transformation induces a 3–4% volumetric expansion of the crystal inducing internal stresses eventually making the material prone to fracture. The addition of a stabilizing agent yttrium oxide to zirconium dioxide leads to the formation of Y-TZP.[6] This yttrium content of 3–5% maintains the stability of zirconia in the tetragonal phase thereby reducing the amount of phase transformation.[7]

Zirconia has been reported to have superior mechanical properties among all ceramic restorations.[8] It exhibits double the fracture toughness and bending strength as compared to the other ceramics.[9] This material fulfills the prerequisites of an ideal restorative material due to its excellent physical properties which include high strength, translucency, color stability, and superior biocompatibility.[10,11]

In spite of the excellent properties of zirconia, the surface grinding of zirconia for occlusal adjustments can result in a relatively rough surface of the restoration, which may cause severe wear of opposing enamel.[12] A smooth surface of the restoration is necessary to avoid the plaque accumulation, gingivitis, periodontitis, wear of antagonist's tooth and other complications that can lead to the failure of restoration.[13]

Grinding zirconia decreases its flexural strength and fracture resistance.[14] However, many a times, it is not possible to avoid grinding during routine clinical or laboratory procedures. This has led to the development of newer materials that minimize, if not prevent any damage to the zirconia surface.

Newer instruments are being fabricated to improve the efficiency of grinding at the same time reducing the ill effects of the grinding procedure. Investigators have reported the effects of various grinding procedures on the surface properties of Y-TZP ceramics in the previous studies.[15-23] Kosmac *et al*. and Iseri *et al*. documented a decrease in the strength of zirconium oxide after grinding procedure.[15,18] Preis *et al*. reported an increase in surface roughness after dental adjustments, which can subsequently be improved using a polishing kit.[19] Xu *et al*. reported an improvement in the strength of zirconia on fine grinding with diamond points.[24] The residual surface compressive layers introduced during the grinding procedure strengthens the zirconia considerably.[25] However, severe grinding process introduces deep surface flaws which are difficult to remove and act as stress concentrators.[26] The studies have also reported a phase transformation from the tetragonal (T) to the monoclinic (M) phase due to the superficial modifications.[20,21]

The design and cutting efficiency of instruments used for surface grinding procedure can also affect the surface properties. Comparison between the various grinding tools that can be used for surface grinding has been reported in the past. Ferrari and Conti concluded that tungsten carbides had a better finishing potential as compared to diamond points.[23] Ercoli *et al*. in his study demonstrated the superior performance of carbides in comparison to diamond points. He concluded that during the cutting process carbides require less load and advances faster within the substrate.[27] Carbides at high speed produce a very smooth surface.[28] Hotta *et al*. assessed the durability of tungsten carbide and concluded that the damage to the blades increases the machining time, but this increase could be acceptable for a polishing effect.[29] Despite having a better cutting efficiency of carbides, the studies in the past have not documented their effect on zirconia.

This study evaluated the effect of different commercially available grinding tools such as tungsten carbides and diamond points of varying grit sizes, after surface grinding of zirconia restorations. The changes in physical properties (surface roughness, hardness, and phase transformation) were assessed.

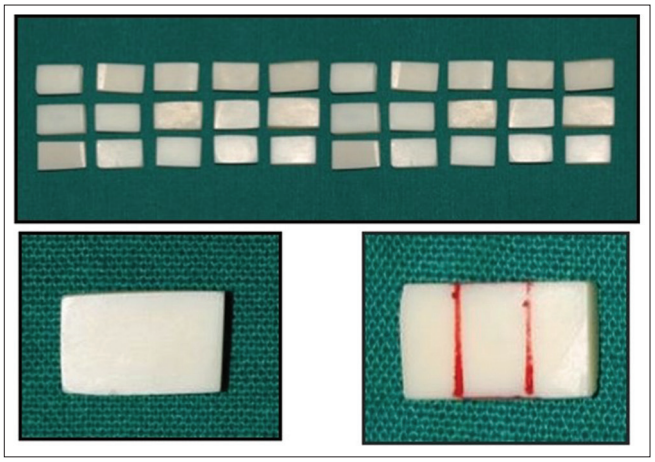


Figure 1: Specimens and the tested area marked

Figure 2: Tri Hawk diamond bur, coarse grit

Figure 3: Mani diamond bur, standard grit

Figure 4: Predator carbide bur

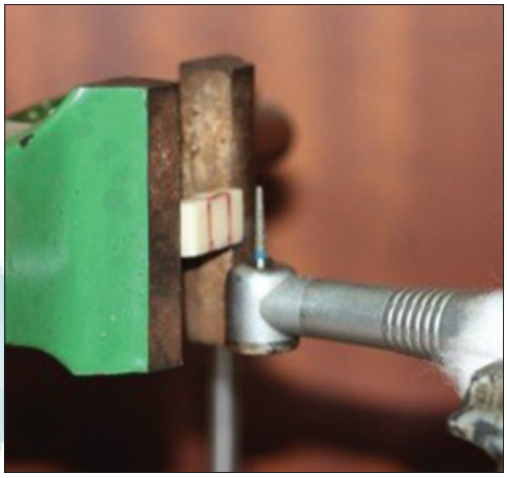


Figure 5: Customized assembly used for grinding of the zirconia specimens

The null hypothesis studied was that surface roughness, surface hardness, and phase transformation are not influenced by the grain size and design of commonly used commercially available and zirconia-specific abrasive agents.

MATERIALS AND METHODS

Thirty specimens of zirconia (3M™ ESPE™ Lava™, St. Paul, Minnesota, United States) were cut into the blocks of dimensions 15 mm length × 10 mm width × 3 mm thickness at the presintered stage and smoothened with silicon carbide grinding paper #400, #600, and #1000 (3M 101 Q Wetordry, 3M). The prepared specimens were then sintered. They were divided into three groups with ten specimens per group. The required area for testing was marked [Figure 1].

The specimens were ground using the standard protocol described later. The specimens in Group T underwent grinding with a diamond point bur (198-018 C, 1.8 D × 8.0 L; Coarse grit, Tri Hawk, Morrisburg, Ontario, Canada) [Figure 2], Group M with another diamond point bur (Standard grit, size 106–125, Mani Dia burs, Mani, Inc., Tochigi, Japan) [Figure 3] and Group P with carbide burs (Predator Turbo PR 3T, 1/10 D × 4.0 L, Prima Dental, United Kingdom) [Figure 4], respectively.

A customized assembly was designed to mount both the handpiece and the specimens [Figure 5]. The handpiece was clamped on a flat platform which could slide sideways. Another clamp to stabilize the specimen was attached to the assembly. Burs inserted in the handpiece were oriented approximately parallel and positioned in contact with the specimen. Stabilizing both the components ensured a constant load application. Specimens removed from assembly were cleaned and air dried before testing. The chairside grinding procedure was simulated using the three different burs as per the manufacturer's instructions. The grinding procedure was the first carried out for Group T, then Group M, and Group P respectively, using the standardized protocol as described by Preis *et al*.[19] Each sample was ground for 10 s.

The pretreatment surface roughness Ra (arithmetic average roughness) analysis was carried out for all thirty specimens from the three groups by means of a profilometric contacts surface measurement device (Perthometer SP6, Feinpruf-Perthen, Mahr, Gottingen, G; 2 measurements per specimen; LT = 1.7 mm/0.25 mm, velocity 0.1 mm/s, 2 μm diamond indenter). Pretreatment surface hardness analysis was done for all the samples using the Vicker's Microhardness Tester (Reichert Austria Make, Sr. No. 363798, using load: 100 g).

After wear simulation, the surface roughness R_a and surface hardness were determined.

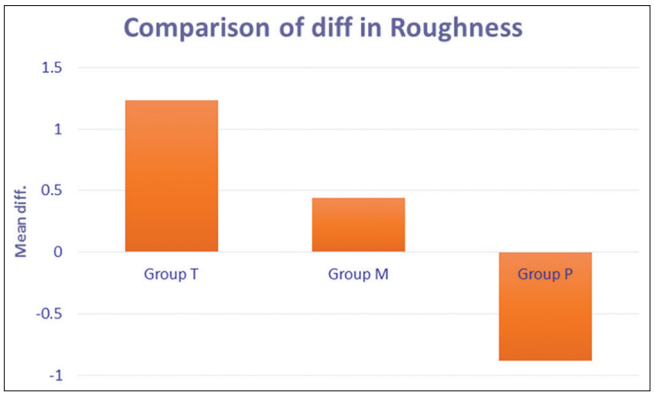
Phase transformation of zirconia was investigated by X-ray powder diffraction technique (Bruker, D8 Advance) using CuKα (1.54) X-rays. The diffraction profiles were acquired in the 2 Θ range from 20° to 80°, where Θ is the angle of reflection with the step size of 0.03 and scan rate of 0.6 s/step. The relative amount of phase transformation for the specimens was determined as described by Karakoca and Yilmaz.[21]

RESULTS

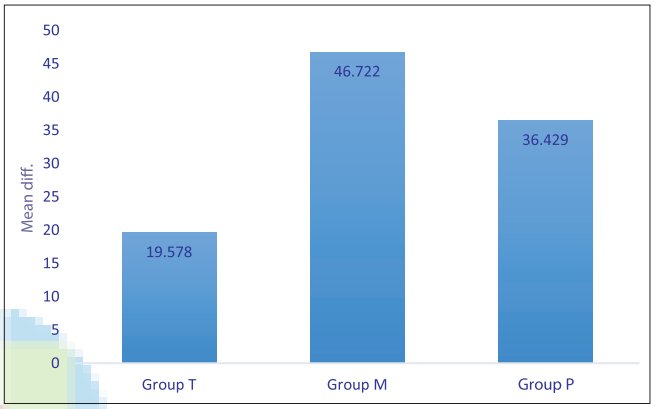
Average values of change in roughness were 1.235 μm, 0.44 μm, and −0.88 μm for Groups T, M, and P, respectively. Statistical analysis was carried out using the average values of change in roughness [Graph 1]. Surface roughness R_a values showed a statistically significant difference between the groups ($P < 0.001$). Grinding of the sintered zirconia specimens significantly increased R_a in Group T and Group M, whereas the same procedure caused a reduction in the R_a for Group P. The one-way ANOVA demonstrated differences in the mean values ($P < 0.001$), and the Bonferroni *post hoc* test revealed statistically significant differences among the groups ($P < 0.001$).

Similarly, average values of change in hardness were 19.578 HV, 46.722 HV, and 36.429 HV for Groups T, M, and P, respectively. Statistical analysis was carried out using the average values of change in hardness [Graph 2]. The one-way ANOVA demonstrated differences in the mean values ($P < 0.020$), and the Bonferroni *post hoc* test did not reveal any statistically significant differences among the groups ($P > 0.05$).

The X-ray diffraction pattern and analysis of the peaks of the control specimen confirmed tetragonal crystalline phase. After surface manipulation with the abrasives, the intensity of the peaks in specimens of Group P, M, and T decreased in that order. As compared to the sintered state, the ground specimens presented asymmetrical broadening of the tetragonal peak and increase of full width at half maximum. The least distortion of the peaks was observed in Group *P* as indicated in the graph [Figure 6]. The grinding procedure had no significant effect on the relative amount of tetragonal zirconia in all the groups.



Graph 1: Average values of change in surface roughness



Graph 2: Average values of change in surface hardness

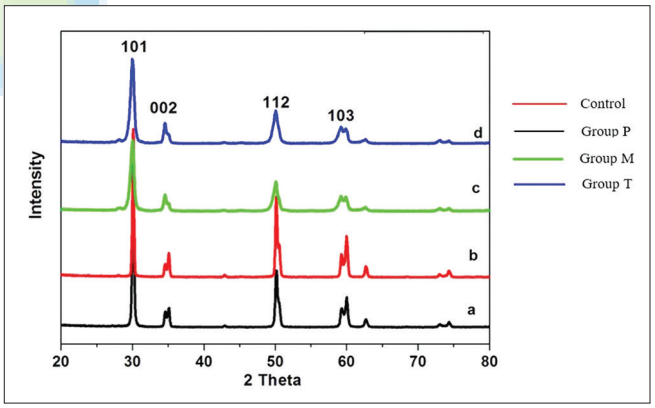


Figure 6: X-ray diffraction pattern following grinding of specimens

DISCUSSION

Chairside adjustment of a restoration is a standard protocol followed by clinicians for establishing optimal occlusal contacts. Following such adjustments, the restoration should be reglazed or mechanically polished to restore the surface

smoothness.[30] However, reglazing is not always convenient or possible. Therefore, the use of polishing is recommended to restore the surface finish and properties.[20]

Advancements in material science and excellent physical properties have made zirconia, a popular alternative to traditional metal or PFM restorations for fixed dental prostheses.[9]

Although zirconia meets the requirement of a prosthetic material, it has a disadvantage of causing irreversible wear of the antagonist tooth.[13] This process of wear also results in an increase in the surface roughness and loss of glaze of the restoration.[20] The surface smoothness of a restoration is essential to avoid complications such as plaque accumulation, gingivitis, periodontitis, and wear of antagonist tooth.[15] As studied by Bollen *et al*., surface roughness higher than 0.2 μm will lead to bacterial adhesion, plaque maturation, and increased the risk of caries.[30] The rough surface of zirconia will cause more wear of the opposing tooth and also compromise the clinical performance of the restoration; hence, a polished zirconia surface is preferred.[19,31,32]

The previous studies show that reglazing the restoration after chairside adjustments are necessary.[33] While others show that mechanical polishing of the restoration can help restore the surface properties.[21]

In this study, the authors carried out a comparison between diamond points and carbide burs. Diamond points were used (Mani Inc., Japan) as they are the most common abrasives clinicians use to grind zirconia chairside. The high hardness of zirconia necessitates the use of these coarse diamond rotary instruments.[32] Carbides are known to have a high cutting efficiency at high speed.[34] Hence, these were chosen in the study. A commercially available zirconia-specific abrasive was also used to study its effect on the zirconia surface in comparison to the popularly used burs described above.

Surface grinding usually leads to an increased surface roughness.[35,36] The results of this study indicated an increase in the surface roughness in Group T (1.235 μm) and Group M (0.44 μm). The mean R_a value obtained for Group T (1.235 μm) was more than that of Group M (0.44 μm). The grit size of the diamonds used in Group T was much coarser as compared to the one used in Group M thereby causing a greater surface roughness. As studied by Okhuma *et al*. larger the grit size of diamond, more will be the grinding depth.[37] Coarse grinding introduces surface and subsurface flaws causing grain pull out and strength degradation.[14] The results obtained in this study were similar to previously reported studies.[31,38,39] Güngör *et al*. studied the effects of surface treatment on zirconia and observed highest surface roughness in specimens which were ground using diamond rotary instruments (100 μm grain size). They concluded that surface grinding was an abrasive surface treatment. It results in removing a greater amount of material and higher level of stress generation.[38] Ramos *et al*. reported an altered micromorphological pattern after grinding zirconia ceramic. They stated that the grit size of diamond disks affected the surface roughness values. Lower surface roughness values were observed with small grit size diamond disks. Fine grit instruments have a large number of grains and less distance between them, which results in greater number of scratches which are close to each other thereby creating a more homogeneous surface.[39] Hmaidouch *et al*. reported a significant increase in surface roughness after coarse grinding. After polishing of the same specimen, smooth surface was obtained that was comparable to untreated glazed zirconia surfaces. This was possible due to the removal of weakly attached surface grains and elimination of the grinding trace lines. They concluded that polished surfaces were better than glazed surfaces and produce less wear on the opposing enamel.[31] In this study, the high surface roughness in Group T and Group M could be attributed to the grit size of the diamond points, with a higher grit size leading to deeper surface flaws.

The R_a value obtained for Group P (−0.88 μm) showed a decrease in surface roughness and had a polishing effect. This could be explained by the 8-bladed toothed geometry of the carbide which caused a polishing effect on the zirconia specimens. Carbides have a shearing action on the cutting substrate, whereas diamond points have an abrasive action.[34,40-42] Carbides have blades with slight negative rake angle and 90 degrees edge angles. The clearance faces are either curved or have two faces to provide a low clearance angle near the edges and greater clearance space ahead of the following blade.[34] As studied by Hotta *et al*., damage to the blade of a carbide bur increases with increase in machining time, but the bur could yet be acceptable for polishing.[29]

The result of the surface hardness values obtained indicated a reduction in the hardness of the zirconia in all the three groups. Group M (46.722 HV) showed the highest reduction, whereas Group T (19.578 HV) showed the least reduction. The difference was statistically significant. This is in agreement with Okhuma *et al*. and Siegel.[37,40] They stated that heat generated during grinding process caused destruction and exfoliation of diamonds. Hence, the larger grit size of diamonds in Group T compared to that in Group M grinds the zirconia specimens faster and efficiently, causing less change in surface hardness. The values of change in hardness obtained for Group *P* were not statistically significant when compared to Group T and M. These findings are in agreement with those of Traini

et al. and Pittayachawan *et al*.[22,43] Traini *et al*. reported a higher value of hardness for machined surfaces than for fine polished surfaces while a lower value of hardness for coarse polished surface. They used silicone wells green-coarse grit and silicone wells yellow–super-fine grit (Edenta AG, Dental Rotary Instruments, AU/SG, Switzerland) at 10,000 rpm to grind zirconia specimens. The reported differences between these were statistically insignificant.[22] Pittayachawan *et al*. reported an increased hardness value of machined specimens as compared to polished specimens. The specimens were grounded sequentially with 300, 500, 800, and 1000 grade silicon carbide papers (Struers, UK). The specimens were polished with a DP-suspension (Struers, UK) containing polycrystalline diamond (Struers, UK) of size 9 μm and 3 μm for 10 min at a polishing machine speed of 150 rpm. The difference in hardness between these two groups tested was statistically insignificant.[43]

The X-ray diffraction pattern of the ground specimens showed a reduction in the peaks in all the three Groups T, M, and P, respectively as compared to the peaks seen in the control. The grinding procedure did not have any distinct influence on the phase transformation of specimens in this study. Phase transformation did not take place as the surface treatment was not effective enough to initiate a T→M transformation, but a low amount of monoclinic phase was observed due to grinding.[44] The broadening of the tetragonal peaks could be due to the lattice distortion of the crystalline structure of zirconia.[19]

The results obtained in this study were similar to previously reported studies.[21,35,39,45] Karakoca and Yilmaz studied the phase transformation after grinding and sandblasting of Y-TZP and reported that grinding has no significant influence on the phase transformation.[21] Lee *et al*. studied the effect of different grinding burs on physical properties of zirconia and reported a small amount of monoclinic phase in all experimental groups. They believed that the increase in local temperature due to excessive grinding and sparks could be the possible reason for inducing a reverse phase change to the tetragonal phase.[35] Similarly, in this study, some amount of lattice distortion was seen which could be due to the excessive heat and sparks generated while grinding the surface. Continuous copious water irrigation was able to control the amount of heat generated. Ramos *et al*. reported that grinding promoted a higher monoclinic phase in the test group than the control group. This test group underwent a heat treatment that induced a reverse transformation of the monoclinic phase achieving a monoclinic phase content similar to that of the control group. They related the transformation rate to the grain size, larger the grain size lower will be the stability.[39] Lava zirconia (Lava Frame, 3M ESPE) which was the same brand used in the present study, is known to have large grain size, thus greater possibility of the phase transformation. The results of phase transformation of this study are in agreement with that of Ramos *et al*. Juy *et al*. in their study, stated that the monoclinic phase induced was transformed back to the tetragonal phase due to the increase in temperature of the surface undergoing the grinding procedure.[46] Other studies also reported a decrease in the monoclinic phase due to reverse phase transformation by heat generation on excessive grinding.[46,47]

Thus, the results obtained in the above study showed that the null hypothesis was rejected for surface roughness and surface hardness, whereas accepted for phase transformation.

CONCLUSION

Within the limitations of this study, it may be concluded that carbides used for abrasion of the zirconia had a polishing effect on the zirconia surfaces. Diamond points abraded and roughened the zirconia surface, resulting in surfaces that required further finishing, and polishing. The use of the zirconia-specific diamond bur seems questionable as this study shows that carbides have the potential to be used with greater efficiency on zirconia surfaces. There was a reduction in the hardness of the zirconia when all the different abrasives were used, though this reduction was not statistically significant. No phase transformation was observed following abrasion of zirconia with either diamond points of different coarseness and carbide burs. Thus, this study advocates the use of carbides for chairside grinding of zirconia.

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Conflicts of interest
There are no conflicts of interest.

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