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Biofilm Adhesion and Surface Roughness of PEEK VS Monolithic Zirconium: Comparative "An In-Vitro Study"

Farah T. Khalifa[1], Ahmed Hassanien[2], Tamer Hamza[3]

ABSRACT

Background: PEEK material has been widely used recently. It serves multiple advantages being biocompatible, light material and has modulous of elasticity close to bone. It is used for fabrication of fixed partial dentures, implants abutment and superstructure. However, its surface roughness and bacterial adhesion needs further investigations. ***Aim:*** Evaluate surface roughness and bacterial adhesion of zirconia and PEEK. ***Materials and methods:*** A total of ten samples were obtained from PEEK and Zirconia where 5 samples were obtained from each material and sliced into discs. Polishing of the samples was done followed by surface roughness measurement for each disc. This was followed by incubating the samples in bacterial suspension to prepare them for bacterial adhesion testing. ***Results:*** Results showed that PEEK (0.52±0.06) had a significantly higher mean value than Zirconia (0.23±0.04) ($p<0.001$). Regarding bacterial adhesion test, PEEK showed higher adhesion values with 19.00±1.41, 6.20±1.30 and 5.66±0.44 for Streptococcus sangius, Streptococcus mutans and Candida albicans respectively whereas zirconia had bacterial adhesion values of 7.60±3.58, 3.60±0.55 and 2.80±0.84 for Streptococcus sangius, Streptococcus mutans and Candida albicans respectively. ***Conclusion:*** Within the limitations of this study, we concluded that Zirconia could provide smoother surfaces than that of PEEK. Moreover, bacterial adhesion on surfaces of PEEK exceeded that of Zirconia.

Keywords: PEEK, BioHPP, Zirconia, Surface roughness, Bacterial adhesion.

INTRODUCTION

The development of innovative dental materials is now obligatory to meet up with the on-growing demands of dental applications, especially when it comes to dental implant restorations. Modern dentistry presents one of the challenges, which is to improve the biocompatibility and biomechanical properties of the materials used for implant treatments.

Implant-supported prostheses have demonstrated biological, mechanical, and functional advantages with long-term

1.Postgraduate Researcher, Fixed Prosthodontics Department, Faculty of Oral and Dental Medicine, Misr International University, Cairo, Egypt.
2.Professor of Fixed Prosthodontics, Fixed Prosthodontics Department, Faculty of Dentistry, Cairo University, Cairo, Egypt.
3.Professor of Fixed Prosthodontics, Fixed Prosthodontics Department, Faculty Dental Medicine, Al-Azhar University, Cairo, Egypt.

success rates; hence, they have become a widespread treatment modality in clinical dentistry.[1,2] Implants lack periodontal ligaments as they contact bone directly, therefore they display different biomechanical behaviors from those of natural teeth.[3]

Consequently, the surrounding bone structure is directly subjected to occlusal loads that are received by the implant.[4,5]This occurrence affects the stress distribution in implants and peripheral bone, which happens to be one of the major factors determining success ofimplants.[6] Factors such as the direction of loading, the design and the material characteristics of the implant or the implant-retained crown, affect the stress or energy transfer between implant and peripheral bone.[3,7]

Various materials are currently available for CAD/CAM restorations, which are categorized into metals, ceramics, resin-based and composites. Zirconia ceramics display enhanced esthetics, outstanding biocompatibility and exceptional mechanical properties with flexural strength of 900–1200 MPa and compressive strength of 2000 Mpa, which are considered superior. Glass ceramics have proven to be superior in esthetics to zirconia. Lithium disilicate is the toughest and strongest of the glass ceramics with moderate flexural strength of 360–440 MPa. However, ceramics in general are rigid and are prone to transmit excessive forces to the implant-prosthesis complex, resulting in numerous biological and mechanical complications.[8,9]

High performance polymers (HPPs) such as modified composite resins and PEEK materials are becoming well-known for the fabrication of dental restorations. Various studies have reported favorable mechanical and biological properties for HPPs. HPPs have a lower modulus of elasticity compared to ceramics, that is similar to that of natural bone structure; therefore, HPPs are thought to have a damping effect, thus are more fit for implant-supported prostheses. This damping effect may be valuable for dental implants given their lack of periodontal ligaments where the loads applied to implant-supported prostheses are directly transmitted to the surrounding bone.[10,11]

As it is impossible to replace the periodontal ligaments, the choice of the restorative material is the only chance of creating a cushioning effect in the implant-prosthesis complex. Brittle ceramics are not considered problematic for tooth-supported restorations due to the presence of the periodontal ligaments; however, it might cause complications when used on implants. Polymer-based materials can offer a cushioning effect, which may lead to decreased load transmission and micro-movements between the implant components.[11,12]

Polyetheretherketone (PEEK) is a synthetic thermoplastic polymer that demonstrates high mechanical properties and has been used since the 1980s as a biomaterial for medical uses. Recently, PEEK biomaterials have gained much attention and are being utilized instead of metal alloys as an implant material, a CAD/CAM-milled framework material and an abutment material. The compatibility between the modulus of elasticity of the PEEK biomaterial and bone tends to reduce the effects of stress on the peripheral bone.[3,13]

In comparison to rigid framework materials such as zirconium oxide and metal alloys, PEEK has a low elastic modulus of 4 GPa and displays an identical elasticity to bone, providing a shock-absorbing effect and reduction of the stresses that are transferred to the implants.[13]

However, another highly significant factor in choosing the fixed prosthesis implant supra-structure is the surface roughness and biofilm accumulation of the restoration material. Ceramics are popular for their smooth surfaces, which subsequently reduces the adhesion of the bacteria on these materials. Meanwhile, Polymer-based materials are also known to have a suitable surface finish when polished accurately, as well as having low plaque affinity which can be highly significant in implant-supported suprastructure in order to maintain the periodontal health and eliminate the incidence of peri-implantitis.[14,15]

According to the available review of literature, this study will be directed to evaluate surface between the tested materials roughness and biofilm adhesion of the recently introduced polyetheretherketone (PEEK) in comparison to monolithic zirconia. The null hypothesis of this study stated that there will be no differences.

MATERIALS AND METHODS

A total of 10 disc samples were constructed from monolithic zirconia and PEEK. These 10discs were divided into two equal groups according to the type of material. The two groups were: Group Z: monolithic zirconia samples (Bruxzir) and Group P: Monolithic PEEK (BioHPP).

Disc dimensions were 2mm in thickness and 10mm in diameter. Zirconia discs were then sintered according to the manufacturer's instructions.[16]

To standardize the polishing procedure, a straight hand piece was mounted on a surveyor. A gypsum base with a holder for the discs was poured and attached to the surveyor in order to position the disc in a 90 degrees angle in relation to the polishers attached to the straight hand piece. This was done to standardize the polishing procedure direction and pressure **(Figure1**). Zirconia samples' polishing was carried out using Eve Diacera polishing kit, (Gmbh, Germany) according to the manufacturer's instructions.[16]As for PEEK polishing, Visio.lign polishing tool kit (Bredent, Gmbh, Germany) was used for polishing according to the Manufacturer's recommendations.[17,18]

Figure (1): Surveyor modified device for standardization of discs polishing.

The surface roughness of the samples was determined through the use of surface roughness tester (SJ-210 surface roughness tester, Mitutoyo, Japan).

Following surface roughness testing, the samples were then sterilized through the use of flow chamber (Vertical laminar airflow chamber, Telstar, Mexico) with ultraviolet light. Five disks of each of the tested materials (PEEK & Zirconia) were incubated in (Precision Scientific, Incubator, NAPCO, USA) in bacterial suspensions that contained 1X106 cfu/ml of bacteria (Streptococcus mutans, Streptococcus sangius and candida albicans) in 5 ml of brain heart agar infusion to allow bacterial adherence and biofilm formation. After incubation at 37̊C for 24 h, the samples were removed and rinsed three times with phosphate buffer saline (PBS). Samples were then placed in 10 ml fresh sterile saline and sonicated for 30 seconds to dislodge the sessile adherent cells from the surface of the discs.

Serial dilutions of the sonicated saline were cultured each on brain heart infusion agar. A pipette was used to transfer the bacterial suspension on each broth. A glass rod was used to spread the bacterial suspension onto the broth. The number of sessile bacteria that indicates the degree of adherence was determined by the viable count technique.

RESULTS

Numerical data were presented as mean and standard deviation values. They were explored for normality by checking the data distribution using Shapiro-Wilk test. Data showed parametric distribution and were analyzed using independent t-test. The significance level was set at $p \leq 0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.1.3 for Windows.

For surface roughness, mean and standard deviation (SD) values of surface roughness (Ra) for PEEK was (0.52±0.06) which is significantly higher than the mean value of Zirconia (0.23±0.04) ($p<0.001$) **(Table 1).**

Table (1): Mean ± standard deviation (SD) of surface roughness (Ra) for different groups and statistical comparison between them.

Surface roughness (Ra)(mean±SD)		t-value	p-value
PEEK	Zirconia		
0.52±0.06	0.23±0.04	**7.67**	**<0.001***

** Significant (p ≤ 0.05)*

As for mean and standard deviation (SD) values of bacterial count (CFU/ml), PEEK recorded (19.00±1.41), a significantly higher value than Zirconia (7.60±3.58) ($p<0.001$) for Streptococcus sangius whereas for Streptococcus mutans PEEK (6.20±1.30) had a significantly higher value than Zirconia (3.60±0.55) ($p=0.003$). As for Candida albicans, PEEK (5.66±0.44) had a significantly higher value than Zirconia (2.80±0.84) ($p<0.001$). **(Table 2)**

Table (2): Mean ± standard deviation (SD) of bacterial count (CFU/ml) for different groups and statistical comparison between them.

Bacteria/fungus	Bacterial count (CFU/ml) (mean±SD)		t-value	p-value
	PEEK	Zirconia		
Streptococcus sangius	19.00±1.41	7.60±3.58	**6.63**	**<0.001***
streptococcus mutans	6.20±1.30	3.60±0.55	**4.11**	**0.003***
Candida albicans	5.66±0.44	2.80±0.84	**6.75**	**<0.001***

** Significant (p ≤ 0.05)*

DISCUSSION

Although PEEK is becoming widespread in clinical practice, only a few studies are available focusing on the use of this material for fixed partial dentures with respect to its surface roughness and bacterial adhesion, since this greatly affects the prognosis of the restoration and the health of the neighboring periodontal structures especially when created over implants. The purpose of this study was to assess the surface roughness and bacterial accumulation of PEEK material compared to the commonly and most frequently used zirconia.

BioHPP is one of the PEEK modifications. It has been enhanced by 20% ceramic fillers to give the material strength and enhance its mechanical properties. It has several advantages, including low density, biocompatibility and mechanical properties similar to enamel and dentin. Therefore, it is a good option for patients who suffer from bruxism or clenching because it prevents the antagonist from wearing out and the prosthesis from breaking making it suitable for fixed partial dentures thus it was chosen for this study.[15,17]

Although PEEK is a more aesthetic material than metal alloys are, it is not as transparent as hybrid ceramics. Another major disadvantage of PEEK is its low bonding strength with resin cement materials due to its low surface energy. It is difficult to establish strong and resistant adhesion between PEEK and composite resin materials owing to PEEK's low surface energy and its strength to surface modification via chemical treatment. Consequently PEEK was used in its monolithic form.[18]

Bruxzir monolithic Zirconia was used in this study being the most frequently used material for implant superstructures. Consequently, PEEK was compared to Bruxzir since it is considered a viable option for implant superstructures according to recent literature.[19]

In this study, polishing was done instead of glazing for zirconia samples. Many studies addressed the comparison between glazing and polishing for monolithic zirconia restorations. The common result of these studies is that the glaze application showed the best surface smoothness, but the longevity of glaze is not well-established when restorations are in function. Therefore, prevention or reduction of antagonist abrasion can be achieved by appropriate polishing.[16,20-23]

Surface roughness was then determined using the (Ra) parameter. It was used because it is a representative estimate of surface roughness, it is also easily calculated [24].Profilometry (Surface roughness tester) was used. This method, tactile profilometry, was used since it provides quantitative measurement of surface profile and its use is reliable and representative.[25,26]

For the microbiological in vitro test, streptococcus species was chosen since they prevail in the early phases of biofilm formation and prepare the ground for the subsequent adhesion of anaerobic and more pathogenic micro- organisms, which are dominant in more mature biofilms after 48 hrs. Also, they are commonly used for evaluation of bacterial accumulation investigations because Streptococcus mutants are characterized by the high capacity for adhesion and biofilm formation.[27]

The null hypothesis of this study which stated that there will be no difference between the tested materials was rejected as the results showed that there was significant difference between surface roughness values of PEEK samples that recorded 0.52±0.06 and Zirconia samples that recorded 0.23±0.04. Also, PEEK had higher bacterial adhesion values with a significant difference having a bacterial count of 19.00±1.41, 6.20±1.30, 5.66±0.44 for streptococcus sangius, streptococcus mutans and candida albicans respectively whereas Zirconia had lower values giving 7.60±3.58, 3.60±0.55, 2.80±0.84 bacterial count for streptococcus sangius, streptococcus mutans and candida albicans respectively.

Comparing PEEK to Zirconia regarding the surface roughness, in the current study Zirconia surface roughness appeared to be lower than that of PEEK.

The explanation of these results was clarified by ***Hahnel et al.***[28] stating that zirconia possess homogeneous grains with an average grain size of about 0.3um, which corresponds to the intermediate values for surface roughness that have been found for the Zirconia samples.

Moreover, ***Hmaidouch et al.***[29] added that roughness values of the Zirconia samples were improved after polishing, which in turn suggested that polishing may have an effect in favoring the flaw distribution in the material. This would support the hypothesis that polishing is able to remove the grinding-induced defects.

In addition, the high surface roughness values of PEEK were explained ***by Batak et al***.[14] who stated that the presence of nanoceramic fillers in PEEK might have contributed to the variation in surface roughness after polishing. Also, ***Sturz et al***.[20] stated that PEEK is a filled thermoplast and hence inhomogeneous in regards to the properties which affects the surface roughness of the material.

On the other hand, ***Giudice et al***.[30] stated that the roughness profile for PEEK was significantly lower than that of zirconia. The analysis of his data shows how PEEK has a mean Ra of 0.116 ± 0.06 µm. Their study was different from the current study in the polishing and testing methods which could be the reason for the difference in results.

According to dental literature, it was mostly agreed upon surface roughness value

(Ra) of 0.2um as being the maximum clinically acceptable range to be biologically competent for a restoration and to reduce the plaque formation and bacterial accumulation on the surface of a material.[31,32]

Surface roughness of PEEK was observed in several studies with conflicting results. In this study, PEEK surface roughness was Ra 0.52um which technically exceeds that of the clinically accepted range. Similar to our results, ***Batak et al.***[14] concluded that before and after polishing the surface roughness of PEEK exceeded the clinically acceptable range.

However, this was opposed by ***Elsherbini et al***.[33] who reported that PEEK had surface roughness values below 0.2um which is considered within the clinically acceptable range. In addition, previous studies differ from the present study with results for PEEK surface roughness below Ra 0.2um because Ra was measured after using a standardized procedure with abrasive papers of different grits with an automatic polishing machine. This difference in the polishing procedure is the main reason for different surface roughness values.[34-38]

As regards to the bacterial adhesion, our study concluded that Zirconia had less bacterial adhesion than PEEK. Results of the current study came in agreement with ***Bolat et al.,***[39] in which they compared the bacterial adhesion of three dental materials used for crown constructions (Modified PEEK (BIOHPP), Ceramic, and Zirconia) by using adenosine triphosphate (ATP) driven bioluminescence as an innovative tool for the rapid chair-side evaluation of oral bacteria and assessment of oral hygiene. The results showed that zirconia had the lowest value of biofilm formation.[40] This can be explained by the increased surface roughness of PEEK in comparison to Zirconia leading to increased bacterial adhesion.

Also, authors of previous studies, ***Scarano et al.***[41] and ***Nascimento et al.,***[42] concluded that zirconia allows less bacterial adhesion on its surface. Another study by ***Bremer et al***.[43] concluded that zirconia is characterized by low plaque accumulation in addition to its high strength.[40]

On the other hand, another study investigated the biofilm formation on the surface of three materials including PEEK, zirconia, and titanium. They prepared the samples to be highly glossy by polishing them using silicon carbide paper and the profilometry was used to measure the degree of roughness. Regarding the surface roughness, the results showed that zirconia and titanium has higher surface roughness than PEEK and PMMA which in turn leads to less bacterial accumulation. Difference in results between this study and the current study is the method of polishing where silicon carbide paper may result in smoother surface finish for PEEK.[40,44]

In future studies, further investigations should be carried out to determine the effect of different polishing techniques on surface roughness of PEEK and zirconia.

As for the limitations of this study, in vitro results should be interpreted cautiously because testing conditions cannot exactly reflect the clinical situation in contrast with in vivo studies. Nevertheless, such results might provide valuable information and guidelines for clinical applications. In the present in vitro investigation, every effort was made to standardize conditions and to simulate the clinical situation.[45]

CONCLUSION

Within the limitations of this study, it could be concluded that Zirconia can provide smoother surfaces than that of PEEK. Moreover, bacterial adhesion on surfaces of PEEK exceeded that of Zirconia.

CONFLICT OF INTEREST

The author denies any conflict of interest concerning this study.

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