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In-Vitro Microleakage Evaluation Of Polyetheretherketone (PEEK) Abutments At Implant Abutment Interface (I.A.I)

Dr Vigneswaran Sekar[1], Dr Lakshmi Shivasubramaniam[2], Dr Sendhilnathan Dakshinamoorthy[3], Dr Lambodaran Ganesan[4], Dr Annapoorni Hariharan[5], Dr Sivakumar Ramadoss[6]

[1]Associate Professor, Dept of Prosthodontics and Crown and Bridge, Meenakshi Ammal Dental College, Meenakshi Academy of Higher Education and Research (Deemed to Be University), Chennai drvignesh.prostho@madch.edu.in
[2]Professor, Dept of Prosthodontics and Crown and Bridge, Meenakshi Ammal Dental College, Meenakshi Academy of Higher Education and Research (Deemed to Be University), Chennai
[3]Private Practitioner, Sendhil Dental Clinic and Implant Centre, Chennai
[4]Professor, Dept of Prosthodontics and Crown and Bridge, Meenakshi Ammal Dental College, Meenakshi Academy of Higher Education and Research (Deemed to Be University), Chennai
[5]Professor, Dept of Prosthodontics and Crown and Bridge, Meenakshi Ammal Dental College, Meenakshi Academy of Higher Education and Research (Deemed to Be University), Chennai
[6]Post Graduate Trainee, Dept of Prosthodontics and Crown and Bridge, Meenakshi Ammal Dental College, Meenakshi Academy of Higher Education and Research (Deemed to Be University), Chennai

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ABSTRACT

Aim: To investigate the Microleakage of titanium implants with PEEK abutments, as well as their fracture resistance at 0 and 30-degree loads

Materials and methods: 20 titanium implants with titanium abutments were chosen as the control group (Group A) while 20 titanium implants with PEEK abutments were the test group (Group B). Each group was further subdivided into two subgroups; sub group 1A containing 10 titanium implants with titanium abutments at 0-degree load and sub group 2A at 30-degree load. Sub group 1B had 10 titanium implants with PEEK at 0-degree load and sub group 2B at 30-degree load. Fatigue testing for every group was conducted using Universal Testing Machine and microleakage was assessed using Nano CT

Results: Occlusal loading for 100000 cycles at 1 Hz frequency at 100 N did not cause failure of titanium or PEEK abutments at 0 degree, but it caused relevant vertical deformation in the PEEK abutment at 30 degree which is suggestive of failure of PEEK abutments.

Conclusion: Within the occlusal load limit, there is absence of microleakage in both the Titanium and PEEK abutment samples. But when the occlusal load limits exceed the maximum load, the PEEK abutment fractures leading to microleakage whereas the Titanium abutments had higher fracture resistance compared to that of the PEEK.

KEYWORDS

PEEK abutment, Titanium abutment, implant abutment interface, Microleakage, Nano CT

INTRODUCTION

Dental implant systems, which consist of an endosseous implant and a prosthetic abutment, are becoming increasingly popular and are regarded as a viable treatment option for tooth replacement and fixation.[1] Biofilm formation caused by microorganism accumulation at the implant-abutment interface in two-piece implants will result in bacterial leakage into the implant wells via the microgap between the implant and abutment.[1]

Research has shown that during mastication, this microgap serves as a reservoir for bacteria, causing the release of byproducts and potentially inducing inflammatory reactions in both hard and soft tissues surrounding the implants, triggering inflammatory processes of the peri-implant tissues and affecting the long-term success of osseointegrated implants.[2] It is an important risk factor for complications such as peri-implant inflammation, bone resorption, and central screw loosening.[3] The extent of microscopic leakage along the Implant-Abutment Interface (IAI) may be influenced by a variety of factors, including the accuracy of the implant-abutment relationship, final torque effect, bacterial species, sealing material use, and the micromovements of the various components during masticatory cycles.[4] Thus, improving the sealing ability of IAI from bacterial colonization may be a determinant in long-term success.

Schmitt et al. claimed that nearly no IAI connection method can totally prevent implants from bacterial infection.[5] Furthermore, it has been observed that the use of various abutment components [e.g., titanium, polyetheretherketone (PEEK)] with the positioning of sealing agents such as silicon sealant may affect the degree of microleakage along the IAI.[6]

Quirynen and Von Steenberg's 1993 in vivo study demonstrated Streptococcus sanguinis' capacity to permeate into as well as the implant abutment fixture. These bacteria are typically associated with Candida, a commensal fungus species commonly found in peri-implant biofilms that infiltrate mucosal and oral tissues only if the host's defences are compromised.

It has been discovered that bacteria detected surrounding implants in the oral cavity of individuals with clinical indications of periimplantitis have a microbiome pattern identical to that found in natural teeth damaged by periodontitis.[2]

Broggini et al. discovered invasion of white blood cells surrounding the implants, which varies depending on the implant type. Wachtel et al. investigated bacterial leakage at the implant-abutment interface (IAI) of two-piece prosthetic systems using an Enterococcus faecium suspension prior to abutment attachment. Bacterial leakage occurred prior to cyclical loading in three of the seven implants. Rismanchian et al. examined the microgap extent and microbial leakage in the surrounding area of four different abutments to International Team for Implantology (ITI) implants.[4]

The authors discovered a considerable mean microgap size in various types of abutments, as well as an average number of leak out colonies, by combining the implant and abutment surfaces. A wide variety of microorganisms, including gram-positive cocci and gram-negative rods (Bacteroides species, Fusobacterium species, and Peptostreptococcus micros), have been discovered to penetrate the implant abutment contact and are associated with peri-implantitis.[4]

Several studies have found that the kind of abutment material utilized minimizes microleakage at the implant-abutment interface. Studies have revealed that PEEK abutments have a lower incidence of microleakage and a higher fracture resistance than other materials. Thus, the purpose of this study was to investigate the microleakage of titanium implants with PEEK abutments, as well as their fracture resistance at 0 and 30-degree loads.

MATERIALS AND METHODS

For the present study, Titanium implants with 11 degree tapered conical connection was chosen (4.2*11.5 Neodent Straumann Implant). 20 titanium implants with titanium abutments were chosen as the control group (Group A) while 20 titanium implants with PEEK abutments were the test group (Group B).

Each group was further subdivided into two subgroups; sub group 1A containing 10 titanium implants with titanium abutments at 0-degree load and sub group 2A at 30-degree load. Sub group 1B had 10 titanium implants with PEEK at 0-degree load and sub group 2B at 30-degree load. Fatigue testing for every group was conducted using Universal Testing Machine and microleakage was assessed using Nano CT (Burker Skyscan 2214 Nano CT) analysis.

Titanium and PEEK abutments were fixed with the implants respectively at 30N torque which was then subjected to thermocycling. Each implant with the abutment was embedded in acrylic resin at a level of 3mm below the implant platform. The protruding parts of all the samples were immersed in 1ml of silver nitrate solution and then placed on top of the sample holder using a cylindrical container, after which the samples were left at room temperature overnight. Before loading the samples were subjected to microleakage test using Nano CT (Fig 1a and Fig 1b). Since there was no leakage observed before loading, the same samples were used for the further proceedings. A ball-shape load adapter made of cobalt chromium was inserted onto the abutment to simulate the prosthesis, the center of which was 12 mm above the platform (Fig 2a and Fig 2b).

For the subgroups; 1A and 1B, cyclic loading was done at 0 degree for 100000 cycles at 1 HZ frequency at 100 N (Fig 3a and Fig 3b). For the subgroups; 2A and 2B cyclic loading at 30 degrees for 100000 cycles at 1 Hz frequency at 100 N was done. After each cyclic loading Nano CT analysis to test microleakage of all the sub-groups was done.
Finally, Fracture resistance test was conducted using Instron Machine (Instron Electronplus E3000 UTM) until fracture at 0 degree for Sub Group 1A and 2A and until fracture at 30 degrees for Sub Group 1B and 2B, after which the samples were analyzed using Nano CT analysis. The data from the results were collected and compared.

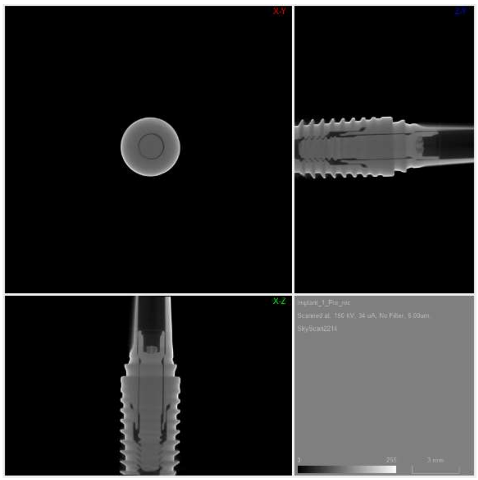

Fig 1a– Pre Load Nano CT of Ti Implants and Abutments shows no Leakage

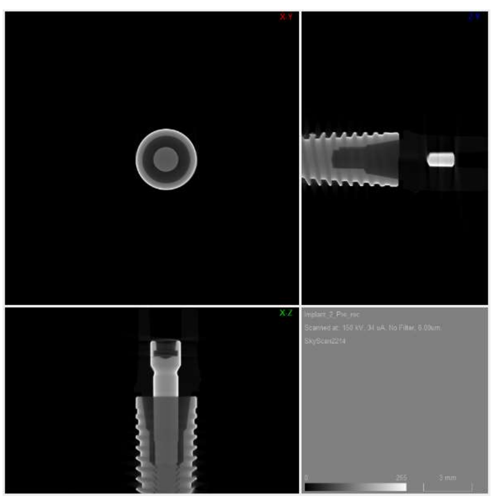

Fig 1b– Pre Load Nano CT of Ti Implants and PEEK Abutments shows no Leakage

RESULTS

To evaluate leakage at IAI, Nano CT image analysis is done. A mean score was calculated for each load and then the results of the all subgroups were compared to find the best results.

Fig 2a – load Adapter with Ti Implant Ti abutment

Fig 2b – load Adapter with Ti Implant PEEK abutment

Fig 3a – Cyclic loading of Ti Implant Ti abutment at 0 degree

Fig 3b – Cyclic loading of Ti Implant PEEK abutment at 0 degree

Statistical analysis was done using SPSS Software version 25.0. Paired t test was used for intra group comparison and independent t test was used for intergroup comparison. The level of statistical significance was kept as p value less than or equal to 0.05. When seepage was observed under Nano CT, all the test groups; 1A and 2A, at 0 degree occlusal load for 100000 cycles at 1 Hz frequency at 100 N, showed no seepage of the silver nitrate solution into the implant abutment interface

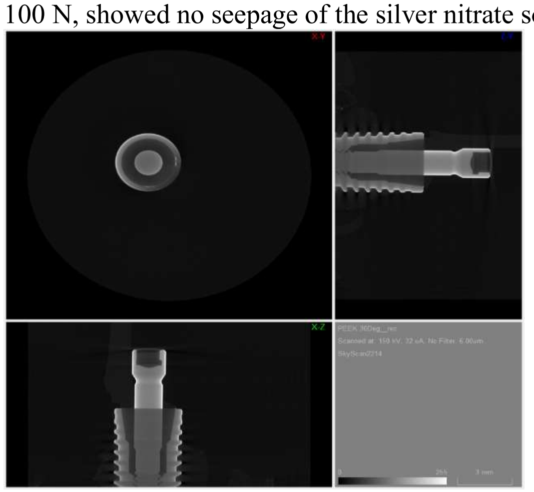

Fig 4 – Microleakage visible at IAI in Peek abutments after fracture at 30 degree load

The test group 1B at 30 degree occlusal load for 100000 cycles at 1 Hz frequency at 100 N, showed no seepage of the silver nitrate solution into the implant abutment interface whereas in the group 2B, there was tendency of seepage after the fracture of the abutment.

Thus, it was observed that when the load applied to the crown is at 0 degree, there was no tendency of microleakage in the titanium implant abutment interface and the titanium implant with PEEK abutment interface. However, when the eccentric load was applied at 30 degree and after the fracture of the abutment, tendency for microleakage was observed in the titanium implant with PEEK abutment interface and not in the titanium implant abutment interface.

Table 1 and Table 2 depicts the descriptive status of the test groups using mean and standard deviation values. From the tables, it can be observed that the mean fracture resistance values at 0 degree were 969.3980 and at 30 degree were 841.1260 for all the titanium samples, (Table 1) whereas, for PEEK; values at 0 degree were 515.5430 and at 30 degree was 403.3250 (Table 2)

Descriptive Statistics – Group 1					
	N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Maximum force at 0º	10	898.27	1042.54	969.3980	50.03003
Compressive strength at 0 º	10	96.25	113.01	105.3070	5.11638
Maximum force at 30 º	10	780.10	910.01	841.1260	44.04836
Compressive strength at 30 º	10	80.28	100.21	91.6940	5.93860

Table 1

Descriptive Statistics – Group 2					
	N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Maximum force at 0 º	10	470.29	555.20	515.5430	26.33589
Compressive strength at 0 º	10	35.01	44.80	40.8500	2.97800
Maximum force at 30 º	10	377.78	424.76	403.3250	15.41801
Compressive strength at 30 º	10	26.72	33.01	31.3640	1.88707

Table 2

Intragroup comparison between the groups was done using paired t test. When the maximum force for fracture resistance and the compressive strength at 0 degree and 30 degree were compared for group 1, p values were observed to be significant which shows that the fracture resistance was better for titanium samples which in turn shows no significant seepage in the implant abutment interface (Table 3)

Group 1 (Paired t test)	N	Mean	Std. Deviation	p-value
Maximum force at 0 º	10	969.3980	50.03003	**0.000***
Maximum force at 30 º	10	841.1260	44.04836	
Compressive strength at 0 º	10	105.3070	5.11638	**0.001***
Compressive strength at 30 º	10	91.6940	5.93860	

Table 3

When the maximum force for fracture resistance and the compressive strength at 0 degree and 30 degree were compared for group 2, p values were observed to be significant which shows that the fracture resistance was comparatively less for PEEK samples which in turn shows significant seepage in the implant abutment interface (Table 4)

Group 2 (Paired t test)	N	Mean	Std. Deviation	p-value
Maximum force at 0 º	10	515.5430	26.33589	**0.000***
Maximum force at 30 º	10	40.8500	2.97800	
Compressive strength at 0 º	10	403.3250	15.41801	**0.000***
Compressive strength at 30 º	10	31.3640	1.88707	

Table 4

Intergroup comparison was done using independent t test. (Table 5). The mean value for maximum fracture resistance force at 0 degree for group 1 was 969.39 and group 2 was 515.543. The mean value for compressive strength test at 0 degree for group 1 was 105.30 and group 2 was 40.85 which indicates that the fracture resistance was better for group 1 when compared to that of group 2. The p-values were statistically significant at 0.000.

The mean value for maximum fracture resistance force at 30 degree for group 1 was 841.12 and group 2 was 403.32. The mean value for compressive strength test at 30 degree for group 1 was 91.694 and group 2 was 31.364 which indicates that the fracture resistance was better for group 1 when compared to that of group 2. The p-values were statistically significant at 0.000.

Independent t test	Groups	Mean	Std. Deviation	p-value
Maximum force at 0 º	**Group 1A**	969.3980	50.03003	**0.000***
	Group 2	515.5430	26.33589	
Compressive strength at 0 º	**Group 1**	105.3070	5.11638	**0.000***
	Group 2	40.8500	2.97800	
Maximum force at 30 º	**Group 1B**	841.1260	44.04836	**0.000***

	Group 2	403.3250	15.41801	
Compressive strength at 30 º	**Group 1**	91.6940	5.93860	**0.000***
	Group 2	31.3640	1.88707	

Table 5

Occlusal loading for 100000 cycles at 1 Hz frequency at 100 N did not cause failure of titanium or PEEK abutments at 0 degree, but it caused relevant vertical deformation in the PEEK abutment at 30 degree which is suggestive of failure of PEEK abutments.

DISCUSSION

Many implant-abutment connection solutions have been created in an effort to reduce the microgap and improve the integrity of the abutment. Studies show that the connection with the highest risk of bacterial microleakage is the exterior one.[7]

Several studies support the idea that, in comparison to external and internal hexagon connections, there may be less bacterial invasion in Morse Cone connections. Morse taper connection implants demonstrated less microleakage over external connection implants, according to Verdugo et al.[7]

After analyzing 55 publications, Lauritano et al. conducted a narrative analysis and concluded that conical connectors performed better in terms of bacterial sealing.[7] Therefore, titanium implants with an 11-degree tapered conical connection were selected for our investigation.

Sen et al. showed that, in unloaded settings, zirconia external samples exhibited greater resistance to bacterial leakage than titanium external abutments. In their assessment of ten polyetheretherketone (PEEK) abutment–crown–complex connections with conical design, Wachtel et al. found that no contamination happened during the course of the follow-up period. PEEK, being an elastic material with a relatively low elastic modulus of 3.5 GPa, may be the perfect abutment material to avoid micromovements along the IAI when compared to high stiffness materials like titanium and zirconia, which have elastic moduli of 110 GPa and 210 GPa, respectively. Martinez et al. did, however, claim that titanium groups outperformed PEEK material in terms of mechanical qualities and microbiological tightness. For this reason, PEEK and titanium abutments were the preferred materials for our investigation.[8]

One commonly accepted technique for in vitro microleakage research is thermocycling. Specimens are subjected to thermal cycles that replicate the intraoral temperature in the thermocycling procedure. Some oral thermal stressors may be simulated by thermocycling, although not in the same way as they are in vivo. Thermocycling should be utilized in In-vitro investigations to imitate the oral environment because it was shown to have at least some influence on in vitro samples, but occasionally statistically insignificant (Ongthiemsak et al. 2005).[9]

Implant-retained crowns and abutments develop fatigue by masticatory forces, which can have a negative impact on retention. It is significant to note the relationship between the retentive forces and the number of load cycles. In this study, application of compressive cyclic loading for 1000000 cycles was given which amounted to roughly two months of human mastication.[10]

Constant technological developments in CT system development have made ultra-high spatial resolution "nano-CT" devices possible. The interior ultrastructure of bone trabeculae and submicron hard tissue fissures, as well as features at the level of individual cells, can be clearly visualized using the nano-CT technology. Another benefit over micro-CT is the capacity to obtain faster images. Cuijpers et al. assessed the nano-CT system's sensitivity and spatial resolution using a dog dental implant model. The findings verified the system's high resolution in line with histological evaluations. Sub-micron structures buried in radiodense matrices could be seen using nano-CT.[11]

Numerous studies have demonstrated that on CT scans, silver nitrate showed greater intensity than either pure titanium or its alloy, suggesting that it might be utilized as a contrast agent to examine micro-leakage at the interface between the implant and abutment.[12] This study uses silver nitrate solution to analyze microleakage at the implant abutment interface because its contrast is higher than PEEK's.

In the current investigation, titanium abutments exhibited a much lower incidence of microleakage compared to PEEK abutments. When exposed to occlusal forces, the optimal abutment and implant interface ought to decrease the gap between components. According to the current research, there may be more space between the PEEK abutment and titanium implant during functional use than there is between the titanium abutment and titanium implant junction.

Triveni et al. evaluated the bacterial seepage of two distinct internal implant abutment associations that responded differently to dynamic loading and solely used internal hexagonal and trilobe connections. According to their research, microgaps serve as entry points for germs that cause implant failure. To increase the success rates of implants, microgaps ought to be avoided. The findings of this study are consistent with our findings, which demonstrates the presence of seepage in the PEEK abutment-implant interface.[4]

In their assessment of ten polyetheretherketone (PEEK) abutment–crown–complex linkages with conical design, Wachtel et al. found that no contamination happened during the course of the follow-up period. PEEK may be a better abutment material than high stiffness materials like zirconia and titanium if you want to stop micromovements across the IAI. Nonetheless, Martínez et al. proposed that titanium groups exhibited superior mechanical qualities and microbiological tightness when compared to PEEK material, which aligns with our research findings.[7]

In an in vitro investigation, Ortega-Martínez et al. assessed PEEK's mechanical and functional qualities as dental implant abutments, allowing it to be utilized as a nonmetallic substitute for titanium abutments. They discovered that, in contrast to PEEK, which had a 50% torque loss, the torque loss with titanium abutments was only about 10%. Just 8.4% of the titanium abutments exhibited microleakage under dynamic loading, compared to 100% of PEEK abutments. The same results were observed from our experiment. PEEK showed microleakage at 30 degree occlusal load when compared to that of titanium.[8]

In an in vitro investigation, Matos et al. assessed the biomechanical behavior of various PEEK abutment sizes on titanium implants. They came to the conclusion that because PEEK abutments only withstand mild forces, they should be employed carefully. PEEK abutments displayed a significant vertical displacement along with plastic strain at the abutment-implant junction. They recommended that PEEK abutments only be used for temporary restorations in individuals who need anterior rehabilitation and do not have parafunction.[9]

The wear resistance of titanium and PEEK implant abutments during cyclic stress was examined by Ragupathi et al. They discovered that PEEK abutments are less wear-resistant than titanium abutments, the difference is not statistically significant. Our investigation yielded statistically significant findings when comparing the contact between the titanium implant abutment and PEEK.[8]

In their work using immunohistochemistry and histology, Milinkovic et al. examined how the soft tissues responded to healing abutments made of PEEK and titanium. It was discovered that the PEEK abutments appeared to elicit a strong inflammatory response. The inflammatory response was milder in this instance of titanium healing abutments.[7]

This study's limitation was that the test groups' leakage volumes were not measured. To verify PEEK as a substitute material for producing temporary abutments in various clinical settings, more investigation is required. Owing to the scant data from the research that are now available, the sealing capacity of various materials is still unknown. More homogeneous, well-conducted in vitro research is necessary.

There aren't many in vivo studies that contrast titanium and PEEK abutments. PEEK has not been favored as a certain abutment since the majority of research on PEEK as an abutment material has been conducted in vitro. To determine whether PEEK is a viable substitute for titanium, longer-term in vivo investigations are required with PEEK serving as a definitive abutment.

CONCLUSION

From the results of the present study considering its limitations, we can conclude that within the occlusal load limit, there is absence of microleakage in both the Titanium and PEEK abutment samples. But when the occlusal load limits exceed the maximum load, the PEEK abutment fractures leading to microleakage whereas the Titanium abutments had higher fracture resistance compared to that of the PEEK and did not have leakage. Although the minimum load required to bridge the internal implant space was within the range of human biting force, the relation between bacterial invasion and micro-gaps needs further research.

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