Original Article

In vitro wear of four ceramic materials and human enamel on enamel antagonist

Jun Nakashima, Yohsuke Taira, Takashi Sawase

Department of Applied Prosthodontics, Graduate School of Biomedical Sciences,
Nagasaki University, 1-7-1 Sakamoto, Nagasaki 852-8588, Japan

Running title: Wear of four ceramics and enamel

Correspondence to: Yohsuke Taira

Department of Applied Prosthodontics

Graduate School of Biomedical Sciences, Nagasaki University

1-7-1 Sakamoto, Nagasaki 852-8588, Japan

Tel: +81-95-819-7688, Fax: +81-95-819-7689

E-mail: yohsuke@nagasaki-u.ac.jp

Nakashima J, Taira Y, Sawase T
In vitro wear of four ceramic materials and human enamel on enamel antagonist
Eur J Oral Sci

Abstract

The purpose of the present study was to evaluate the wear of four different ceramics and human enamel. The ceramics used were lithium disilicate glass (e.max Press), leucite-reinforced glass (GN-Ceram), yttria-stabilized zirconia (Aadva Zr), and feldspathic porcelain (Porcelain AAA). Hemispherical styli were fabricated with these ceramics and tooth enamel. Flattened enamel was used for antagonistic specimens. After 100,000 wear cycles of a two-body wear test, the height and volume losses of the styli and enamel antagonists were determined. The mean and standard deviation for eight specimens were calculated and statistically analyzed using a non-parametric (Steel-Dwass) test ($\alpha = 0.05$). GN-Ceram exhibited greater stylus height and volume losses than Porcelain AAA. E.max Press, Porcelain AAA, and enamel styli showed no significant differences, and Aadva Zr exhibited the smallest stylus height and volume losses. The wear of the enamel antagonist was not significantly different among GN-Ceram, e.max Press, Porcelain AAA, and enamel styli. Aadva Zr resulted in significantly lower wear values of the enamel antagonist than GN-Ceram, Porcelain AAA, and enamel styli. In conclusion, leucite-reinforced glass, lithium disilicate glass, and feldspathic porcelain showed wear values closer to those for human enamel than did yttria-stabilized zirconia.

Keywords: Wear, Ceramics, Enamel

Yohsuke Taira
Department of Applied Prosthodontics, Graduate School of Biomedical Sciences,
Nagasaki University, 1-7-1 Sakamoto, Nagasaki 852-8588, Japan
Telefax: +81-95-819-7689, E-mail: yohsuke@nagasaki-u.ac.jp

Introduction

Dental ceramics have been widely used in prosthodontic treatments to satisfy the aesthetic demands of patients (1). Computer aided design/computer assisted manufacturing (CAD/CAM) systems use a variety of ceramic blocks, such as lithium disilicate glass, leucite-reinforced glass, and yttria-stabilized zirconia. Also, there is a heat-press fabrication system that uses a custom block made of lithium disilicate glass (2,3). These ceramic materials have better mechanical properties, especially flexural strength and fracture toughness, when compared to feldspathic porcelains (4,5).

Wear between ceramic restorations and tooth substrates at the occlusal contact area is of great concern to many clinicians. Some dental porcelains are not the material of choice because of their abrasiveness (6-9). Reduction of opposing tooth substrates from abrasive restorative materials may cause broken incisal anatomy, tooth hypersensitivity or unbalanced occlusion (10). Enamel wear caused by antagonistic enamel and ceramic crowns has been investigated in vivo (11-15). Although such clinical studies are useful, they are also time consuming. Therefore, it is important to preclinically estimate which types of materials are suitable for opposing teeth as a crown restoration.

Several wear testing methods have been developed in order to investigate the wear characteristics of restorative materials (16,17). The wear of enamel against porcelains in a three-body wear test was much smaller than that in a two-body wear test (18). Zirconia exhibited less enamel wear than porcelain and lithium disilicate glass (19). Lithium disilicate glass was not only resistant to wear, but was also wear friendly to enamel antagonist surfaces (20). In a previous study using bovine enamel, no significant difference was found between the wear values for opposing enamel caused by lithium disilicate glass and enamel (21). A glazed porcelain caused more antagonist enamel wear than polished zirconia (22). An experimental fine and nano-scale-crystal-sized leucite glass reduced tooth wear (23).

However, the available information on the wear of enamel/leucite-reinforced glass, enamel/lithium disilicate glass, and enamel/enamel pairs was limited. A systematic study was desired in order to compare wear characteristics between various ceramics and an enamel antagonist by means of the same simulation method, as opposed to fragmentary information. Objective data comparing enamel-to-ceramics (24-26) and enamel-to-enamel wear (27,28) are preclinically useful for choosing an occlusal material for restoratives.

The purpose of the present study was to evaluate the wear of four different ceramics (leucite-reinforced glass, lithium disilicate glass, yttria-stabilized zirconia, and feldspathic porcelain) and human enamel, as well as the wear of opposing enamel by means of a two-body wear simulation. The null hypothesis was that there would be no difference in the wear of the ceramics and enamel.

Material and methods

Preparation of stylus head

The materials used in the present study are listed in Table 1. A 3.175-mm (1/8-inch) diameter hemispherical tip made of stainless steel was used for the master model of the stylus head. The shape of the master model was duplicated with two CAD/CAM systems (GN-Ceram and Aadva Zr), a lost-wax and heat-press system (e.max Press), and a powder/liquid porcelain firing system (Porcelain AAA). The stylus heads were polished with a polishing paste (Zircon-Brite, Dental Ventures of America, Corona, CA, U.S.A.) and a felt wheel. As a control, the cusps of extracted human molar teeth were ground with custom-shaped rotary instruments (Carborundum Point, Shofu, Kyoto, Japan) to standardize the stylus head (22), and were then polished with silicone mounted polishing points (M2 and M3, Shofu). Before wear testing, a representative stylus head for each test group was observed with a color laser

3D profile microscope (VK-8500, Keyence, Osaka, Japan), and the arithmetic average roughness (Ra) was determined.

Wear test

Two-body wear tests were carried out using a wear-testing device (Higuchi, Nagasaki, Japan) according to a method developed at the University of Alabama (18,29-34). The proximal surface of human premolar teeth was ground flat with 2000 grit silicon carbide paper and was used for enamel antagonist. As the stylus head vertically contacted the enamel-antagonist surface in water, it rotated clockwise 15° (with increasing load up to 75 N), and then counter-rotated to the starting position (Fig. 1). In this test, 100,000 wear cycles were applied with a frequency of 1.2 Hz. Eight specimens were fabricated for each test group.

The worn surfaces were subjected to multiple scans by color laser profile microscopy (VK-8500, Keyence) at a magnification of 100×, and the height and volume losses of the stylus and enamel antagonist were determined. The height losses of the stylus and the enamel antagonist were defined as the distance from the original surface of the specimen to the deepest point of the indentation generated by the wear test. The volume loss of the stylus was calculated as follows (29) (Fig. 2):

$$\text{Volume loss of stylus} = \pi/6 \times h(3c^2 + h^2)$$

$$c = \sqrt{h(2r-h)}$$

h: height loss of stylus head

r: radius of stylus head =1.5875 mm

The volume loss of the enamel antagonist was determined using analysis software (VK shape analysis application VK-H1W, Keyence).

Statistical analysis

The mean and standard deviation for eight measurements of Ra on one sample were calculated. After the homoscedasticity assumption was confirmed through Levene's test, Ra values were analyzed by ANOVA at a statistical significance of 0.05.

The mean and standard deviation for eight specimens were calculated for the wear values (height and volume losses of the stylus and enamel antagonist). After the homoscedasticity assumption was analyzed by Levene's test, the wear values were compared using a non-parametric (Steel-Dwass) test at a statistical significance of 0.05.

Scanning electron microscopy

After completion of the wear tests, a replica of the specimen surface was made using a polyvinylsiloxane impression material (Exafine, GC, Tokyo, Japan) and an epoxy resin (Diemet-e, Erkodent Erich Kopp, Pfalzgrafenweiler, Germany). The surfaces were sputter coated with gold (Ion Coater IB-3, Eiko Engineering, Mito, Japan) and then observed using scanning electron microscopy (SEM; S-3500N, Hitachi, Tokyo, Japan) at a magnification of 50×.

Results

The Ra values of all stylus heads were not statistically different (Table 2). The maximum height loss of the stylus was obtained for the GN-Ceram, e.max Press, and enamel styli, and the values were not significantly different. Although no significant differences were found between the e.max Press, Porcelain AAA, and enamel styli, GN-Ceram exhibited significantly greater height loss ($P = 0.0491$) and volume loss of the stylus ($P = 0.0082$) as compared to Porcelain AAA. Among the styli that were evaluated, Aadva Zr exhibited the minimum height and volume losses.

The height losses of the enamel antagonists against the GN-Ceram, e.max Press, Porcelain AAA, and enamel styli exhibited no significant differences (Table 3). There were no significant differences between Aadva Zr and e.max Press, but Aadva Zr exhibited significantly lower values than the GN-Ceram ($P = 0.0117$), Porcelain AAA ($P = 0.0117$), and enamel styli ($P = 0.0166$). The use of the Aadva Zr stylus resulted in the smallest volume loss of the enamel antagonist. No significant differences were detected among the GN-Ceram, e.max Press, Porcelain AAA, and enamel styli.

In a series of representative SEM images of worn stylus surfaces, GN-Ceram, e.max Press, and Porcelain AAA exhibited a clear edge wear facet, whereas Aadva Zr and enamel did not (Fig. 3). GN-Ceram exhibited the coarsest surface with concentric wear patterns, followed by e.max Press and Porcelain AAA. GN-Ceram and e.max Press exhibited a small convex bump at the center of the wear surface. No clear facet was observed on the contact area of the Aadva Zr stylus. The worn surface of the enamel stylus was smooth, and exhibited a small concave dimple centered within the peripheral wear facet.

With regard to the worn surfaces of enamel antagonists, GN-Ceram exhibited the coarsest surface, with a concentric wear pattern (Fig. 4). GN-Ceram and e.max Press exhibited a small concave dimple centered within the peripheral wear facet. Enamel antagonists against e.max Press and Porcelain AAA exhibited concentric wear patterns, whereas the worn surface of Aadva Zr was smooth and quite small. The area worn by the enamel stylus was smooth and exhibited a small convex dimple centered within the peripheral wear facet.

Discussion

The present study revealed that the substrates of the styli (leucite-reinforced glass, lithium disilicate glass, yttria-stabilized zirconia, feldspathic porcelain, and human enamel) influenced the wear loss of the stylus and enamel antagonist. Therefore, the null hypothesis was rejected.

In vivo enamel-to-enamel wear has been reported to be 38 μm over 1 year (11) or 10 μm over 6 months (14). The wear loss of enamel over 3 years in the molar region (105 μm) was more than that in the premolar region (54 μm) (12). Accordingly, the 107-μm height loss of the enamel stylus against the enamel antagonist at 100,000 wear cycles could be converted to approximately 3 years in the molar region.

The wear of other material combinations was also evaluated in accordance with the method validated in the literature (18,36). The in vitro wear test can be regarded as a tool for comparing the loss of restorative materials and the enamel antagonist in a shorter period than that required for a clinical study. In the wear test, 100,000 wear cycles at 1.2 Hz took approximately 23 hours. A force of 75 N was used, based on a report that this is similar to a typical biting force (34).

Standardization of the enamel by grinding preparation influenced the wear properties (19,24,25). We standardized the enamel cusp without modifying the cusp tip in order to quantify enamel wear and minimize the changes in the wear properties based on a previous study (22). As a result (Table 2), the standard deviations for the enamel stylus were relatively high, which is in agreement with in vivo observations (12). Although the variations of enamel may be overcome using control materials such as steatite (25), the microstructure of enamel is essentially different from that of isotropic materials.

Fabrication of a replica is a useful technique for decreasing artifacts, such as cracks that occur when cutting and evacuating an enamel specimen for SEM observation. In addition, the replica method enables repeated observation of a worn surface for any number of wear cycles without damaging the stylus head (18).

GN-Ceram contained leucite ($K_2O \cdot Al_2O_3 \cdot 4SiO_2$) in a glass matrix and was characterized by the high crystallinity of the leucite (71%) (4). The surface texture of the styli changed during the wear test (Figs. 3a and 4a). The reason that GN-Ceram exhibited the coarsest surface with concentric wear patterns may be that the leucite crystals possess higher wear resistance than the glass matrix.

Generally, feldspathic porcelains contain leucite crystals, cracks, and voids in the glass matrix, and their worn surfaces became rough and abrasive (9). Interestingly, the enamel antagonist against Porcelain AAA exhibited concentric wear patterns (Fig. 4d), but the worn porcelain AAA stylus was smooth (Fig. 3d). This suggests that fragments from the porcelain contribute both to the wear of the ceramic itself and to the creation of third-body abrasive particles (22,35). Therefore, we speculate that third-body abrasive particles of porcelain, rather than the porcelain itself, ground the enamel surface.

The wear loss of enamel by e.max Press was equivalent to that of enamel-to-enamel wear in vivo (13) and to that reported for an in vitro study using a sliding wear test (17). These reports are supported by the present data, indicating that the wear values of e.max Press-to-enamel and enamel-to-enamel wear exhibited no significant difference. Numerous several-micron-length needle-like crystals of lithium disilicate ($Li_2Si_2O_5$) exist in the e.max Press ceramic (2). The complex microstructure of lithium disilicate with glass and the crystalline needles plow and deform the enamel surface, resulting in an abrasive surface (Fig. 3b), and enhanced friction (3). The concentric wear pattern on the enamel surface (Fig. 4b) may have resulted from the crystalline needles of e.max Press.

The enamel wear against polished yttria-stabilized zirconia is lower than that against enamel cusp (27,28). Yttria-stabilized zirconia caused less wear on the antagonistic enamel than a feldspathic porcelain and e.max Press (19). The present results for enamel wear against Aadva Zr, enamel, Porcelain AAA, and e.max Press agree with the results in these reports.

An ideal material possesses the same wear resistance as enamel and has no potential to abrade the opposing tooth structure (35,36). Aadva Zr appeared to have a much higher wear resistance than enamel and no potential to excessively abrade opposing enamel. GN-Ceram, e.max Press, and Porcelain AAA exhibited similar wear resistance to human enamel and abraded opposing enamel as much as the enamel stylus. The high standard deviations for enamel-to-enamel wear suggest that the living body will tolerate some variation of wear characteristics, but yttria-stabilized zirconia seems to exceed this tolerance. Therefore, a speculation that may be added to the literature is that the ideal material should not exceed the tolerance of natural tooth enamel.

The physical and microstructural characteristics, chemical degradation, and surface roughness of ceramics affect wear between ceramics and enamel (9). For example, yttria-stabilized zirconia ground with 100-µm diamond bur caused higher enamel antagonist wear than polished zirconia (26). Furthermore, a number of factors, including food, saliva, pellicle, tooth position, occlusion, biting force, sliding, parafunction, and bruxism, influence intraoral wear (14,17,36-38). The in vitro wear testing used in the present study does not reflect all of the factors that clinically occur. Therefore, long-term clinical data will be required in order to clarify the wear for different ceramics and an enamel antagonist in the future. When ceramic restoratives and adjacent intact teeth support the occlusal force together, clinicians should periodically carefully examine the wear facet.

Within the limitations of the present study, the following conclusions are drawn. Leucite-reinforced glass (GN-Ceram), lithium disilicate glass (e.max Press), and feldspathic porcelain (Porcelain AAA) exhibited wear values comparable to human enamel. The wear resistance of Porcelain AAA against enamel was higher than that of GN-Ceram. Yttria-stabilized zirconia (Aadva Zr) exhibited the greatest wear resistance and the lowest abrasion of the enamel antagonist.

Conflicts of interest – The authors declare no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

1. DENY IL. All-ceramic restorations. In: ROSENSTIEL SF, LAND MF, FUJIMOTO J, eds. *Contemporary fixed prosthodontics*. 4th edn. St. Louis: Mosby Elsevier; 2006; 774-804.
2. TANG X, TANG C, SU H, LUO H, NAKAMURA T, YATANI H. The effects of repeated heat-pressing on the mechanical properties and microstructure of IPS e.max Press. *J Mech Behav Biomed Mater* 2014; **40**: 390-396.
3. LEE A, SWAIN M, HE L, LYONS K. Wear behavior of human enamel against lithium disilicate glass ceramic and type III gold. *J Prosthet Dent* 2014; **112**: 1399-1405.
4. YOSHIDA K, MENG X, KAMADA K, ATSUTA M. Influence of surface characteristics of four silica-based machinable ceramics on flexural strength and bond strength of a dual-curing resin luting agent. *J Adhes Dent* 2007; **9**: 407-413.
5. MIYAZAKI T, HOTTA Y, KUNII J, KURIYAMA S, TAMAKI Y. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. *Dent Mater J* 2009; **28**: 44-56.

6. AL-HIYASAT AS, SAUNDERS WP, SHARKEY SW, SMITH GM, GILMOUR WH. Investigation of human enamel against four dental ceramics and gold. *J Dent* 1998; **26**: 487-495.

7. HACKER CH, WAGNER WC, RAZZOOG ME. An in vitro investigation of the wear of enamel on porcelain and gold in saliva. *J Prosthet Dent* 1996; **75**: 14-17.

8. KREJCI I, LUTZ F, REIMER M, HEINZMANN JL. Wear of ceramic inlays, their enamel antagonists, and luting cements. *J Prosthet Dent* 1993; **69**: 425-430.

9. OH WS, DELONG R, ANUSAVICE KJ. Factors affecting enamel and ceramic wear: a literature review. *J Prosthet Dent* 2002; **87**: 451-459.

10. JACOBI R, SHILLINGBURG HT Jr, DUNCANSON JR MG. A comparison of the abrasiveness of six ceramic surfaces and gold. *J Prosthet Dent* 1991; **66**: 303-309.

11. ESQUIVEL-UPSHAW JF, YOUNG H, JONES J, YANG M, ANUSAVICE KJ. In vivo wear of enamel by a lithia disilicate-based core ceramic used for posterior fixed partial dentures: first-year results. *Int J Prosthodont* 2006; **19**: 391-396.

12. LAMBRECHTS P, BRAEM M, VUYLSTEKE-WAUTERS M, VANHERLE G. Quantitative in vivo wear of human enamel. *J Dent Res* 1989; **68**: 1752-1754.

13. ESQUIVEL-UPSHAW JF, ROSE JR WF, BARRETT A, OLIVEIRA ER, YANG MCK, CLARK AE, ANUSAVICE KJ. Three years in vivo wear: core-ceramic, veneers, and enamel antagonists. *Dent Mater* 2012; **28**: 615-621.

14. STOBER T, BERMEJO JL, RAMMELSBERG P, SCHMITTER M. Enamel wear caused by monolithic zirconia crowns after 6 months of clinical use. *J Oral Rehabil* 2014; **41**: 314-322.

15. ANSELM WISKOTT HW, PERRIARD J, SCHERRER SS, DIETH S, BELSER UC. In vivo wear of three types of veneering materials using implant-supported restorations: a method evaluation. *Eur J Oral Sci* 2002; **110**: 61-67.

16. HEINTZE SD, FAOUZI M, ROUSSON V, ÖZCAN M. Correlation of wear in vivo and six laboratory wear methods. *Dent Mater* 2012; **28**: 961-973.

17. LAWSON NC, JANYAVULA S, SYKLAWER S, MCLAREN EA, BURGESS JO. Wear of enamel opposing zirconia and lithium disilicate after adjustment, polishing and glazing. *J Dent* 2014; **42**: 1586-1591.

18. IMAI Y, SUZUKI S, FUKUSHIMA S. Enamel wear of modified porcelains. *Am J Dent* 2000; **13**: 315-323.

19. KIM MJ, OH SH, KIM JH, JU SW, SEO DG, JUN SH, AHN JS, RYU JJ. Wear evaluation of the human enamel opposing different Y-TZP dental ceramics and other porcelains. *J Dent* 2012; **40**: 979-988.

20. SILVA NR, THOMPSON VP, VALVERDE GB, COELHO PG, POWERS JM, FARAH JW, ESQUIVEL-UPSHAW J. Comparative reliability analyses of zirconium oxide and lithium disilicate restorations in vitro and in vivo. *J Am Dent Assoc* 2011; **142**: 4S-9S.

21. TAIRA Y, NAKASHIMA J, SAWASE T, SAKIHARA M. Wear of tooth enamel against silver-palladium-gold alloy and two other restorative materials in vitro. *J Prosthodont Res* 2015; **59**: 210-212.

22. JANYAVULA S, LAWSON N, CAKIR D, BECK P, RAMP LC, BURGESS JO. The wear of polished and glazed zirconia against enamel. *J Prosthet Dent* 2013; **109**: 22-29.

23. THEOCHAROPOULOS A, CHEN X, HILL R, CATTELL MJ. Reduced wear of enamel with novel fine and nano-scale leucite glass-ceramics. *J Dent* 2013; **41**: 561-568.

24. HEINTZE SD, CAVALLERI A, FORJANIC M, ZELLWEGER G, ROUSSON V. Wear of ceramic and antagonist - a systematic evaluation of influencing factors in vitro. *Dent Mater* 2008; **24**: 433-449.

25. KREJCI I, ALBERT P, LUTZ F. The influence of antagonist standardization on wear. *J Dent Res* 1999; **78**: 713-719.

26. MITOV G, HEINTZE SD, WALZ S, WOLL K, MUECKLICH F, POSPIECH P. Wear behavior of dental Y-TZP ceramic against natural enamel after different finishing procedures. *Dent Mater* 2012; **28**: 909-918.

27. BURGESS JO, JANYAVULA S, LAWSON NC, LUCAS TJ, CAKIR D. Enamel wear opposing polished and aged zirconia. *Oper Dent* 2014; **39**: 189-194.

28. PASSOS SP, TORREALBA Y, MAJOR P, LINKE B, FLORES-MIR C, NYCHKA JA. In vitro wear behavior of zirconia opposing enamel: a systematic review. *J Prosthod* 2014; **23**: 593-601.

29. SUZUKI S, SUZUKI SH, COX CF. Evaluating the antagonistic wear of restorative materials. *J Am Dent Assoc* 1996; **127**: 74-79.

30. LEINFELDER KF, BEAUDREAU RW, MAZER RB. An in vitro device for predicting clinical wear. *Quintessence Int* 1989; **20**: 755-761.

31. SUZUKI S, LEINFELDER KF. Localized wear and marginal integrity of posterior resin composites. *Am J Dent* 1993; **6**: 199-203.

32. RAMP MH, RAMP LC, SUZUKI S. Vertical height loss: an investigation of four restorative materials opposing enamel. *J Prosthodont* 1999; **8**: 252-257.

33. RAMP MH, SUZUKI S, COX CF, LACEFIELD WR, KOTH DL. Evaluation of wear: Enamel opposing three ceramic materials and a gold alloy. *J Prosthet Dent* 1997; **77**: 523-530.

34. LEINFELDER KF, SUZUKI S. In vitro wear device for determining posterior composite wear. *J Am Dent Assoc* 1999; **130**: 1347-1353.

35, GHAZAL M, HEDDERICH J, KERN M. Wear of feldspathic ceramic, nanofilled composite resin and acrylic resin artificial teeth when opposed to different antagonists. *Eur J Oral Sci* 2008; **116**: 585-592.

36. SUZUKI S, NAGAI E, TAIRA Y, MINESAKI Y. In vitro wear of indirect composite restoratives. *J Prosthet Dent* 2002; **88**: 431-436.

37. JOHANSSON A, HARALDSON T, OMAR R, KILIARIDIS S, CARLSSON GE. An investigation of some factors associated with occlusal tooth wear in a selected high-wear sample. *Scand J Dent Res* 1993; **101**: 407–415.

38. JOHANSSON A, KILIARIDIS S, HARALDSON T, OMAR R, CARLSSON GE. Covariation of some factors associated with occlusal tooth wear in a selected high-wear sample. *Scand J Dent Res* 1993; **101**: 398–406.

Figure legends

Fig. 1. Schematic diagram of the wear-test device used in the present study.

Fig. 2. Schematic diagram of the stylus head used in the calculation of volume loss.

Fig. 3. Scanning electron micrographs of worn stylus surfaces after 100,000 wear cycles. a: GN-Ceram, b: e.max Press, c: Aadva Zr, d: Porcelain AAA, e: enamel.

Fig. 4. Scanning electron micrographs of worn surfaces of enamel antagonists after 100,000 wear cycles. a: for GN-Ceram, b: for e.max Press, c: for Aadva Zr, d: for Porcelain AAA, e: for enamel.

Table 1

Materials and tooth enamel used for stylus head.

Name (Color)	Abbreviation	Type of ceramic	Manufacturer	Lot No.
GN-Ceram Block (A3)	GN-Ceram	leucite reinforced glass	GC, Tokyo, Japan	1107291
IPS e.max Press Ingots (LT A3)	e.max Press	lithium disilicate glass	Ivoclar Vivadent AG, Schaan, Liechtenstein	R78685
Aadva Zirconia Disk (ST)	Aadva Zr	yttria-stabilized zirconia	GC	1112011
Super Porcelain AAA (E3)	Porcelain AAA	feldspathic porcelain	Kuraray Noritake Dental, Tokyo, Japan	0D318

Table 2

Arithmetic average roughness (Ra) of stylus head before wear test, and loss of stylus after wear test.

	Ra	Height loss (µm)				Volume loss** (mm^{3})			
Stylus head	Mean (SD)	Mean (SD)	P value*			Mean (SD)	P value		
GN-Ceram	0.5 (0.1)^{a}	152.8 (15.4)^{a}		0.0083	0.0491	0.11 (0.02)^{a}		0.0083	0.0082
e.max Press	0.4 (0.1)^{a}	142.0 (26.0)^{ab}	0.0083			0.10 (0.03)^{ab}	0.0083		
Aadva Zr	0.5 (0.2)^{a}	6.1 (3.2)	0.0082	0.0315		0.23×10^{-3} (0.18×10^{-3})	0.0082	0.0315	
Porcelain AAA	0.6 (0.2)^{a}	93.6 (29.2)^{b}				0.05 (0.03)^{b}			
enamel	0.5 (0.1)^{a}	107.4 (79.2)^{ab}				0.08 (0.08)^{ab}			

Identical letters in each column indicate values that are not statistically different ($p>0.05$).

[*] P values of different pairs determined by non parametric (Steel-Dwass) comparison ($P<0.05$).

[**] Approximate values calculated from height loss of stylus.

Table 3

Loss of enamel antagonist after wear test.

	Height loss (μm)			Volume loss (mm^3)		
Stylus head	Mean (SD)	P value*		Mean (SD)	P value	
GN-Ceram	196.9 (46.4)^{a}			0.42 (0.09)^{a}		
			0.0117			0.0083
e.max Press	133.9 (35.7)^{ab}			0.33 (0.12)^{a}		
					0.0119	
Aadva Zr	104.6 (24.3)^{b}			0.07 (0.03)		
		0.0117			0.0083	
Porcelain AAA	186.0 (40.7)^{a}			0.62 (0.27)^{a}		
			0.0166			0.0083
enamel	184.3 (42.4)^{a}			0.40 (0.16)^{a}		

Identical letters in each column indicate values that are not statistically different (*p*>0.05).

*P values of different pairs determined by non parametric (Steel-Dwass) comparison (P<0.05).

Fig. 1

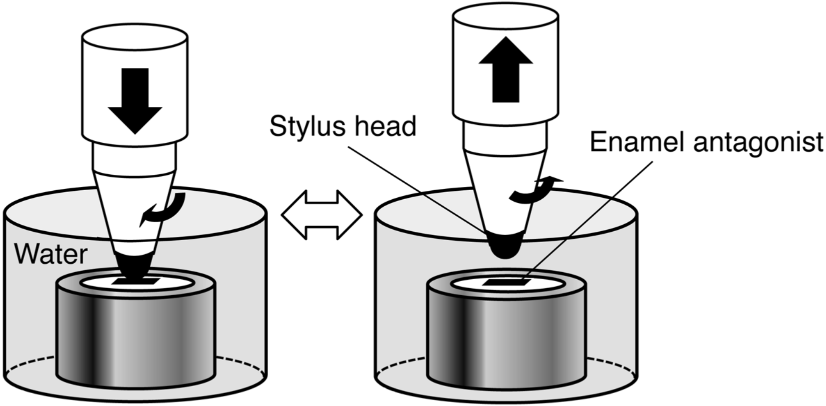
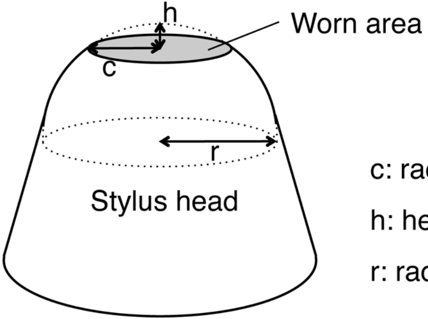


Fig. 2



c: radius of worn surface

h: height loss of stylus head

r: radius of stylus head

Fig. 3

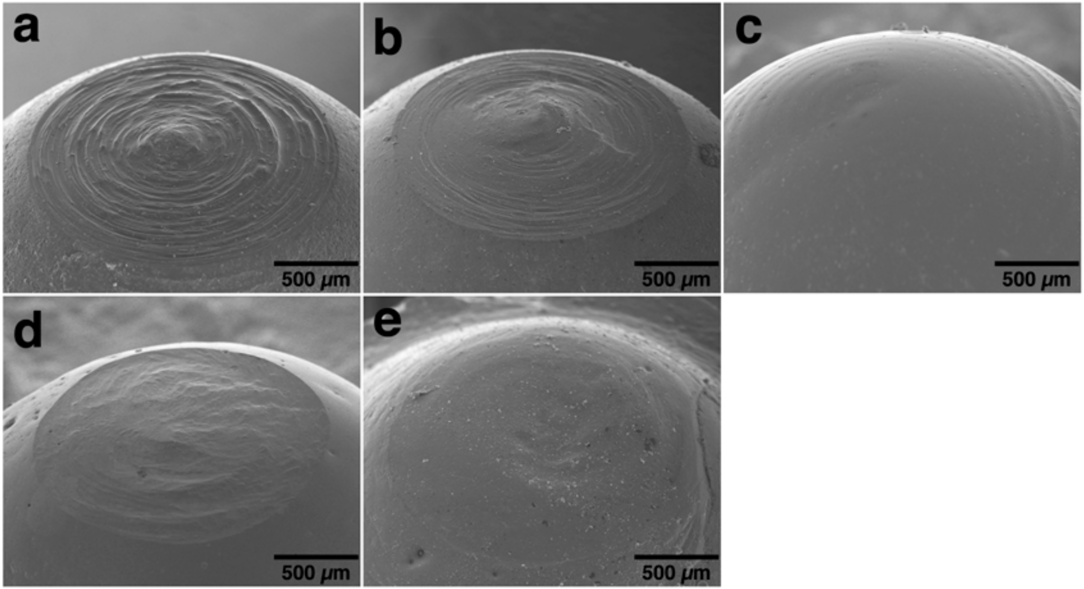


Fig. 4