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THE EFFECT OF TWO BODY WEAR ON CAD/CAM PEEK AGAINST MONOLITHIC ZIRCONIA, LITHIUM DISILICATE, ANDTOOTH ENAMEL "AN IN VITRO STUDY"

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ABSTRACT

Statement of the Problem: The fracture of the veneering material of any bi-layered fixed restoration is a decisive factor. Recently developed PEEK has gained an attention in being used in the oral cavity as a fixed partial denture framework. However, deciding whether PEEK restoration will withstand function and retain its form is still under investigation.

Introduction; PEEk which is basically a result when manufacturer included ceramic filler particles in its matrix BioHPP, making it a suitable polymer to be used as a temporary and permanent restorations. To test whether this new BioHPP will withstand the function in the oral cavity, in terms of wear and volumetric loss, and determine its efficacy as permanent or final restoration.

Materials and Methods; 30 BioHPP discs, apposing human enamel and lithium disilicate and zirconia six millimeter hemispheres, were tested in a dual axis chewing simulator. The number of cycles was 120,000 corresponding to six months intra-orally. Then the specimens were scanned pre and post testing, and volume was evaluated using Geomagic qualify software.

Results; There was a statistically significant difference between volume loss in the three groups (P-value = 0.003, Effect size = 0.361). Pair-wise comparisons between the groups revealed that enamel showed the statistically significantly highest mean volume loss whereas L. Zirconia showed lower mean value and Lithium Disilicate showed the lowest mean weight loss.

Conclusion; BioHPP is a convenient material to use intra orally in a monolithic form, its also expected to cause less wear than most used ceramics.

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INTRODUCTION

Tissue-substitute materials with human bone-like mechanical properties have sparked a lot of curiosity and became a point interest in modern prosthodontics research. High performance polymers (HPPs) are the most suitable to fit to the following criteria, as they provide the new concept of metal-free dental restorations with the added benefits of being biocompatible, with mechanical qualities such as heat resistance, solvent resistance, as well as a high level of wear and fatigue resistance. [1]

High-performance polymers (HPPs) are semi-crystalline thermoplastic materials made of aromatic benzene molecules linked together by functional ether or ketone groups, resulting in various polyaryletherketone combinations, which are present in the dental field as polyetheretherketone (PEEK) and polyetherketoneketone (PEKK), both whom are descendants from the polyarylyetherketone (PAEK) family.[2] Several attempts have been done to incorporate fillings inside the PEEK material ranging from titanium particles, carbon fibers and ceramic particles.[3]

BioHPP which is PEEK variant that has been specifically optimized for the utilization in the dental field. Strengthened with a special ceramic filler that has a grain size of 0.3 to 0.5 μm, which consists of about 20% by weight.[4] Documented evidence suggests the physical properties such as the elastic modulus of BioHPP is 3-4 GPa which is close to that of cortical bone which is around 15GPa, density of 1.3 to 1.5 g/cm3, flexural strength 150 MPa to 165 MPa, and a melting temperature of 334 c.[5] BioHPP is also supplied in different forms either in pressed pellets or readymade pre-pressed blocks that are ready for CAD/CAM manufacturing. BioHpp blocks are supplied in three sizes which are 16mm/20mm/24mm blocks, which are usually dry milled.[3]

BioHPP, has been used in the field of dentistry in many aspects ranging from implants, implant abutments, partial & fixed dentures frameworks, maxillofacial obturatotrs and in the majority of cases single crowns.

One disadvantage of PEEK restorations is that they suffer from a pearl-white opaque color or grayish-brown color, which necessitates there veneering using composite resin to achieve better esthetics. [6]

Several methods have been created to veneer the Polyetheretherketone (PEEK) which include digital veneering with breCAM.HIPC, conventional veneering with crea.lign, conventional with crea.lign paste, and using pre-manufactured veneers visio.lign.[2]

Several methods have been suggested for the composite resin bonding to the BioHPP surface, Lorena Tavares et.al, conducted a systematic review that found that a surface pretreatment is utilised in conjunction with a bonding system, the bonding strength between HPP and veneering resin composite increases dramatically, especially when PEEK is used. The optimum technique to strengthen bonding to resin veneering for PEKK surfaces appears to be tribochemical silica-coating applied in conjunction with 98% percent sulfuric acid etching.[1]

Wear:

Wear is a gradual condition in which the original anatomical structure of the oral cavity is lost. This might happen as a result of physiological or pathological circumstances.(7) It is desirable that the wear characteristics of dental restorative materials match those of natural teeth to protect opposing tooth surfaces, opposing dental restoration and as much as possible minimize occlusal disturbances.[8]

An ideal dental restorative material should replicate the wear behavior of natural tooth structure the wear of enamel in contact with restorative materials should not exceed the physiological wear of about 20m–40m per year.[9] The main types of wear occurring in the oral cavity are abrasive wear (two-body wear and three-body wear), fatigue wear, and corrosive wear.[8]

In order to assess and observe wear, the wear mechanism should be fully understood, wear could be measured both clinically and in a laboratory. Wear occurs through three main mechanisms abrasion, attrition and corrosion, these three mechanisms were thought be one, but in recent years it was concluded that each of them is a separate entity. Evaluating the lost tooth structure due to wear could be measured used direct measuring techniques using tooth wear indices and indirect measuring techniques using cast replicas to be able to quantify the amount of lost structure. (10)

Wear is evaluated based on two methods qualitative and quantitative. Quantitative assessment is presented through the volumetric assessment of wear values of either the restorative material or the human dentition. Many methods have been suggested to evaluate wear ranging from scanning electron microscopy, non-contact profilometry and contact profilometry.

One of the recent indirect methods for wear assessment is the three dimensional (3D) measuring techniques, which protects the scanned object and provides highly accurate data with providing quantitative data, and could be applied clinically and in a laboratory.(11) To obtain 3D images contact profilers, non-contact white light, micro/cone computerized tomography (CT) scanners, laser scanners and computer-aided design/computer-aided manufacturing systems (CAD/CAM).(10) These scans are then introduced through a wear measuring software, which superimposes the before and after scans, and automatically calculating the amount of volume lost due to wear.

MATERIALS AND METHODS

Bio-HPP Polyetherether ketone

From CAD/CAM dics of 20mm thickness and 98 mm diameter, 8 cylinders of 20 mm height (thickness of the Disc) and 10mm diameter were machine milled using the Mc X5 (DENTSPLY sirona) To design these cylinders the Z Brush software (Figure) was used. The designed objects were exported as STL files and imported into the Dentsply sirona Inlab CAM software 18.1. The designs were nested into the PEEK disc and milled using the Dentsply sirona Inlab Mc X5 milling machine.

To obtain the required discs for the study, the cylinders were then sectioned using a longitudinal sectioning machine. The sectioning was performed mesio-distally using a low-speed cutting machine (Low Speed Saw 11e1180; Isomet, Manassas,VA, USA) which was used to create a total of thirty discs of the High performance polymers Poly ether ether ketone (PEEK) Bio-HPP (Bredent GmbH).

The final outcome was 30 flat specimens with 3mm thickness and 10mm diameter, which were later divided into three groups each group containing 10 flat discs (n=10)

Hemispheres of lithium disilicate and zirconia with a diameter of 6mm was designed attached to an 8 mm long rod. To design these hemispheres the Z Brush software was also used. The designed objects were exported as STL files and imported into the Dentsply sirona inlab CAM software 18.1. The designs were nested into C14 E-max CAD blocks and milled using the Dentsply sirona Inlab M X5 milling machine.

The Hemispheres were polished with the EVE extra- oral polishing kit for lithium disilicate 3 steps polishing each for one minute lot#305638

A total of 15 lower premolars recently extracted for orthodontic demands, from the outpatient clinic of the Misr International University, Cairo, Egypt were used in this study for in-vitro wear testing against the experimental materials. Teeth that had worn-out cusps or were too sharp or fractured were excluded.

All teeth were disinfected by immersing them in a 0.5% chloramine solution (Chloramine-T; Sigma–AldrichLaborchemikalien, Seelze, Germany, LOT 53120, CAS No. 7080-50-5) at room temperature for a maximum period of one week after extraction. Afterwards, they were stored in distilled water at 5°C for a maximum time period of 6 months according to the ISO 11405/TR.

III Sample grouping:

A total of 30 Bio-HPP disc specimens were constructed with dimensions of 10mm diameter x 3 mm height. The disc specimens were divided according to the antagonist material into three equal groups (n=10).

Group I: Disc Bio-HPP opposing Monolithic Katana HTML Zirconia.

Group II: Disc samples of Bio-HPP opposing lithium di-sislicate IPS e.max CAD.

Group III: Disc samples of Bio-HPP opposing Human enamel (lower second premolars).

TABLE (1) Sample grouping

Antagonist type	Group	Base specimen	Surface finish	Number of samples
Lithium disilicate	#1	Bio-HPP discs	Polished	10 anatagonist 10 Discs
HTML Zirconia	#2	Bio-HPP discs	Polished	10 anatagonist 10 Discs
Huamn enamel (lower premolars)	#3	Bio-HPP discs	No surface modification	10 anatagonist 10 Discs
Total number of samples				30 antagonists 30 Discs

Wear test parameters:

TABLE (2) wear test parameters

Stroke length/ horizontal movement	1mm per direction
Frequency of loading cycles	1.7 Hz = 102 cycles/minute
Operational liquid temperature	37oC(±2oC)
Water jet frequency	2 seconds on/ 30 seconds off

The simulator was programmed to perform 120,000 loading cycle backwards and forwards by holding an antagonist against a sample (fig 1), which according to several studies 120,000 to 130,000 loading cycles in a chewing simulator are comparable to Six months chewing condition.

All specimens (n=30) and antagonists (n=30) were stored in distilled water 24 hours before wear testing. The custom designed two-body wear simulator simulates horizontal movements that occur naturally in oral cavity. The upper sample holder was designed to house a natural tooth or the antagonist (figure 44). The lower sample holder was designed to house Bio-HPP disc sample (figure 45). For fixation during two-body wear simulation, the specimens were embedded in the middle of their holders using a light cured dental composite resin to ensure proper positioning during the test.

A weight of 5 kg, which is equivalent to 49N of chewing force, was applied. A number of 120,000 cycles were repeated on each sample to clinically simulate one year in oral cavity at a frequency of 1.7 Hz (which equals to 102 cycles /minute). The stroke length of the horizontal movement equals to 1mm2. A continuous flow of distilled water was directed on the wear area maintaining the environmental temperature at 37˚C.

Statistical analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Volume loss data showed non-normal (non-parametric) distribution. Data were presented as median, range, mean and standard deviation (SD) values. Kruskal-Wallis test was used for comparison between three groups. Dunn's test was used for pair-wise comparisons when Kruskal-Wallis test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

RESULTS

There was a statistically significant difference between volume loss in the three groups (P-value = 0.003, Effect size = 0.361). Pair-wise comparisons between the groups revealed that enamel showedthe statistically significantly highestmean volume loss.Zirconia showed statistically significantly lower mean value. Lithium Disilicate showed the statistically significantly lowest mean weight loss.

TABLE (3): Descriptive statistics and results of Kruskal-Wallistest for comparison between volume loss (mm3) in the three groups

	Zirconia	Lithium Disilicate	Enamel	P-value	Effect size (Eta squared)
Median (Range)	0.089 (0.003-0.129) B	0.033 (0.014-0.103) C	0.118 (0.032-0.229) A	0.003*	0.361
Mean (SD)	0.081 (0.041)	0.042 (0.028)	0.131 (0.065)		

****: Significant at P ≤ 0.05, Different superscripts are statistically significantly different***

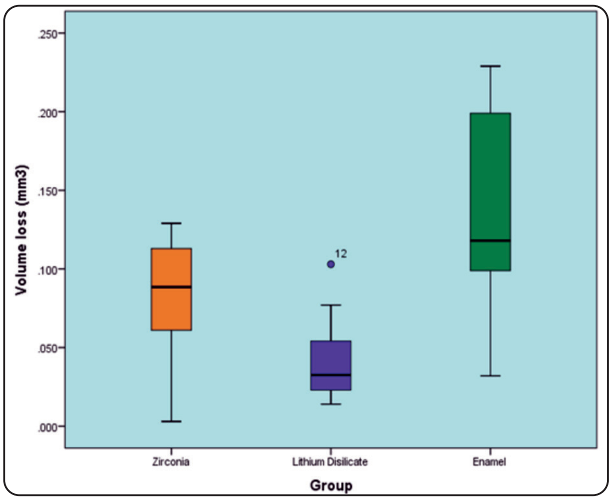

Fig. (1) Box plot representing median and range values for weight lossin thethreegroups (Circle represents outlier)

DISCUSSION

The purpose of this study was to compare and evaluate the wear behavior of PEEK BioHpp (polyetheretherketone) when opposed by human enamel and different restorative materials. In accordance with the finding results of this study, that the null hypothesis was that there will be no significance difference in the amount of wear between the human enamel and the different restorative materials was rejected.

Fixed dental restoration should have minimum wear effects on their antagonistic counterparts, with the ability to resist the wear. Current materials such as high performance polymers, ceramics and composite resins used in the field of fixed prosthodontics, have different wear behaviors. [12] Wear is a complex process trying to measure it directly in the oral environment makes it a relatively harder. Wear simulation methods have been developed to study the wear behavior of dental restorative materials. [13,14]

An esthetic restoration should wear at approximately the same rate as the enamel it replaces which is in the range of about 20-40µm per year. [15] which is consistent with the average rate of enamel occlusal wear contact area in the molar region that is approximately 30 to 40 μm per year. [16] Ceramics are known to cause wear to the antagonist natural teeth.[15] On the contrary polymers have antagonist-friendly wear behavior making new emerging polymers a good candidate to be used as fixed dental restorations in the oral cavity.[16,17]

Using BioHPP in a non-veneered state, is an attempt to prove whether it will be able to withstand functional performance intra-orally, in which part of the veneering composite has chipped or when there wasn't sufficient occlusal restorative space, which demanded that the BioHPP restoration be used in the non-veneered state as a permanent or temporary restoration.[18] Several factors influence wear such as hardness, fracture toughness, porosity, surface finish , presence of staining materials and frictional resistance of the opposing materials.[7] It was assumed that the difference in hardness values will increase the wear resistance. The total loss of substance depends on the hardness of the materials involved, the geometry of the particles involved, and the load and length of the contact area.[19]

The BioHPP specimens were all flat discs during wear testing full anatomical crowns exhibited lower wear values than flat ones. The reason for the higher material wear of flat specimens might be the higher strain distribution in flat specimens than in crown ones.[18]

Natural enamel is an unsuitable antagonist material for standardized wear tests. The composition, surface shape, and wear properties of biological substances are variable, and in turn may influence the statistical outcomes.[20] The variation in wear data can be attributed to the enamel specimen preparation, and morphological and structural differences of natural enamel. [21] Prepared cusps caused variations in the wear data which is directly related to the enamel thickness. The higher the enamel thickness, the lower the wear of the prepared enamel cusps. [22] It was found that the un-prepared non-standardized human premolar cusps with the shape and size radius of six millimeters did not alter nor reduce variations in resulting wear . Thus, in the present study, tooth enamel cusp was not standardized. [23]

This six millimeter diameter was found to be the most suitable to simulate physiologic occlusal contacts. Acordingly both Zirconia and Lithium disilicate hemispheres, were designed and milled accordingly. [9][24] Zirconia and lithium disilicate ceramic balls retained their shape during the entire test period, so that the influence of changes in the antagonist's surface on the wear of specimens can be minimized.[25]

Various numbers of cycles were used by various studies ranging from 5,000 till 1,000,000 cycles. Approximate to one year of functional chewing inside the oral cavity a minimum number of cycles required from 240,000 to 250,000 cycles, making the period of six months ranging from 120,000 to 130,000 cycles. [26,23,27,28] Forces used in this study is 50 N which appear to align with those encountered in the molar region of subjects with artificial dentitions or in the incisor region of subjects with natural dentitions. [29]

Two-body wear occurs during direct tooth-to-tooth contact with absence of any abrasive substances, a process similar to what occurs during dynamic occlusion movements. In the oral cavity, wear representing itself in two-body wear is also present with high prevalence during parafunctional habits such as bruxism.[30] To avoid the occurrence of byproducts that could change the testing parameters from two body wear into three body wear, an addition of an intermedium demineralized water, ensured that the byproducts were washed away, and it will have no corrosive effects on any of the tested specimens, since no chemical reaction layer will form between the substrates.[31]

All the used restorative materials were only polished this coincides with the common dental practice to polish fixed restorations following occlusal adjustments. Was found that polished specimens of both zirconium dioxide and lithium disilicates, caused less wear on opposing enamel, each other and other restorative dental materials. Thus, in this study it was preferred to just polish the antagonist specimens with no need to glaze the opposing specimens. [32,33] The thin galzed layer which various in thickness from 10 to 40 microns according to many authors, is the first to wear off, creating a third medium between testing specimens.

In this present study volumetric wear loss was calculated through superimposition of the specimens pre-testing and post-testing to create three-dimensional images, which are then introduced into the three-dimensional analysis software (Geomagic Qualify 2013; Geomagic, North Carolina, USA). The accuracy of the analysis software has been validated within 0.5 mm. [32] Three-dimensional images with an expected deviation within 20 mm between pre- and post-testing images was deemed acceptable.[32]

In the scope of this study, the results showed that between the groups Biohpp PEEK showed loss to enamel that was statistically significantly with the highest mean volume loss 0.065 mm3, zirconia showed statistically significantly lower mean value 0.041 mm3, while lithium disilicate showed the statistically significantly lowest mean weight loss 0.028 mm3. The null hypothesis was that there will be no significance difference in the amount of wear between the human enamel and the different restorative materials was rejected.

In a study by Syed Rashid Habib et.al., when comparing two-body wear behavior of human enamel versus monolithic zirconia, lithium disilicate, composite resin and ceramo-metallic sepecimens, in a chewing simulator after 240,000 with a load of 50N, 3D profilometric findings showed that the highest surface roughness values were created in enamel within the monolithic zirconia group followed by the ceramo-metallic , while the lowest values were caused by the lithium disilicate group and the composite resin respectively. This was related to the hardness of zirconia 1250 HV that caused more abrasion to the opposing enamel.[34]

When assessing the Microstructure–toughness–wear relationship of tetragonal zirconia ceramics Bikramjit Basu et.al., came to the conclusion that the lower yttria content with tetragonal grains are thought to be very susceptible to transformation when under mechanical stresses. The higher volumetric wear of the ceramic can also be related to the presence of cubic zirconia grains, which are inferior in wear resistance. Decreasing the yttria content will enhance the esthetics of the ceramic but will produce and increase in transformability and fracture toughness. The observation that volumetric wear increases with the increase in grain size can be attributed to the fact that a larger tetragonal grain size increases the transformability of the tetragonal to monoclinic phase causing microcracks at the fretting contacts, which enhances spalling of material from the contacting surfaces. [35]

Tooth enamel that's known to be the hardest and most mineralized biological structure in the human body, is present in heterogeneous form with anisotropic properties. Fundamentally, the tribological responses depend on the mechanical properties any given material. Xu et al., mentioned that the Young's modulus of the permanent enamel at the occlusal aspect is 94.5 GPa .Considering that clinical studies present considerable limitations, such as complex methodology and difficulties with measurement and precise analyses, in vitro studies can be more readily controlled, thus increasing our understanding of wear mechanisms.

Despite extensive research into the elements that influence the wear of dental ceramics, published evidence is either inconsistent or inconclusive. Many bioceramics are sensitive to contact morphologies, therefore surface characteristics are critical. As a result, friction and wear behavior would be influenced by these characteristics. The abrasive wear of dental ceramics in the oral environment is typically caused by very hard, rough food particles. Zhongxiao Peng et.al.,[36] studied the effects of surface preparation and contact loads on abrasive wear properties pressable lithium disilicate ceramics (LDC). Using a pin-on-disk device in which LDC disks with different surface finishes against alumina pins at different contact loads he measured abrasive wear. The main outcomes were firstly, that all measured coefficients of friction increased with the time at first then reached a steady plateau during the remaining wear processes, to second that wear volumes and friction coefficients of LDC increased as the load increased with the increased surface roughness. The results of this study showed that in the rough LDC surfaces, three-body wear was dominant while for smooth LDC surfaces, two-body wear played a key role. However, using a pin-on-disk device with opposing alumina pins is different to the scope of our study, this review gave us an indication that the relation between surface roughness and the amount of applied load is crucial in two-body wear testing. Which is in conclusion with our results.

Knowing that no material introduced in the oral cavity is expected to act within the normal range, that's why the wear rates differed significantly between different research groups for instance Etman et al. stated wear of 148 µm after first year for lithium disilicate glass-ceramic posterior crowns, whereas Kramer et al. determined it as 78 µm after 4 year for ceramic inlays made of lithium disilicate. Only very few studies investigated wear of posterior composite crowns in vivo and reported wear to be around 40 µm/year, which is considerably lower than values found in this study. [11]

Two main factors for the application and selection of polymers in high-performance applications are mechanical strength and thermal characteristics. Fibers increase the strength of the material and allow it to be utilized as a construction material. Fibers can promote the production of transfer films on the counter surface in a tribological situation. However, they may be abrasive, producing wear. As a result, better mechanical qualities may not improve tribological properties. In tribological tests, PEEK composites outperform pure PEEK.[37]

Although PEEK has a very high friction coefficient when sliding without lubrication, the wear rates are quite low. During reciprocating sliding, unfilled PEEK showed low scuffing resistance and a high wear rate. Scuffing resistance was equally poor in reinforced PEEK, although it had superior sliding and micro abrasive wear resistance.[38] Davim et al.[39] studied the friction and wear behavior of PEEK and PEEK reinforced with glass (GF-PEEK) or carbon fibers (CFPEEK) against a stainless steel counter body on dry sliding. Zhang et al. [40] concluded that PEEK veneers exhibit lower coefficient of friction than that on PEEK/SiC composite veneer. However, PEEK/SiC showed a higher wear rate than that on PEEK at high sliding test speed.

Several attempts have also been made to relate mechanical properties to wear resistance of restorative materials, for years modulus of elasticity has been used in research for the prediction of clinical wear. Nonetheless, in correlation to the modulus of elasticity the flexural strength and modulus of elasticity were found to have significant effects on the quantitative clinical testing of dental material wear. Thus to our notice and concern it seems valid that both will reflect on the in vitro wear performance. In the light of the following theory the resilience of a material will influence the abrasion resistance; this comes in relation that the amount of energy needed to break the material, forming cracks more readily, and thus an increased wear rate. Consequently, in theory a polymer with a lower modulus will wear more than its counterpart with a higher modulus.[41]

CONCLUSION

Within the limitations of this study we can conclude that

1. BioHPP is a convenient material to use intra orally in a monolithic form.
2. BIoHPP causes less wear than most of the ceramics used nowadays as permanent restoration.
3. Wear is a complex procedure and constantly requires deep and thorough investigations.

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