In vitro wear of human enamel opposing YTZP zirconia

And various polished dental porcelain surfaces

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Fig. 1a

Fig. 1b

_Introduction

Porcelain fused to metal restorations are the most widely used restorations in dentistry today. However, in some clinical situations a lack of inter-occlusal space does not allow for the appropriate thickness of opaque and dentine porcelains to be applied to the metal substructure. Consequently, the opaque layer may still be visible and imparts a matt, lifeless appearance to the final restoration. The dentist should also consider the effect the restorative surface will have on opposing enamel. The hardness of a ceramic material has been viewed as a predictor of its potential to abrade human enamel, and thus manufacturers have been pushed to develop ceramics with equivalent hardness to enamel to try and solve the wear issue.[1, 2] However, the microstructural elements of a ceramic as well as fracture toughness and hardness all influence the wear characteristics of the material.[3, 4, 5] In an attempt to replicate the colour, texture, translucency and shape of the natural dentition a variety of all ceramic systems have been developed. Many of these systems have a dense core material, replacing the metal substructure, onto which dental porcelain is veneered to achieve the desired aesthetics. Zirconia has rapidly become the material of choice for use as the core of all ceramic (implant and tooth borne) restorations. The translucency and colour of these cores allow the ceramist to produce a natural looking, aesthetic restoration. Yttrium-Stabilized-Zirconia (YTZP) is one such material and several companies have recently introduced CAD/CAM based systems for milling such units. The physical properties of zirconia have been widely documented: however, the effect of these materials on the natural dentition and on other restorative materials has not been fully investigated.

In normal masticatory function if the veneering porcelain is lost due to modification of the occlusion (chairside adjustment by the dentist or attrition) the zirconia core may come into direct contact with the opposing dentition. Another situation where this might occur is when there is insufficient interarch space for the veneering porcelain resulting in occlusal stops directly on the zirconia core material. One must then consider if it is possible to place the

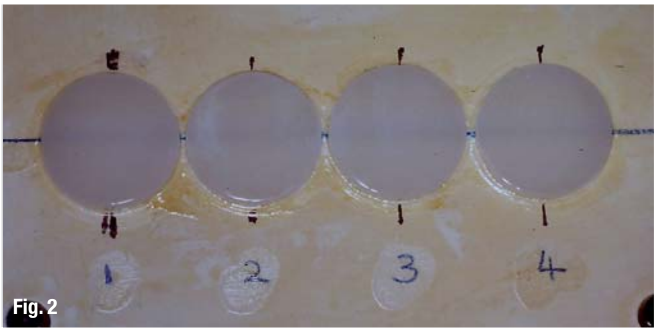

Fig. 2

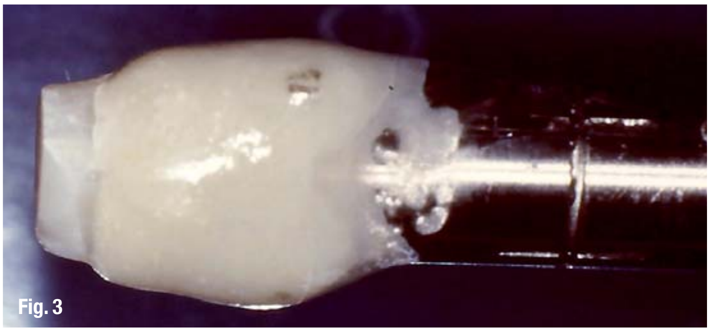

Fig. 3

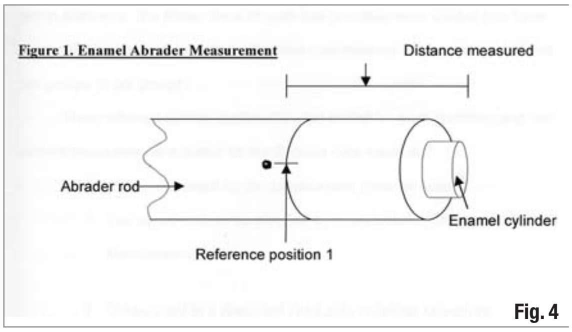

Fig. 4


Fig. 5

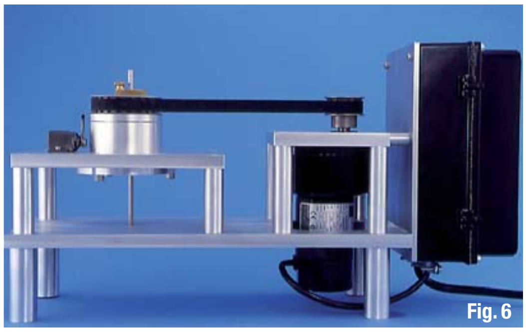
Fig. 6

forces of occlusion directly on the zirconia core material and the possible effects of direct contact with the zirconia core on the opposing dentition. In both situations two—surface (body) wear will occur resulting in loss of both enamel and restorative material. The goal of restorative dentistry is to develop a restorative surface that has the same wear characteristics as human enamel.

The specific aim of this study was to compare the *in vitro* wear characteristics of human enamel against a zirconia based core material with two surface finishes and various zirconia and aluminium oxide specific porcelains. The zirconia core material was studied in its as-manufactured state and after undergoing polishing with a proprietary polishing kit and diamond polishing paste. The dental porcelain surfaces underwent various surface treatments of which the polishing process was identical to that applied to the zirconia, allowing a direct comparison of zirconia and porcelain surfaces. A polished type IV gold surface acted as the control surface for the wear study. Laser videography (Mitutoyo / MTI corp. Aurora III™) was the method employed to assess the wear that occurred on the porcelain, gold and zirconia samples as a result of abrasion by human enamel, however, only the enamel wear data will be presented here.

_Materials and Methods

Discs of YTZP stabilised zirconia core material 13.0 mm in diameter and 2.00 mm in thickness (Figs. 1 & 2) were supplied by the manufacturer (Procera; Nobel Biocare, Kloten, Zurich, Switzerland). For the purposes of the article the term "zirconia" will equate to "YTZP stabilised zirconia core material". Discs of type IV gold of the same dimensions were fabricated by the examiner to serve as a control surface—"G" in the results tables and graphs. The zirconia samples were divided into two groups:

- _The as manufactured group—"Za" in the results tables and graphs with the surface finish as delivered from the manufacturer (Procera; Nobel Biocare, Kloten, Zurich, Switzerland).
- _The polished group—"Z" in the results tables and graphs—the test surface of the zirconia samples underwent polishing with a proprietary polishing system (Dialite ceramic polishing system, Brasseler™) and diamond polishing paste (Ultradent™).

Discs of dental porcelains 20 mm in diameter and 3–5 mm in thickness were supplied by the various manufacturers outlined below (Fig. 3). The dental porcelains underwent three separate surface treatments, specifically:

- _Application of an external glaze (powder glaze).
- _Autoglazing (self glaze procedure).
- _Mechanical polishing (same method used with the zirconia core material).

The dental porcelains evaluated in the study were:

- _CZR Cerabien—Zirconia specific porcelain (Noritake™)—"C" in results tables and graphs.

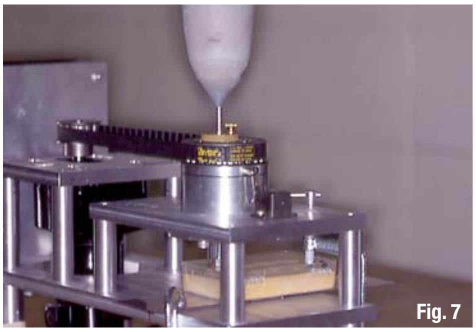
Fig. 7

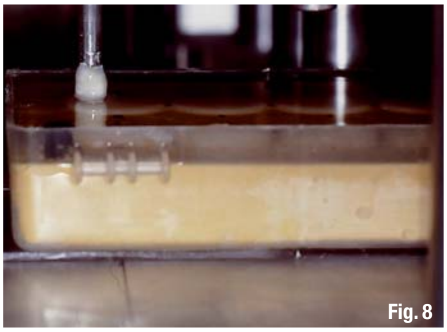
Fig. 8


Fig. 9

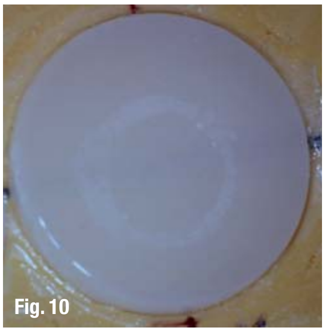
Fig. 10

_Cerabien—alumina framework specific porcelain (Noritake™)—"C" in results tables and graphs.
_Willi Geller Creation AV—for use with aluminium oxide cores, InCeram Spinell and InCeram Zirconia core material (Jensen Industries™) —"J" in results tables and graphs.
_VITA Alpha 900 – alumina specific porcelain (VITA Zahnfabrik™)—"V" in results tables and graphs.

The test porcelains in Groups 1 and 2 (CZR Cerabien and Cerabien) are both designated "C". Most porcelain systems have enamel porcelain as the final layer when fabricating a crown. However, Noritake™ has designed the CZR Cerabien and Cerabien systems to use a second distinct layer of super-fine particle sized enamel porcelain on top of the basic enamel porcelain in an attempt to improve the wear characteristics of the restoration. This layer is called the Luster porcelain. It is not an over-glaze. The rational behind the development of the Luster porcelain is that the glass particle size is more important than the hardness of the porcelain in determining the wear characteristics of the material. The Luster layer utilized in both the CZR Cerabien and Cerabien is the same material forming the final surface finish of the restoration. For this reason only one set of test samples was fabricated from the Luster porcelain. The results produced by the wear study would apply to both porcelains as the Luster layer undergoes any and all surface treatments. Therefore, the designation "C" is given to both the CZR Cerabien (zirconia specific) and Cerabien (aluminous) porcelains. The polished surface treatment was the only surface treatment that the dental porcelains and the zirconia core material experienced so only this data will be presented here. The type IV gold control sample was polished to high shine finish using gold polishing compounds and a buffing wheel attached to a polishing lathe. A proprietary polishing system (Dialite®) was used to polish the porcelain and zirconia samples. The system consists of a series of colour coded, diamond impregnated, abrasive wheels of increasing fineness, blue—course, red—intermediate, grey—extra-fine. Once the Dialite® polishing sequence was completed a final polish was carried out using 1 micron grit diamond polishing paste (Ultradent™) and a flannel cloth wheel (Brasseler™).

A motor driven wear machine was fabricated to simulate the accelerated wear of human enamel against various surfaces (Fig. 4). The wear machine consisted of a variable speed motor connected to a rotating drum by a belt driven bearing assembly through which a series of abrader rods, on to which the enamel samples were attached, could be fed. The test sample blocks were positioned beneath the rotating drum within a water bath. The water bath contained a solution consisting of 50 % Glycerine and 50 % Ethanol which was also the storage medium used to preserve the enamel samples.

The abrader rods were held in position by a holding sleeve that passed through the rotating drum parallel to the rotational axis of the drum but off centre. This resulted in the abrader rods producing a circular path of motion with an inner diameter of 7 mm and a maximum outer diameter of 12 mm. The variable speed motor allowed the wear machine to run at a frequency of 0–100 rpm. All test samples were run at a frequency of 65 rpm. A 500 g external load was applied to each enamel abrader sample by means of a weight placed on the abrader rod and all samples were run for a total of 10,000 cycles (Figs. 5 & 6). Newly extracted, caries free human third molars were used to obtain adequate enamel specimens. All teeth were stored in a solution consisting of 50 % Glycerine and 50 % Ethyl alcohol to avoid desiccation and maintain enamel integrity. A trephine bur (used to biopsy bone) was used to score the enamel surface to aid cutting samples of similar dimensions. All cutting was completed with high-speed diamond burs with copious irrigation to prevent overheating the enamel and desiccating the samples. The enamel was cut into 3 mm diameter cylinders that extended at least 5 mm into dentine and placed in the storage medium. The enamel cylinder was then attached to the reference end of an abrader rod with a small drop of cyanoacrylate resin and reinforced with polymethyl methacrylate resin (Fig. 7).

The dentine side of the enamel sample was pressed against the flat end of the abrader rod leaving the enamel exposed to wear. All enamel measurements (Fig. 8) were made using a digital travelling micrometer (Mitutoyo™) accurate to 0.001 mm as follows. At the reference end of each abrader rod a fine line was scribed around the circumference of, and 10 mm from the end of, the abrader rod. A second set of lines were then scribed parallel to the long axis of each abrader rod bisecting the initial scribe line at 90 intervals to produce four cross-hair marks. One of the cross hair marks had a further "dot-mark" placed and this was designated "reference position 1" (Fig. 8). Measurements of enamel length were made from each reference position to the edge of the enamel with the digital travelling micrometer.

The arithmetic mean of these four readings per sample was taken to be the overall sample length. By subtracting the post wear measurement from the

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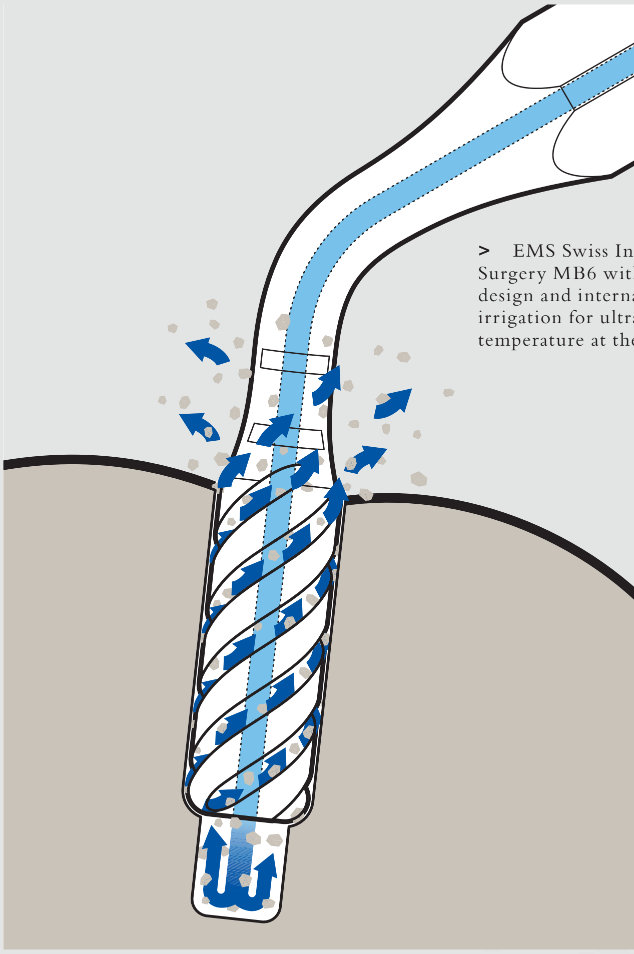

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initial baseline measurement the amount of enamel wear that occurred during the experiment (in microns) was determined. A custom jig made from an aluminium block with a locking set-screw ensured that the abrader rod (and enamel sample) could be repositioned in the same location on the table of the digital micrometer (Fig. 9) when taking measurements. This meant all enamel measurements were made with the cross-hair marks on the abrader rod in the same focal plane for both the baseline and post-wear measurements. At each measurement "reference position 1" was lined up with the locking set screw on the custom jig so all measurements were completed in the same clockwise sequence. All measurements were completed by the same observer to avoid inter-observer error and each measurement for each reference position was made five times (arithmetic mean determined) to ensure all readings were accurate.

Each enamel sample was held perpendicular to the test substrate to ensure uniform wear. Enamel samples were initially run in the wear machine against 600 micron grit silicon carbide paper in the artificial saliva medium to produce a smooth, uniform flat surface with at least 0.5 mm thickness of enamel remaining. The sample was then removed from the wear machine and baseline enamel length figures were recorded as outlined above. The test block was then placed in the water bath filled with saliva substitute and positioned on the wear machine. Enamel specimens were then passed through the rotating drum in the holding sleeve and lined up on the appropriate test sample. An unloaded test cycle (1 revolution) was carried out to ensure the enamel was abrading around the centre of the test specimen. The test block was then secured to the wear machine by means of two C-clamps. The 500 g load was applied to the abrader rod and the wear machine was activated at a speed of 65 rpm and run for exactly 10,000 cycles. The process was repeated for each test sample in each test group (Figs. 10 & 11).

The amount of wear experienced by the test surface after being abraded by human enamel was also determined. This was achieved by using a laser videography procedure that involved scanning the sample surface (pre and post enamel abrasion) to determine how much wear the test surface experienced from abrasion by human enamel. Thus the total amount of wear in microns that occurred within this two-body wear system—enamel plus substrate—was determined. This was equal to 100 % of the total wear occurring in that sample group. By converting the micron loss figures to a ratio the percentage enamel wear figures were determined. The data obtained was analyzed using a One-way ANOVA statistical analysis with a significance level of $P = 0.05$.

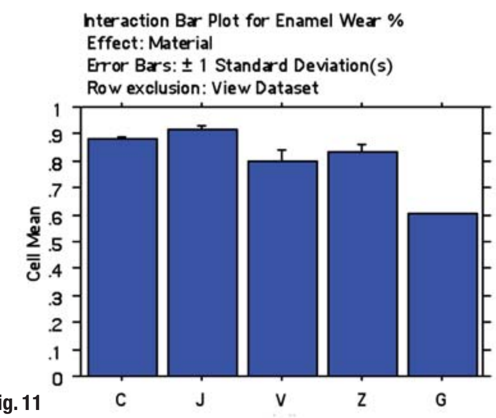

Fig. 11

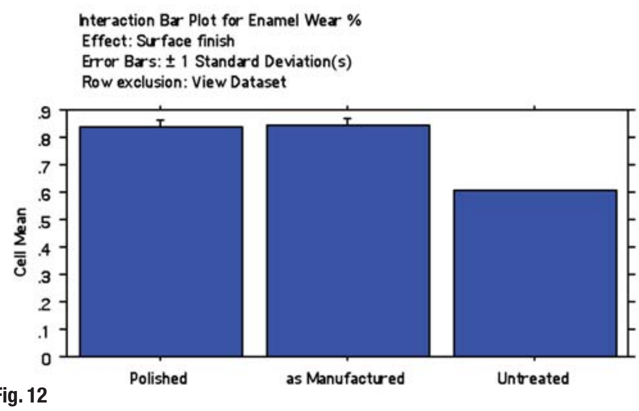

Fig. 12

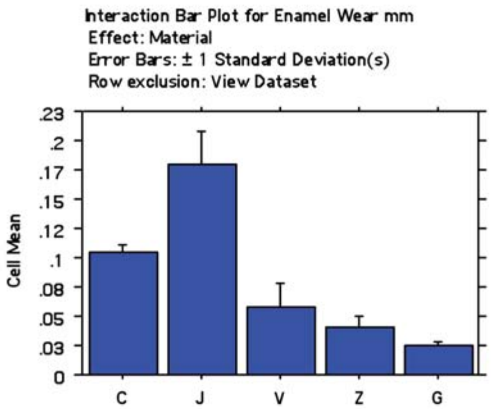

Fig. 13

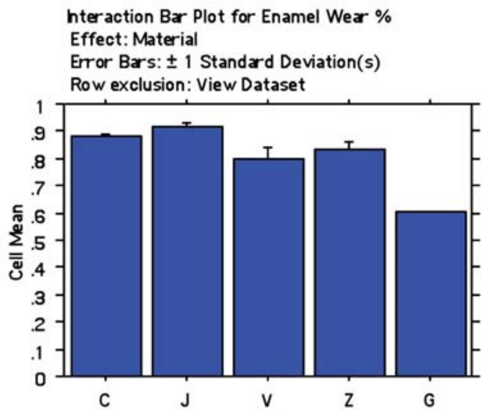

Fig. 14

Fig. 11_Enamel wear micron loss zirconia vs gold.
Fig. 12_Enamel wear percentage loss zirconia vs gold.
Fig. 13_Enamel wear wear micron loss polished surface finish.
Fig. 14_Enamel wear percentage loss polished surface finish.

_Results

Key for table headings: SS = Sum of Squares, MS = Mean Squares, SD = Standard Deviation, SE = Standard Error, MD = Mean Difference, CD = Critical Difference.

	Za	Z	G
Sample 1	0.030 mm	0.036 mm	0.023 mm
Sample 2	0.050 mm	0.055 mm	0.028 mm
Sample 3	0.051 mm	0.034 mm	0.021 mm
Sample 4	0.045 mm	0.036 mm	0.026 mm

Tab. 1

Tab. 1_ Mean values for enamel loss in microns when opposing zirconia core material as manufactured and post-polishing.

	DF	SS	MS	F-Value	P-Value	Lambda	Power
Surface finish	2	0.001	4.28E.04	6.384	0.0188	12.768	0.774
Residual	9	0.001	6.71E.05				

Tab. 2

Tab. 2_One-way ANOVA on surface finish zirconia (Za, Z) gold control (G): p = 0.05).
anova table for enamel wear mm
row exclusion: view data set.

	DF	SS	MS	F-Value	P-Value	Lambda	Power
Surface finish	2	0.049	0.025	35.151	0.0005	70.303	1.000
Residual	6	0.004	0.001				

Tab. 3

Tab. 3_ANOVA Table for enamel wear %
Row exclusion: view dataset.

	Count	Mean	SD	SE
Z	4	0.04	0.01	0.005
Za	4	0.044	0.01	0.005
G	4	0.025	0.003	0.002

Tab. 4

	Count	Mean	SD	SE
Z	4	0.834	0.028	0.014
Za	4	0.847	0.025	0.012
G	1	0.605		

Tab. 5

Tab. 4_Means table for enamel wear mm
Effect: surface finish
Row exclusion: view dataset

Tab. 5_Means table for enamel wear %
Effect: surface finish
Row exclusion: view dataset

	MD	CD	P-Value	
Z : Za	-0.004	0.013	0.5335	
Z : G	0.016	0.013	0.0236	S
Za : G	0.019	0.013	0.0083	S

Tab. 6

	MD	CD	P-Value	
Z : Za	-0.012	0.046	0.5427	
Z : G	0.229	0.073	0.0002	S
Za : G	0.241	0.073	0.0002	S

Tab. 7

Tab. 6_Fisher's PLSD for enamel wear mm
Effect: surface finish
Significance level: 5%
Row exclusion: view dataset

Tab. 7_Fisher's PLSD for enamel wear %
Effect: surface finish
Significance level: 5%
Row exclusion: view dataset

Tab. 8_One-way ANOVA on material, polished surface finish. P = 0.05 C (CZR, Cerabien), J (Willi Geller Creation AV), V (VITA Alpha 900), Z (zirconia), G (gold) ANOVA table for enamel wear mm Row exclusion: view dataset

	DF	SS	MS	F-Value	P-Value	Lambda	Power
Material	4	0.063	0.016	6.384	0.0188	12.768	0.774
Residual	15	0.004	2.760E-4				

Tab. 8

Tab. 9_ANOVA table for enamel wear % Row exclusion: view dataset

	DF	SS	MS	F-Value	P-Value	Lambda	Power
Material	4	0.094	0.024	35.727	< 0.0001	142.906	1.000
Residual	12	0.008	0.001				

Tab. 9

Tab. 10_Means table for enamel wear mm Effect: material Row exclusion: view dataset

Tab. 11_Means table for enamel wear % Effect: material Row exclusion: view dataset

	Count	Mean	SD	SE
C	4	0.105	0.006	0.003
J	4	0.180	0.028	0.014
V	4	0.057	0.021	0.011
Z	4	0.040	0.010	0.005
G	4	0.025	0.003	0.002

Tab. 10

	Count	Mean	SD	SE
C	4	0.882	0.010	0.005
J	4	0.919	0.013	0.006
V	4	0.797	0.040	0.020
Z	4	0.834	0.028	0.014
G	1	0.605		

Tab. 11

Tab. 12_Fisher's PLSD for enamel wear mm Effect: material Significance level: 5% Row exclusion: view dataset

Tab. 13_Fisher's PLSD for enamel wear % Effect: material Significance level: 5% Row exclusion: view dataset

	MD	CD	P-Value	
C, J	-0.075	0.025	< 0.0001	S
C, V	0.048	0.025	0.0010	S
C, Z	0.065	0.025	< 0.0001	S
C, G	0.081	0.025	< 0.0001	S
J, V	0.123	0.025	< 0.0001	S
J, Z	0.140	0.025	< 0.0001	S
J, G	0.155	0.025	< 0.0001	S
V, Z	0.017	0.025	0.1684	
V, G	0.033	0.025	0.0138	S
Z, G	0.016	0.025	0.1999	

Tab. 12

	MD	CD	P-Value	
C, J	-0.036	0.040	0.0686	
C, V	0.085	0.040	0.0005	S
C, Z	0.048	0.040	0.0218	S
C, G	0.277	0.063	< 0.0001	S
J, V	0.122	0.040	< 0.0001	S
J, Z	0.084	0.040	0.0006	S
J, G	0.313	0.063	< 0.0001	S
V, Z	-0.037	0.040	0.0619	
V, G	0.192	0.063	<0.0001	S
Z, G	0.229	0.063	<0.0001	S

Tab. 13

TIP:

Please have a look at Figs. 11 & 12 after the Tabs. 6 & 7 and at Figs. 13 & 14 after Tabs. 12 & 13.

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LEADING REGENERATION

_Discussion

Wear of dental hard tissues is a naturally occurring and inevitable phenomenon. However, when human enamel is opposed by ceramic (or other restorative material) the enamel experiences accelerated wear. Developing a material of equivalent hardness to human enamel was seen as the solution to the enamel wear problem.[1, 2] However, it has now been shown that microstructural differences and changes in surface topography are much more important than hardness.[3] To account for these variables the chemical make up of the veneering porcelain was (and still is being) modified to produce the conventional aluminous porcelains e.g. VITADUR ALPHA, machinable ceramics e.g. VITA Mark II and the hydrothermal porcelains e.g. Duceram-LFC. Studies on the wear characteristics of these porcelains produced varying results[13, 14, 15] with no significant reduction in abrasiveness to human enamel. The pattern of enamel wear varies according to the ceramic system used and its surface characteristics.[4, 6, 7, 8, 9, 13, 16] The amount of wear that will occur on both the restored surface and opposing enamel is an important consideration in dentistry as this will affect tooth movement and the vertical dimension of occlusion. Restorative dentistry must therefore provide restored occlusal surfaces that are wear resistant themselves and more importantly, do not promote excessive wear of the opposing occlusion.[4, 5]

The major driving force in dentistry today is aesthetics. Several all ceramic systems have been developed. Most of these systems rely on a core material onto which a porcelain veneer is applied. Some of the most studied systems are Dicor™ (a castable glass ceramic), IPS Empress (leucite core, lithium disilicate core in Empress II and E-max) and In-Ceram (aluminium oxide core). The advent of improved zirconia systems such as Procera™ and Etkon™ shows a wide availability of systems on the market today. However, all these systems rely on veneering porcelains and several studies have demonstrated that these veneering porcelains are more abrasive to human enamel than the core material itself.[4, 6, 7, 8, 9, 13, 16]

Zirconia based core materials have recently been introduced. Several companies have introduced CAD/CAM systems to produce cores for natural tooth restorations as well as abutments and bridges for implant based single and multiple unit restorations. This study examined the *in vitro* wear of human enamel against a zirconia (YTZP) core material with two surface finishes and various dental porcelains designed specifically for veneering zirconia and alumina cores to produce all ceramic restorations. A polished type IV gold surface acted as a control surface. The porcelain surface was compared to the zirconia surface to determine if the application of the veneering porcelain was beneficial or detrimental to human enamel i.e. is it less harmful to enamel to have the zirconia core exposed or veneered? Studies have shown that a polished dental porcelain surface is the least abrasive porcelain surface finish to human enamel.[10, 11, 12] The entire study did evaluate the autoglaze and powder glaze surface finishes as well but only the polished finish was the same for both zirconia and the test porcelains so it was the only data presented here.

Wear does not occur in isolation. It is not just the enamel that is abrading but also the opposing restorative surface. The ideal situation is for the enamel and the opposing restorative material to have the same physical and mechanical properties. This way the restorative: enamel interface should wear at the same rate as an enamel: enamel interface. To date, the least abrasive surface to human enamel is a highly polished type IV gold surface.[5] This is seen as the standard to which all other materials are compared. Most, if not all, studies show that dental porcelains (regardless of surface finish) and all the ceramic core materials are far more abrasive to human enamel than a polished type IV gold surface.[4, 6, 7, 9]

Zirconia has greater strength and flexibility compared to aluminium oxide, allowing thinner cores of equivalent strength to be fabricated. This allows the use of zirconia in situations where inadequate occlusal clearance exists for an aluminium oxide core. The only alternative would then be a metal-ceramic restoration with exposed metal occlusal contacts. Zirconia has now largely superseded aluminium oxide as the core material of choice for most all ceramic restorations. Initially the zirconia cores had a bluish white colour; however, shaded versions are now available to improve aesthetics.

The Power value for the one-way ANOVA data set for the polished zirconia and porcelain surfaces versus the type IV gold control is 1.00. The Power value for the one-way ANOVA data set for zirconia versus type IV gold is 0.774 for zirconia mm wear data set making the results statistically significant although the sample size is small. Considering the polished zirconia vs type IV gold results (Tab. 1) samples 1, 3 and 4 produced virtually identical levels of enamel wear (mean 0.035 mm) where as sample 2 produced significantly more wear (0.055 mm). Thus sample 2 had a significant negative impact on the data set.

The significance level for this study is $P = 0.05$. The results of this experiment show that the zirconia core material in its as-manufactured state and after a proprietary polishing procedure produces minimal wear of human enamel. When compared directly with a polished type IV gold surface, the zirconia (both surface finishes) does produce statistically significantly more enamel wear than the control. When comparing the two zirconia surface finishes to each other, the polished zirconia surface produced less enamel wear than the as-delivered surface but the difference was not statistically significant.

Several all-ceramic veneering porcelains were also evaluated in this study. The polished zirconia surface underwent the same polishing procedure as the veneering porcelains allowing a direct comparison between gold, zirconia and porcelain. This was to determine whether the application of veneering porcelain would have a positive or negative impact with regards to the abrasiveness of the restorative surface. Firstly, when the polished porcelain surfaces were compared to the type IV gold control surface all the polished porcelain surfaces were statistically significantly more abrasive to human enamel. This result corresponds with earlier studies.[8, 9, 10, 11, 12] Secondly, there was no statistically significant difference between the polished zirconia surface and the polishedtype IV gold control surface ($p > 0.05$) indicating that the polished zirconia surface was equivalent to a polished gold surface in its level of abrasiveness to human enamel.

In this study the application of veneering porcelain to the zirconia core material statistically significantly increased the abrasiveness of the zirconia surface to human enamel. The polished zirconia surface was statistically comparable to a polished gold surface in its degree of abrasiveness to human enamel indicating that it is beneficial to have polished zirconia forming the occlusal contact surfaces rather than applying a porcelain veneer.

Zirconia has far greater strength than aluminium oxide when in similar dimension. The possibility therefore exists to use zirconia as a core material in the posterior region of the mouth and in high occlusal load areas where the occlusion can be placed directly on the core material (cingulum of upper canines and occlusal surfaces of molars) if the restoration is opposing enamel. The porcelain veneer is then placed mainly for aesthetics. If the restoration is opposing another crown then the application of a porcelain veneer is optional.

The use of CAD/CAM technology allows fabrication of customized zirconia cores, abutments and bridges to restore natural teeth and dental implants with the appropriate reduction for veneering porcelain. This is known as the "dual scan" technique where the technician uses either casting wax or a composite resin to build up the proposed restoration—crown or bridge—to full contour and in occlusion with the opposing arch. The wax or resin pattern is then "cut back" leaving all the centric stops intact and supporting the opposing occlusion. This modified pattern is then scanned to produce the customised zirconia framework with all the occlusal loads being borne directly on the core material. The increased thickness of the zirconia in these areas improves both the physical and mechanical properties of the core. This does not imply that one can simply rely on the strength of restorative materials to withstand high occlusal loads and simply ignore the underlying causes, such as bruxism and parafunctional habits. Diagnosis, treatment planning and prescribing the appropriate restorative surfaces are just as important today as they have been in the past.

_Conclusions

Within the limitations of this study the following conclusions can be made:

- _The type IV gold surface produced the least amount of enamel wear.
- _The polished zirconia surface produced less enamel wear than the as-manufactured zirconia surface but the result was not statistically significant when compared directly to the type IV gold control surface.
- _The polished and as-manufactured surfaces produced statistically significantly greater enamel wear than the type IV gold control surface.
- _All the veneering porcelains produced statistically significantly more enamel wear than the type IV gold control surface.
- _When viewing all the polished surface data (zirconia, porcelains and type IV gold) the polished zirconia surface was not statistically significantly more abrasive than the type IV gold control surface $p > 0,05$). All the porcelains were significantly more abrasive than the type IV gold control surface.

Editorial note: The literature list can be requested from the author.

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