Wear evaluation of the human enamel opposing different Y-TZP dental ceramics and other porcelains

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A B S T R A C T

Purpose: This study examined the wear resistance of human enamel and feldspathic porcelain after simulated mastication against 3 zirconia ceramics, heat-pressed ceramic and conventional feldspathic porcelain.

Materials and methods: Human teeth and feldspathic porcelain cusp were tested against ceramic discs. 5 brands were tested – 3 monolithic zirconia, Prettau, Lava, and Rainbow, one lithium disilicate, IPS e.max Press, and one feldspathic porcelain, Vita-Omega 900. The surface was polished using a 600 grit and 1200 grit SiC paper. Each group was loaded for 300,000 cycles in a chewing simulator. The wear resistance was analyzed by measuring the volume of substance lost. The wear surfaces were observed by scanning electron microscopy to determine the wear characteristics.

Results: Vita-Omega 900 led to the greatest amount of enamel wears followed by IPS e.max Press, Prettau, Lava and Rainbow. There was a significant difference between Vita-Omega 900 and IPS e.max Press (p < 0.05). The wear values for human enamel were significantly greater than those for feldspathic porcelain, regardless of the surface roughness of the ceramic specimens (p < 0.05).

Conclusion: The wear behaviour of human enamel and feldspathic porcelain varies according to the type of substrate materials. On the other hand, 3 zirconia ceramics caused less wear in the abrader than the conventional ceramic.

Clinical significance: Dental professionals should be aware of the wear effect of dental restorations on the opposing teeth or restorations. The amount of enamel wear was highest in feldspathic porcelains whereas zirconia ceramics caused less wear on the opposing teeth.

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1. Introduction

Dental prosthetic materials should have good mechanical properties that will enable them to withstand a repetitive masticatory pressure; be biocompatible; chemically durable so that they can be used for a long time in the oral environment; have aesthetic properties that are similar to those of natural teeth; and have a high level of wear resistance, while minimizing the wear of the opposing teeth.5 Despite the biocompatibility and aesthetic advantages of ceramic crowns in the early days, they had limitations in clinical use due to their susceptibility to fracture and their excessive wear of opposing teeth.7

First introduced to dental clinics in the late 1990s, Y-TZP (Yttria partially stabilized tetragonal zirconia) has considerably higher bending and fracture strength than other ceramics.3,4 Generally, a zirconia ceramic crown consists of a zirconia core in the lower part and a feldspathic porcelain in the upper part, as in most all-ceramic crowns.

This ceramic crown has good physical properties in the lower core as well as improved physical properties and good aesthetic features due to the condensation of the upper ceramic.5 A ceramic crown has disadvantages such as the susceptibility of the upper veneer ceramic to fracture, the possibility of structural weakening of the veneer ceramic during the construction, and the need to remove a larger portion of teeth for the abutment preparation. Sailer et al.8 recently reported that the most common failure of ceramic crowns was fracture of the veneer ceramic lining, with a failure rate of 15.2%. Such fractures are attributed to the difference in the thermal expansion coefficients of the lower core and upper ceramic, and to mechanical error during condensation of the ceramic. Hence, the possibility of a fracture is unavoidable.

All-ceramic crowns made from zirconia can replace metal-ceramic restorative materials in terms of their mechanical strength by employing the physical advantages of zirconia. Despite this, ceramic crowns made only of zirconia, monolithic zirconia crowns are not used widely in clinical practice because of the absence of a sound standard and the possibility of wear of the opposing teeth due to the hardness of zirconia. Particularly, in relation to the possibility of wear of the opposing teeth, the selection of an appropriate restorative material is important for preserving the function of normal opposing teeth and the balance of articulation.7 Among the restorative materials, the type III gold alloy is ideal in terms of the possibility of wear of the opposing teeth with its minimal wear of the enamel of opposing teeth, unlike ceramics that have a disadvantage, such as the high likelihood of wear of the opposing teeth, despite their good aesthetic features and biocompatibility, which limits their clinical applications.8,9 Studies on the wear of opposing teeth in relation to ceramic crowns have been conducted. Many studies reported that the ceramic destroys the enamel.10

These same studies also reported that although dental ceramic is resistant to wear, it is extremely hard and causes wear of the enamel and other restorative materials.8,9,11–14 Monasky and Taylor reported that ceramic with a rough surface causes excessive wear of the natural opposing teeth; more than gold alloy, amalgam, composite resin and enamel.15 Krejci et al.14 concluded that a ground surface causes less wear than a glazed surface, and that the rate of enamel wear depends on the hardness, texture and surface finish of the opposing restorative materials. The surface roughness of restorative materials is clinically important in relation to the wear of opposing teeth, and has attracted considerable attention from studies of dental restorative materials.16 The rough surface of restorative material may cause gingivitis, periodontitis, physical irritation of the surrounding gingiva, or aesthetic problems due to the deposition of dental plaque or increased retention.17,18

Turissi et al.19 reported that surface roughness plays an important role in the wear pattern of the restorative material itself or of the opposing teeth. Oh et al.7 reported that the hardness and strength of the ceramic are not related strongly to the wear of enamel, and that enamel wear is strongly related to the microstructure of the ceramic, roughness of the contact surface, and the environmental effect.

Many studies have reported the effect of different finishing and grinding methods in relation to the surface roughness of dental restorative materials.10,20,21 Although many studies have examined the possibility of wear of enamel in relation to the effect of veneering porcelain or composite resin on the possibility of wear of the enamel, few studies have investigated the influence of zirconia ceramic directly on enamel wear.

Therefore, this study evaluated the possibility of wear of the opposing teeth to establish structural criteria for the safe intraoral use of zirconia monolithic crowns for dental restorations. To achieve this goal, specimens were made using three types of ceramics (zirconia, heat-pressed ceramic, and feldspathic porcelain), and the degree of enamel wear due to the surface roughness were observed and compared.

2. Materials and methods

Five kinds of substrates were tested. Three types of commercially available zirconia blocks and heat-pressed ceramic and low-fusing feldspathic porcelain were used for the wear test. The three types of zirconia blocks were Prettau (Zirkonzahn GmbH, Bruneck, Italy), Lava (3M ESPE, St. Paul, MN, USA) and Rainbow (Dentium, Seoul, Korea). The heat-pressed ceramic was IPS e.max Press (Ivoclar Vivadent, Liechtenstein) and the low-fusing feldspathic porcelain was Vita-Omega 900 (Vita Zahnfabrik, Bad Säckingen, Germany) (Table 1). The extracted

| Table 1 – Y-TZP dental zirconia and ceramic materials examined. |
|---------------------------------|-----------|----------------|
| Materials                        | Type      | Manufacturer   |
| Prettau                          | Y-TZP     | Zirkonzahn GmbH, Bruneck, Italy |
| Lava                             | Y-TZP     | 3M ESPE, St. Paul, MN, USA      |
| Rainbow                          | Y-TZP     | Dentium, Seoul, Korea           |
| e.max Press                      | Lithium  disilicate | Ivoclar Vivadent, Liechtenstein |
| Low fusing porcelain             | glass ceramic |                             |
| Vita-Omega 900                   | Low fusing porcelain | Vita Zahnfabrik, Bad Säckingen, Germany |


normal premolar teeth of the maxilla and mandible, and feldspathic porcelain were used as the corresponding abraders.

A total of 100 substrate specimens (20 per product) were prepared and divided into two groups. The surface of the specimens of one group was ground with 600-grit silicone carbide paper (SiC), and that of the other group was ground with 1200-grit silicone carbide paper.

2.1. Making of the abrader specimen

2.1.1. Making of the human enamel specimen
The cusps of the premolar teeth of the maxilla and mandible extracted recently for orthodontic treatment were used as the abrader specimens. The cusps of the teeth that had a worn or fractured surface or were too sharp were excluded.

2.1.2. Making of the cusp specimen of the feldspathic porcelain
The low-fusing feldspathic porcelain was condensed into a 6 mm × 8 mm (width × height) right square column and fired. The column was designed to be 6 mm tall from the bottom to the top to have a circular arc with a diameter of 6 mm on the apex of the cusp. All specimens were prepared by a single dental technician.

2.2. Making of the substrate specimen

2.2.1. Making of specimens of three types of zirconia
Commercial zirconia blocks manufactured from Prettau, Lava, and Rainbow were used, and cuboidal specimens, 20 mm × 10 mm × 5 mm (width × length × thickness) in size, were prepared according to the instructions of the manufacturer by sintering the blocks.

2.2.2. Making of the heat-pressed ceramic specimen
A wax pattern with a 20 mm × 10 mm × 5 mm (width × length × thickness) cuboidal shape was made using inlay wax and buried. The IPS e.max Press was made according to the manufacturer’s instructions, and the specimen was embedded in acrylic resin to fit the jig of the wear test device.

2.2.3. Making of the low-fusing feldspathic porcelain specimen
A cuboid-shaped silicone mould was made for the ceramic specimen. Vita-Omega 900 was condensed using the mould and fired on a heat-resistant tile according to the manufacturer’s instructions, and a 20 mm × 10 mm × 5 mm (width × length × thickness) specimen was made.

2.3. Wear test and measurement

2.3.1. Wear test
A wear test was performed using a chewing simulator CS-4.8 (SD Mechatronik, Feldkirchen-Westham, Germany). The device had eight sample holders, and the vertical and horizontal movements between the opposing specimens were simulated using two motors controlled by a computer (Fig. 1). The circulation of heat was possible by controlling the flow of cold and warm water with a computer. Each of the eight interior chambers consisted of an upper sample holder that could be tightened with a screw, and a lower sample holder into which the specimen could be embedded. To use the teeth specimen as the abrader, the tooth specimens were embedded in the lower sample holder using acrylic resin. Each of the ceramic specimens that were embedded in the acrylic resin was fixed on the upper sample holder using a screw. A 5 kg load, which is equivalent to a masticatory force of 49 N was applied, and heat circulation (5–55 °C) was allowed during the test.

2.3.2. Measurement of the worn amount of the abrader specimen
The three-dimensional surface of the abrader specimen was scanned before and after the wear test using an MTS 3D profiler (MTS Systems Corporation, Eden Prairie, MN, USA), and the actual volumetric loss was calculated using the Ansur 3D software (Minneapolis, MN, USA) by superimposing the three-dimensional surfaces before and after the wear test.

2.3.3. Observation of the wear of ceramic substrate specimens
Before the wear test, the mean roughness (Ra) of the ceramic specimens was measured using a laser scanning microscope (LSM 5 Pascal, Carl Zeiss, Jena, Germany). After the test, the specimen surface was observed by scanning electron microscopy (SEM) (JSM-6360, JEOL Techniques, Tokyo, Japan) under magnifications of 50× and 2000×.

2.4. Statistical analysis
The wear amount of the enamel and feldspathic porcelain cusp was analyzed via 3-way ANOVA using SPSS (version 12.0, SPSS, Inc., Chicago, USA), and a post hoc test was performed to test the significance of the wear amount using a Scheffe test ($\alpha = 0.05$).

3. Results

3.1. Wear of the enamel
Table 2 lists the mean and standard deviation of the wear amount of the enamel and feldspathic porcelain cusp. For both of the surface roughness values, the amount of enamel wear
Table 2 – Mean values and SDs of wear volume of the enamel and feldspathic porcelain cusp (mm³).

<table>
<thead>
<tr>
<th>Abrader</th>
<th>Grit</th>
<th>Substrate materials</th>
<th>Prettau</th>
<th>Lava</th>
<th>Rainbow</th>
<th>e.max Press</th>
<th>Vita-Omega 900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>600</td>
<td>0.04 ± 0.02</td>
<td>0.04 ± 0.02</td>
<td>0.04 ± 0.02</td>
<td>0.08 ± 0.03</td>
<td>0.13 ± 0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1200</td>
<td>0.04 ± 0.02</td>
<td>0.04 ± 0.02</td>
<td>0.04 ± 0.02</td>
<td>0.06 ± 0.03</td>
<td>0.11 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Feldspathic porcelain</td>
<td>600</td>
<td>0.03 ± 0.02</td>
<td>0.03 ± 0.01</td>
<td>0.02 ± 0.01</td>
<td>0.06 ± 0.02</td>
<td>0.03 ± 0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1200</td>
<td>0.03 ± 0.02</td>
<td>0.03 ± 0.01</td>
<td>0.03 ± 0.02</td>
<td>0.02 ± 0.01</td>
<td>0.03 ± 0.01</td>
<td></td>
</tr>
</tbody>
</table>

was highest in the Vita-Omega 900 group followed by the IPS e.max Press, Prettau, Lava, and Rainbow groups, although there was no significant difference seen between the latter three groups, i.e. Prettau, Lava and Rainbow groups (p > 0.05). A significant difference was seen between Vita-Omega 900 and IPS e.max Press (p < 0.05) in terms of enamel wear.

3.2. Wear of the feldspathic porcelain cusp

In the 600-grit group, the wear amount of the feldspathic porcelain cusp was highest in the IPS e.max Press group, followed in order by the Vita-Omega 900, Prettau, Lava, and Rainbow groups. In the 1200-grit group, the amount of wear was lowest in the e.max group.

From the results of 3-way ANOVA, The amount of wear significantly differed depending on the type of abrader materials, the substrate materials, and surface roughness. Result showed significant interaction between abrader and substrate, and between substrate and surface roughness (p < 0.05). However, there was no significant interaction between abrader and surface roughness, and among three factors (p > 0.05).

A post hoc test in ANOVA was performed using the Scheffe test. There were no significant differences in the wear amounts of the Prettau, Lava, and Rainbow groups, whereas the wear amounts were significantly different for the IPS e.max Press and Vita-Omega 900 groups from those of the Prettau, Lava, and Rainbow groups (p < 0.05) (Table 3).

Fig. 2 shows the mean amount of wear of the enamel and feldspathic porcelain cusp according to the materials with different degrees of surface roughness. When the abrader was the enamel, the wear amount was higher in the 600-grit group than in the 1200-grit group in all ceramic substrate material groups. The amount of wear of the enamel was highest in the Vita-Omega 900 group in the 600-grit group, and lowest in the three types of zirconia groups in the 1200-grit group. The amount of wear of the enamel group was higher than that of the feldspathic porcelain cusp group regardless of their surface roughness (p < 0.01).

Table 3 – Scheffé analysis to evaluate the mean enamel volume loss (mm³) differences between the material groups showing multiple comparisons (P, Prettau; L, Lava; R, Rainbow; E, e.max Press; V, Vita-Omega 900).

<table>
<thead>
<tr>
<th>(i) Groups</th>
<th>(j) Groups</th>
<th>Mean difference (i – j)</th>
<th>Std. error</th>
<th>Sig.</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>P</td>
<td>L</td>
<td>0.0071</td>
<td>0.005316</td>
<td>0.778</td>
<td>–0.0098</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.0054</td>
<td>0.005316</td>
<td>0.901</td>
<td>–0.0115</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>–0.0175*</td>
<td>0.005316</td>
<td>0.038</td>
<td>–0.0343</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>–0.0257*</td>
<td>0.005316</td>
<td>0.000</td>
<td>–0.0426</td>
</tr>
<tr>
<td>L</td>
<td>P</td>
<td>–0.0071</td>
<td>0.005316</td>
<td>0.778</td>
<td>–0.0240</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>–0.0016</td>
<td>0.005316</td>
<td>0.999</td>
<td>–0.0185</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>–0.0246*</td>
<td>0.005316</td>
<td>0.001</td>
<td>–0.0415</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>–0.0328*</td>
<td>0.005316</td>
<td>0.000</td>
<td>–0.0497</td>
</tr>
<tr>
<td>R</td>
<td>P</td>
<td>–0.0054</td>
<td>0.005316</td>
<td>0.901</td>
<td>–0.0223</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>0.0016</td>
<td>0.005316</td>
<td>0.999</td>
<td>–0.0153</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>–0.0229*</td>
<td>0.005316</td>
<td>0.002</td>
<td>–0.3983</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>–0.0312*</td>
<td>0.005316</td>
<td>0.000</td>
<td>–0.0481</td>
</tr>
<tr>
<td>E</td>
<td>P</td>
<td>0.0175*</td>
<td>0.005316</td>
<td>0.038</td>
<td>0.0006</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>0.0246*</td>
<td>0.005316</td>
<td>0.001</td>
<td>0.0077</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.0229*</td>
<td>0.005316</td>
<td>0.002</td>
<td>0.0060</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>–0.0083</td>
<td>0.005316</td>
<td>0.663</td>
<td>–0.0251</td>
</tr>
<tr>
<td>V</td>
<td>P</td>
<td>0.0258*</td>
<td>0.005316</td>
<td>0.000</td>
<td>0.0089</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>0.0328*</td>
<td>0.005316</td>
<td>0.000</td>
<td>0.0159</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.0312*</td>
<td>0.005316</td>
<td>0.000</td>
<td>0.0142</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>0.0083</td>
<td>0.005316</td>
<td>0.663</td>
<td>–0.0086</td>
</tr>
</tbody>
</table>

*p < 0.05 indicates significant difference.

* Difference in the mean values between group pair (p < 0.05).
3.3. Wear surface of the ceramic substrate specimens

3.3.1. Average Ra

Table 4 lists the average Ra and standard deviation of each of the ceramic substrate specimens measured by laser scanning microscopy before the wear test. In the 600-grit SiC wear group, the average Ra was lowest in the IPS e.max Press group. In the 1200-grit SiC wear group, the average Ra was highest in the Vita-Omega 900 group, and in both the 600-grit and 1200-grit, the average Ra was lowest in the IPS e.max Press group.

3.3.2. Scanning electron microscopy (SEM)

Figs. 3–7 show SEM images of the five ceramic substrate specimens of 1200-grit group, which was performed after the wear test (the marks of wear are shown in each of the specimens). In the IPS e.max Press and three types of zirconia substrate specimens, the inner structure was consistently dense and air bubbles were rarely observed, whereas a large crystalline shape and numerous air bubbles were observed in the Vita-Omega 900 porcelain substrate specimen.

Table 4 – Mean values and SDs of the surface roughness of the ceramic substrate specimens before the wear test (μm).

<table>
<thead>
<tr>
<th>Materials</th>
<th>600 grit</th>
<th>1200 grit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prettau</td>
<td>0.784 ± 0.069</td>
<td>0.284 ± 0.052</td>
</tr>
<tr>
<td>Lava</td>
<td>0.785 ± 0.123</td>
<td>0.459 ± 0.075</td>
</tr>
<tr>
<td>Rainbow</td>
<td>0.678 ± 0.026</td>
<td>0.411 ± 0.034</td>
</tr>
<tr>
<td>e.max Press</td>
<td>0.455 ± 0.066</td>
<td>0.249 ± 0.015</td>
</tr>
<tr>
<td>Vita-Omega 900</td>
<td>0.823 ± 0.383</td>
<td>0.704 ± 0.094</td>
</tr>
</tbody>
</table>

4. Discussion

Tooth wear is a complex process that involves a range of factors, such as the food, non-functional habits, neuromuscular force, thickness and hardness of enamel, acidity and other properties of saliva, masticatory pattern, and opposing restorative materials. 

The progressive wear of natural teeth is a normal physiological phenomenon.

This physiological wear can be affected if restorative materials with different wear rates from that of natural teeth are used for intraoral restorations. Lambrechts et al. reported that vertical wear of enamel is 20–40 μm a year under normal condition. Seghi et al. reported that the wear rates of intraoral restorative materials should be similar to that of the human enamel. Therefore, it is important to evaluate the wear resistance of restorative materials against the opposing natural teeth and the physical properties of restorative materials. Among the dental restorative materials, ceramic has the best aesthetic features as well as good compressive strength and biocompatibility, although it presents certain disadvantages such as relatively low tensile strength and can cause an excessive wear of the opposing teeth. Restorative materials that significantly wear down the opposing teeth can cause hypersensitivity and articular imbalance by rapidly wearing down the opposing teeth. To overcome this problem, new ceramics that produce less wear on the opposing teeth have been developed.

Among the improved all-ceramic crowns, the zirconia crown has a feldspathic porcelain lining in its upper part, and it is used in clinical practice. Recently, the construction of an all-ceramic crown made only of zirconia has become possible.

Fig. 2 – Mean wear volume of the enamel and porcelain cusp. Standard deviations are shown by error bars.

Fig. 3 – SEM images after wear test of e.max Press (1200 grit SiC polished) against human enamel (A) original magnification 50x, (B) original magnification 2000x.
This has made it possible to overcome the susceptibility of its veneer ceramic layer to wear, while maintaining its physical advantages. Most studies on the wear of enamel have focused on the veneering porcelain and resin,\textsuperscript{15,28} and few studies have examined the effect of zirconia ceramic on enamel wear. This study examined the possibility of wear against the opposing teeth to establish a structural standard for the safe intraoral use of zirconia for monolithic ceramic crowns. A clinical study on wear takes at least 6 months to 1 year, and involves difficulties in accurate measurements due to many uncontrollable variables.\textsuperscript{29}

Although an in vitro study has limitations in perfectly simulating the intraoral masticatory movement,\textsuperscript{30} it can simulate simple movements, such as grinding and clenching teeth,\textsuperscript{30} and the mechanism behind the wear resistance of various materials or the order of susceptibility of various materials to wear can be assessed at the pre-clinical stage using specific test variables. Because of the advantages of an in vitro study, the test devices that can simulate the intraoral masticatory movement were developed to assess the wear of natural teeth and restorative materials.\textsuperscript{13,29,31–34} The 2-axes wear test device used in this study is currently being used in many studies, and is known to be practical, durable and cost-effective. This device has a total of 8 interior chambers, and simulates the mandibular closing movement that occurs during masticatory movement by simulating the occlusal contact followed by the sliding movement.\textsuperscript{35} In this study, a 2-body wear test was performed. This test is used widely in wear resistance measurements,\textsuperscript{36} and was used to simulate the attrition caused by the occlusal contact between restorative materials and the teeth during bruxism and clenching.

This method could also simulate the friction and fatigue wear caused by direct contact between the maxilla and mandibular teeth during swallowing or non-functional dynamic occlusal movement.\textsuperscript{37} The load of the wear test device was 5 kg, which is the mean physiological occlusal force without bruxism based on the intraoral occlusal force reported in previous studies on ceramic wear.\textsuperscript{38} The subsequent sliding movement plays an important role in simulating the intraoral wear as microfatigue occurs during the opposing wear material slides on the specimen.\textsuperscript{39} In the present study, 0.3 mm lateral movement was applied. Mair et al.\textsuperscript{40} reported that as the load that accompanies the sliding factor causes 10 times greater stress than that caused by a static load, and a crack may be formed on the surface of the ceramic. During the test, the 8 interior chambers were filled with water, and the continuous change of water enabled the removal of wear particles created by the wear test from the contact surface. In addition, heat circulation was performed during the wear test to simulate changes in the intraoral temperature.

This study and subsequently the in vitro wear test device, will be used to perform future studies on ceramic materials.
Up to 300,000 masticatory movements were simulated, which is equivalent to the masticatory movement performed at 1 year in a clinical environment. After the test, the volumetric loss was measured using an MTS 3D profiler and Ansur 3D software by superimposing the 3D surfaces before and after the test. Standardization of the enamel surface of natural teeth that was used as the opposing wear material has been a subject of considerable controversy. In most studies, a standardized enamel cusp was used for the wear test of ceramic and enamel. Krejci et al. reported that the non-standardized enamel cusp of natural teeth is most appropriate for the opposing wear materials in the wear test, which was consistent with previous studies by Krejci et al. and Lutz et al. In a preliminary experiment, Kunzelmann et al. used an enamel cusp surface that was not treated, and reported that the standardization of the enamel through grinding preparation altered the wear properties of the opposing wear material, unlike that with the non-standardized cusp. Heintze et al. reported that a standardized enamel cusp could result in a range of results, and the results obtained from these cusps were slightly inconsistent. Therefore, in this study, the enamel surface of the premolar teeth of the maxilla and mandible, which were extracted for orthodontic treatment, was used without standardization.

In this study, the amount of wear of the opposing abrader shows a significant difference depending on the type of ceramic substrate, opposing abrader and surface roughness. Of the five types of ceramic substrate material, the amount of enamel wear was the highest in the Vita-Omega 900 group, followed by the IPS e.max Press, Lava, Rainbow, and Prettau groups. In particular, the amount of enamel and feldspathic porcelain cusp wear was the lowest in the Prettau, Lava, and Rainbow groups, and was significantly higher in the Vita-Omega 900, IPS e.max Press, and three types of zirconia substrate groups.

The amount of wear in the Vita-Omega 900 group was higher when the abrader was the enamel rather than of the feldspathic porcelain cusp. Unlike the other wear materials, IPS e.max Press group significantly wore out the abrader at a 600-grit surface. The mean wear amounts of the three types of zirconia substrate specimen that were measured after the wear test were all too small to be measured. This suggests that compared to feldspathic porcelain, the superior physical properties and surface features of zirconia, such as its hardness, bending strength, fracture toughness and density, enabled it to maintain a smooth surface during the wear test, which is consistent with the results reported by Ghazal et al. on the wear of a zirconia specimen. In this study, the amount

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Fig. 6 – SEM images after the wear test of Rainbow (1200 grit SiC polished) against human enamel (A) original magnification 50×, (B) original magnification 2000×.

Fig. 7 – SEM images after the wear test of Vita-Omega 900 (1200 grit SiC polished) against human enamel (A) original magnification 50×, (B) original magnification 2000×.
of the enamel wear of natural teeth was higher than that of feldspathic porcelain cusp, possibly due to the higher wear resistance of feldspathic porcelain than the human enamel.

The lower level of enamel hardness than feldspathic porcelain could cause greater wear of enamel than feldspathic porcelain. Enamel generally has a Vickers hardness of 320–380 kg/mm² and a fracture toughness of 0.8 Mpa m¹/². Also these values have variations caused by anatomical characteristics in enamel such as Hunter–Schreger Band (HSB). It is known that higher packing densities of HSB are noted in those areas subjected to greater external forces. Feldspathic porcelain, however, has a higher degree of hardness of 500 kg/mm² or more, and its wear of the opposing enamel could be accelerated by a rougher surface and by broken particles during the masticatory test. Additionally the wear of enamel could increase considerably as the fracture toughness of enamel is significantly lower than that of feldspathic porcelain. This superior property of feldspathic porcelain to that of the human enamel can affect the wear amount, which is consistent with these results. The surface roughness of ceramic can vary according to the methods and degree of surface grinding, and a rough ceramic surface decreases the physical properties of the materials, or causes an excessive wear of the opposing teeth, surface discoloration, and inflammation of soft oral tissue. Schuh et al. reported that a high friction coefficient between low-fusing ceramic and the opposing wear materials increases the fatigue and ceramic wear.

The results of this study showed that the amount of enamel wear in relation to the surface roughness differed significantly (p < 0.05) and decreased in the 1200-grit grinding group. The average Ra of the specimen was measured by laser scanning microscopy before the wear test, and the surface was observed after the test using SEM. In the SiC grinding group of 600 grit, the average Ra was the lowest in the IPS e.max Press group and in the SiC grinding group of 1200 grit, and the degree of roughness was the highest in the Vita-Omega 900 group. In the IPS e.max Press group, the average Ra was the lowest both in the 600-grit group and 1200-grit group. In the three types of zirconia groups where grinding was performed using 1200-grit SiC, the mean surface roughness of the Lava, Rainbow, Prettau, and IPS e.max Press groups were similar. Willems et al. reported that the roughness of the contact surface of the enamel after wear was 0.64 μm, and Al-Wahadni reported that the average Ra of the ceramic after grinding was 0.26–0.75 μm.

The hardness of metal is related to enamel wear. Based on the results of various studies, however, Seghi et al. and Oh et al. reported the hardness of ceramic and the wear of opposing teeth by ceramic restorative materials. The hardness and wear of ceramic are closely related to each other, and that wear is closely related to the microstructure of ceramic, the roughness of the contact surface, and environmental factors. Although the correlation between the surface roughness and amount of enamel wear can be expected, the correlation was not analyzed in the present study.

The effect of the surface roughness on wear was reconsidered because in the present study, some ceramic materials with similar degrees of surface roughness showed significantly different enamel wear after the wear test. Metzler et al. reported that although the surface condition of ceramic is important at the initial stages of wear, the inner properties of ceramic affected the wear rate once the effect of roughness disappeared with wear progression. The surface roughness is one of the factors that affect wear. This study examined the possibility of the wear of zirconia ceramic against the opposing teeth as part of a study to apply a zirconia monolithic crown to clinical practice. These results suggest that zirconia ceramic can be used as zirconia monolithic crown with an advantage as it showed less enamel wear than feldspathic porcelain and heat-pressed ceramics.

As this is an in vitro study, which involves many factors, such as occlusal force, masticatory habits, type of food, and location of the teeth in the maxillary and mandibular arch, the conditions used in this study could differ from the clinical intra oral conditions. In addition, in this study, only 2-body wear was evaluated. Therefore, different results could be achieved if a 3-body wear test is performed using different wear materials, further studies with well simulated intra oral condition are required for better clinical implication.

5. Conclusion

(I) The enamel wear was significantly greater than the feldspathic porcelain abrader wear (p < 0.05).

(II) The feldspathic porcelain substrate caused the most wear of the enamel abrader (p < 0.05).

(III) The zirconia substrates caused the least wear of the enamel abrader (p < 0.05) and had no difference among them (p > 0.05).

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