Tufts University School of Dental Medicine

Department of Advanced and Graduate Education

Title: The Effect of Different Dental Ceramic Systems on The Wear of Human Enamel: an in vitro Study

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Thesis submitted by

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Abstract

Purpose: The purpose of this study was evaluating the wear effect of advanced ceramic systems on the opposing tooth enamel.

Materials and Methods: Four ceramic systems (e.max Press, e.max CAD, Super Porcelain EX-3, LAVA Plus Zirconia) and one control group, containing natural enamel specimens, were evaluated in this study (n=12). Procedure was run in the form of two-body contact of bi-directional back-and-forth sliding movements in which a stylus runs against a flat surface with no lifting of stylus. Specimens were fabricated into the form of 11 mm diameter and 3 mm thickness disks according to the respective manufacturer's instructions. Enamel disks were cut off the lingual surfaces of lower molar teeth. For enamel styluses, mesio-plalatal cusps of upper molar teeth, along with their roots, were cut and then embedded individually in 25 mm^3 acrylic resin holders. A specifically designed cyclic loading machine was used for wear simulation. All enamel cusps were scanned three dimensionally using the SmartOptics Activity 880 Digital Scanner. Data of base line and follow/up scans were compared using the 3D digital inspection software Qualify (Geomagic) which aligned the models and detected the resultant geometrical changes that illustrate the wear results opposing each specimen. Data were analyzed using One Way Analysis of Variance and the software SPSS Statistics version 19.0 (SPSS).

Results: After 125,000 bi-directional loading cycles, control group showed the minimal mean of opposing enamel volume loss (37.08 μm^3), followed by the e.max Press system (39.75 μm^3), the e.max CAD (40.58 μm^3), the Noritake Porcelain system (45.08 μm^3), and the Lava Plus Zirconia system (48.66 μm^3). This study showed no significant difference in the amount of opposing enamel wear between the evaluated ceramic materials and the control enamel group (*p-value* 0.225).

Conclusion: Within the limitations of this study, there was no significant difference in the volume reduction of natural enamel cusps abraded against natural enamel surfaces and those abraded against evaluated ceramic materials. Furthermore, additional clinical and laboratory studies are needed in order to evaluate different ceramic systems, compare similar materials fabricated by different techniques, and also to standardize wear test parameters for better clinical correlation.

Index Words: Dental Ceramic, Opposing Enamel, Antagonist Enamel, Wear.

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Introduction: Material selection for restoring tooth structure is a case sensitive issue, it depends in some degree on specific circumstances leading sometimes to a complex clinical decision. It also depends on understanding the constraints of the mechanical, thermal, and chemical properties of the available materials and their color characteristics as well.[1]

Some published articles in the last two decades have shown that the use of tooth colored materials that satisfy patients' demands for highly esthetic and naturally appearing restorations has become more popular recently.[2-4] Authors referred that to the advantages of excellent performance, newly available fabrication techniques, and to the lack of corresponding amounts of scientific information on non-metallic restorative materials when compared to the questionable biocompatibility and inferior physical properties of alternative metals and certain alloys.[5]However, and in order to maintain a stable and harmonic vertical dimension of occlusion, the wear behavior between the restorative material and tooth enamel should always be related to the stomatognathic system in which the restoration will function.[6] Ideally, loads placed on the occlusal surfaces of teeth should be kept at a level commensurate with normal physiologic wear and aging, and occlusal contacts should not create excessive amounts of wear or abrasion by rubbing teeth against one another.[6]

Dental Ceramics

In accordance with some publications; the classification of ceramic restorations and materials can be obtained from understanding their microstructural composition and the method of their fabrication.[7,8] Kelly et al have considered all dental ceramics within the spectrum of (i) predominantly glassy; (ii) particle filled glasses; and (iii) polycrystalline ones as all being "Composites", meaning a composition of two or more distinct substances.[9]

Understanding these two concepts may allow dental clinicians and laboratory technicians to utilize a specific guideline when making treatment plans. Thus; to achieve highly esthetic requirements, a predominantly glassy choice is considered, where moderate strength increases can be obtained by an appropriate addition and uniform dispersion of filler particles throughout the glass.[10] On the other hand; polycrystalline ceramics provide the restoration with the highest strength substructure,[11] although they tend to be relatively opaque.

Despite all inherent shortcomings of dental ceramics, modern ceramics are available as a result of their highly esthetic appearance, chromatic stability, biocompatibility, low plaque retention and fluids absorption, high hardness, wear resistance, low thermal conductivity, chemical inertness, and recent development of stronger ceramic materials.[12] Such properties have led to a wider use of all ceramic restorations compared to other alternative options even in the posterior region of the mouth.[13] The search for all ceramic restorations of high strength, enhanced marginal integrity, and improved color quality has resulted in the introduction of pressable glass ceramics and computer aided design/computer aided manufacturing (CAD/CAM) ceramics.[14] On the contrary, one of the primary challenges for using dental ceramics is their noticeable abrasive action when they are used on occlusal surfaces opposing natural enamel.[15] When compared to the mean annual occlusal wear of human tooth enamel (15-38 micron), dental ceramics are considered wear-resistant, they tend to cause damage to the opposing enamel and this damage varies according to the ceramic material used.[15] However, a significant difference in the amount of opposing enamel wear has been found between these types of restorations and the laboratory processed composite.[16]Yet there was a significant difference in opposing enamel wear between all ceramic restorations and the metal ceramic ones.[17]Such differences in affecting antagonist tooth enamel could be obvious as well even with some variations in ceramic composition and microstructure, and differences in fusing temperatures did not necessarily guarantee low enamel wear.[18]

Leucite reinforced ceramics

Since early 1700s, One major discovery in porcelains was the formation of a certain kind of glass ceramic containing a new crystalline component known as leucite (17 - 25 mass %).[19]

Leucite was known for its ability to increase the coefficient of thermal expansion of porcelains to a degree that matches that of any dental alloy.[20] Leucite with higher quantity (35–50 mass %) and more homogenous distribution was then considered a strengthening filler for restorations.[21] With its index of refraction close to that of feldspathic glass, and the ability to be easily etched, leucite was such a good choice of filler. It facilitated the creation of micromechanical retentive features, for resin bonding, and it also strengthened dental restorations leaving no potential for severely increasing their opacity. These key developments in the properties of dental porcelains along with patients' demands for highly esthetic restorations have led to a wider use of porcelains in restorative dentistry in the form of veneers and veneering materials for both metal and ceramic cores.[22] However, porcelain based restorations have some disadvantages, mainly brittleness and the wear they cause on opposing dental hard tissues including teeth.[23-25]It is possible to think that the development of low fusing porcelain restorations with a low amount of crystalline fillers and glassier matrixes could improve their abrasive actions on opposing structures. It is also possible to expect that glazing and polishing of restorations could affect the antagonist surfaces differently. However, the review of previous laboratory data shows contradictory results, depending on the wear simulation test and the results quantification instruments.[26-29]

Lithium di-silicate ceramics

In two different reports, crowns made of these glass ceramics showed survival rates of 95%[30] and 100%[31] after five years in service. In a previous randomized control clinical trial, lithium di-silicate crowns were followed for three years. The occlusal surfaces of crowns, opposing teeth, and their contralateral teeth were laser scanned and compared to their correspondent base line one-week images.[32]The mean volume wear was calculated at each of the four sites. Results' analyses showed that crowns made of the full contour lithium di-silicate ceramics were not only wear resistant but also wear friendly to the natural antagonist teeth. Conversely, glazing of heat pressed crowns before insertion, in another clinical trial, has resulted in a significantly lower material volume loss when compared to the mean volume loss of enamel after one year of clinical performance.[33] However, testing whether the composition and processing of lithium di-silicate dental ceramics may or may not influence their biological properties revealed that these materials are not biologically inert, and that many of the machined and pressed systems have similar cytotoxicity and suppression of cellular mitochondrial activity regardless of small differences in composition or processing.[34]

Zirconia based ceramics

Zirconia has been introduced recently as a restorative dental material that can be fabricated by CAD/CAM systems. There are various types of zirconia-containing ceramic systems but only three of which are used in dentistry. These are zirconia-toughened alumina (ZTA), magnesia partially stabilized zirconia (Mg-PSZ) and yttrium tetragonal zirconia (3Y-TZP).[35]

The advantages of zirconia-based restorations; including high toughness, excellent mechanical properties, and long-lasting esthetics have generated considerable interest in using zirconia for posterior crowns and fixed partial dentures.[36] However, high strength might appear as a beneficial property for a restoration but long-term performance and reliability should also be considered.

Yttrium tetragonal zirconia

It is available in dentistry for the fabrication of crowns and fixed partial dentures. The restorations are processed either by the more popular soft machining of pre-sintered blanks followed by sintering at the range of (1350-1550 ◦C), or by the hard machining of fully sintered blocks.[35] Examples of the soft machining processed systems in dentistry are Cercon (Dentsply, York, PA), Lava (3M ESPE, St. Paul, MN), Procera zirconia (Nobel Biocare AB, Göteborg, Sweden), YZ cubes for Cerec InLab (Vident, Brea, CA), and IPS e.max ZirCAD (Ivoclar Vivadent Inc. Schaan, Liechtenstein), whereas two examples are available for hard machining of zirconia dental restorations including Denzir (Cadesthetics AB, Skellefte, Sweden) and DC-Zirkon (DCS Dental AG, Allschwil, Switzerland).[35]

Glass-infiltrated zirconia-toughened alumina

It is obtained by promoting a fine and uniform dispersion of stabilized zirconia grains in an alumina matrix, for example; In-Ceram Zirconia (Vident, Brea, CA).[37]

Partially stabilized zirconia (Mg-PSZ)

This material has not been successfully used for biomedical applications mainly due to the presence of porosity, associated with a large grain size (30-60 micron) that can induce wear.[38] Despite potential complications of using zirconia-based systems in dentistry; like opacity and veneer chipping and cracking issues, [39] they have been considered good choices for fabricating single-unite posterior restorations. Furthermore, they are the only all ceramic system that is indicated for multi-unit fixed prostheses.[36]

When monolithic translucent and shaded experimental zirconia samples were examined, they yielded superior wear behavior, and lower antagonistic wear compared to monolithic lithium di-silicate and veneering porcelain samples.[40,41] Regarding surface treatments, polished monolithic zirconia showed significantly lower wear rate on enamel antagonists than that produced by glazed monolithic samples.[42]More interestingly, polished zirconia that were glazed using a glaze spray showed less enamel wear than air-abraded zirconia that was glazed using a layering technique with glaze ceramic.[42]

Aiming at getting an evidence-based validation of dental ceramics, which have been considered lately among the most promising restorative options, large numbers of studies and scientific data have been conducted recently to investigate factors limiting the acceptable restoration longevity, mainly the mechanical properties.[26-42]

Wear measuring studies

Clinical wear measurements in general are complicated, expensive, and time-consuming. In addition, such studies may result with relatively high standard deviations due to the biological spread between the studied individuals.[32] This explains the complexity of the wear process and its dependence on both intrinsic and extrinsic factors; like enamel thickness and hardness, masticatory function, tooth form and type, time of teeth eruption, teeth position in relation to the arch, and finally; the type and PH of the eaten food.[43] Laboratory studies on the contact relationship between restorative materials and the opposing enamel may be helpful for accurately predicting the clinical performance intra-orally. They may also assist researchers for standardizing the wear test parameters so a better correlation with clinical circumstances can be achieved. However, to date, not much in-vitro or in-vivo studies are available on the comparison of opposing enamel wear between the currently used all ceramic restorations.

Wear simulation

Any laboratory investigation considering the wear of dental hard tissues including teeth and restorations needs to consider the oral conditions in which they perform, so that in-vitro wear results can be correlated, to some degree, with in-vivo findings. There are different wear devices that use different force application methods (Ivoclar "Willytech", Zurich, OHSU, Munich, ACTA, Minnesota, and Alabama), but only some of them are specified by the ISO Technical Specification on two-body and three-body wear testing.[44] Following the FDA guidelines on good laboratory practice, most of the mentioned simulators are not designed to be used effectively for the wear simulation process.[45] A round robin test evaluating the wear of nine dental materials with six wear simulation methods showed non-comparable results. Relative ranks of the materials varied tremendously between test simulators as all methods follow different wear testing concepts.[46]

Force application

Studies on human beings who chewed on different food items revealed that the vertical force impulses evoked in the molar region are of 20–30 Ns, and that the horizontal chewing forces are measured to be approximately 35% of the vertical ones.[47,48] The sliding movement has been shown to be 0.8 mm with a sliding speed of 40 mm/s and a complete chewing cycle frequency of 1.6 Hz.[49]

A two-body wear contact of bi-directional back-and-forth sliding movements in which a stylus runs against a flat surface, with no lifting of stylus, has been shown to build up more homogenous forces, and avoid the uncontrolled force impulses seen in configurations that involve lifting of the specimens.[50] It has also shown a reduction in the importance of the material brittleness and represented the fatigue property which results generally in more wear than that seen in unidirectional sliding movements.[51]

Tooth Stylus

In a previous comparative study, tooth cusps, standardized tooth cusps, and Steatite styluses (Steatite: synthetic material mainly composed of Magnesium Silicate) were tested using two different data recordings; ground sectioning and profilometric plotting, in order to highlight the most preferable antagonist for the in-vitro simulation of wear in occlusal contact areas.[52]This study showed that standardization of cusp shape and size was correspondent to an average natural enamel cusp. The natural mesio-palatal cusps of non-erupted upper wisdom teeth were rotationally symmetrical in the form of conical shape that is 0.6 mm diameter at a height of 600 micron from its apex. It showed also that the resultant wear of the standardized cusps was at least twice the substance loss in the natural enamel cusps. Explanation was suggested to be from the loss of 20–100 micron thick aprismatic enamel surface during the process of standardization.[52]

Ceramic configuration

Ceramic restorations in general are wear resistant. In practice, most restoration failures occur because of recurrent caries, fracture, debonding, discoloration or marginal deterioration.[53-55] In laboratory wear tests however, there is no difference in antagonist wear between flat and crown ceramic specimens, [56] but surfaces of such specimens must remain smoothly glazed or highly polished to minimize the potential damage to opposing teeth and restorations.[57, 58]

Control specimens

Although Steatite balls can be successfully used as the control antagonistic specimens, natural enamel surfaces, obtained from extracted human teeth, are preferably used for simulating wear in the occlusal contact areas.[59]

Storage media

Extracted human teeth should be cleaned manually from any tissue debris and then kept in closed containers filled with 10% Formalin solutions at 25 C^0 for two weeks. This procedure is considered compatible with the guidelines adopted by the Centers for Disease Control and Prevention (CDC), [60] and it can effectively sterilize the extracted teeth.[61] Furthermore; it will not jeopardize the subsequent cutting characteristics of teeth.[62] In order to minimize the effect of biological variations in confounding the data, extracted teeth should be grouped based on the patient's age and gender. Such factors have been approved to be influencing variables on the process of wear of human tooth structure.[63]

Heat application

When recalling the influence of simulating intraoral temperatures on the results of composite wear tests, it was shown that the comparison between thermo-cycling (5 ^{0}C/ 55 ^{0}C) and the application of constant temperature (20 ^{0}C, 37 ^{0}C) is a material dependent issue. In some composite resins, thermo-cycling may increase the wear rates while in other materials it may decrease the wear rates and in others still, thermo-cycling has no effects on results.[64-66] No previous in vitro experiment has studied the effect of heat application or temperature changes on the wear of human enamel.

Number of cycles

Previous wear test studies have shown that maintaining test parameters like those mentioned above for 250,000 cycles can be equivalent to one year clinical wear in occlusal contact area.[67]

Wear evaluation

Although it was previously mentioned that a strong correlation exists between volume loss and vertical height loss for both the ceramic and the antagonist enamel,[56] two-body wear as an outcome is preferably evaluated by measuring the volume loss of tested materials.[68] The comparison between three different means of wear quantification systems including profilometry, 3D laser scanning and optical sensation have revealed a high level of agreement between these methods, however, the data acquisition with the 3D laser scanner was far more rapid than with the mechanical profilometer or the optical sensor.[69]

Objectives: The purpose of this in-vitro study was to evaluate the effect of different dental ceramic systems on the wear rates of opposing tooth enamel.

Clinical Significance: The consequences of wear of dental hard tissues that is caused by abrasive restorative systems may include impaired esthetic appearance, tooth hypersensitivity, and loss of vertical dimension of occlusion. The results of such study could be helpful for both clinicians and dental technicians in the certainty of material selection when crowns and fixed partial dentures are considered opposing natural teeth surfaces.

Hypothesis: Full contour Zirconia samples will produce higher opposing enamel wear when compared to other all ceramic systems and control enamel.

Materials and methods:

Four groups of all ceramic systems (used for the fabrication of crown restorations) and one control group, containing natural enamel specimens, (n=12) were evaluated in this study, Table 1. Wear test procedure was run in the form of two-body wear contact of bi-directional back-and-forth sliding movements in which a stylus (enamel cusps) runs against flat surfaces (ceramic and control enamel disks), with no lifting of stylus.

Specimens of each ceramic system were fabricated into the form of 11 mm diameter and 3 mm thickness discs according to the respective manufacturer’s instructions.

For enamel styluses, upper wisdom teeth with completely formed roots were cut mesio-distally then bucco-palataly to remove their buccal and disto-palatal cusps respectively. Cutting was done under water cooling using the Isomet 1000 Precession saw (Buehler, Lake Bluff, IL). The Mesioplalatal cusps, along with their roots, were then embedded individually in 25 mm^3 holders using the auto polymerizing resin (Caulk Orthodontic Resin, Dentsply, Milford, Del.). Teeth were randomly assigned to groups using the website (www.random.org)

A specifically designed, electro-mechanical, cyclic loading machine (TA-317C, Texture Technologies corp. Hamilton, MA) was used to allow for force application and control, Figure1.

The ceramic and control enamel discs were fixed on the lower base of the machine, Figure 2a, while the upper arm carried the antagonist enamel styluses, Figure 2b.

A plastic container (Sterilite, Townsend, MA) was fixed to the feed table of the cyclic loading machine. This container was filled with artificial saliva that covered the loaded cusps and disk specimens, the debris were cleared from the test chamber manually by a constant exchange of the liquid media after every other cycle.

Five samples were run every time under the test parameters shown in Table 2.

Group I: IPS e.max Press *(Ivoclar Vivadent Inc., Schaan, Liechtenstein)*; This is a lithium di-silicate glass-based ceramic (approx. 70%) that is provided in the form of pressable ingots with four different degrees of opacity. It is indicated for the fabrication of frameworks, veneers, or full contour restorations by processing in the dental laboratory using the lost-wax technique.

Specimens for this system were prepared by contouring the soft wax (ABF-wax; Metalor Dental, Inc.) into disk forms that are 3 mm thick and 11 mm in diameter.

An impression key of the wax pattern was made using the polyvinyl siloxane (Dentsplay/Caulk, Milford, DE) to allow for repetition, Figure 3.

All wax specimens were then attached to wax sprues (Lincoln Dental Supply Inc., Cherry Hill, NJ) at their peripheries and in the direction of subsequent flow of the ceramic materials.

Investing was then carried out with IPS Press VEST investment material (Ivoclar Vivadent Inc., Schaan, Liechtenstein) using the 200 gm IPS silicone ring (Ivoclar Vivadent Inc., Schaan, Liechtenstein). Four wax disks were invested together every time, Figure 4.

After setting of the investment material, the investment was removed from the silicone ring. Wax burnout was then carried in a Vulcan 3-130 burnout Oven (Ney, Dental Inc., Bloomfield, CT) at a temperature of 1562 ^{0}F for 50 minutes. After finishing, the whole investment body was taken to the pressing furnace using the ring tongs.

The IPS e.max ingot was placed into its place in the investment ring with its imprinted side facing upward, and the cold plunger was then inserted to press the ingot.

The completed investment ring was placed in the center of the furnace Programat EP 5000/G2 (Ivoclar Vivadent Inc., Schaan, Liechtenstein) and the recommended pressing program was started.

After finishing of the press cycle, the investment ring was removed from the furnace using the ring tongs and it was then placed in a cooling grid and lift to cool to room temperature. The investment ring was then divested using an ultra-thin, end-cutting disc No. 5173 (Dedeco International Inc., New York, NY).

The reaction layers formed on the disks during the press procedure were removed in an ultrasonic bath using IPS e.max Press Invex Liquid (Ivoclar Vivadent Inc., Schaan, Liechtenstein), Figure 5. For cutting of sprues, fine diamond disks No. 2751(Dedeco International Inc., New York, NY) in a laboratory micro-motor unit at a speed of up to 20,000 rpm (Ultimate XL, NSK Nakanishi Inc., Japan) working under light pressure were used in order to prevent overheating and chipping.

The projecting sprue attachment points were removed using the Fine-grained (grain size < 60 μm), ceramic-bonded grinding instruments (005565U0, Brasseler, Georgia).

Finishing of IPS e.max Press disks:

To assure surface smoothness and parallelism prior to wear tests, one surface of each specimen was finished with silicone carbide grinding paper (Buehler Ltd) using (Ecomet 250, Buehler, Lake Bluff, IL.). The discs were attached to stainless steel rods using double sided mounting square stickers (Scotch Magic 810, 3M Corporation, St Paul, MN) and these rods were placed up-side down on the Ecomet 2 specimen holder.

Different grits were used for finishing; starting from course 120, 240, 320 to very fine 600 grit.

Water was used as the lubricant during the finishing procedure which was run following the parameters shown in Table 3.

After finishing was completed, the disks were cleaned for one minute using a steam jet (11706, Triton SLA, Bego, Germany).

For glazing, IPS e.max Ceram Glaze Spray (Ivoclar Vivadent Inc. Schaan, Liechtenstein) was applied on every specimen and all specimens were fired in the Programat EP 5000/G2 furnace (Ivoclar Vivadent Inc., Schaan, Liechtenstein) at a temperature of 770 ^{0}F for 8 minutes.

Group II: IPS e.max CAD *(Ivoclar Vivadent Inc., Schaan, Liechtenstein)*; This is In Lab lithium disilicate (40%) that is provided in the form of CAD/CAM blocks with three levels of translucency. It is indicated for the fabrication of either frameworks or full contour restorations using optional cut-back and incisal layering.

Blocks for this system were designed and milled to rods measuring 11 mm in diameter and 17 mm in length, using an E4D processor (D4D, Richardson, Texas), Figure 6a**.** After milling, the rods were cut into disks of the desired shapes and dimensions in their crystalline intermediate block stage, using the Isomet 1000 Precision Saw (Buehler, Lake Bluff, IL), Figure 6b.

Disks for Group II were finished in the Ecomet 250 (Buehler, Lake Bluff, IL.) in a manner similar to those of Group I, sprayed with IPS e.max CAD Crystal/Glaze spray (Ivoclar Vivadent Inc. Schaan, Liechtenstein), and then crystallized and glazed simultaneously in the ceramic furnace Programat P 300/G2 (Ivoclar Vivadent Inc., Schaan, Liechtenstein) at 840-850°C (1544 - 1562°F) for 25 minutes.

Group III: Super Porcelain EX-3 (*Noritake Dental Supply CO Ltd., Nagoya, Japan);* This is a synthetic leucite reinforced feldspathic porcelain material that is supplied in the form of powder.

Disks, for this system, were prepared by backing the porcelain mix (EX-3 Noritake Powder and Noritake Meister Liquid Kizai Co., Ltd., Nagoia, Japan) into a specially designed stainless steel mold, after the use of a separating medium. After the mix dried out and initial setting was achieved, disks were carefully removed from the mold and fired up to 930°C (1706 °F) in the furnace (Programat P300/G2, Ivoclar Vivadent Inc., Schaan, Liechtenstein).

After cooling to room temperature, a second mix was applied around the already set porcelain disk in the mold, Figure 7, and re-firing of the whole specimen was carried out in the same furnace to a temperature of 880 °C (1616 °F).

The disks were then finished, to assure the surface smoothness, using the same procedure used with Groups I and II, and self-glazing was obtained by heating them up to 920 0C (1688 °F) in the same furnace.

Group IV: LAVA Plus Zirconia (*3M ESPE, St. Paul, MN);* This is a 3% mol partially yttria-stabilized CAD/CAM Zirconia system that is used for the fabrication of cores and frameworks for crowns and fixed partial dentures that are subsequently finished with veneering ceramics. However, this system has been recently recommended for the fabrication of full contour restorations.[70] Disks, for this system, were provided by the manufacturer in the desired shape, size and surface finish.

Adjustment of all ceramic disks

All ceramic disks were adjusted in a way that simulates to a specific degree what happens in clinical situations. Disks were held in a metal block with double-sided mounting square stickers (Scotch Magic 810, 3M Corporation, St Paul, MN) which were placed in a mini-lathe (Unimat 3; Emco, Atlanta, Ga). A high-speed handpiece with a fine diamond bur, 6 mm in length (4380U0,Brasseler, Georgia), was held parallel to the disk surfaces and mounted to the lathe feed table. A single stroke in a single direction was applied to the glazed surfaces of disks under the cooling effect of water. The lathe feed table was then turned 360^0 for the adjustment of the other halves of disks, Figure 8. A new bur was used for each set of six disks.

For re-polishing, a slow-speed handpiece with a lithium di-Silicate polishing bur, 7.5 mm in length (W17DM, Brasseler, Georgia), was held parallel to the disk surfaces and mounted to the lathe feed table. Four strokes in a single direction were applied to re-polish adjusted disk surfaces and a new bur was used each time, Figure 9.

Group V: Enamel disks

Extracted human wisdom teeth were collected from the Department of Oral and Maxillofacial Surgery at Tufts School of Dental Medicine.

The collected teeth had no caries, no fillings, and no visible damage caused by the extraction procedure. Only one extracted tooth per patient was selected.

After extraction, teeth were cleaned manually of any tissue debris and then kept in closed containers filled with 10% Formalin solution at 25 C^0 for two weeks, after which the teeth were kept in distilled water.

Enamel disks with almost equal dimensions to those of ceramic systems were prepared using a slow speed handpiece and (Ø 6.0 mm) Trephine burs No. 04-9485-01(ACE Surgical Supply, Inc. Brockton, MA) to cut the lingual surfaces of lower molar teeth.

The outmost surfaces of these enamel disks were then ground with 2500 grade wet/dry silicon carbide paper (Buehler Ltd) and polished (with 6 micron followed by 1 micron diamond suspension) to obtain the flat enamel specimens.

Mounting of study disks

All ceramic and enamel disks were mounted on acrylic resin blocks (Caulk Orthodontic Resin, Dentsply, Milford. MA) using a specifically designed silicone mold (Coltene-Whaledent. Inc.,Alstätten, Switzerland). Using this mold ensured the precise horizontal alignment of the external surfaces of disks, leaving the top 2 mm of each disk uncovered with resin. The mix was then left to polymerize.

Wear quantification

After completion of the wear generating procedure, opposing enamel wear for each tested specimen was determined as the volume loss of its antagonist cusp.

All enamel cusps were scanned three dimensionally using the SmartOptics Activity 880 Digital Scanner (Smart Optics Sensortechnik GmbH. Bochum, Germany).

Comparing the baseline scans to the follow-up scans was done using the scanner’s matching 3D digital inspection software, Qualify (Geomagic Inc., Research Triangle Park, NC), Figure 10.

This software generated color-mapped models of each enamel cusp, and then aligned the models (best fit alignment) to detect the resultant geometrical changes that illustrate the wear results opposing each specimen, Figure 11.

Using the same software, we were able to detect the linear reduction of enamel cusps as well. This was done by aligning the profiles of cusp scans and comparing those two dimensionally, Figure 12.

A data report was then created for each experimental specimen indicating the lost enamel volume and height in microns.

Statistical Analysis

A power calculation was conducted using nQuery Advisor (Version 7.0).

Assuming an effect size of $\Delta^2 = 0.485$ (the effect size that was observed in a pilot study using 3 samples per group), a sample size of $n = 12$ per group was adequate to obtain a Type I error rate of 5% and a power greater than 99%.

Descriptive statistics (means, SD's, minima, and maxima) were calculated by group. One-way analysis of variance (ANOVA) was used to assess statistical significance. All analyses were conducted using the software package IBM SPSS Statistics version 19.0 (SPSS). P-values less than 0.05 were considered statistically significant.

Assumptions of the one-way (ANOVA) were verified to be true:

1- The data of each group resembled the normal distribution; all histograms looked like the normal curve.

2- Levene's test was used to check the assumption of equal population variances among the groups; it showed no significant evidence that the population variances are unequal (*p-value* 0.210).

Results

Descriptive statistics are shown in Table 4 and 5, and the data are presented as side-by-side box-plots in figure 13.

Enamel disks of the control group showed the minimal mean of opposing enamel volume loss (37.08 μm^3), followed by the e.max Press system (39.75 μm^3), the e.max CAD (40.58 μm^3), the Noritake Porcelain system (45.08 μm^3), and the Lava Plus Zirconia system (48.66 μm^3).

In terms of opposing enamel height loss, Lava Plus Zirconia system showed the minimal mean (27.5 μm), followed by the e.max CAD system (27.91 μm), control enamel (29.08 μm), the e.max Press system (33.25 μm), and the Noritake Porcelain system (34.75 μm).

ANOVA showed no significant difference between the groups neither in opposing enamel volume loss (*p-value* 0.225) nor in opposing enamel height loss (*p-value* 0.149).

Discussion

Although data from randomized control clinical trials with a validated method for wear quantification are rare, studies in-vivo have shown that ceramic materials in general are wear-resistant.[23, 24] On the other hand, these materials may cause damage to the opposing enamel and this damage varies according to the ceramic material used.[26-29] However, clinical wear measurements in general are complicated, expensive, and time-consuming. In addition, such studies can result in relatively high standard deviations due to the biological spread between the studied individuals in terms of dietary habits, dysfunctional occlusion, biting force and bruxism.[32]

The results of previous in-vitro studies, in which a specific material and the antagonist wear of the human enamel were examined, have been inconsistent, mainly due to the fact that the test parameters differed widely. [26-42]Most studies used flat polished ceramics and prepared enamel specimens from extracted molars as their antagonists. The test chambers were filled with water and some sort of sliding movement was integrated in the wear generating processes. However, there were huge variations in relation to used force actuators, applied forces, numbers of cycles, frequencies of cycles per test, and numbers of used specimens.[46] Therefore, laboratory data cannot directly be verified with clinical data, thus a lack of external validity, calling the whole in vitro approach into question.

As far as correlation with clinical studies is concerned, the in-vitro set-up that consisted of glazed ceramic crowns against unprepared enamel of molar cusps seemed to be the most appropriate method to evaluate ceramic materials with regard to antagonist enamel wear.[56]

The findings of the current study showed no significant difference between the evaluated materials. They also showed no significant difference between the evaluated ceramic systems and the control enamel group, which is incompatible with some previous studies.[17,23,24,27-29] However, the following factors may explain in part some of the limitations faced in this study.

- The fact that Lava Plus Zirconia disks were not glazed before the test was run may play a role in decreasing the wear of their opposing cusps.[42] Previous studies showed that during the application of the glaze material on the ceramic surface, a rough external surface is needed to allow for perfect glazing.[56]When the antagonist cusp has worn the glazed top layer, the cusp hits the rough surface of the ceramic layer, which results in increased enamel wear.[53] However in this study, evaluated ceramic systems fabricated following the respective manufacturers' recommendations. In addition, all ceramic disks were adjusted using a high speed handpiece bur in a manner somewhat similar to what most clinicians experience when delivering an indirectly fabricated restoration. This adjustment, along with the consequent low speed polishing, could have resulted in the removal of the superficial glazing layer from the top of all ceramic disks.
- The force exerted by the cyclic loading device was not controlled during all movements of the natural enamel cusps. The force applied by each enamel cusp on its opposing disk was only measured once before the test was run.
- It has been well documented in the literature that wear increases with the increasing number of cycles.[42] However, most in-vitro wear test methods demonstrate a steep increase in wear in the initial phase, and a flattening of the curve thereafter.[56] As long as enamel wear is concerned, wear increases in an even linear pattern.[56]
- Heat application has been proven to be effective in some studies, and somewhat insignificant in others.[61-63] However, this was applicable when different composite

materials were evaluated, and further studies are required to assess that factor when all ceramic systems are considered.

- In terms of biological spread, unfortunately, this study could not make it possible to group cusps extracted from molar teeth based on the patient's age and gender. Such factors have been approved to be influencing variables on the process of wear of human tooth structure.[63]However, cusps of extracted teeth were randomly assigned to the study groups, and this randomization could have minimized that biological variation.
- Physiologic occlusal biting forces were not simulated in this study. However, sliding is an essential component of a wear testing method, as a material is stressed in terms of micro-fatigue only. This configuration has been shown to build up more homogenous forces, and avoid the uncontrolled force impulses seen in configurations that involve lifting of the stylus.[50]It has also shown a reduction in the importance of the material brittleness, and represented the fatigue property which results generally in much more wear.[51]
- Explanation for differences in 2D and 3D rankings of studied materials is due to the fact that software two dimensional comparisons take into consideration height loss at selectable points on the longitudinal cross section of the cusps, calling the whole 2-dimensional comparison approach into question.

Conclusion

Within the limitations of this study, it can be concluded that there was no significant difference in the volume reduction of natural enamel cusps abraded against natural enamel surfaces and those abraded against evaluated ceramic materials using a specifically designed, electro-mechanical, cyclic loading machine in a chamber filled with artificial saliva Furthermore, additional clinical and laboratory studies are needed in order to evaluate different ceramic systems, compare similar materials fabricated by different techniques, and also to standardize wear test parameters for better clinical correlation.

Clinical Significance:

The findings of the current study point to the recommendation that advanced ceramic systems could be appropriate choices for the fabrication of full contour restorations in the oral cavity, since they are esthetically appealing, and produce opposing enamel wear similar to that caused by natural tooth surfaces.

Acknowledgement:

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Tables

Table 1: Materials used in the study

Material	Characteristics	Composition	Manufacturer
IPS e.max CAD	In Lab lithium disilicate 40% (pressure casting procedure)	SiO_2, Li_2O, K_2O, P_2O, ZrO, ZnO Grain size 0.2-1 µm (Lithium Metasilicate)	Ivoclar Vivadent Inc., Schaan, Liechtenstein
IPS e.max Press	Pressed lithium disilicate 70 % (casting/pressing procedure)	SiO_2, Li_2O, K_2O, P_2O, ZrO, ZnO Grain size 3-6 µm (Lithium Disilicate)	Ivoclar Vivadent Inc., Schaan, Liechtenstein
Lava Plus 3M ESPE	CAD/CAM Zirconia	3% mol partially yttria-stabilized zirconia Grain size 0.5 µm	3M ESPE, St. Paul, MN, USA
Super Porcelain EX-3	Feldspathic Porcelain		Noritake Dental Supply CO Ltd., Nagoya, Japan

Table 2: Wear test parameters

Test Parameter	Value
Sliding Movement	0.8 mm
Sliding Speed	40 mm/sec
Abrasive load per specimen	13.5 N (3 lb.)
Cycle Frequency	2.5 Hz (150 cycles/min)
Number of cycles	125,000
Contact Duration	0.04 Sec
Dwell Time	0.35 Sec

Table 3: Finishing parameters

Factor	**Value**
Speed, rpm	350
Applied Force, lb.	15
Time, Minutes	2

Table 4: Descriptive statistics for volume loss (cubic microns)

Ceramic	N	Mean Volume Loss	SD	Min	Max
IPS e.max Press.	12	39.75	7.33	29	55
IPS e.max CAD	12	40.58	13.26	25	72
Noritake Porcelain.	12	45.08	16.64	23	82
Lava Plus Zirconia.	12	48.66	14.85	31	81
Control Enamel.	12	37.08	11.88	16	56
Total	60	42.23	13.38	16	82
Levene's significance	0.21				
Significance	0.225				

Table 5: Descriptive statistics for height loss (microns)

Ceramic	N	Mean Linear Loss	SD	Min	Max
IPS e.max Press.	12	33.25	8.2	18	44
IPS e.max CAD	12	27.91	6.8	18	44
Noritake Porcelain	12	34.75	13.2	21	63
Lava Plus Zirconia.	12	27.5	7.4	17	41
Control Enamel.	12	29.08	4.6	20	36
Total	60	30.50	8.8	17	63
Levene's significance	0.06				
Significance	0.149				

Figures

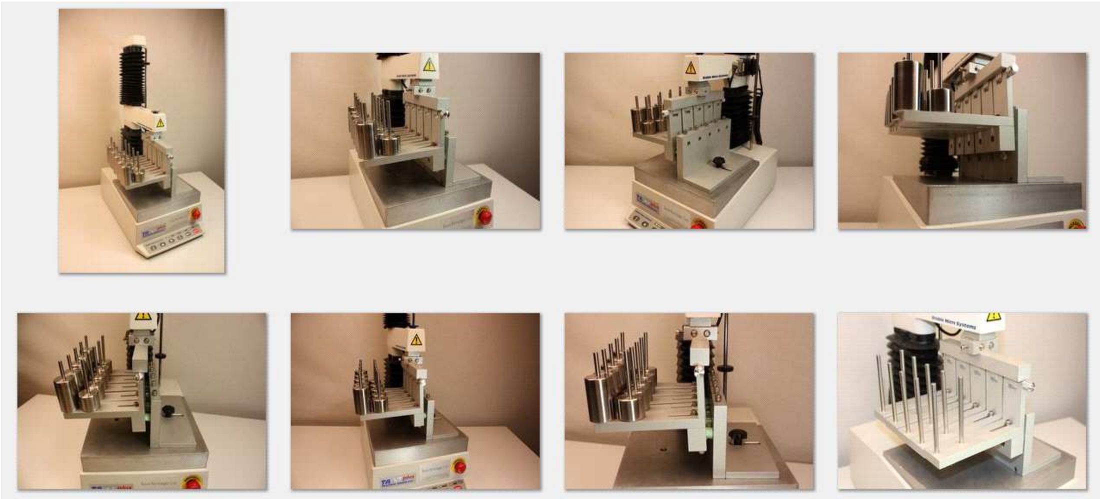

Figure 1: Wear simulator

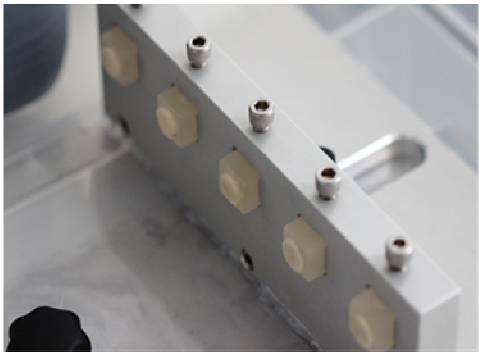

Figure 2 a: Mounted ceramic disks

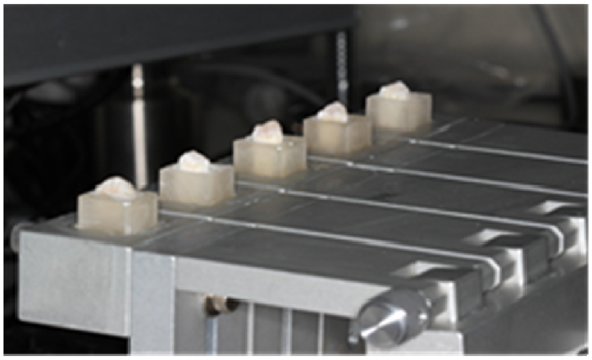

Figure 2 b: Mounted enamel styluses

Figure 3: Preparation of wax disks

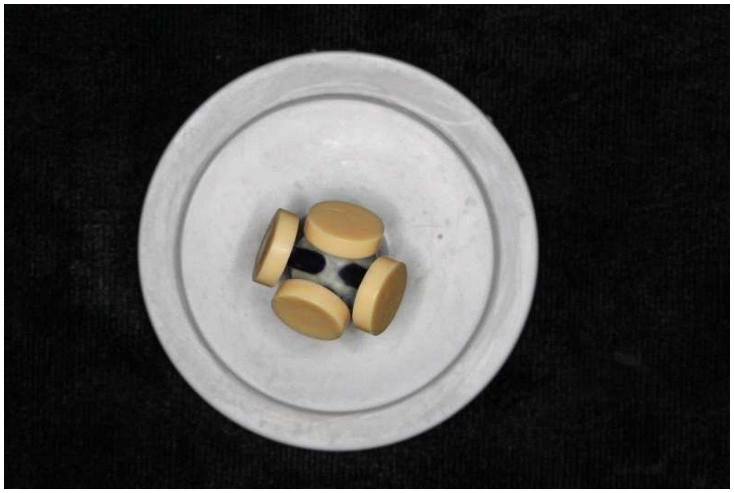

Figure 4: Wax spruing

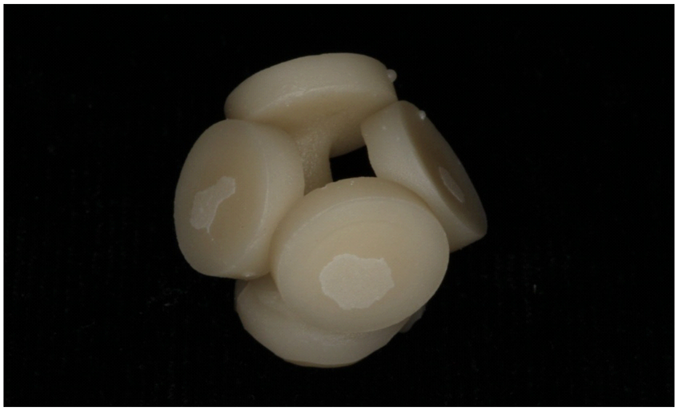

Figure 5: Reaction layer

 

Figure 6a: Milled e.max CAD rod

Figure 6b: Un-crystallized e.max CAD disks

Figure 7: Pre-fired Noritake EX-3 disk

Figure 8: Adjustment of ceramic disks

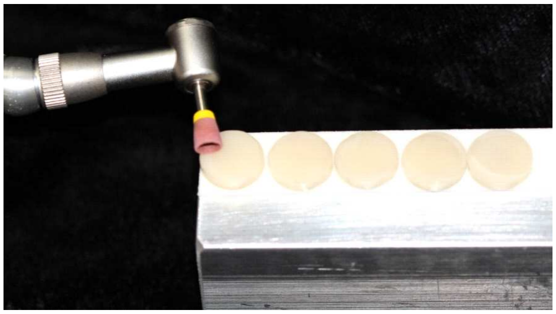

Figure 9: Re-polishing of ceramic disks

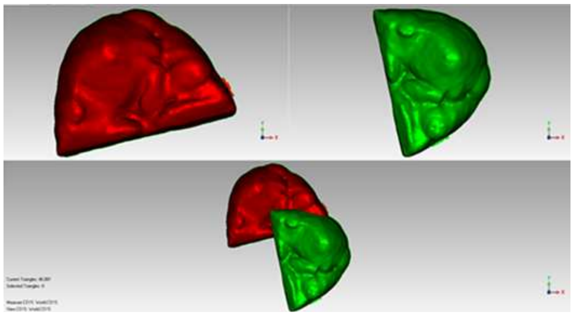

Figure 10: Alignment of cusp scans

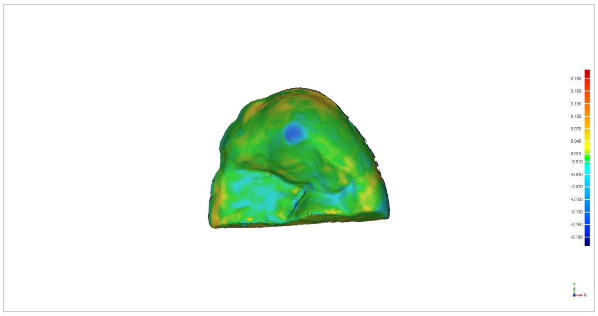

Figure 11: 3-D cusps comparison

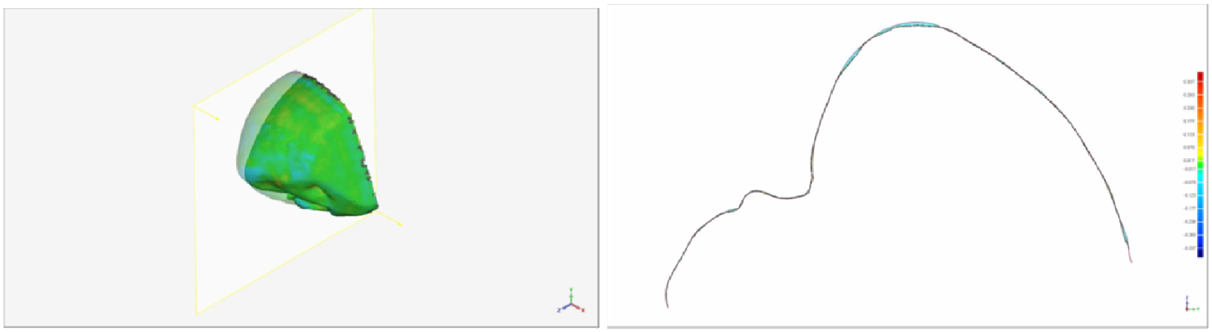

Figure 12: 2-D Cusps comparison

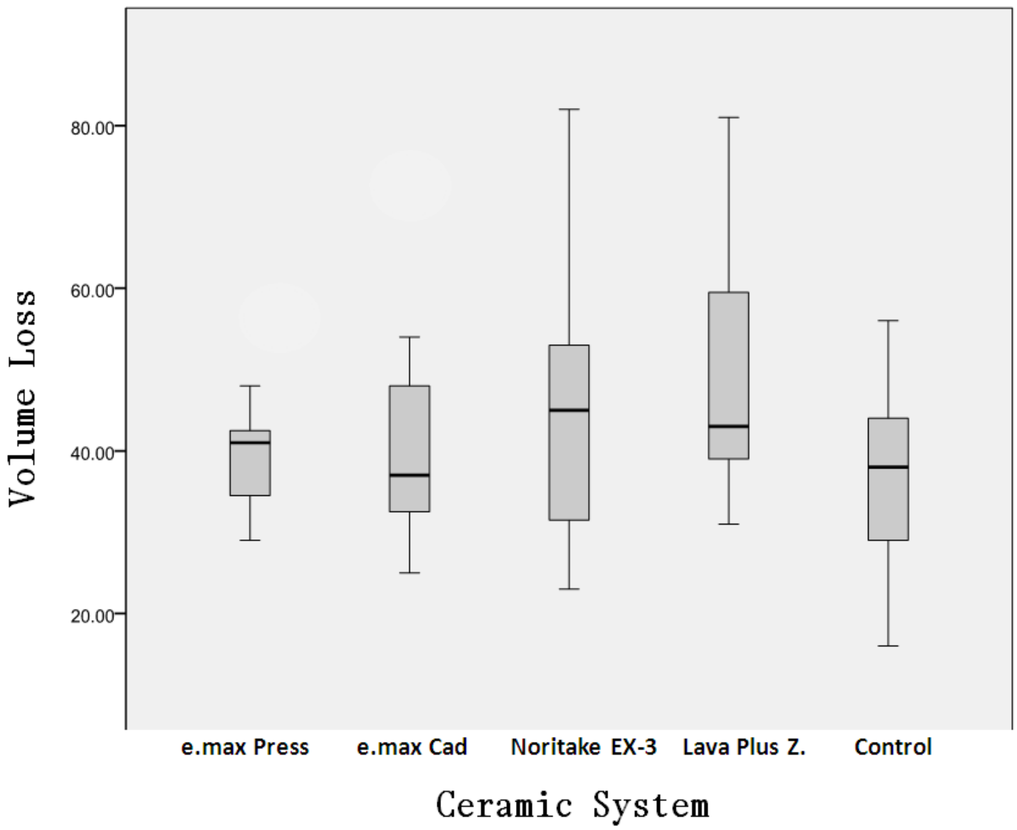

Figure 13: Box-plots of enamel volume loss opposing ceramic and enamel disks