ORIGINAL RESEARCH

A Study of the Antagonist Tooth Wear, Hardness, and Fracture Toughness of Three Different Generations of Zirconia

Abid S Khan[1], Smita Musani[2], Pallavi Madanshetty[3], Taufique Shaikh[4], Mosin Shaikh[5], Quraish Lal[6]

Received on: 02 July 2023; *Accepted on:* 04 August 2023; *Published on:* 20 September 2023

Abstract

Aim: The objective of this study was to evaluate the wear of opposing natural teeth, hardness, and fracture toughness of all three generations of zirconia.

Materials and methods: Three groups were divided based on the generation of zirconia ($n = 12$): groups I (first generation of zirconia), II (second generation of zirconia), and III (third generation of zirconia). Wear of opposing tooth: the discs and extracted human premolars were placed onto holders on a two-body wear machine under a constant load of 5 kg. Hardness was calculated using Vicker's microhardness tester, Reichert Austria Make. International Organization for Standardization (ISO) standardized chart was used to check the hardness number based on the indentation length. Fracture toughness was calculated using Niihara's formula.

Results: Statistical analysis was done using paired *t*-test and one-way analysis of variance (ANOVA). The maximum amount of wear was seen with the first generation of translucent zirconia—group I (0.93 mm) followed by group II and III (0.76 and 0.22 mm, respectively). Hardness and fracture toughness value from highest to lowest was in the following order group I > group II > group III.

Conclusion: Within the limitations of this *in vitro* study, it can be concluded that the third generation of zirconia (group III) showed the least amount of wear of a natural opposing tooth, hardness, and fracture toughness values among all three generations of zirconia.

Clinical significance: Around 5% of yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) monolithic translucent zirconia is clinically significant in anterior aesthetic restorations since it is superior to glass ceramics in terms of mechanical properties and is almost similar in terms of translucency. Good esthetic results can also be achieved in the posterior region with minimal occlusal reduction. Also, monolithic translucent zirconia (third generation of zirconia) abrades the antagonist dentition less than other esthetic ceramics.

Keywords: Fracture toughness, Hardness, Translucent zirconia, Three generations of zirconia, Wear.

World Journal of Dentistry (2023): 10.5005/jp-journals-10015-2276

Introduction

Achieving the complex optical characteristics and light-scattering properties that provide an extremely pleasing esthetic in an artificial restoration is a demanding process that has led to a great shift in metal-free restorations.[1–3] Many patients are choosing metal-free restorations because they mimic the light-scattering properties of natural teeth, provide excellent esthetic results, and are well tolerated biologically. Choosing the right framework material goes beyond esthetics and biocompatibility. Dental ceramics such as zirconia have high flexural strength and fracture toughness. The use of zirconia has been widespread in the dental laboratory for over 15 years, whether as a framework material or an anatomical replacement material. Due to its efficiency in production, there is increasing interest in this type of restorative option for teeth.[2] Being a tooth-colored material, zirconia has several advantages like good esthetics, excellent mechanical and biological properties, is less expensive, and has a wide application in prosthodontics and restorative treatment when compared to precious alloys.[4] The set-in of the digital era has led to chairside milling, rapid sintering technology, and automated and precise fabrication. Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is the most robust of all restorative ceramics.[5]

Zirconia exists in three crystalline phases: monoclinic, tetragonal, and cubic. At temperatures above 2370°C purest zirconia is found in cubic structures which possess moderate mechanical properties. The best mechanical properties are seen in the tetragonal phase, which consists of crystals having the form of straight prisms with rectangular sides and occurs at temperatures between 1170 and 2370°C. At room temperature, to 1170°C occurs, the monoclinic phase, which is the weakest phase with a deformed parallelepiped shape. On cooling after sintering, zirconia undergoes a phase transformation from tetragonal to monoclinic phase, making the sintered material unstable and resulting in a 3–5% expansion in the volume of the grain. This transformation ensues in surface roughening, microcracking, and deterioration of mechanical characteristics.[6,7] Main attraction towards zirconia is its exceptional mechanical properties and resistance to corrosion. The match with existing dentition is the greatest challenge to achieving

[1,2,4–6]Department of Prosthodontics and Crown and Bridge, M.A. Rangoonwala College of Dental Science & Research Centre, Pune, Maharashtra, India

[3]Department of Prosthodontics, SDM College of Dental Sciences, Dharwad, Karnataka, India

Corresponding Author: Abid S Khan, Department of Prosthodontics and Crown and Bridge, M.A. Rangoonwala College of Dental Science & Research Centre, Pune, Maharashtra, India, Phone: +91 9860671696, e-mail: abid.skhan@yahoo.com

How to cite this article: Khan AS, Musani S, Madanshetty P, *et al.* A Study of the Antagonist Tooth Wear, Hardness, and Fracture Toughness of Three Different Generations of Zirconia. World J Dent 2023;14(8):688–695.

Source of support: Nil

Conflict of interest: None

sufficient esthetics.[5] Competition is between Y-TZP and lithia-based silicates; the latter is more translucent but weaker glass ceramic.[8] Esthetic outcomes were hampered due to the opaque appearance of zirconia; hence to mask this appearance, layering of zirconia was proposed.[9] Bilayer structures are susceptible to chipping and delamination, exacerbated by thermally induced residual stresses.[5] Chipping of porcelain is the most prevalent technical problem, with annual rates ranging from 0 to 54% in veneered zirconia.[10] Phenomenon of chipping may occur due to adhesive failure (the weak link between core and veneering) or cohesive failure (fracture within the veneering porcelain body)and is common in the molar region.[11–13] Full-contoured monolithic zirconia could be a solution to reduce porcelain chipping.[14,15] Translucent monolithic zirconia was introduced in 2011 to overcome the problem of poor optical properties and chipping. This material has good esthetic properties with high load-bearing capacity at minimal occlusal reduction.[16] It may require only 1.0 mm of occlusal thickness, that is, minimal occlusal reduction and 0.5 mm of margin thickness, while providing a functional and aesthetic solution.[17] Hence, there is a recent push toward monolithic restorations, focusing mainly on counterbalancing durability, conservation of tooth structure, and esthetic requirements.[5]

Highly translucent zirconia (compared with zirconia for copings and frameworks) may serve as a conservative tooth-colored alternative in the posterior quadrants for crowns and fixed dental prostheses.[17] Color (hue, value, and chroma), translucency, opalescence, fluorescence, and iridescence are the necessary optical properties of both teeth and dental materials. One of the most important factors which make the tooth appear life-like is translucency, and it has a great role in the selection of restorative material.[1] The size and shape of the constituent crystals, the quantity and type of additives, the heating methods, temperature, and atmospheric conditions used for sintering, and the inclusion of pores that influence light scattering determines the translucency of zirconia.[1]

Modification of sintering temperature and molecules gave rise to different generations of zirconia.

The first generation of zirconia (3Y-TZP): The number and grain size of the aluminum oxide (Al_2O_3) grains were more in the first generation. Changes in sintering temperature rendered more translucency. Higher will be translucency when the integral area of the sintering temperature is larger. Studies show that the translucency is also affected by the duration of the dwell time, the temperature increase, and cooling. There is a tetragonal to monoclinic phase transformation in this generation.[2]

The second generation of zirconia (3Y-TZP)—changes at the molecular level resulted in a second generation from 2012 to 2013. Reduction in the number and grain size of Al_2O_3 was done. Al_2O_3 grains were relocated in the zirconia framework. Refraction occurs on the grain boundaries of zirconia, which means a higher transmittance of light. Tetragonal to monoclinic phase transformation is present.[2] Third generation of zirconia (5Y-TZP)—the International Dental Show 2015 witnessed the introduction of the third-generation zirconia. It contains 53% cubic phase proportion.

The tetragonal crystals have a lower volume compared to the cubic ones. Tetragonal to monoclinic phase transformation is absent.

The third generation, when compared to the first and second generations, exhibits higher translucency due to its specific (mixed cubic/tetragonal) structure. Material is more translucent, as the cubic crystals have a comparatively large volume; hence the light scatters less strongly at the grain boundaries and porosities. The incident light is reflected uniformly in all directions due to the geometry of the cubic crystal structure, thereby increasing the translucency additionally.[2] 5Y-TZP is resistant to hydrothermal aging. Zirconia with a cubical phase is brittle, and zirconia with a higher yttria content has a lower ability of transformation toughening. The lower ability of transformation toughening, along with the larger grain size of 5Y-TZP, resulted in a much lower strength.[18]

The difference in structure and physical properties of tooth and dental restorative materials results in their differential wear.[19] Hardness is commonly used to estimate the degree of wear of restorative dental materials and natural enamel. The greater the hardness more will be the wear. Enamel generally has a Vickers hardness of 320–380 kg/mm^2. Zirconia has a high surface hardness in comparison with other low-fusing feldspathic porcelains.[20]

One major drawback of zirconia is the irreversible loss of opposing tooth structure. According to several investigations, ceramic substrates cause greater abrasive wear of human enamel. A ceramic with a combination of good strength and decreased enamel wear would be a significant addition to dental practice.[21] Since the hardness of zirconia is more, more will be the loss of enamel. In this study, the wear of teeth was studied, as there is no literature comparing all three generations of zirconia with respect to the wear of opposing teeth.

The zirconia most commonly found in the market is 3% Y-TZP. The proportion of yttrium oxide has been increased in the third generation of zirconia. This has led to the formation of a metastable tetragonal phase and more of a cubic phase simultaneously. This mixed structure is known as fully stabilized zirconia and represents the third generation. In the third-generation cubical phase is more; hence, tetragonal to monoclinic transformation will be less. From this, we can hypothesize the fracture toughness of the third generation will be less.[2]

Therefore, this *in vitro* study was carried out to select the most beneficial generation of zirconia with respect to the wear of opposing natural teeth, hardness, and fracture toughness of three generations of zirconia.

Materials and Methods

Ethical clearance was obtained from the Ethics committee of the institute, reference no–mces/Ethics/488/2018. The study was conducted over a period of 18 months after the approval of the Ethics Committee was obtained.

Designing and Milling of Disk-shaped Zirconia Samples and Sampling

Software (Autodesk Tinkercad) was used to design the STL file of disks measuring 10 mm in diameter and 1.2 mm in thickness. This file was then sent from hyperDENT Lava™ Edition software to computer-aided manufacturing (CAM) for milling (Yenadent D43).

A total of 36 disk-shaped samples of 10 mm diameter and 1.2 mm thickness were milled with the help of computer-aided design (CAD)/CAM devices from commercially available zirconia blanks. A total of 12 samples were milled from each of the following zirconia blanks 3Y-TZP zirconia disk specimens of first generation (3M™ Lava™ Frame, 3M, United States of America), which made up the group I, 3Y-TZP zirconia disc specimen of second generation (3M™ Lava™ Plus, 3M, United States of America) which made up the group II and 5Y-TZP zirconia disc specimen of 3rd generation (3M™ Lava™ Esthetic, 3M, United States of America) which made up the group III.

The total sample size for the study was 36 ($n = 36$). Samples were divided into three groups.

Each group had a sample size of 12 ($n = 12$).

- Group I*:* 1st generation of translucent zirconia ($n = 12$).
- Group II*:* 2nd generation of translucent zirconia ($n = 12$).
- Group III: 3rd generation of translucent zirconia ($n = 12$).

A total of 36 freshly extracted premolars indicated for orthodontic extraction were collected and randomly divided into three groups of 12 each. Teeth were embedded into an acrylic block. Inclusion criteria for teeth: vital premolars indicated for orthodontic extraction, unrestored tooth, fully developed tooth, caries-free surfaces, and patients who gave consent/assent to use their tooth for study. Exclusion criteria for teeth: attrition of tooth, carious tooth, nonvital tooth, restored tooth, root canal treated, and the patient refused to give consent/assent to use their tooth for study.

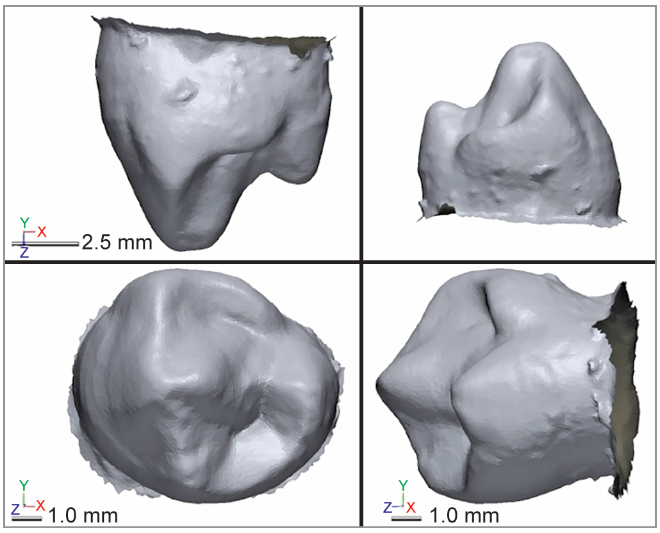


Fig. 1: Scanned images of a tooth before subjecting it to the wear cycle

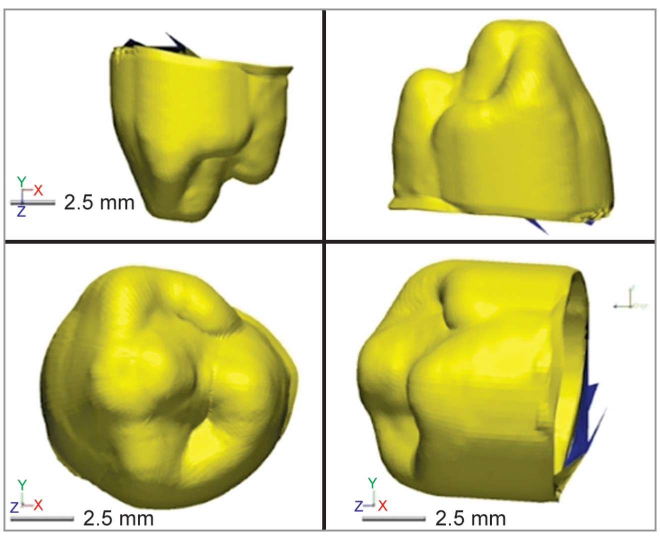


Fig. 2: Scanned images of a tooth after subjecting to wear cycle

Determination of wear of opposing tooth: Prewear three dimensional (3D) scans (before wear test)—contrast spray (EASY SCAN contrast spray, Alphadent, Korea) was sprayed on the extracted tooth mounted on the acrylic block and was then placed inside the extraoral laboratory scanner (Dental Wings, DWOS, 3 Series scanner). Contrast spray helped in increasing the accuracy of the scan; it was extremely thin in layer and easily washable with water. The prewear scanned image of the 3D object was obtained in stereolithography (.stl) format (Fig. 1).

Wear test: The tooth embedded in an acrylic block was placed onto the upper holder of a two-body wear machine. The zirconia disc was placed on the lower holder of two body wear machines. The cusp tips and ceramic discs were positioned under a constant load of 5 kg. The specimens were made to rub against one another in a circular motion, and 10,000 cycles were carried out for each sample. Artificial saliva was sprayed in between to simulate the oral conditions.

Postwear 3D scan (after wear test): After completion of 10,000 cycles of wear, contrast spray was sprayed again to prepare it for postwear extraoral 3D scanning. The tooth embedded in an acrylic block was again placed inside the extraoral laboratory scanner, and the scanned image of the 3D object was obtained in stereolithography (.stl) format (Fig. 2). Now, both the prewear and the postwear 3D object stereolithography (.stl) files were exported to a software (Geomagic® Control X™ 64 Bit Build version 2018, Copyright© 3D Systems) for superimposing both the images. Superimposition of images helped in the easy comparison of prewear and postwear scans. The difference between prewear and postwear 3D scans was calculated, and the amount of wear that occurred was determined (Fig. 3).

Determination of Hardness: After wear testing was completed, the same samples were used to check for the hardness of zirconia. Using Vicker's microhardness tester (Reichert Austria Make), a 100 gm load for a dwell time of 20 seconds was applied to the zirconia disc surface to obtain an indentation (Fig. 4). The length of the diagonals formed by this indentation was measured, and the hardness number was evaluated using the reference standard: International Organization for Standardization (ISO) 6507.[22]

Determination of fracture toughness: Fracture toughness was calculated using Niihara's formula:

$$K_{IC} = 0.203(c/a)^{-3/2}Ha^{1/2}$$

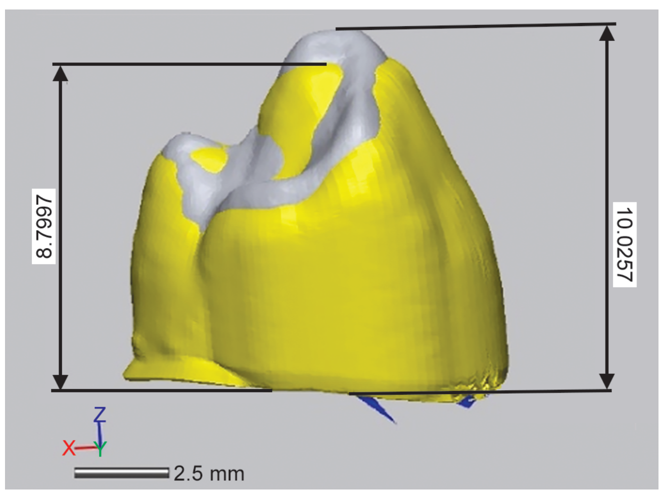


Fig. 3: Superimposition of images for easy comparison of prewear and postwear scans

where K_{IC} is the fracture toughness value (MPam1/2); *a* is the half of indentation diagonal length (mm); *c* is the half of the crack length (mm); and H is the Vickers hardness (*H*v).

Crack initiation: An initial load of 19.6N (2 kg) was applied using an universal testing machine (Star Testing System, India. Model no. STS-248) with Vicker's indenter (diamond)—136° and increased subsequently until a crack developed on the zirconia disc sample. The load holding time was of 20 seconds. The load was increased to 294 N (30 kg).

Measurement of crack length: Visual inspection system (100× magnification) with geometrical DRO was used for measuring the crack length and the length of diagonals (Fig. 5). Hardness value was already obtained for each sample. Once the value of crack length and the diagonal length was obtained, it was substituted into Niihara's formula. Statistical analysis of tooth height before and after the wear cycle was compared using paired *t*-test *post hoc* Tukey test. Values of hardness and fracture toughness were subjected to one-way analysis of variance (ANOVA) test for statistical analysis. Statistical Package for the Social Sciences version 22.0 (IBM Analytics, New York, United States of America) was used to carry out the statistical analysis; $p < 0.05$ was considered to be statistically significant.

Results

Comparison of Change in Tooth Height Before and After the Wear Cycle

The results revealed that there was a statistically significant difference ($p = 0.001$) in all three groups. The maximum amount of wear was seen with the first generation of translucent zirconia—group I (0.93 mm), followed by the second generation of translucent zirconia—group II (0.76 mm), and least amount of wear was seen in the third generation of translucent zirconia—group III (0.22 mm) (Table 1 and Fig. 6).

Comparison of Hardness among Three Groups

The mean score of hardness in group I was 1424.75 ± 56.64 VHN, in group II was 1303.83 ± 72.91 VHN, and in group III was 1194.08 ± 32.83 VHN. All groups showed statistically significant differences ($p = 0.001$); group I demonstrated the highest value of hardness, where the least was with group III. Group II showed a higher hardness value than group III but lesser than group I (Tables 2 and 3).

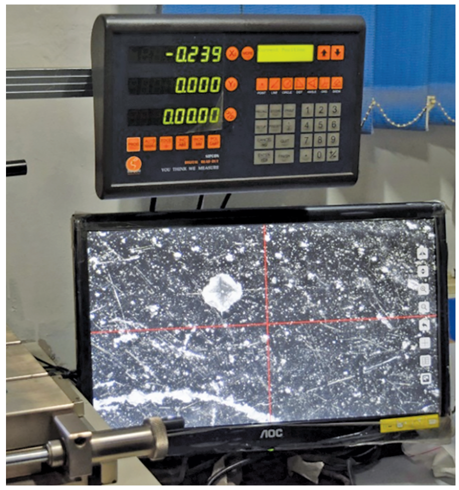
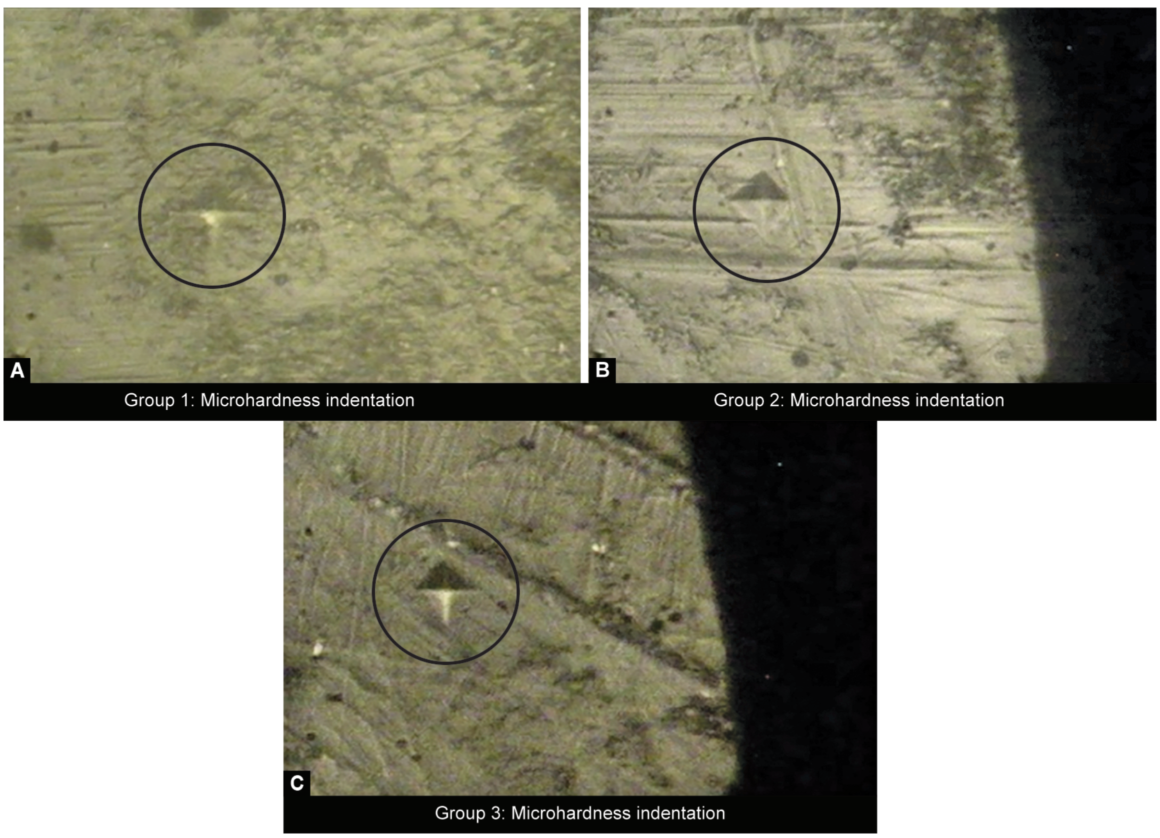


Fig. 5: Geometrical DRO for measuring the crack length



Figs 4A to C: Indentations formed by the Vicker's microhardness indenter on zirconia disc

Table 1: Comparison of change in tooth height before and after the wear cycle

Groups	*Height of tooth before wear cycle (in mm)*	*Height of tooth after wear cycle (in mm)*	*Actual loss of tooth structure/wear (in mm)*	*t-value*	*p-value*
Group I	9.36 ± 0.68	8.43 ± 0.61	0.93	16.576	0.001*
Group II	9.17 ± 0.80	8.41 ± 0.79	0.76	30.750	0.001*
Group III	9.35 ± 0.90	9.13 ± 0.84	0.22	7.678	0.001*

*Indicates a significant difference at $p \leq 0.05$

Table 2: Comparison of hardness and fracture toughness among three groups

Variable	*Groups*	*Mean score*	*F-value*	*p-value*
Hardness (VHN)	Group I	1424.75 ± 56.64	49.916	0.001*
	Group II	1303.83 ± 72.91		
	Group III	1194.08 ± 32.83		
Fracture toughness	Group I	5.34 ± 0.22	300.137	0.001*
	Group II	4.97 ± 0.06		
	Group III	3.61 ± 0.22		

*Indicates a significant difference at $p \leq 0.05$

Table 3: Pairwise comparison of hardness and fracture toughness

Interval	*Pair*	*Difference*	*p-value*
Hardness	Group I vs II	120.92	0.001*
	Group I vs III	230.67	0.001*
	Group II vs III	109.75	0.001*
Fracture toughness	Group I vs II	0.37	0.001*
	Group I vs III	1.73	0.001*
	Group II vs III	1.36	0.001*

*Indicates significant difference at $p \leq 0.05$

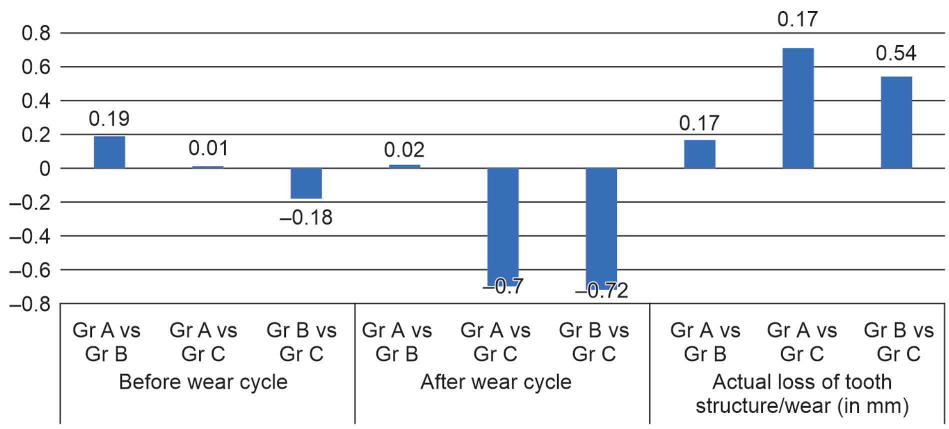


Fig. 6: Pairwise comparison of tooth height before and after the wear cycle

Comparison of Fracture Toughness among Three Groups

The mean score of fracture toughness in group I was 5.34 ± 0.22 $MPam^{1/2}$, in group II was 4.97 ± 0.06 $MPam^{1/2}$, and in group III was 3.61 ± 0.22 $MPam^{1/2}$. All groups showed statistically significant differences ($p = 0.001$). The fracture toughness value from highest to lowest was in the following order group I > group II > group III (Tables 2 and 3).

Discussion

Numerous factors, such as the food, non-functional habits, thickness and hardness of enamel, neuromuscular force, pH of saliva, masticatory pattern, and opposing restorative materials, are involved in tooth wear making it a complex process.[23] The progressive wear of natural teeth is a normal physiological phenomenon that can be affected if restorative materials with different hardness from that of enamel are used for restoring the teeth.[24,25] Higher wear rate value of restorative material will significantly wear down the opposing natural tooth and cause hypersensitivity and articular imbalance.[26] The aim of this study was to investigate the wear of opposing natural teeth, hardness, and fracture toughness of three different generations of zirconia.

Studying wear directly is challenging. Wear can be determined based on indirect factors such as volume loss, vertical loss, and topography on the worn surface.[23,27–29] Vertical loss was studied in this *in vitro* study on the two-body wear test.[30] Functioning of the two-body wear test is based on the simulation of attrition during mastication and grinding, which is created by direct occlusal contact or teeth or restorative material. Hence a two-body wear test was used in this *in vitro* study.[31,32]

Two-body wear test machines combined the action of impact, closure, and grinding of teeth during the masticatory cycle of maxillary and mandibular teeth by a total of 10,000 cycles under a constant load of 5 kg (49 N).[23] Lubrication is an important role of saliva and natural teeth are greatly protected by this lubricating property, hence spraying artificial saliva greatly reduces the risk of excess wear and burn of tooth texture.[33]

Pairwise comparison was done to evaluate the difference in wear of natural opposing tooth among all three groups; values were subjected to *post hoc* Tukey test. The results of this study indicate that all three groups showed statistically significant difference with respect to the wear of natural opposing tooth and was dependent on the yttria content of zirconia. When the first generation of zirconia was compared with the second generation, the difference was 0.17 mm ($p = 0.011$), suggesting increased wear of opposing teeth in the first generation. Further comparing the first generation with the third generation, it showed a difference of 0.71 mm ($p = 0.001$), which again indicated more wear of opposing natural teeth against the first generation. Comparison of the second generation with the third generation gave a difference of 0.54 mm ($p = 0.001$), indicating that the least wear of the natural opposing tooth was caused by the third generation of zirconia. So, the order of most to least amount of wear of natural opposing tooth caused by zirconia is first generation of zirconia > second generation of zirconia > third generation of zirconia.

The null hypothesis was rejected, which stated that no there was no difference between the wear of natural opposing teeth against all three generations of zirconia. The study carried out by Lambrechts et al. accounted that 20–40 µm vertical wear of enamel per year is normal.[34] This study showed that the wear of the natural opposing tooth was greatly dependent on the yttria content, cubic phase, monoclinic phase, tetragonal phase, and Al_2O_3 of zirconia. It has been reported that hydrothermal aging is absent in the third generation of zirconia, which means that the material can retain its strength and microstructure even with increasing wearing time. Also, no phase transformation (tetragonal to monoclinic) takes place in the structure when placed under induced stresses, which means that more of cubic phase is retained than the tetragonal phase in the third generation of zirconia making it less hard.[2] Highest wear was seen with the first generation of zirconia, this could be attributed to the tetragonal phase and the Al_2O_3 particles which increases the mechanical properties of zirconia.[35–37]

According to Stawarczyk et al., the polished monolithic translucent zirconia shows a lower wear rate on enamel antagonists as well as within the material itself.[15]

Emam et al. studied wear behavior and surface roughness of enamel when opposed by ultratranslucent monolithic zirconia with two surface finishing procedures (glazed or polished); within the limitations of his study, polished ultratranslucent monolithic zirconia was more wear friendly to the antagonist enamel than both the glazed ultra-translucent monolithic zirconia and natural enamel.[38]

Y-TZP zirconia becomes clinically usable after sintering which leads to monoclinic phase to tetragonal phase transformation, enhancing its hardness. Conversely, the tetragonal to monoclinic (t to m) phase transformation can be harmful by increasing the surface roughness and decreasing the hardness.[39–41]

The hardness of enamel is in the range from 270 to 360 VHN for enamel; results obtained in this study showed the hardness of third-generation zirconia as 1194.08 ± 32.83 VHN. The first generation of zirconia showed the highest value for hardness (1424.75 ± 56.64 VHN), the second generation of zirconia showed more hardness (1303.83 ±72.91 VHN) than the third generation but was lesser than the first generation. Values were subjected to the *post hoc* Tukey test in a pairwise comparison of hardness in all three groups. All the pairwise comparisons showed statistically significant differences ($p = 0.001$). Intergroup comparison of the first generation of zirconia vs second generation of zirconia, the first generation of zirconia vs third generation of zirconia, and the second generation of zirconia vs third generation of zirconia gave a difference of 120.92, 230.67, and 109.75 VHN, respectively. On comparing the hardness of all three generations of zirconia, the third generation showed the least value of hardness. The null hypothesis for hardness was also rejected, which stated that there is no difference between the hardness among the three generations of zirconia. In this study, the third generation showed the least, the second generation showed moderate, and the first generation showed the maximum value of hardness.

According to Curtis et al., 3% yttria-stabilized zirconia samples, which were abraded using different particles, had values of hardness ranged in between 1524 and 1734 VHN.[42] According to Emam et al., polished ultratranslucent monolithic zirconia was more wear friendly to the antagonist enamel than both the glazed ultratranslucent monolithic zirconia and natural enamel.[38] This study also supports that surface roughness plays an important role in the hardness of the material in terms of wear of opposing natural teeth.

Seghi et al. reported that wear rates of human enamel and of restorative material should be more or less similar to each other.[43] Harder the restorative material more it will be worn. Recent studies have shown that the surface roughness of ceramic determines the wear of opposing teeth and not the hardness of the material. Aboushahba et al. concluded that surface property (hardness) was high in zirconia. He recommended polishing the surface of zirconia restorations because this polishing favors the surface properties (wear and hardness) of opposing natural teeth. Highly polished zirconia with high hardness has shown lesser wear of opposing teeth.[44]

Increased proportion of yttrium oxide is a striking feature of the new generation of zirconia. This has resulted in the formation not only of metastable tetragonal phase but also of the cubic phase structure simultaneously. The first and second generations are partially stabilized zirconia, whereas fully stabilized zirconia is the third generation and has a mixed structure consisting of metastable tetragonal and cubic phases. There is no transformation of structure in this generation, even under induced stresses.[4]

Stawarczyk et al. stated that increased cubic phase enhanced the translucency of zirconia but had an adverse effect on material strength; further, they stated that fully stabilized zirconia offered fewer mechanical advantages due to the absence of transformation toughening.[4]

Ceramics being brittle material produces a very small amount of deformation when loaded with stress, and it fractures before the plastic deformation.[45] In the single-edge precracked beam method, it is difficult to get experimental cracks, and also Young's modulus needs to be obtained from different experiments. Thus, because of its ease and simplicity, the indentation fracture method was used in this study.

A semicircular or semielliptical and vertical crack is generated around the indentation when the indenter is pressed onto the surface.[45] Fracture toughness is calculated by substituting the value of hardness, indentation length, and the diagonal crack length in Niihara's formula.[46] The results obtained were subjected to the *post hoc* Tukey test, and all three groups showed statistically significant difference ($p = 0.001$) in relation to fracture toughness. The difference between the first generation and second generation was 0.37 MPam$^{1/2}$, which indicated that fracture toughness was almost similar. Comparing the first generation with the third generation and the second generation with third generation showed a great difference of 1.73 and 1.36 MPam$^{1/2}$, respectively. Results of this study indicated that fracture toughness was more in the first generation of zirconia (group I) and least in the third generation of zirconia (group III).

Lange reported in his study that fracture toughness for yttria-stabilized zirconia seemed to be inversely proportional to the content of yttria; the greater the yttria content lesser will be the fracture toughness.[47] He stated that the fracture toughness value dropped from 6.5 to 3 MPam$^{1/2}$ as the yttria content was increased from 3 to 7%.[47]

Alkadi and Ruse carried out the study in which they determined the fracture toughness of IPS e.max CAD and IPS e.max Press which turned out to be 1.79 and 2.50 MPam$^{1/2}$, respectively.[48] When we compare the values of group III (3rd generation zirconia) with the values obtained by Akladi and Ruse, third-generation zirconia has a higher value of fracture toughness than both IPS e.max CAD and IPS e.max Press justifying the use of a new translucent material with greater strength than the glass ceramic in the esthetic zone. Comparing translucency and strength on the graph, Zhang et al. stated that translucent zirconia could fill the gap between the conventional 3% yttria-stabilized zirconia and lithium disilicate glass-ceramic.[49]

Within the limitation of this *in vitro* study, results show that the increase in yttria content of monolithic zirconia reduces the hardness and fracture toughness of monolithic zirconia. In simple words, an inverse correlation was found between zirconia's translucency and strength.

Conclusions

Within the limitations of this *in vitro* study, it can be concluded that the third generation of zirconia showed the least amount of wear of a natural opposing tooth, the least value of hardness, and the least fracture toughness values among all three generations of zirconia. The third generation of zirconia is 5% Y-TZP monolithic translucent zirconia is clinically significant in anterior esthetic restorations since it is superior to glass ceramics in terms of mechanical properties and is almost similar in terms of translucency.

Clinical Significance

Good esthetic results can be achieved in the anterior aesthetics restorations and also a posterior region with minimal occlusal reduction. Also, monolithic translucent zirconia (third generation of zirconia) abrades the antagonist dentition less than other esthetic ceramics.

An increase in the translucency of zirconia is not always advantageous; in the case of a discolored tooth, there is reduced masking potential in monolithic zirconia, which can give negative results. Keeping the range of indications in mind, it is, therefore, very crucial for us to select and use the correct material. Further research is needed to know whether monolithic zirconia can be used as a veneer and its adhesion to the tooth structure after subjecting it to different surface treatments.

References

1. Manziuc MM, Gasparik C, Negucioiu M, et al. Optical properties of translucent zirconia: a review of the literature. EuroBiotech J 2019;3(1):45–51. DOI: 10.2478/ebtj-2019-0005
2. Stawarczyk B, Keul C, Eichberger M, et al. Three generations of zirconia: from veneered to monolithic. Part I. Quintessence Int 2017;48(5):369–380. DOI: 10.3290/j.qi.a38057
3. Zhang Y, Kelly JR. Dental ceramics for restoration and metal veneering. Dent Clin North Am 2017;61(4):797–819. DOI: 10.1016/j.cden.2017.06.005
4. Ghodsi S, Jafarian Z. A review on translucent zirconia. Eur J Prosthodont Restor Dent 2018;26(2):62–74. DOI: 10.1922/EJPRD_01759Ghodsi13
5. Zhang Y, Lawn BR. Novel zirconia materials in dentistry. J Dent Res 2018;97(2):140–147. DOI: 10.1177/0022034517737483
6. Helvey GA, Cam CAD. Zirconia and computer-aided design/computer-aided manufacturing (CAD/CAM) dentistry. Editorial Categories 2018. https://www.aegisdentalnetwork.com/special-issues/2007/10/zirconia-and-cad-cam-dentistry
7. Chevalier J, Gremillard L, Virkar AV, et al. The tetragonal-monoclinic transformation in zirconia: lessons learned and future trends. J Am Ceram Soc 2009;92(9):1901–1920. DOI: 10.1111/j.1551-2916.2009.03278.x
8. Pieger S, Salman A, Bidra AS. Clinical outcomes of lithium disilicate single crowns and partial fixed dental prostheses: a systematic review. J Prosthet Dent 2014;112(1):22–30. DOI: 10.1016/j.prosdent.2014.01.005
9. Tsukuma K, Yamashita I, Kusunose T. Transparent 8 mol% Y2O3–ZrO2 (8Y) Ceramics. J Am Ceram Soc 2008;91(3):813–818. DOI: 10.1111/j.1551-2916.2007.02202.x
10. Marchack BW, Sato S, Marchack CB, et al. Complete and partial contour zirconia designs for crowns and fixed dental prostheses: a clinical report. J Prosthet Dent 2011;106(3):145–152. DOI: 10.1016/S0022-3913(11)60112-1
11. Cattani-Lorente M, Durual S, Amez-Droz M, et al. Hydrothermal degradation of a 3Y-TZP translucent dental ceramic: A comparison of numerical predictions with experimental data after 2 years of aging. Dent Mater 2016;32(3):394–402. DOI: 10.1016/j.dental.2015.12.015
12. Wang G, Zhang S, Bian C, et al. Fracture mechanics analyses of ceramic/veneer interface under mixed-mode loading. J Mech Behav Biomed Mater 2014;39:119–128. DOI: 10.1016/j.jmbbm.2014.07.019
13. Rinke S, Fischer C. Range of indications for translucent zirconia modifications: clinical and technical aspects. Quintessence Int 2013;44(8):557–566. DOI: 10.3290/j.qi.a29937
14. Johansson C, Kmet G, Rivera J, et al. Fracture strength of monolithic all-ceramic crowns made of high translucent yttrium oxide-stabilized zirconium dioxide compared to porcelain-veneered crowns and lithium disilicate crowns. Acta Odontol Scand 2014;72(2):145–153. DOI: 10.3109/00016357.2013.822098
15. Stawarczyk B, Özcan M, Schmutz F, et al. Two-body wear of monolithic, veneered and glazed zirconia and their corresponding enamel antagonists. Acta Odontol Scand 2013;71(1):102–112. DOI: 10.3109/00016357.2011.654248
16. Harianawala HH, Kheur MG, Apte SK, et al. Comparative analysis of transmittance for different types of commercially available zirconia and lithium disilicate materials. J Adv Prosthodont 2014;6(6):456–461. DOI: 10.4047/jap.2014.6.6.456
17. Harada K, Raigrodski AJ, Chung KH, et al. A comparative evaluation of the translucency of zirconias and lithium disilicate for monolithic restorations. J Prosthet Dent 2016;116(2):257–263. DOI: 10.1016/j.prosdent.2015.11.019

18. Zhang F, Inokoshi M, Batuk M, et al. Strength, toughness and aging stability of highly-translucent Y-TZP ceramics for dental restorations. Dent Mater 2016;32(12):e327–e337. DOI: 10.1016/j.dental.2016.09.025
19. Yip KH, Smales RJ, Kaidonis JA. Differential wear of teeth and restorative materials: clinical implications. Int J Prosthodont 2004;17(3):350–356. PMID: 15237885.
20. Mundhe K, Jain V, Pruthi G, et al. Clinical study to evaluate the wear of natural enamel antagonist to zirconia and metal ceramic crowns. J Prosthet Dent 2015;114(3):358–363. DOI: 10.1016/j.prosdent.2015.03.001
21. Rupawala A, Musani SI, Madanshetty P, et al. A study on the wear of enamel caused by monolithic zirconia and the subsequent phase transformation compared to two other ceramic systems. J Indian Prosthodont Soc 2017;17(1):8–14. DOI: 10.4103/0972-4052.194940
22. ISO - ISO 6507-2:2018 - Metallic materials — Vickers hardness test — Part 2: Verification and calibration of testing machines
23. Elmaria A, Goldstein G, Vijayaraghavan T, et al. An evaluation of wear when enamel is opposed by various ceramic materials and gold. J Prosthet Dent 2006;96(5):345–53. DOI: 10.1016/j.prosdent.2006.09.002
24. Monasky GE, Taylor DF. Studies on the wear of porcelain, enamel, and gold. J Prosthet Dent 1971;25(3):299–306. DOI: 10.1016/0022-3913(71)90191-0
25. 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(3):320–323. DOI: 10.1016/0022-3913(94)90347-6
26. Jacobi R, Shillingburg HT Jr, Duncanson MG Jr. A comparison of the abrasiveness of six ceramic surfaces and gold. J Prosthet Dent 1991;66(3):303–309. DOI: 10.1016/0022-3913(91)90254-t
27. Hahnel S, Schultz S, Trempler C, et al. Two-body wear of dental restorative materials. J Mech Behav Biomed Mater 2011;4(3):237–244. DOI: 10.1016/j.jmbbm.2010.06.001
28. DeLong R. Intra-oral restorative materials wear: rethinking the current approaches: how to measure wear. Dent Mater 2006;22(8):702–711. DOI: 10.1016/j.dental.2006.02.003
29. Condon JR, Ferracane JL. Evaluation of composite wear with a new multi-mode oral wear simulator. Dent Mater 1996;12(4):218–226. DOI: 10.1016/s0109-5641(96)80026-1
30. Lambrechts P, Debels E, Van Landuyt K, et al. How to simulate wear? Overview of existing methods. Dent Mater 2006;22(8):693–701. DOI: 10.1016/j.dental.2006.02.004
31. Kadokawa A, Suzuki S, Tanaka T. Wear evaluation of porcelain opposing gold, composite resin, and enamel. J Prosthet Dent 2006;96(4):258–265. DOI: 10.1016/j.prosdent.2006.08.016
32. Harrison A. Wear of combinations of acrylic resin and porcelain, on an abrasion testing machine. J Oral Rehabil 1978;5(2):111–115. DOI: 10.1111/j.1365-2842.1978.tb01202.x
33. Li H, Zhou ZR. Wear behaviour of human teeth in dry and artificial saliva conditions. Wear 2001;249(10–11):980–984. DOI: 10.1016/S0043-1648(01)00835-3
34. Lambrechts P, Braem M, Vuylsteke-Wauters M, et al. Quantitative in vivo wear of human enamel. J Dent Res 1989;68(12):1752–1754. DOI: 10.1177/00220345890680120601
35. Tsubakino H. Isothermal tetragonal-to-monoclinic phase transformation in a zirconia–yttria system. Mater Trans 2005;46(7):1443–1451. DOI: 10.2320/matertrans.46.1443
36. Masaki T. Mechanical properties of Y2O3-stabilized tetragonal ZrO2 polycrystals after ageing at high temperature. J Am Ceram Soc 1986;69(7):519–522. DOI: 10.1111/j.1151-2916.1986.tb04786.x
37. Masaki T. Mechanical properties of toughened ZrO2-Y2O3 ceramics. J Am Ceram Soc 2021;69(8):638–640. DOI: 10.1111/j.1151-2916.1986.tb04823.x
38. Emam SA, Koheil SA, Afif RR. Wear of human enamel opposing ultra-translucent zirconia with two surface finishing procedures. Alexandria Dent J 2020. DOI: 10.21608/adjalexu.2020.21675.1033
39. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials 1999;20(1):1–25. DOI: 10.1016/s0142-9612(98)00010-6
40. Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater 2008;24(3):299–307. DOI: 10.1016/j.dental.2007.05.007
41. Candido LM, Fais LMG, Reis JMDSN, et al. Surface roughness and hardness of yttria stabilized zirconia (Y-TZP) after 10 years of simulated brushing. Rev Odontol da UNESP 2014;43(6):379–383. DOI: 10.1590/1807-2577.1049
42. Curtis AR, Wright AJ, Fleming GJ. The influence of surface modification techniques on the performance of a Y-TZP dental ceramic. J Dent 2006;34(3):195–206. DOI: 10.1016/j.jdent.2005.06.006
43. Seghi RR, Rosenstiel SF, Bauer P. Abrasion of human enamel by different dental ceramics in vitro. J Dent Res 1991;70(3):221–225. DOI: 10.1177/00220345910700031301
44. Aboushahba M, Katamish H, Elagroudy M. Evaluation of wear and hardness of zirconia with different surface treatment protocols a systematic review. Indian J Sci Technol 2016;9(39):1–15. DOI: 10.17485/ijst/2016/v9i39/88542
45. Harada K, Shinya A, Yokoyama D, et al. Effect of loading conditions on the fracture toughness of zirconia. J Prosthodont Res 2013;57(2):82–87. DOI: 10.1016/j.jpor.2013.01.005
46. Niihara K, Morena R, Hasselman DPH. Evaluation of KIc of brittle solids by the indentation method with low crack-to-indent ratios. J Mater Sci Lett 1982;1(1):13–16. DOI: 10.1007/BF00724706
47. Lange FF. Transformation toughening - Part 3 Experimental observations in the ZrO_2-Y_2O_3 system. J Mater Sci 1982;17(1):240–246. DOI: 10.1007/BF00809059
48. Alkadi L, Ruse ND. Fracture toughness of two lithium disilicate dental glass ceramics. J Prosthet Dent 2016;116(4):591–596. DOI: 10.1016/j.prosdent.2016.02.009
49. Zhang F, Reveron H, Spies BC, et al. Trade-off between fracture resistance and translucency of zirconia and lithium-disilicate glass ceramics for monolithic restorations. Acta Biomater 2019;91:24–34. DOI: 10.1016/j.actbio.2019.04.043