Original Article

Comparative evaluation of the wear resistance of two different implant abutment materials after cyclic loading – An in vitro study

Abstract

Purpose: To comparatively evaluate the wear resistance of two different implant abutment materials with titanium implants after cyclic loading. **Methodology:** Two groups utilizing 20 titanium implants secured in resin blocks, in which 10 titanium implants are connected with titanium abutments (Group I, $n = 10$) and the other 10 titanium implants are connected with Polyether ether Ketone (PEEK) abutments (Group II, $n = 10$). Abutments are cyclically loaded for 550,000 cycles. Surface profilometry, scanning electron microscopy (SEM), and energy-dispersive X-ray spectrometry (EDS) are carried out for all the abutment in both Group I and Group II before and after cyclic loading. The abutment surface at the implant-abutment interface is analyzed for wear. **Results:** On comparison using independent "*t*"-test, it was found that the mean difference values of pre- and post-cyclic loading surface roughness (Ra value) of Group I (premachined titanium straight abutments) (−0.073 µm) was lower than the Group II test samples (premachined PEEK straight abutments) (−0.0004 µm), and this was found to be statistically insignificant ($P = 0.272$). SEM micrographs and EDS results also corroborate with the results of surface profilometry. **Conclusion:** The new concept in this study is Group II (PEEK abutments) are connected with titanium implants, to prove its compatibility and aesthetics. Within the limitations of the study, the surface roughness values before and after cyclic loading of two different abutment materials revealed that the wear resistance of titanium abutments is more than PEEK abutments, but the difference was found to be statistically insignificant.

Keywords: *Abutment, implant-abutment interface, Polyether ether Ketone, scanning electron microscope, surface roughness, titanium*

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Introduction

Rehabilitation of partially and completely edentulous arches utilizing dental implants have become a well-established treatment modality with an overall success rate of 89.7% over 15 years.[1,2] Clinical expertise, techniques, and continued research and development of implant biomaterials have significantly introduced newer avenues in oral implantology.[3,4]

Traditionally, implant abutments are manufactured from the titanium due to its very high resistance to corrosion and good biocompatibility.[5-8] However, due to the metallic nature of titanium, esthetics of the implant restoration is compromised, resulting in graying of the peri-implant tissues, mainly when the soft-tissue thickness is <2 mm.[7,9-11]

The need for improved esthetics led to the development of metal-free abutments, so materials such as ceramics and polymers were used for the manufacturing of implant abutments.[12,13] A common problem that occurred in implant-supported restorations with either metal or zirconia core was chipping of porcelain, which was reduced by the introduction of newer resin-based restorative materials and CAD-CAM technology. Recently, synthetic tooth colored polymeric thermoplastic material named Polyether ether Ketone (PEEK) has gained popularity as a dental restorative material.[5]

PEEK, belonging to the family of PolyArylEtherKetone has good mechanical properties, chemical inertness, biocompatibility, and stress shielding effect.[2,8,14-20] The most beneficial property of PEEK is its elastic modulus, which is equivalent to the elastic modulus of human bone. Considering these properties, implants and its abutments are fabricated using PEEK.[4,19]

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The most important physical property of restorative material is its wear resistance. The various factors influencing the wear of the material are its contact, surface roughness, velocity, load, temperature, and lubrication.[11,20,21]

Most of the abutments fail at the area of connection.[7,22] When abutment with internal conical connection are used, and the force is applied at the angle of 30° to implant axis, representing the maxillary anterior region, the output load applied in this area of the internal cone of the abutment.[7] Thus, stress concentration and torque are higher in the internal cone of the abutment, which explains the failure of abutment at the area of connection.[7]

In the anterior region, bite forces were found to be 140 N. The physiological maximum incisor biting forces may be up to 290 N depending on facial morphology and age.[23,24] The simulation of mastication is a preclinical method of studying the materials and devices which create forces comparable to those which develop during horizontal and vertical components of masticatory motion. Cyclic loading tests have been employed to simulate clinical loading conditions. The irregularities generated during manufacturing may be minimized by mechanical cycling.[20,25]

In the study performed by Stimmelmayr *et al.*,[11] the wear of the interface of titanium implants connected with one-piece zirconia and titanium abutments were measured.[11] scanning electron microscopy (SEM) micrographs were used to analyze the wear before and after cyclic loading; only minimal wear or abrasion was noticeable on the titanium abutment than one piece zirconia abutment.[11] The metal erodes and wears when the ceramic and metal meets. SEM analysis alone cannot confirm this, because it might have occurred during the test due to the amount of debris created.[11,20]

A similar study performed by Sampaio *et al.*,[26] revealed that PEEK showed a lower wear rate under two-body abrasion test than Ti6Al4V by testing between the two materials. Here, in this study, we compared the abrasion at implant-abutment connection area with Ti implant-Ti abutment and Ti implant-PEEK abutment.

Previous studies done by Najeeb *et al.*,[4] reported that PEEK dental implants have lesser stress shielding compared to Titanium dental implants and mentioned that PEEK can also be used as permanent abutment material.

Here, in this study, we tested the compatibility between Titanium dental implants and PEEK abutment at the implant-abutment connection area when compared with Titanium implants and Titanium abutments.

In the present study, SEM and energy dispersive X-ray Spectrophotometry method is used for the wear analysis. Surface profilometry is also used in this study as an additional tool for quantitative assessment of surface roughness (Ra value) of abutments, which were dynamically loaded. Surface roughness correlates with the wear behavior of the abutment material.[11]

In light of the above, the aim of this present study is a comparative evaluation of the wear resistance of two different abutment materials with the effect of cyclic loading, thereby it shows the compatibility between Ti implant-PEEK abutment compared with Ti implant-Ti abutment.

The null hypothesis is as the elastic modulus of PEEK is lower than the titanium, the wear of the PEEK abutment will be expected to be higher when compared to the titanium abutment.

Methodology

Twenty titanium implants with standard platform, internal hexagon, tapered, 4.2 mm diameter, 10 mm length (NORIS dental implants) were embedded in the autopolymerizing acrylic resin block after positioning in the center of the custom made stainless steel block [Figure 1] using dental surveyor (Saeshin precision Ind., Co., Korea) [Figure 2]. The implant shoulder was 2 mm above the resin, to mimic oral conditions with minimal bone loss in Type III cancellous bone. Ten titanium straight abutments (Group I) [Figure 3a] and ten PEEK (Group II) [Figure 3b] straight abutments, both groups with 4.0 mm wide and 9 mm long were connected to these implants with the torque of 35 Ncm using a calibrated torque controller based on ISO 14801:2007 standard.[20]

Reference points were marked for orientation in the resin blocks and for testing on the abutments at the implant-abutment interface, where they emerged from the implant and 90° from the mid labial point of loading.

The test samples were subjected individually to three dimensional (3D) surface profile scanning before cyclic loading, which was measured at the mid labial point of

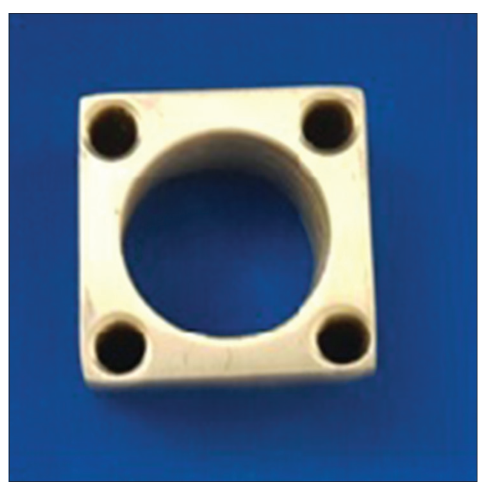

Figure 1: Custom made Stainless steel block 29 mm ×29 mm ×18 mm with a cylindrical mold space of diameter 23 mm and depth of 18 mm

the abutment-implant interface with a reference point from where 90• point at the implant-abutment interface using a 3D noncontact profilometer. The average surface roughness (Ra) value of each sample was obtained. The magnification of the optical lens was standardized at ×50 for all the samples. Each sample was placed under the objective lens, and resultant pictograph was obtained. This image was viewed as 3D and advanced 3D views using advanced aspheric analysis software.

Each test sample was gold-sputtered, and SEM images were obtained at the reference point by SEM S-3400N (Hitachi high technologies corporation, Japan) at 10 Kv acceleration voltages. Images are obtained at different magnification such that the implant abutment interface area of each test sample could be visualized either completely under a lower (×30) or a specific area could be visualized under suitable higher magnification (×200, ×500, ×1000) in separate images to aid in accurate measurement of the interface wear subsequently [Figures 4 and 5].

Cement retained Ni-Cr single crowns of uniform dimensions for each of the Group I and Group II abutments were fabricated and cemented with GIC (GC Corporation, Tokyo, Japan).[27,28] Then the test sample was subjected to cyclic loading [Figure 6]. A sinusoidal waveform at 2 Hz for load up to 200N (approximately) simulating human masticatory frequency and loads was applied 3 mm below the incisal edge. The angle of loading and applied force were representative of Class I anterior occlusion and induced a second lever effect on the internal cone of the abutment at the labial side. This cycle was continued for 72 h (with a break of 2 h, every 21 h) simulating 5,50,000 cycles, which was approximately 1 year of function. The sample cross-checked for any damage for every 10 h. The cyclic loading was performed in a dry environment. This procedure was repeated for all the twenty test samples.

These abutment test samples were disconnected from the implants and visually inspected for any damage or deformation. Then again, 3D surface profilometry, SEM, and energy-dispersive X-ray spectrophotometry were carried out as stated above for all the twenty abutment samples. After the cyclic loading with 5, 50,000 cycles the micrograph of the SEM shows striations caused by wear of abutment surface at the implant-abutment interface [Figures 7 and 8].

Results

The data obtained were tabulated using Microsoft Excel and SPSS software (IBM, NewYork, USA).

Qualitative and quantitative assessment of abutments at the implant-abutment interface for both the groups were evaluated using Surface profilometry, SEM, and Energy Dispersive X-ray Spectrophotometry before and after cyclic loading.

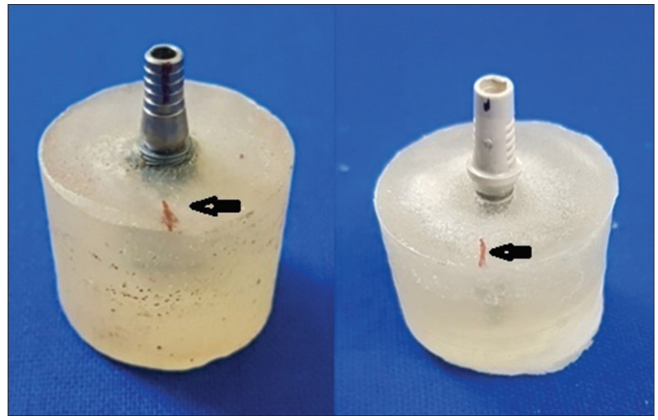

Figure 2: Placement of implant abutment assembly in a the stainless steel block and autopolymerizing resin pour

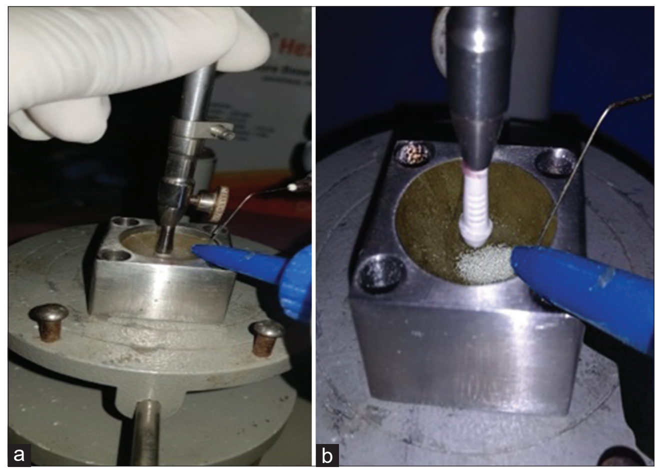

Figure 3: Implant abutment assembly with reference marks for reorientation in mounted resin blocks. (a) Titanium abutment, (b) Polyether ether Ketone abutment

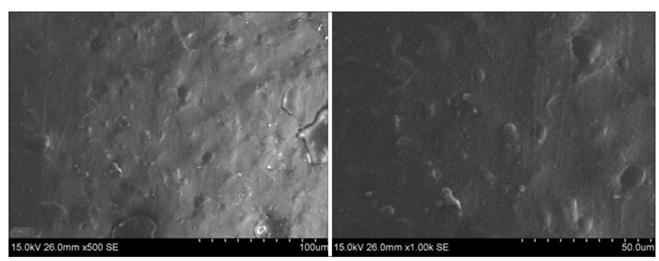

Figure 4: Scanning electron microscopy image before loading (Group I)

On comparison using Independent "*t*" test, it was found that the mean difference values of pre and postcyclic loading Surface roughness values (Ra value) of Group I (−0.073 µm) [Table 1] was lower than the Group II test samples (−0.0004 µm) [Table 2] and this was found to be statistically insignificant(P = 0.272) [Table 3].

The qualitative observations were made using SEM images. SEM micrographs taken before and after cyclic loading at ×30, ×200, ×500, ×1000 shows patterns of wear in both the titanium and PEEK. At high magnification, the intensity and size of the wear could be seen. SEM micrograph

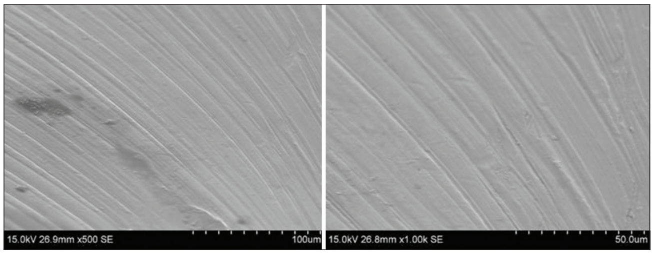

Figure 5: Scanning electron microscopy image before loading (Group II)

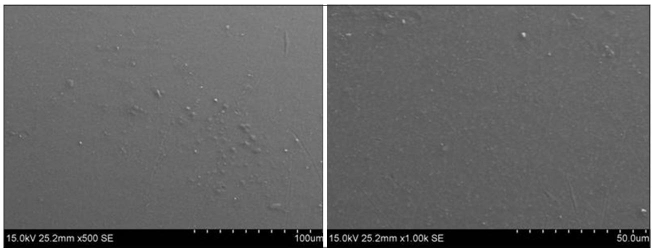

Figure 7: Scanning electron microscopy image after loading (Group I)

of Group I test sample before cyclic loading revealed patchy irregularities and presence of voids under ×500 and at ×1000, it appeared as sparsely distributed voids which indicating the rough surface and after cyclic loading revealed micro irregularities and diminution of voids under ×500 and at ×1000, it appeared as sparsely distributed diminished voids indicating higher wear rate compared to pre cyclic loading. SEM micrograph of Group II test sample before cyclic loading revealed micro striated irregularities under ×500 and at ×1000, it appeared as sparsely distributed striations indicating smoother surface and after cyclic loading revealed increased micro striated irregularities under ×500 and at ×1000 it appeared as sparsely distributed striations indicating changes in surface topography which exhibits slightly higher wear compared to preloading. Energy-dispersive X-ray spectrometry (EDS) results of Titanium abutment before loading indicates the presence of 100% Titanium and after loading indicates the presence of 83.94% titanium. EDS results of PEEK before loading indicates the presence of 100% carbon and after loading indicates the presence of 66.04% carbon. The overall analysis shows lesser wear of titanium abutments compared to PEEK abutments. Titanium abutment shows wear resistance higher than that of PEEK abutments, but the difference between these two implant abutment materials does not show any statistical significance. The overall result of the present study revealed that PEEK abutment can also be used as a permanent abutment with titanium implant.

Discussion

Implant dentistry has become a trend and going through significant developments in past decades. The success criteria for the implant restorations were believed to be the osseointegration then the focus has gradually changed and

Figure 6: Cyclic loading of test samples with cemented Ni-Cr crowns

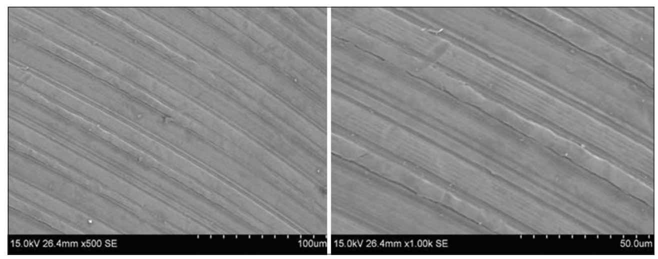

Figure 8: Scanning electron microscopy image after loading (Group II)

included a variety of mechanical and esthetic challenges. Mechanically there should be healthy, harmonious and maintainable interface between the implant-supported restorations and the peri-implant tissues. Esthetically, the parameters considered are color and shape of restoration, topography and appearance of soft tissues.[5,29,30]

A study conducted by Truninger *et al*.[31] also demonstrated that both the abutment material and type of connection influence the bending moments of abutments after aging and chewing simulation.

PEEK has very high mechanical resiliency and resistant to corrosion and also has shock absorption properties. Due to its excellent chemical stability, resistance to the radiation used in sterilization procedure and transparency to radio waves, compatibility with reinforcing agents, PEEK is considered as the best alternative material to titanium in constructing implant abutments.[4,8,17,32]

A study by Rea *et al*.[6] evaluated the marginal soft and hard tissue healing at titanium and PEEK healing abutments over a 4 months period, which shows that when using PEEK as healing abutments, the risk for marginal bone loss and soft tissue recession during the healing period is not increased.[6]

Stawarczyk *et al*.[33] suggested PEEK in the fabrication of fixed partial denture. Hahnel *et al*.[5] investigated the formation of biofilms on different implant-abutment materials and found that even though PEEK has high

Table 1: Comparative evaluation of the mean precyclic loading and postcyclic loading surface roughness values for Group I test samples (Premachined Titanium straight abutments)

Group I (premachined titanium straight abutments)	Number of samples	Mean surface roughness value (Ra) (µm)	Standard Deviation	*P*
Preloading	10	0.422800	± 0.14	0.140
Postloading	10	0.495400	± 0.14	

P=0.140; insignificant at 5 level. Inference: On comparison using Paired *t*-test, it was found that the mean postcyclic loading Surface Roughness (Ra) Value of Group I test samples was higher than the mean precyclic loading Surface Roughness (Ra) Value and this was found to be statistically insignificant (*P*=0.140)

Table 2: Comparative evaluation of the mean precyclic loading and postcyclic loading surface roughness values for Group II test samples (premachined Polyether ether Ketone straight abutments)

Group II (Premachined PEEK straight abutments)	Number of samples	Mean surface roughness value (Ra) (µm)	Standard Deviation	*P*
Preloading	10	0.232620	0.10	0.976
Postloading	10	0.233000	0.091	

P=0.976; insignificant at 5 level. Inference: On comparison using Paired *t*-test, it was found that the mean postcyclic loading Surface Roughness (Ra) Value of Group II test samples was the same as the mean precyclic loading Surface Roughness (Ra) Value and this was found to be statistically insignificant (*P*=0.976). PEEK: Polyether ether Ketone

Table 3: Comparative evaluation of the mean difference values of pre and postcyclic loading Surface roughness (Ra value) of Group I (Premachined Titanium straight abutments) and Group II test samples (Premachined Polyether ether Ketone straight abutments)

Group	Number of samples	Mean surface roughness value (Ra) (µm)	SD	*P*
I surface roughness (Ra) value	10	−0.072600	0.1420408	0.272
II surface roughness (Ra) value	10	−0.000380	0.0387657	

P=0.272, insignificant at 5 level. Inference: On comparison using Independent *t*-test, it was found that the mean difference values of pre and postcyclic loading Surface roughness (Ra value) of Group I (Premachined Titanium straight abutments) was lower than the Group II test samples (Premachined PEEK straight abutments) and this was found to be statistically insignificant (*P*=0.272). SD: Standard deviation; PEEK: Polyether ether Ketone

surface free energy than other abutment materials, the biofilm formation on the surface of PEEK is not higher than the zirconia and titanium. He suggested PEEK abutments to be used as a definite abutment material.[33]

In light of the above, the aim of the present study was to comparatively evaluate the effect of cyclic loading on implant-abutment interface of two different materials. The hypothesis for the present study was that, since the elastic modulus of PEEK is low, there will be more wear in the PEEK abutment when compared with the titanium abutments. A previous study examined the wear effects of dynamically loaded external connection titanium abutment with loose ceramic abutments and found that wear does occur between the components.[34]

Since the abrasive resistance of PEEK is also excellent when compared to other metals. In this study, we used premachined PEEK abutments connected with titanium implants and compared them with a group that contains premachined titanium abutments connected to titanium implants. To evaluate the 1 year simulation of clinical situation indicating the mastication, the abutments were cyclically loaded and analysed the effect of whether there is plastic deformation and wear when two different materials were connected.[4,6,13,32,33]

The methodology employed in the present study was able to quantify the wear at the implant-abutment interface. Sterile titanium dental implants of the same dimension with an internal hexagon design were employed for standardization of the implant fixtures. The internal hexagonal connection system was selected because of its following advantages: Ease in abutment connection, suitability for one-stage implant installation and single-tooth restoration, higher stability, and restoration to lateral loads due to the lower center of rotation and better stress distribution than external hexagon implant connection systems. Premachined straight abutments were selected for both the test groups simulating the clinical situation of maxillary anterior teeth.

Klotz *et al*.[20] stated that differences in the mechanical properties and designs could lead to wear at the interface. The quantitative measurements were made using SEM images. So, for analysis surface profilometry, SEM and Energy Dispersive X-ray spectrophotometry were carried out. These values were designated as pre cyclic loading surface roughness values, namely Pre-Ra $value_1$ and Pre-Ra $Value_2$ for Group I and II test samples, respectively. Then the abutments were connected to implants with 35 N cm torque value.[20] Then the Ni-Cr cast restorations were cemented.

A cyclic load between 0 and 200 N was applied at a loading rate 2 Hz to simulate the force acting on maxillary anterior teeth. Loading done simulated 1 year of clinical loading based on previous literature on cyclic loading study.[7,20]

The forces applied were at 30º inclination to the crown to stimulate the functional stresses along the central incisor root angulations. To achieve this nonaxial loading force for maxillary anterior region between 30° and 40° angulations, a custom made positioning jig was used in the present study. Following cyclic loading, each test sample was subjected to visual and tactile inspection for any deformation, decementation, and abutment rotation or loosening as recommended in the previous studies. The restorations were decemented.

After cyclic loading, quantitative and qualitative analyses were carried out for the samples of both the Groups. The post cyclic loading surface roughness values were measured and designated as Post-Ra Value_1 and Post-Ra $\text{Value}_{2,}$ respectively, for Group I and Group II samples. Further, the mean Surface Roughness value Difference (Ra Value D) was obtained for both the test groups to assess the rate of wear. The data were analysed statistically using SPSS Software (version 20.0) (IBM, NewYork, USA).

In the present study, (Ra Value) the mean surface roughness value which indicates the wear rate following cyclic loading demonstrated that Group I test samples had exhibited higher surface roughness value in post cyclic loading compared to precyclic loading and the difference (P = 0.140) is statistically insignificant.

Klotz *et al*. had mentioned in a study that titanium implant connected to titanium abutment showed a lesser wear rate compared to zirconia abutment because the interfacing materials had similar properties. The results of the present study also in line with Klotz *et al*.'s observation that titanium abutment had exhibited lesser wear rate.

The mean precyclic loading and postcyclic loading surface roughness values for Group II test samples (Premachined PEEK straight abutments) were 0.232 μm and 0.233 μm. The mean Surface roughness difference value (Ra value D_2) of Group II test samples (Premachined PEEK straight abutments) was −0.0004 μm.

The surface roughness values between the two groups were compared. Surface roughness difference is the difference between precyclic loading surface roughness value and the post cyclic loading surface roughness value, which was calculated to assess the rate of wear. On comparison using Independent "*t*" test, it was found that the mean difference values of pre and postcyclic loading Surface roughness (Ra value) of Group I (Premachined Titanium straight abutments) (−0.073 μm) lower than the Group II test samples (Premachined PEEK straight abutments) (−0.0004 μm) and this was found to be statistically insignificant (P = 0.272). The comparison of the effect of cyclic loading on the implant abutment interface between two different abutment materials was statistically insignificant. [Table 3] The result of the present study is in line with the study done by Almeida *et al*.[35] on comparative analysis of the wear of titanium/titanium and titanium/zirconia interfaces in implant/abutment assemblies after thermocycling and mechanical loading showed that there was no significant wear in simulating 5 years loading.[35]

SEM micrographs taken before and after cyclic loading at ×30, ×200, ×500, ×1000 shows patterns of wear in both the titanium and PEEK.

EDS results show that the percentage of depletion of titanium (16.06%) from the Titanium abutments is less compared to the percentage of depletion of PEEK (33.96%) from PEEK abutment which indicates lesser wear rate of Titanium abutment when compared to PEEK abutment.

The results obtained from quantitative and qualitative analysis coincide with each other and showed that wear was observed in both Group I and Group II test samples. Group II (PEEK abutment) test samples showed more wear when compared to Group I (titanium abutment) test samples, which might be due to differences in mechanical properties of implant abutment assembly in Group II. However, the differences in wear for both the Groups were statistically insignificant.

Within the limitations of the present study, the results revealed PEEK could also be used as a definite abutment. Thus the hypothesis was rejected as the premachined PEEK straight abutment shows wear rate close to premachined Titanium straight abutments.

The present study had some limitations. The duration of the cyclic loading was only 1 year simulation performed under the dry condition and only premachined abutments were used. A longer loading period may affect the stability of implant-abutment interface. The force employed here in this study is 200N only and the wear may vary with varying degrees of force. Wear of the abutment assessed only at the mid labial point and simulated only the maxillary anterior teeth. The presence of oral fluids may also impact the result differently. Parameters such as microbial leakage and fatigue testing may affect the interface differently.

Further studies are needed to understand the influence of longer periods with larger sample size simulating *in vivo* conditions to add merit to the findings obtained with the present study.

Conclusion

3D Surface Profilometry had revealed that Group I samples have higher wear resistance compared to Group II samples, but the difference in wear resistance is statistically insignificant.

The percentage of depletion of titanium from the titanium abutments is less compared to the percentage of depletion of PEEK from PEEK abutment, which indicates a lesser wear rate of titanium abutment when compared to PEEK abutment.

The present study had revealed statistically insignificant wear among the two implant abutment materials after cyclic loading. Hence, PEEK could prove to be a viable alternative to titanium to use as an implant abutment depending on the clinical condition of the patients.

Clinical significance

1. The surface roughness of PEEK abutments was lower than Titanium, which aids in reduced plaque accumulation and decreased marginal bone loss
2. Within the limitations of this study, wear resistance results of this study showed that PEEK can be used as definite abutments.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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