Wear properties of esthetic dental materials against translucent zirconia

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To clarify the influence of translucent tetragonal zirconia polycrystals (TZP) on wear properties of esthetic dental materials, two-body wear test was performed using translucent TZP as abrader specimen, and bovine tooth enamel (BTE), two resin composites including hybrid filler (CRH) and nano filler (CRN), two glass ceramics including leucite reinforced feldspar porcelain (POR) and lithium disilicate (LDC), or translucent TZP as substrate specimen. After the wear test, wear volume were determined from substrate specimen and surface roughness were measured from abrader specimen. In addition, Vickers hardness was measured and surface morphologies were observed after wear test using a scanning electron microscope. The wear volume of the esthetic dental material against translucent TZP was greater in glass ceramics (POR, LDC), smaller in resin composite (CRH, CRN) and BTE, and no wear in translucent TZP. Microstructures of the esthetic dental material may play a crucial role for wear behavior against translucent TZP.

Keywords: Two-body wear test, Zirconia ceramics, Resin composite, Feldspar porcelain, Lithium disilicate

INTRODUCTION

Tetragonal zirconia polycrystals (TZP) possess high mechanical strength and excellent biocompatibility; therefore it is often used as crown restorative material in the oral cavity1). When conventional TZP is used as frame material for prosthetic devices, it becomes necessary to veneer porcelain because of its opaque and inferior esthetic properties. Frequency of chipping was, however, reported to be higher in the porcelain veneered zirconia crowns compared to porcelain fused to metal crown.

In recent years, translucent TZP has been developed where alumina content was reduced to improve translucency compared to conventional TZP3). Furthermore, translucent TZP with added color tone has shown to possess superior color quality while having similar strength as conventional TZP4). By using translucent TZP, it has become possible to fabricate monolithic zirconia crowns, which are highly esthetic and requires no porcelain to be veneered or glazed. However, since translucent TZP is involved in occlusal contact, it is necessary to examine its influence on the antagonist, as wear is raised as one of concerning effects, because translucent TZP possess extremely high hardness.

The reduction in occlusal vertical distance caused by the wear may reduce the masticatory function, possibly leading to muscle fatigue or abnormalities in the temporomandibular joints5,6). For the above reasons, it is necessary to evaluate any wear that translucent TZP may cause on the antagonist. In regards to the influence of TZP on the wear of natural teeth, reports have indicated well-polished TZP causes minimal abrasion on natural teeth7-9). Not much research has been done on the influence of TZP on the wear of restoration materials10,11), and no reports have studied the influence of translucent TZP on wear of esthetic dental materials such as resin composites and ceramics under the same conditions.

Currently, there is a growing demand for metal-free restoration due to concerns such as allergies, and various types of esthetic dental materials are being used in the oral cavity. Accordingly, it is important to investigate the influence of translucent TZP on wear behavior of other esthetic dental materials. This study aimed to clarify the influence of translucent TZP on the wear properties of esthetic dental materials. The null hypothesis of this study is that (1) wear of esthetic dental materials against translucent TZP is smaller in glass ceramics and greater in resin composites, and (2) wear behavior of esthetic dental materials against translucent TZP is not influenced by microstructure of esthetic dental materials.

MATERIALS AND METHODS

Fabrication of specimens

Materials used in this study are shown in Table 1. The translucent TZP (Zpex100) had a composition (mass%) of ZrO2 (balance), Y2O3 (5.2), Al2O3 (0.05), SiO2 (≤0.02), and Fe2O3 (≤0.01) and a particle size of 40 nm. Cold isostatic press was carried out on translucent TZP powder (Zpex 100) at 176 MPa, heating rate of 600°C/h, firing temperature of 1,450°C, and firing time of 2 h in air atmosphere. Thereafter, the sintered TZP was adjusted to a length of 10 mm, diameter of 5 mm, and curvature radius of 2.5 mm at the one end. The curvature surface was polished with ceramic polisher (Show Selection Kit and Zircon Brite, Mokuda, Hyogo, Japan) without change in curvature radius and surface morphology. The prepared sample was mounted on a testing machine as the abrader specimen as shown in Fig. 1.

For substrate specimens, bovine tooth enamel (BTE),
Table 1  Materials used in this study

| Classification | Type          | Shade | Product name  | Manufacturer                      | Code  |
|----------------|---------------|-------|---------------|-----------------------------------|-------|
| Abrader specimen | Translucent TZP | Translucent | Zpex100 | Zpex | Tosoh, Tokyo, Japan | TZP |
| Tooth enamel    | Bovine        | —     | —             | —                                 | BTE   |
| Resin composite | Hybrid filler | A2    | Clearfil AP-X | Kuraray Noritake Dental, Tokyo, Japan | CRH   |
|                | Nano filler   | A2    | MI Gracefil   | GC, Tokyo, Japan                  | CRN   |
| Glass ceramics  | Feldspar porcelain | 58 (A2) | Vintage Halo | Shofu, Kyoto, Japan                | POR   |
|                | Lithium disilicate | LTA2 | IPS.e-max press | Ivoclar Vivadent, Schaan, Liechtenstein | LDC   |
| Translucent TZP | Translucent   | Zpex100 | Zpex | Tosoh, Tokyo, Japan | TZP |

Fig. 1  (a) Experimental wear simulator, (b) Higher magnification of areas shown in rectangle in (a), (c) Schematic illustrations of wear test.

two types of resin composites including hybrid filler (CRH) and nano filler (CRN), two types of glass ceramics including leucite reinforced feldspar porcelain (POR) and lithium disilicate (LDC), and translucent TZP were used (Table 1). Bovine anterior teeth were used for BTE. CRH and CRN were prepared by photopolymerizing resin-composite paste for 7 min using a light curing unit (α Light II N, Morita, Kyoto, Japan) into diameter of 6 mm and thickness of approximately 2 mm.

POR was fired with a diameter of 10.0 mm and thickness of 2.0 mm according to the manufacturer’s recommendations. The firing schedule was as follows: pre-drying, 500°C for 5 min; heating rate, 60°C/min; firing temperature, 930°C; holding time, 1 min. LDC was prepared according to the manufacturer’s recommendations. Briefly, a wax pattern with a diameter of 12.5 mm and thickness of 1.2 mm was invested into designated investment material (IPS press VEST, Ivoclar Vivadent, Schaan, Liechtenstein). Invested molds were heated at 850°C for 60 min; which were then transferred to a separate furnace (Program EP 5000, Ivoclar Vivadent), with firing temperature of 700°C to 917°C, heating rate of 60°C/min for 25 min; then IPS.e-max press was heat pressed at a press speed 250 μm/min. TZP was prepared in the same manner as the abrader specimen using the isostatic press method. Specimens were fired and adjusted to disks 13 mm in diameter and 1.0 mm in thickness.

Each specimen was embedded in an epoxy ring with a diameter of 25 mm using epoxy resin (Scandiplex, ScanDia, Hagen, Germany). Specimens excluding TZP were polished with silicon carbide abrasive paper (#320 to #1200) and buffed with alumina suspension (particle diameter 5 μm, 0.3 μm) using a polishing machine (EcoMet/AutoMet 250 Pro, Buehler, Lake Bluff, IL, USA). BTE specimens were polished until flat enamel surfaces were exposed and finally buffed with alumina suspension. TZP was polished with diamond abrasive paper (70 μm, 45 μm) and buffed with diamond suspension (particle diameter 9 μm, 3 μm). Each prepared sample was mounted on a testing machine shown in Fig. 1 as substrate specimen. The arithmetic mean roughness (Sa) of the substrate specimens after polishing was between 0.03 to 0.07 μm in an area of 120×80 μm.

**Hardness test**

Vickers hardness (Hv) of each specimen was measured under a load of 9.8 N and a load holding time of 20 s using a hardness tester (HMV-1, Shimadzu, Kyoto, Japan). Three specimens were fabricated for each material.
Two-body wear test
A two-body wear test was performed using an experimental wear simulator. As seen in Fig. 1, each abrader specimen was moved back and forth on the fixed substrate specimen over a distance of 3 mm for 30,000 cycles at a speed of 90 cycles/min and with a vertical load of 10 N. The test was conducted at room temperature with distilled water circulated through a water chamber to remove abrasion debris. Five specimens were fabricated for each condition.

Wear volume of substrate specimen
The worn surface and polished surface were established as the lowest and highest position respectively, and an area of 1,280×1,280 μm was observed using the 3D laser microscope (LEXT OL 4000, Olympus, Tokyo, Japan) in increments of 0.1 μm. After acquiring 3-dimensional data, the wear volume of substrate specimens were calculated using a software (OLS 4000 Version 2.2.5, Olympus, Tokyo, Japan).

Surface roughness of abrader specimen (TZP)
The wear behavior of abrader specimen was evaluated by measuring the surface roughness because the wear volume could not be measured on abrader specimens (TZP). Each abrader specimen was coated with Au-Pd using a sputter coater (SC 500, Bio-Rad, Hercules, CA, USA). A 3D scanning electron microscope (ERA-8900, Elionix, Tokyo, Japan) was used to acquire 3-dimensional data in an area of 120×80 μm with a Gaussian filter value of 40 μm. Subsequently, arithmetic mean roughness (Sa) before and after wear test was determined.

Surface observation after wear test
Surfaces of abrader and substrate specimen after wear test were observed using a scanning electron microscope (SU6600, Hitachi, Tokyo, Japan) after each sample was coated with Au-Pd.

Statistical analysis
Statistical analysis was performed by one-way ANOVA, and homoscedasticity was confirmed. Subsequently, Tukey’s multiple comparison test (α=0.05) was carried out using a software (GraphPad prism Version 6, San Diego, CA, USA).

RESULTS

Vickers hardness number
Vickers hardness number (Hv) for each specimen was TZP (1,340±81)>LDC (641±28)>POR (619±79)>BTE (398±79)>CRH (131±9)>CRN (100±17) (Fig. 2). The Hv of TZP was significantly larger than all other materials. POR and LDC showed significantly larger Hv than BTE, CRH and CRN. There is no significant difference in Hv values between CRH and CRN as well as between POR and LDC.

Wear volume of substrate specimen
Wear volume (mm³) for each specimen was LDC (0.329±0.032)>POR (0.163±0.040)>CRH (0.102±0.006)>BTE (0.064±0.023)>CRN (0.016±0.006) (Fig. 3). Significant differences were indicated between each material. The greatest in wear on glass ceramics (POR and LDC) excluding TZP, and to a lesser extent in resin composites (CRH or CRN) and BTE against TZP. Wear volume of TZP could not be measured.

Relationship between Vickers hardness number (Hv) and wear volume
The relationship between Hv and wear volume is displayed in Fig. 4. Wear volume was greater in glass ceramics with larger hardness (POR, LDC) compared to resin composites with smaller hardness (CRH, CRN).

Surface roughness of abrader specimen (TZP)
The surface roughness (Sa value) of the abrader specimen (TZP) before and after wear test is shown in Fig. 5. Before the wear test, Sa value was from 0.03±0.01 to 0.04±0.01 μm with no difference between substrate...
specimens. After the wear test, no significant change in Sa value was shown compared to before wear test when substrates were BTE, CRH, CRN, and TZP. However, the Sa value increased after wear test when substrates were POR and LDC.

Surface observation of substrate specimen
Representative SEM images of substrate specimens after wear test are shown in Fig. 6. On the center area of worn surface (middle row), the surface layer wore off and the enamel rod-like structures (black arrow) were recognized on BTE. Fillers and resin matrix were overserved on CRH and CRN. Scratches were seen on both POR and LDC. In addition, spindle-like lithium disilicate crystals (black arrow) were observed on LDC. No visible wear was found on TZP.

On the end area of worn surface (lower row), surface morphologies of BTE were similar to those on center area. Fillers were exposed (black arrow) on CRH that were slightly different from those on center area. Rougher surfaces and worn off pieces of material (black arrow) were observed on POR compared to center area. No distinct difference was recognized between the center and end area on LDC. No sign of wear was also found on TZP.

Surface observation of abrader specimen (TZP)
Representative SEM images of the abrader specimens (TZP) after wear test are shown in Fig. 7. The abrader samples against BTE, CRH, CRN, and TZP demonstrated no apparent changes in the wear surface. On the other hand, scratches (white arrow) were observed in the abrader specimen against POR and LDC.

DISCUSSION
The purpose of this study was to clarify wear properties of esthetic dental materials against translucent TZP. Translucent TZP (trade name, Zpex) was used in this study instead of conventional opaque TZP. In this material, the alumina content and number of defects in the TZP were reduced in order to ensure translucency. The density of the sintered translucent TZP is 6.06 g/cm³ and the flexural strength is approximately 1,100 MPa.

Esthetic dental materials for substrate specimens
In the present study, we selected bovine tooth enamel, two types of resin composites (hybrid filler type: CRH, nanofiller type: CRN), two types of glass ceramics (feldspar porcelain: POR, lithium disilicate: LDC), and translucent TZP as substrate material. In recent years, resin composite has improved in wear resistance and its range of use has expanded such as for molar occlusal surfaces. Ceramic materials are frequently used on molar restorations. Clinical applications of these materials are becoming more common in order to improve esthetics while avoiding allergic reactions to metals. For the above reasons, the materials used in this study as substrates are highly likely to be in occlusal contact with translucent TZP in the oral cavity.

Two-body wear test
For simulation of wear in the oral cavity, specimen shape, temperature corresponded to intraoral cavity, vertical load equivalent to occlusal force, and occlusion cycle should be taken into consideration. In this study, two-body wear test with reciprocating sliding was used, assuming the attrition between translucent TZP and esthetic restorations in the oral cavity, and this method is believed to consistent with previous studies that were able to evaluate the wear behavior of various substrate specimens as well as of abrader specimens, and they may allow a comparative evaluation of different materials under standardized conditions. In addition, the curvature radius of abrader specimens was set at 2.5 mm. This radius was relied on the literature that...
reported the curvature radius of the molar cusps having between 0.2 and 2.5 mm\textsuperscript{10}.

The abrader specimen was mirror-polished with ceramic polisher and surface roughness (Sa) was 0.03–0.04 μm before wear test in this study. Reports have indicated that wear on antagonist against TZP can be minimized by polishing\textsuperscript{19-21}. Accordingly, the influence of mirror polishing the abrader specimen can be considered insignificant on the wear of substrate specimen, indicating that polishing method was appropriate.

**Wear of substrate specimen**

In the present study, wear volume of substrate was greater in glass ceramics (POR and LDC) compared to resin composites (CRH or CRN) against translucent TZP abrader. No wear was found for translucent TZP substrate. Therefore, the first null hypothesis that wear of esthetic dental materials against translucent TZP is smaller in glass ceramics and greater in resin composites, was rejected. The wear behavior may be influenced by many factors such as hardness, elastic modulus, fracture toughness, surface roughness, and microstructure of the material\textsuperscript{22,23}. Hardness is an index used to predict the wear resistance of dental materials and its antagonist, and it is generally recognized that materials with high hardness wear down materials with smaller hardness\textsuperscript{24}. However, the wear volume was greater in glass ceramics with larger hardness
Fig. 7 Representative SEM images of abrader specimen (TZP) after wear test.

(POR, LDC) compared to resin composites with smaller hardness (CRN, CRH) in this study. It is has been reported that when comparing the wear of ceramics and resin composite against enamel, ceramics displayed more wear despite possessing greater hardness than resin composite\(^{25}\). Accordingly, wear mechanisms other than the abrasive wear related to hardness should be considered. Microstructure of the material is considered to be an important factor for wear mechanism against TZP antagonist. Glass ceramics (POR and LDC) have crystal phases such as leucite and lithium disilicate mixed into the glass matrix, which results in a non-homogenous structure possessing inconsistent hardness within the material. In materials with such structure, the glass matrix is removed in the early stage of wear resulting in the exposure of the crystal phase possessing high hardness and increased surface roughness, as a result promoting wear\(^{17}\). POR and LDC caused an increase in surface roughness of opposing translucent TZP. It was likely that wear volumes of POR and LDC were further increased by the non-homogenous crystal structure in the material, which increased the surface roughness of translucent TZP. Indeed, the surface roughness of the abrader specimen (TZP) increased after wear test when substrates were glass ceramics (POR, LDC) compared to resin composites (CRH, CRN) (Fig. 5), and scratches were observed in the TZP abrader against POR and LDC substrate (Fig. 7). On the other hand, resin composites (CRH, CRN) did not roughen the TZP abrader due to their inherent small hardness, leading to smaller wear volume on the resin composite substrates. Accordingly, the second null hypothesis that wear behavior of esthetic dental materials against translucent TZP is not influenced by microstructure of esthetic dental materials, was rejected.

The wear volume of TZP was extremely small and impossible to measure against TZP in this study. Translucent TZP is a homogeneous material where the microstructure consists of crystal grain less than 0.5 \(\mu\)m in size\(^{3,17}\). Polished translucent TZP subjected to wear test did not roughened in surface, indicating that wear hardly occurs. Other reports have also indicated that no visible wear was found on TZP against steatite and enamel antagonists\(^{26,27}\).

When resin composites were compared, CRH showed greater wear volume than CRN. SEM observation confirmed that filler size in CRH is greater than CRN. Vickers hardness values were similar. Reports have indicated that the large size and hardness of filler in resin composite will affect enamel by increasing wear volume\(^{12,15}\). Therefore, the wear volume against TZP was greater in CRH with large and irregularly shaped filler, similar to effect on enamel.

When ceramic materials were compared, LDC showed greater wear volume than POR in this study. It was reported that the wear volume of lithium disilicate glass-ceramics against TZP did not differ from leucite-containing ceramics\(^{10}\). The reason for inconsistent with our results is still unclear. One possible explanation is due to differences in experimental method and conditions that the abrader was fixed and the substrate samples were rotated in the literature, and the load value was set higher than that in the present study\(^{10}\).

Clinical implications

It is reported that the vertical wear distance is 10–40 \(\mu\)m in oral cavity during one year\(^{28,29}\). In addition, maximum wear depth of enamel against enamel was reported to be 50 \(\mu\)m using same condition as the present study\(^{10}\). In the present study, maximum wear depth of substrate specimens against translucent TZP was 123 \(\mu\)m on LDC, 73 \(\mu\)m on POR, or 40 \(\mu\)m on BTE, respectively, which was determined from 3-dimensional data using the laser microscope. Accordingly, it is expected that clinical application of LDC or POR against translucent TZP as an antagonist may cause the large wear in LDC or POR.

Results of this study indicated that wear of esthetic dental materials against translucent TZP was greatest in glass ceramics (POR, LDC) and smaller in resin composite (CRH, CRN) and BTE. No visible wear was found on translucent TZP. Accordingly, on clinical
application, tooth enamel, resin composite, or translucent TZP may be preferable as antagonists when fabricating crown restoration with translucent TZP. After crown placement, since the wear volume varies depending on antagonist, it is necessary to examine and adjust the occlusion during maintenance.

Further experiments are needed to provide the information about complete wear behavior of esthetic dental materials against translucent TZP, by evaluating the wear volume and wear height on anatomical-shaped specimens under suitable wear conditions including thermocycling, and increasing the number of chewing cycles.

CONCLUSION

Results of this study indicated that wear of esthetic dental materials against translucent TZP was greatest in glass ceramics (feldspar porcelain, lithium disilicate) and smaller in resin composite (hybrid filler type, nano filler type) and bovine tooth enamel. No visible wear was found on translucent TZP. Within the limitations of this study on the evaluation of wear performance against translucent TZP, resin composites or translucent TZP may be preferable as antagonists compared to glass ceramics when performing crown restoration with translucent TZP.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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