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Evaluation of wear characteristics of natural teeth opposing all-ceramic restorations: An *in vitro* study

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Abstract
The study was coducted to evaluate and compare the wear behaviour of human enamel opposing three different newly introduced pressable all ceramic restorations.
Materials and Methods: 45 freshly extracted human first premolar teeth were collected and divided into three groups of 15 each. The teeth were sectioned at CEJ and enamel specimens were mounted onto an acrylic wheel with 2 mm of buccal and lingual cusps exposed. 15 ceramic disks were prepared from each of three pressable ceramics. The enamel specimens and ceramic disks were subjected to wear under load of 100 N for 10000 cycles at 72 rpm. Enamel specimens were weighed before and after wear testing and observed under SEM for wear pattern.
Results: The mean weight loss of Group C was greater than Group B followed by Group A. Pairwise comparision showed there was highly significant difference in weight loss among the groups.
Conclusion: IPS e max press produced least wear followed by VITA PM9 and Ultra Will Ceram. IPS e max press produced least rough surface followed by VITA PM9 whereas Ultra Will Ceram produced roughest surface.

Keywords: All-ceramics, wear characteristics, enamel wear, IPS e max, vita PM9, Ultra will Ceram

1. Introduction
Tooth enamel is most highly mineralised tissue in human body, composed of 97% inorganic and 3% organic material [1]. Unlike other hard tissues, dental enamel cannot regenerate or repair apart from limited remineralisation. Different restorative dental materials such as gold, porcelain fused to metal, All-ceramic materials are being used as inlays, onlays, crowns to replace lost tooth structure. A good restorative material should be aesthetic, durable and not be abrasive to the opposing dentition [2].
Gold has been reported to be "enamel-friendly", but the colour makes it unaesthetic. Search for good aesthetic restorative material ended after the introduction of porcelain-fused to-metal (PFM) in the early sixties. Metal–ceramic restorations have represented the "gold standard" for years in prosthetic dentistry, because of their good mechanical properties and somewhat satisfactory aesthetics. In porcelain-fused-to-metal restorations metallic hue can be visible in anterior teeth [3]. In order to overcome the disadvantages of PFMs, and to achieve closer tooth colour match, All-Ceramics were developed. Pressable glass ceramics has become a popular dental restorative system due to good marginal integrity, mechanical properties and translucency [4, 5]. Leucite crystals enhance the restoration strength and produce a natural deflection and scattering of light, delivering a natural looking restoration. Previous *In vitro* studies suggest that surface wear of enamel opposing low-fusing porcelain was less than the conventional porcelains [6-9]. However, Clelland *et al.* suggested that low-fusing and conventional porcelains lead to similar enamel wear [10].
There have been numerous studies on wear rate of All-ceramic materials. But none of these studies compared wear pattern of different pressable All-ceramic materials.

2. Literature Survey
George E. Monasky, and Duane F. Taylor (1971) [11], conducted a study to evaluate the wear of porcelain, enamel and type III gold. Concluded that rougher the porcelain surface, the more rapid is the rate of tooth wear. Porcelain surface in contact with tooth surface tends to wear

rapidly when compared to polished porcelain. Gold wears rapidly when in contact with porcelain.

DeLong R, Sasik C, Pintado MR, Douglas WH (1989) [12], conducted a study on enamel wear. The wear of enamel when opposed by different ceramic systems was investigated by use of an artificial oral environment. Cerestore, Dicor, and Ceramco disks were opposed by recently extracted natural teeth. The samples were exposed to 300,000 defined masticatory cycles under physiologic conditions. The total volume loss of enamel was 50% less when opposed by Dicor, than when opposed by either the Cerestore or Ceramco porcelains.

D. C. Jagger and A. Harrison. (1995), [13] investigated the wear effects of unglazed, glazed and polished porcelain on human enamel by a wear machine. They concluded that the difference in wear of human enamel was caused by variation in the surface finish of porcelain. The rate of enamel wear produced by glazed and unglazed porcelain was similar. Polished porcelain produced substantially less enamel wear.

Per Derand and Peter Vereby (1999) [7], Conducted an *in vitro* investigation to rank a number of dental porcelains with respect to their wear-resistance properties. The wear test of 9 dental porcelains was carried out and the amount of wear was measured as the reduction of height of the specimens. Concluded that the low-fusing porcelain Finesse showed less abrasion resistance in comparison with Ducera Gold and Ti-Ceram porcelains. Among the high-fusing types, Vita Alpha porcelain was more wear-disposed than the others.

Asmaa Elmaria, Gary Goldstein, Therizhandur Vijayaraghavan, Raquel Z. Legeros, and Eugene L. Hittelman (2006) [14], evaluated enamel wear caused by 3 ceramic substrates in the glazed and polished conditions. Sixty ceramic disks 20 each of Finesse, All-Ceram, and IPS Empress-were prepared and glazed. They concluded that Gold, polished Finesse, and polished All-Ceram caused the least enamel wear, whereas IPS-Empress caused the most wear. Cast gold was significantly different than glazed IPS-Empress whereas other groups overlapped. There was significant correlation between surface roughness and enamel wear.

Josephine F. Esquivel-Upshaw, Henry Young, Jack Jones, Mark Yang and Kenneth J. Anusavice (2006) [15], Conducted an *in vivo* study on wear of enamel by a Lithia Disilicate based core ceramic used for posterior fixed partial dentures. The study aimed to test the hypothesis that no significant relationship exists between the magnitude of occlusal clenching force and wear rates of enamel opposing a new core ceramic (e.max Press, Ivoclar Vivadent) used in posterior fixed partial dentures (FPDs A total of 21 occlusal surfaces were analysed for the presence of wear. The maximum annual wear of enamel by the glazed core ceramic (e.max Press) was 88.3 μm, which is significantly greater than the annual enamel-by-enamel wear of 38 μm. They concluded that further analysis with a larger sample size is needed to determine the relationship between occlusal clenching forces and wear rate and the influence of other factors that cause increased wear of enamel by opposing ceramic restorations.

Kerem Yılmaz and Pelin Özkan (2010) [16], conducted a study to evaluate the changes in surface roughness of dental ceramics with various substances instruments and polishing methods during the course of repeated firings. Three types of dental ceramic (IPS Classic, Empress Esthetic, and Empress 2) were used to form three groups. They concluded that In terms of surface roughness, the best method available is the glaze method and the best material is IPS Classic. The mechanical polishing process generates rough surfaces. Repeated firings should be avoided as much as possible because they have a destructive effect on the glaze layer and deform the surface.

Esquivel-Upshaw JF *et al*. (2012) [17], conducted a study to test the hypothesis that there were equivalent wear rates for enamel-versus-enamel and ceramic-versus-enamel by analysing the *in vivo* wear of ceramic crowns, their natural enamel antagonists and the corresponding two contralateral teeth. They concluded that the ceramics and their antagonists exhibited *in vivo* wear rates within the range of normal enamel.

G Mitov *et al*. (2012) [18], conducted a study to evaluate the influence of different finishing procedures on the wear behaviour of zirconia against natural enamel. If zirconia is used without veneering material for crowns and fixed dental prostheses (FDPs), the surface must be well-polished if occlusal adjustments with coarse diamonds are to be performed. The polishing step reduces the wear of the opposing enamel.

JH Park *et al*. (2014) [19], conducted an *in vitro* study to evaluate the 2-body wear of antagonists for 3 computer-aided design and computer-aided manufacturing (CAD/CAM) anatomic contour zirconia ceramics and veneering porcelain when opposing natural human enamel. Zirkonzahn Y-TZP (polished zirconia, zirconia with staining, zirconia with staining and glazing), Acucera Y-TZP, Wieland Y-TZP, and Noritake feldspathic ceramic were tested (6 groups) They concluded that the antagonist wear of 3 CAD/CAM anatomic contour zirconia ceramics was significantly less than the Noritake veneering ceramic because the surface character of Y-TZP is relatively uniform and homogeneous. Zirkonzahn Y-TZP with staining and glazing was significantly more abrasive than the other zirconia specimens tested. However, it was less abrasive than the Noritake veneering ceramic.

3. Materials and Methods

Materials: Extracted human premolars (45 numbers), Lithium disilicate glass ceramic ingots-IPS e.max press (Ivoclar Vivadent, India), Feldspar ceramic ingots-VITA PM9 (VITA Zahnfabrik, Germany), Leucite reinforced feldspar porcelain ingots- Ultra Will ceram, (Newjersy, USA). Taber®Rotary Abraser 5135 (Taber industries, New York, USA)

3.1 Preparation of enamel specimens

Recently extracted intact 45 human natural first premolar teeth were collected and stored in artificial saliva. The roots of all the 45 human first premolar teeth were sectioned off along the cementum-enamel junction. The dental pulp was excavated. The cutting was performed at a high speed and under copious water irrigation to minimise the influence of generated heat, which could result in dehydration and changes in microstructure and chemistry of the teeth. Enamel specimens were stored in artificial saliva till they were mounted on to the acrylic wheels. Taber abrasive wheel was duplicated by using silicone duplicating material. By using this mold 45 autopolymerising acrylic resin wheels were prepared. Enamel specimens were embedded into acrylic wheel such that 2 mm of buccal and lingual cusps were exposed (fig. 1).

3.2 Preparation of all-ceramic disks

All-ceramic disks were fabricated using the lost-wax technique. 45 Wax patterns of 2mm in thickness and 10 mm in diameter were prepared using inlay pattern wax. After wax elimination the hot investment was transferred to the ceramic furnace. The ceramic ingots were pressed in ceramic furnace with a suitable temperature and time for each type of porcelain following the manufacturer's recommendations as presented in Table!.

Table 1: Descriptive Table of pressing temperature and time for pressable ceramics

Material	Pressing Temperature	Holding time
IPS e.max	925 ^{0}C	10 mins
VITA PM 9	930 ^{0}C	20 mins
Ultra Will Ceram	1150 ^{0}C	20 mins

All the ceramic disks were autoglazed by heating them to the maximum glazing temperature of 800 ^{0}C and holding the temperature for 1 minute in the furnace (fig 2). The ceramic disks were mounted onto the industrial plastic plates using clear autopolymerising acrylic resin fig 3).

Fig 1: Enamel sample

Fig 2: All -ceramic disks

Fig 3: Mounted ceramic disk.

3.3 Grouping of Samples: The prepared enamel specimens were randomly assigned into three groups A, B, and C of 15 each. (n=15). Each group was tested against one particular pressable All - ceramic system as shown in the table 2.

Table 2: Descriptive Table for grouping of samples

Enamel specimens (n=15)	All - ceramic system (n=15)
Group A	IPS e. max press
Group B	VITA PM9
Group C	Ultra Will Ceram

3.4 Testing Samples for Wear: Each enamel specimen was tested against one ceramic disk. After securing the enamel and ceramic samples onto the wear machine, Taber®Rotary Abraser 5135 (Taber industries, New York, USA) (fig. 4) they were abraded under a load of 100 N for 10,000 cycles[23] at 72 rpm.(fig.5) Ceramic disks were weighed in electronic weighing machine before and after wear test. Loss of weight was calculated and tabulated.

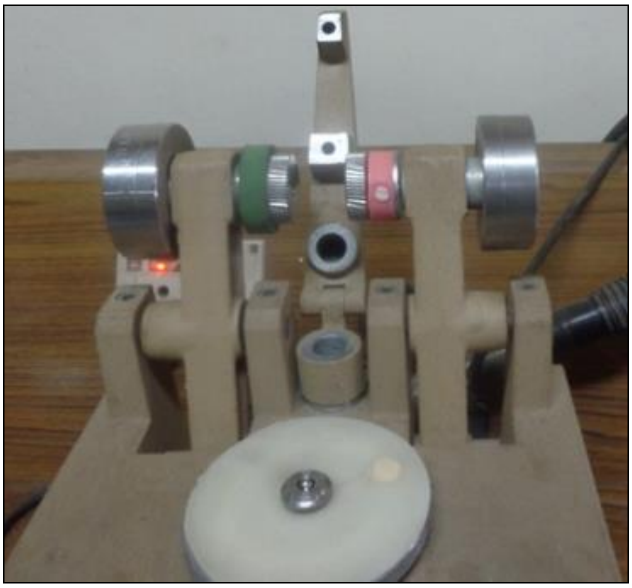

Fig 4: securing enamel and ceramic samples on wear machine

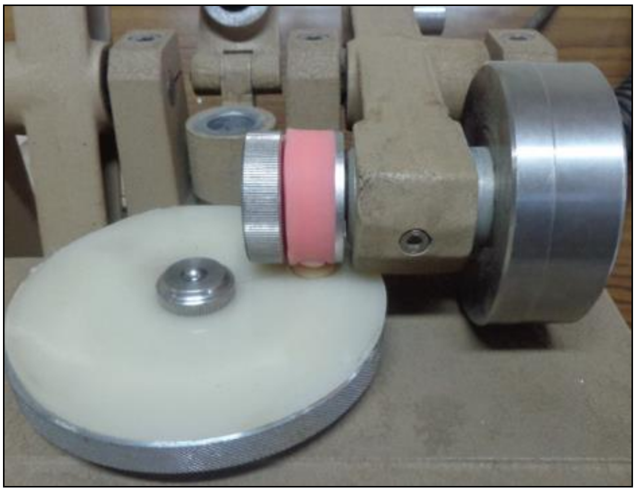

Fig 5: testing of the samples

3.5 Methods of assessment

Statistical analysis: Arithmetic mean, Standard deviation (SD) and Standard error (SE) of each group were calculated and were tabulated.

Table 3: Descriptive Table for Weight Loss

Group	N	Mean	Std. Deviation	Std. Error
Group A	15	10.4600	0.51658	0.13338
Group B	15	13.3400	0.90222	0.23295
Group C	15	14.7333	2.15661	0.55683
Total	45	12.8444	2.24990	0.33540

Among the 3 groups (A, B and C) the mean weight loss of Group C (14.7333 mg) was greater than Group B (13.3400 mg) and followed by Group A (10.4600 mg).
One way analysis of variance (ANOVA) showed a p value of 0.001, which indicate that there was a statistically high significant difference in the weight loss of enamel specimens of each group as shown in table 4

Table 4: weight loss of enamel specimens of each groups using ANOVA

	Sum of Squares	DF	Mean Square	F value	p-value
Between Groups	142.486	2	71.243	37.288	<0.001* Highly Significant
Within Groups	80.245	42	1.911		
Total	222.731	44			

(P*<0.05 = statistically significant).

On pairwise comparison between Group A and Group B weight loss was more for Group B and the difference was statistically highly significant (p<0.001). Likewise comparison between Group A and Group C weight loss was more for Group C and the difference was statistically highly significant (p<0.001). Between Group B and Group C weight loss was more for Group C and the difference was statistically significant (p=0.030). However mean difference between Group B vs Group C was less when compared to between Group A vs Group B and Group A vs Group C (p<0.05).
Pair wise comparison of all the groups were tabulated in table 5.

Table 5: Multiple Comparisons using Post-Hoc Scheffe

Comparison	Mean Difference	P value	Significance
Group A vs Group B	2.880	<0.001	Highly Significant
Group A vs Group C	4.273	<0.001	Highly Significant
Group B vs Group C	1.393	0.030	Significant

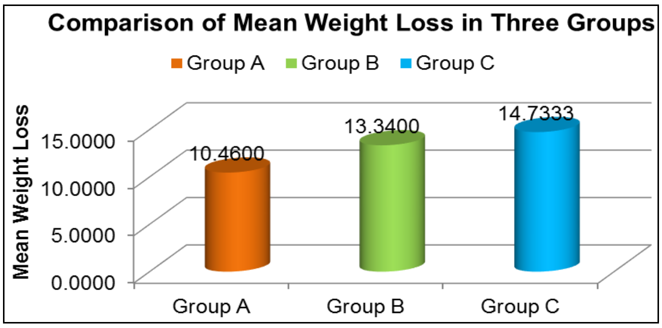

Chart 1: showing the mean weight loss in three groups

3.6 Scanning electron microscopy (SEM) observations

SEM examinations were conducted to study the surface morphology of enamel. No clear wear pattern was present on any of the specimens. But there are distinct differences in the morphology of the enamel wear scar opposing the three different restorative specimens. Enamel specimens abraded with IPS e.max press (fig. 6) showed less rough surface than VITA PM9 (fig. 7) and Ultra Will Ceram (fig 8). Enamel specimen abraded with Ultra Will Ceram showed rougher surface.

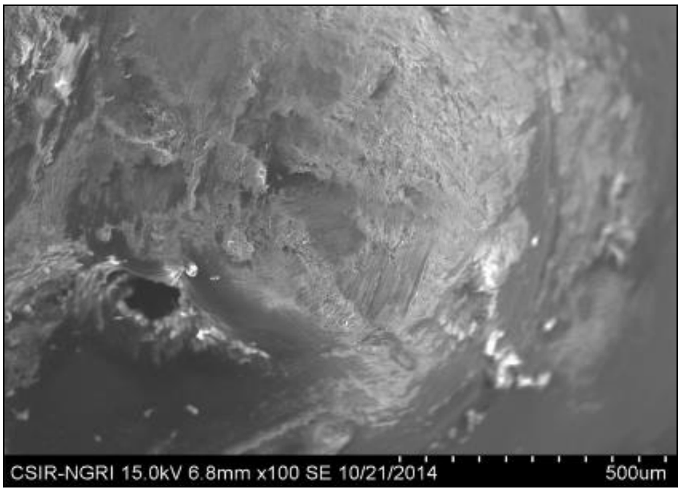

Fig 6: enamel opposing IPS e.max

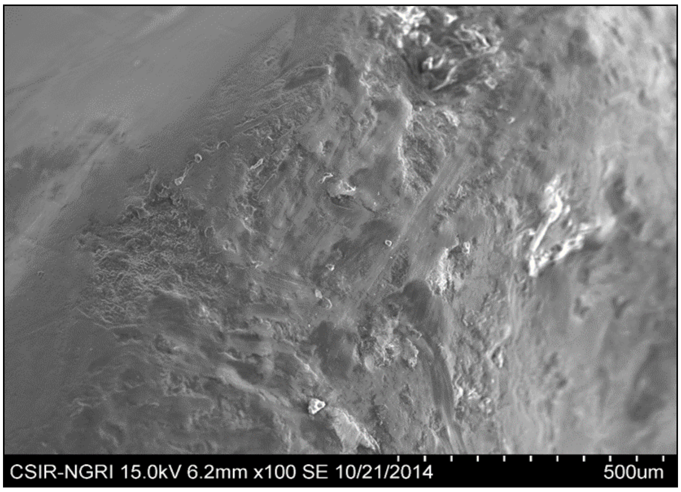

Fig 7: enamel opposing VITA PM9

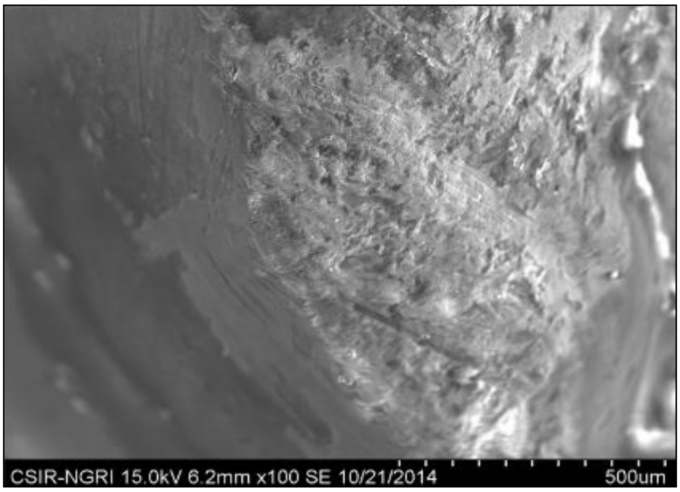

Fig 8: enamel opposing Ultra Will Ceram

4. Discussion

Present study simulated two body wear, in which the human enamel and selected restorative materials were worn against each other without intervening exogenous materials. Pressable glass ceramics has become a popular dental restorative system due to good marginal integrity, mechanical properties and translucency [4, 5]. Leucite crystals enhance the restoration strength and produce a natural deflection and scattering of light delivering a natural looking restoration.
In vitro studies on enamel wear opposing porcelain have been conducted using wear simulators under controlled conditions

like load, number of cycles and the lubricating medium. However, there is no global consensus regarding the design of tooth wear machines and as a result different wear simulators have been used in different studies. For the present study Taber abrasive wear machine was used. On this wear machine enamel specimens were secured to upper member and ceramic disc was secured to lower rotating table. The cusps of enamel specimens made a point contact with the opposing flat ceramic disk, establishing a ball-on-flat contact geometry. This geometric arrangement was considered to be reasonably representative of the masticatory function when investigating the occlusal surface wear of enamel.

In various studies researchers have applied different loads in the range 2N to 162N [20, 21]. A load of 100N has been used in previous studies [22-25] and this falls in the operating range of the available wear machine. For the present study 100N load was used. The number of cycles used in wear studies has varied considerably with an upper limit of 300,000 cycles [26] which is equivalent to 62.5 hours at a rate of 80 cycles per minute. This also indicates that such studies were time consuming to conduct in the laboratory. In the most of the studies 10,000 cycles were used.

The statistical analysis showed that enamel wear was more with Ultra Will Ceram than VITA PM9 and IPS e.max press. Among the three tested materials IPS e.max press was proved to be “enamel-friendly” [table 3]

According to Kenneth J. Anusavice [27], abrasive wear mechanisms for ceramics and tooth enamel include adhesion and microfracture of the ceramic and tooth enamel. Both enamel and ceramic are two phase brittle structures. Ceramic consists of a glass matrix that contain variable levels and sizes of crystals. Tooth enamel consists of small volume fraction of organic phase matrix and a high volume fraction of hydroxyapatite crystals.

The wear of the material depends on the ease with which cracks can propagate through the structure. The microfracture mechanism is the dominant mechanism responsible for surface breakdown of ceramics. Repetitive loading on the porcelain surface cause subsurface cracks which propagate to the surface and eventually the piece of porcelain surrounded by the cracks dislodge, leading to surface irregularities and subsequent damage to tooth enamel [28, 29].

According to Cesar *et al*. glass ceramics contains primarily a glass phase that can be strengthened by increasing the leucite crystal content. Glass ceramics derived their improved fracture resistance from the crack blocking ability of the leucite crystals by dispersion strengthening [30].

Among the selected materials IPS e.max press contains high volume of leucite crystals (60%) [31] With a uniform dispersion when compared to VITA PM9 (35-55%) and Ultra Will Ceram (35-55%) [30]. High leucite content in IPS e.max press may be responsible for crack blocking property, which might explain the least enamel wear with this material in the present study.

In spite of same volume (35-55%) of Leucite content in VITA PM9 and Ultra Will Ceram, enamel wear was more in enamel specimens abraded with Ultra Will Ceram. Any of the above said variables might be responsible for the wear difference between VITA PM9 and Ultra Will Ceram which require further studies

SEM pictures of enamel specimens abraded with IPS e.max press (fig. 6) exhibited less rough surface when compared to VITA PM9 (fig. 7) and Ultra Will Ceram (fig. 8). According to Imai *et al*. and Kadokawa *et al*. [28, 29] microfracture of ceramic will cause more surface irregularities and this results in more enamel damage. High leucite content in IPS e.max press may be responsible for less microfracture of ceramic and less surface irregularites and subsequent less damage to enamel.

According to previous studies variables that influence the abrasive potential of ceramic wear include fracture toughness [32], porosities, crystal size [33], content, type and morphology and its distribution in the glass matrix [34], surface finish and the structure of each phase of the materials [3, 9, 15, 28, 35].

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