ORIGINAL ARTICLE

An *in vitro* evaluation of microleakage in platform-switched implants at implant–abutment interface by contamination assessment of implant wells and respective abutment surfaces

V Yamuna, Roseline Meshramkar, R D Kulkarni[1], Manjunath A Hosamani[1], K Lekha, Ramesh K Nadiger, Nagarajan Chidambaram

ABSTRACT

Background and Objectives: In contemporary implant dentistry, the success of implant treatment is assessed by measuring the crestal bone level apart from osseointegration. Peri-implant bone plays a vital role in the esthetics of implant restorations. With loss of peri-implant bone, soft tissue loss happens which eventually compromises the esthetics and mechanical properties of restorations. To prevent marginal bone loss, many inventions are made by modifying the implant designs, implant–abutment connections, and techniques. Platform-switched concept is one such invention evolved to prevent peri-implant bone loss. This beneficial effect of platform-switched implants was studied by many researchers. However, few studies were reported in the literature on microleakage in platform-switched implants. Thus, the purpose of this study is to evaluate microleakage at implant–abutment interface in platform-switched implants.

Materials and Methods: Fifteen in-built platform-switched implants and corresponding abutments with internal hexagonal design were connected using screws. After the confirmation of the sterility of the implants and abutments, the assemblies were incubated in brain–heart infusion broth inoculated with *Staphylococcus aureus* for 14 days at 37°C. After 14 days, the implants and abutments were disassembled. Samples were collected from three different sites, i.e., walls of the wells of the implants, the deepest portion of the wells of the implants, and the surface of the abutments with help of paper points. Using the samples, colony counting and Gram staining were done to evaluate the microleakage at the implant–abutment interface.

Results: Microbial contamination was found to be present at all the sites from which samples were collected. $P < 0.05$ was found when the different sites were compared with each other. The abutment surface found to have the least contamination, and the walls of the implant wells found to have the highest contamination.

Conclusion: Within the limitations of this study, it was concluded that microleakage is present in the platform-switched implants with screw-retained internal hexagonal connections at the implant–abutment interface.

Department of Prosthodontics, SDM College of Dental Sciences and Hospital, [1]Department of Microbiology, SDM Medical College and Hospital, Dharwad, Karnataka, India

Address for correspondence: Dr. V Yamuna, Department of Prosthodontics, SDM College of Dental Sciences and Hospital, Dharwad, Karnataka, India. E-mail: vyamunalg@gmail.com

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KEY WORDS: Implant–abutment interface, internal hexagonal connection, platform-switched implants, screw retained

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INTRODUCTION

The prime goal to reduce peri-implant crestal bone loss led to the discovery of the concept of platform switching into implant dentistry. Platform switching refers to the use of smaller-diameter abutment on larger-diameter implant collar.[1] Due to inward repositioning of the implant–abutment interface in platform-switched implants, the peri-implant bone loss is less. Added to that, the stress concentration area is away from the cervical bone–implant interface.[2]

In 2006, Lazzara and Porter[3] introduced this amazing platform-switching concept into implantology for the very first time. They described the concept as an inward metal ring in the coronal part of the implant that is in continuity with the alveolar bone crest.

The various advantages[4] of platform-switched implants are shifting the stress concentration away from the bone–abutment interface, crestal bone preservation, and controlled biological space reposition which leads to improved esthetics of the restoration.

The platform-switched implant system is of great significance because peri-implant bone level is the paramount factor[5] in determining implant success. As stated above, one of the advantages of platform-switched implants is the preservation of peri-implant bone. The platform-switched concept has two-stage implant system like other nonplatform-switched systems.[6] The implant–abutment interface of nonplatform-switched system is prone to microleakage and bacterial trap. This will in turn cause inflammatory reaction in peri-implant soft tissue and interfere with osseointegration by causing peri-implant bone loss in nonplatform-switched system. One of the prime causative factors for peri-implantitis is microleakage along the implant–abutment interface.[7]

Microleakage[8] is defined as leakage of minute amount of fluids, debris, and microorganisms through the microscopic space between a dental restoration or its cement and the adjacent surface of the cavity preparation.

A number of investigators tried to quantify bacterial leakage of different implant systems using microorganisms such as *Staphylococcus aureus* or molecules such as endotoxin, rhodamine B, toluidine

Figure 1: Implant used in the study

Figure 2: Biosafety cabinet 2A2

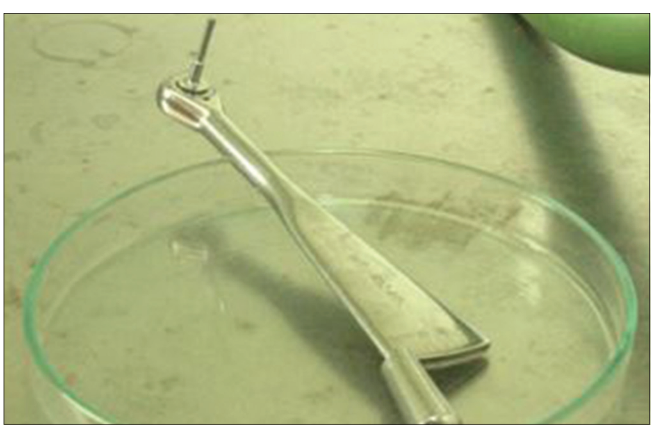

Figure 3: Finger key and manual torque wrench

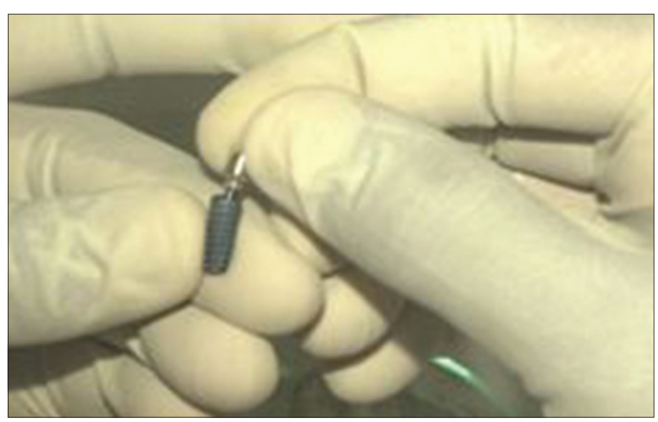

Figure 4: Connecting the implant with the abutment

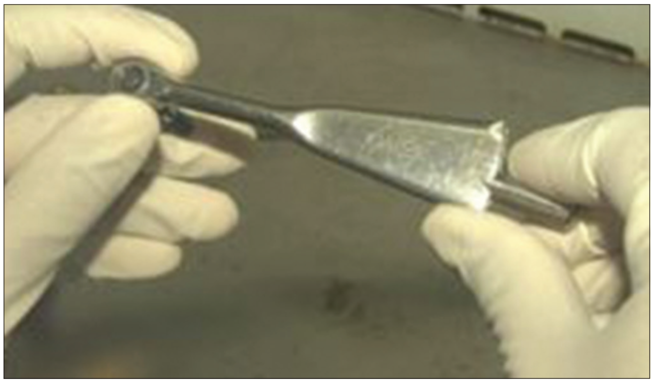

Figure 5: Abutment torqued with implant at 30 N

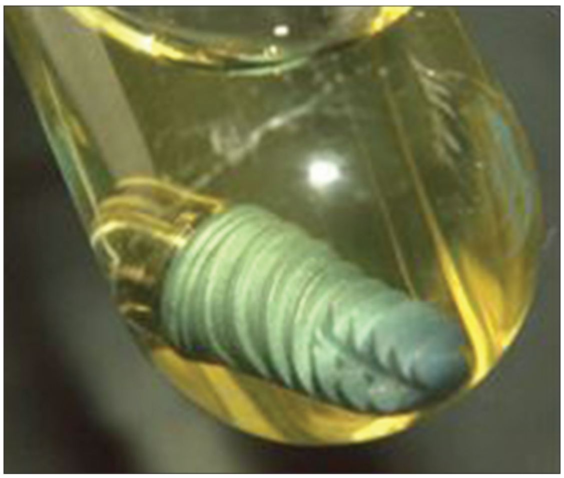

Figure 7: Sterile implant and abutment after 72 h of incubation

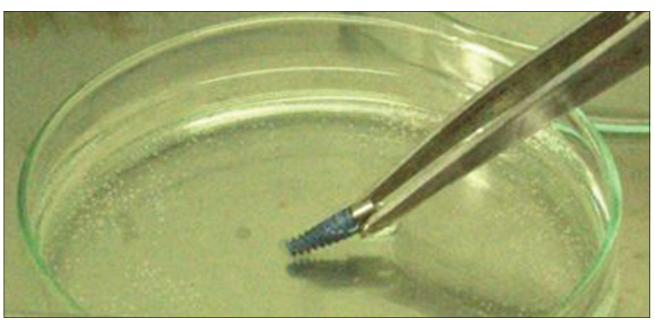

Figure 9: Washing of the assembly in autoclaved distilled water

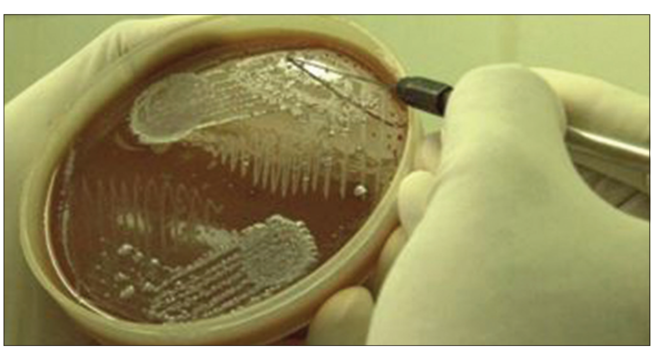

Figure 11: Removing of *Staphylococcus aureus* from pure colonies

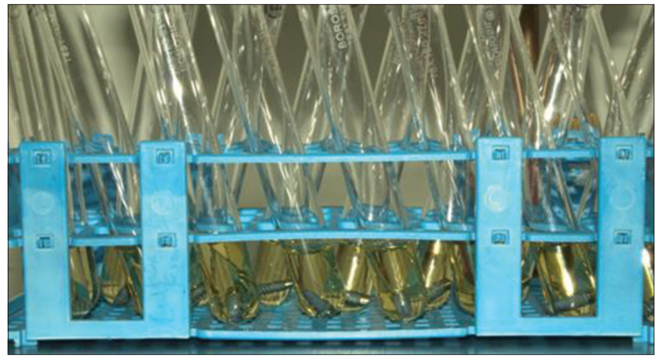

Figure 6: 15 assembled implants and abutments dropped in sterile brain–heart infusion broth

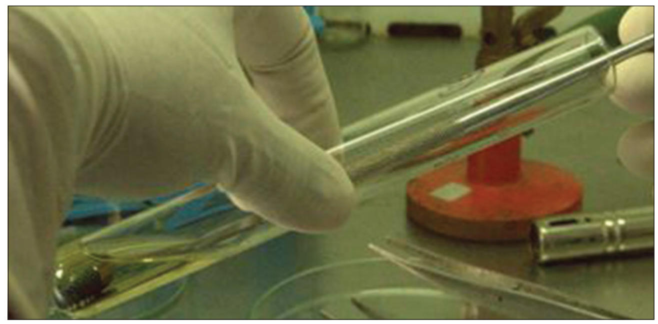

Figure 8: The assembly removed from the sterile brain–heart infusion broth

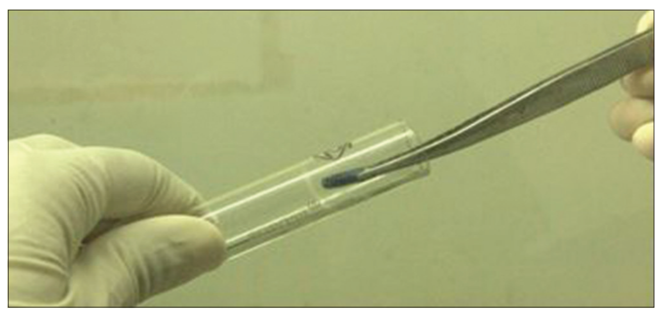

Figure 10: The assembly was dropped in tube with brain–heart infusion broth

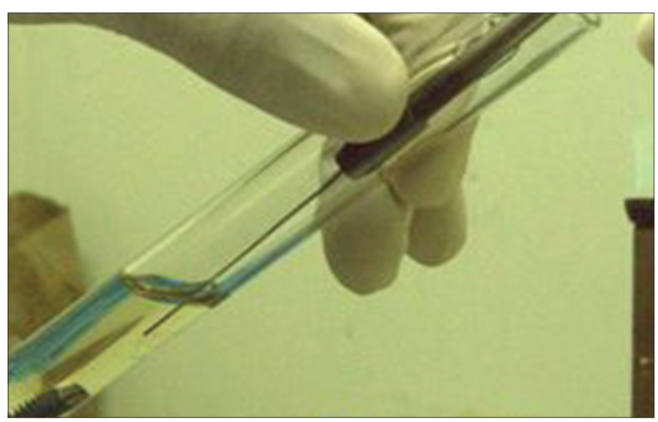

Figure 12: Inoculation of *Staphylococcus aureus* in the sterile brain–heart infusion broth with the assembly

Figure 13: Incubation chamber – 37°C for 14 days

Figure 14: Assemblies after 14 days

Figure 15: Closer view of the sample after 14 days

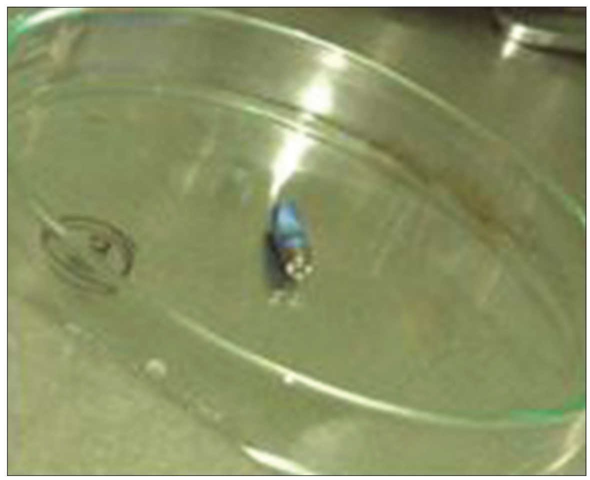

Figure 16: Preparation of the assembly for sample collection

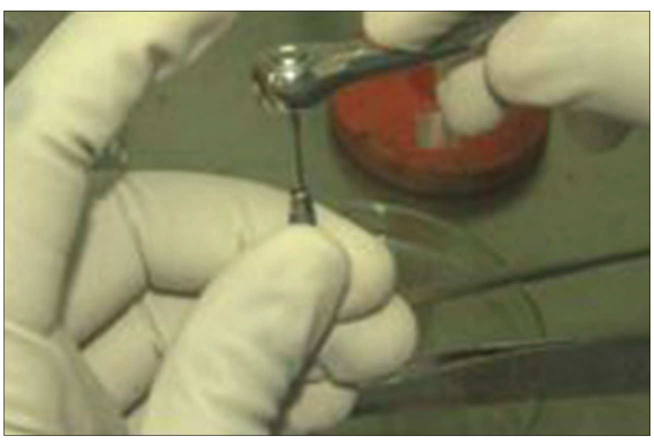

Figure 17: The implant and the abutment disassembled

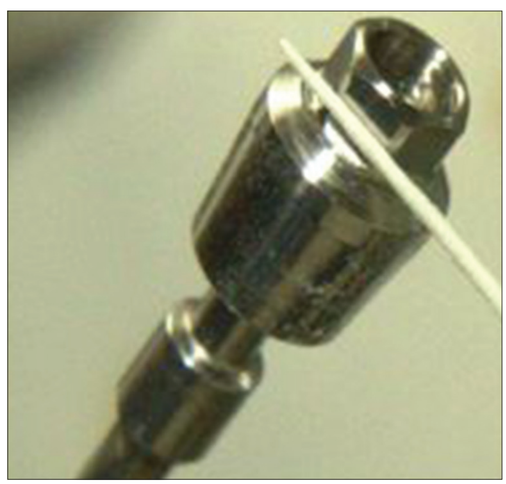

Figure 18: Sample collection from the abutment surface

blue, and gas flow.[9] In spite of various techniques, microbiological tests are always gold standard. Bacterial microleakage tests conducted in the earlier studies used various bacteria, i.e., from facultative to obligate anaerobes, and their size ranges from 1 to 10 µm. The studies also analyzed leakage from the inner parts of the implants to the outside parts, from external portion to the internal parts of an implant or using qualitative and/or quantitative methods, including turbidity analysis of nutritional broth and bacterial DNA analysis.

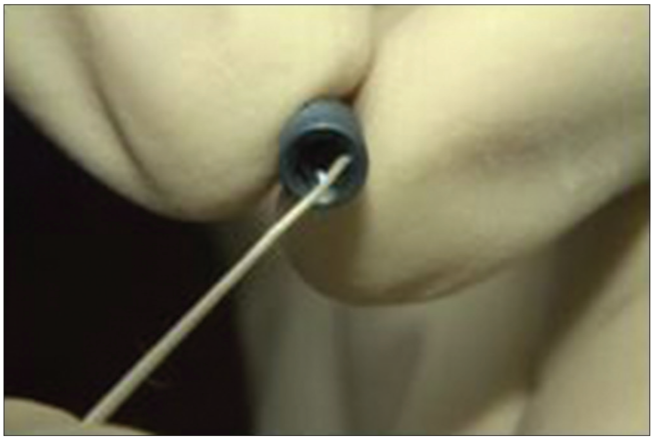

Figure 19: Sample collection from the walls of the wells of the implants

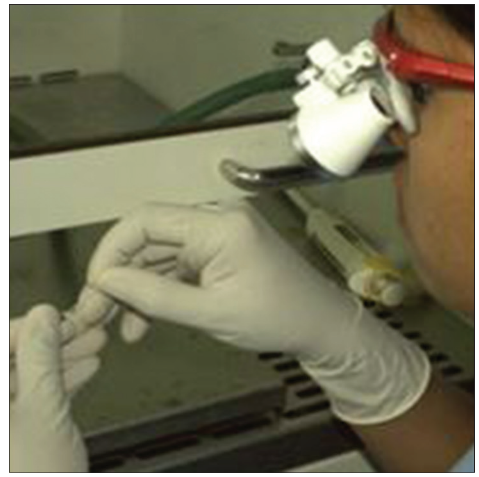

Figure 20: Sample collection from the deepest portion of the well of the implant under × 3.5 magnification

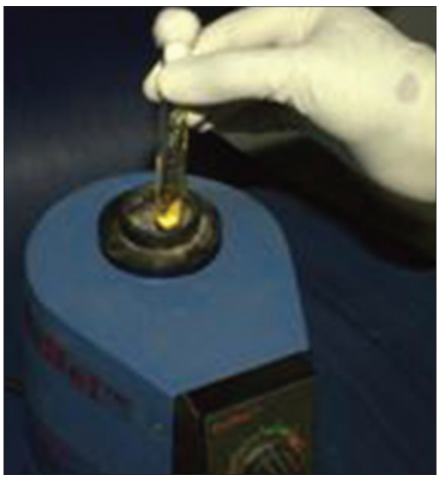

Figure 21: Sample dropped in sterile brain–heart infusion broth and vortexed

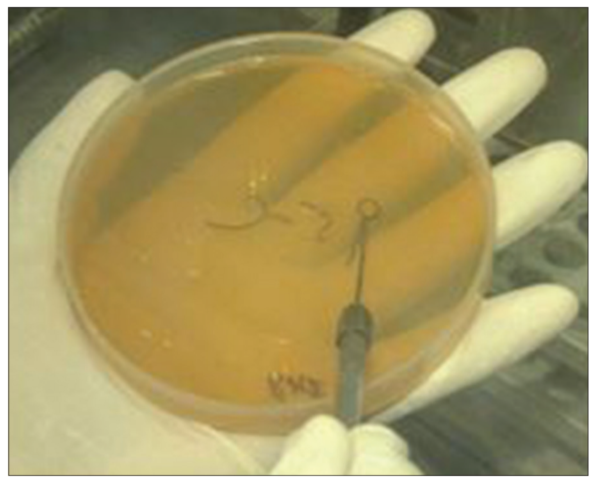

Figure 22: Broth spread evenly all over the plate

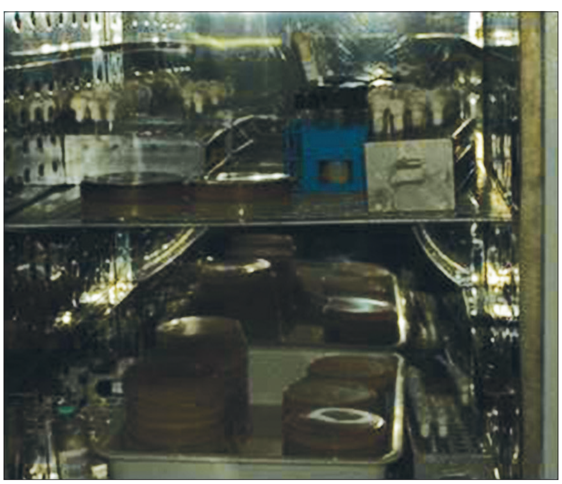

Figure 23: Incubation of brain–heart infusion broth with samples for 72 h

Figure 24: Brain–heart infusion broth after 72 h of incubation

The problems of false-positive or false-negative results are not uncommon due to reasons such as use of forceps or pliers to fix the implants, freehand inoculation of bacterial broth into the implants, total coating of the implants, use of same torque wrench for several samples, lack of knowledge about the implant's internal volume, the bacterial type as well as the disinfection procedure followed to evaluate fluid flow orientation. Studies

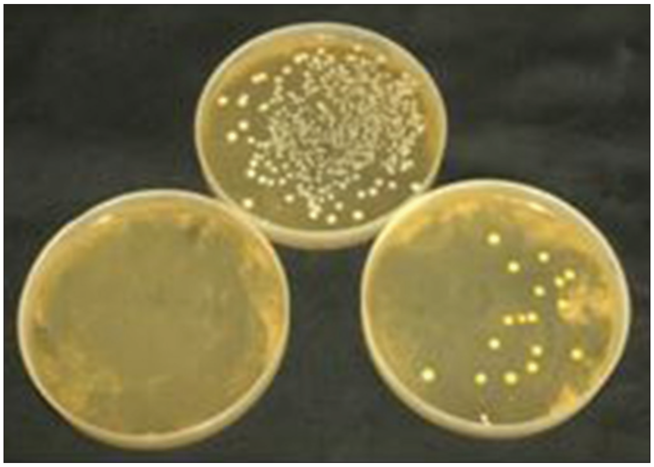

Figure 25: Brain–heart infusion agar after 72 h of incubation

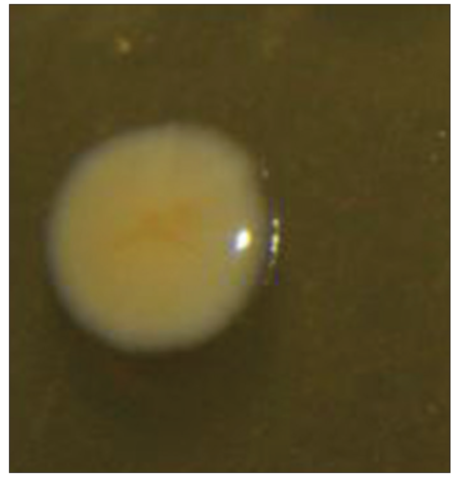

Figure 26: Colony of *Staphylococcus aureus*

used various implant systems such as Nobel Biocare, Straumann, Bicon, Ankylos, Astra Tech, Neodent, and Branemark.[10] Regardless of all the implant systems, the degree of bacterial penetration in specific implant system depends on precision of fit between the implant and the abutment, degree of micromovement between the components, and torque forces to connect them.[11]

Contemporary treatment in dentistry involves implant restorations majorly. This is because of the success that implant enjoys from osseointegration. Still, failures in implant therapy are recorded on account of mechanical and biological consequences.[7] Mechanical nonperformance happens due to loosening or fracturing of screw, rotation of abutment, and loss of developed preload in the screw between the abutment and the fixture. Biological stumbling blocks such as mucositis and peri-implant bone loss have been seen. Remarkable bone loss has been reported with two-piece implants by various studies. In case of two-piece implant systems, gap between implant and abutment are inevitable. This microgap is the principal reason for peri-implantitis by inflammatory reactions.[9]

As mentioned previously, the platform-switched implants are two-piece systems. In this platform-switched implant, very few researches have been conducted to evaluate microleakage. Therefore, the aim of the present study is to investigate the microleakage in platform-switched implants at implant–abutment interface.

MATERIALS AND METHODS

This study was conducted to evaluate the microleakage in platform-switched implant system at the implant–abutment interface in the:

1. Department of Prosthodontics, SDM College of Dental Sciences and Hospital, Dharwad
2. Department of Microbiology, SDM College of Medical Sciences and Hospital, Dharwad.

Armamentarium used for the study

- Dental implant (Touareg™-OS, Adin Dental Implant System Limited, Israel) [Figure 1]
- Titanium abutment (Adin Dental Implant System Limited, Israel)
- Biosafety cabinet 2A2 (Alpha Linear, Bangalore) [Figure 2].

Materials used

- Sterile brain–heart infusion (BHI) broth
- Test tubes
- Broth tubes with *S. aureus*
- Paper points
- Finger key [Figure 3]
- MIS - calibrated manual torque wrench [Figure 3]
- Pipette
- BHI agar plates
- Gram stains.

Implants and abutments

The study was conducted using 15 Touareg™-OS implants of dimension 4.2 mm diameter and 11.5 mm length from Adin Dental Implant System Limited. Touareg™-OS implants are tapered spiral implants that condense the bone during placement and provide immediate stability. The prosthetic connections of this implant system are a standard internal hex 3.5 mm diameter. The advantages of these implants are double lead threads, high primary stability, self–drilling, and self-cutting with built-in platform switching. The abutments were also purchased from Adin Dental Implant System that corresponds with the Touaraeg™-OS implants. The abutments are made of Ti Grade 5 and belong to RS Slim Titanium Abutment 3 mm.

Methods

This study involved platform-switched implants and abutments that were connected and incubated in *S. aureus* broth to check the microleakage at the implant–abutment interface.

Implant and abutment sterility test

Fifteen platform-switched implants with internal hexagon design and abutments were taken. The abutments were connected [Figure 4] with the implants using finger key and torqued to 30 Ncm [Figure 5] inside a biosafety cabinet 2A2. Each abutment along with the connected implant was dropped in individual test tubes containing sterile BHI broth [Figure 6 and 7]. They were incubated for 72 h. After 72 h, the tubes were checked for any turbidity. A sterile BHI broth test tube was used as control tube. Absence of turbidity in all the experimental tubes revealed that all the implants and abutments were sterile and fit to use for the further steps in this research. The implants and abutments were cleaned with autoclaved distilled water thoroughly to remove the BHI broth from them for further use [Figure 8 and 9].

Preparing the implant and abutment assemblies for incubation in *Staphylococcus aureus* broth

The implant and abutment assemblies were dropped in 15 test tubes of BHI broth inoculated with *S. aureus* [Figure 10-12]. The assemblies were kept inside the incubator for 14 days at 37°C [Figure 13-15]. One separate tube with BHI broth inoculated with *S. aureus* was kept as control.

Collection of samples

After 14 days, the assemblies were taken out and immersed in 70% alcohol for 3 min to sterilize the surface [Figure 16]. Then, the assemblies were dried completely. The implants and the abutments were disassembled under sterile conditions in a biosafety cabinet 2A2 [Figure 17]. Samples were collected from three different sites of an assembly using paper points: Site A – The sample from the walls of the abutments [Figure 18]; Site B – The sample from the walls of the wells of the implants [Figure 19]; Site C – The sample from the deepest part of the wells of the implants [Figure 20].

Contamination assessment from the collected samples

The paper points were placed in sterile BHI broth and vortexed. 100 µL of the vortexed broth was pipetted out immediately and evenly spread on BHI agar all over the plate [Figure 21 and 22]. The plates were incubated at 37°C for 72 h [Figure 23]. After 72 h [Figure 24], colonies were counted [Figure 25] and cross-verified using Gram stain. Meanwhile, the tubes were incubated further for 72 h to assess contamination. The tubes showing growth were subjected to Gram stain to confirm the growth of *S. aureus*. Thereby, cross-contamination was ruled out during the procedure.

Evaluation of the colonies

The BHI agar plates were incubated at 37°C for 72 h. The *S. aureus* was identified using the following nature of *S. aureus* presentation in BHI agar plates after 72 h of incubation, i.e., 7 mm or more in diameter, creamy opaque with variable yellow or golden color colonies [Figure 26].

Gram stain of *Staphylococcus aureus*

S. aureus can be characterized by round, purple Gram-positive bacteria that were presented in clusters as a bunch of grapes.

Data analysis

Data analysis was performed using SPSS software (version 20, IBM, Armonk, NY, USA). The values of colony counting units were tabulated [Table 1]. Those values were used for descriptive statistics, i.e., mean and standard deviation. Paired *t*-test was used to find the level of significance. Statistical significance was set to $P < 0.05$.

Ethical approval date and registration number: November/15,/2016, and 02_D018_70774.

RESULTS

The present study was designed to evaluate the microleakage at the implant–abutment interface with platform-switched implants. The data obtained during the study, as shown in Table 1, were subjected to statistical analysis using SPSS software (version 20, IBM, Armonk, NY, USA). An overview of the results is shown in Tables 2-4. The mean value and standard deviation are tabulated in Table 3. The result was analyzed using

Table 1: Microbiology laboratory report

Site A		Site B		Site C	
CC plate	Turbidity BHI	CC plate	Turbidity BHI	CC plate	Turbidity BHI
0	NG	0	NG	0	NG
0	NG	0	NG	0	NG
0	G +ve	6	G +ve	0	NG
0	G +ve	470	G +ve	18	G +ve
0	NG	0	NG	0	NG
0	G +ve	447	G +ve	90	G +ve
0	NG	215	G +ve	0	NG
0	NG	1	G +ve	0	G +ve
0	G +ve	145	G +ve	34	G +ve
2	G +ve	134	G +ve	14	G +ve
1	G +ve	560	G +ve	24	G +ve
0	NG	120	G +ve	34	G +ve
0	NG	0	G +ve	0	NG
0	G +ve	47	G +ve	0	G +ve
0	G +ve	0	NG	0	NG

Site A: Samples collected from the walls of the abutment, Site B: Samples collected from the walls of the implant well, Site C: Samples collected from the depth of the implant well. CC: Colony count, NG: No growth, G +ve: Growth, BHI: Brain–heart infusion "paired *t*-test" in which the significance level was set as $P < 0.05$, as shown in Table 4.

Microleakage

The mean and standard deviation of Site A, Site B, and Site C are tabulated in Table 3. The mean and standard deviation of comparisons among the various sites are shown in Table 3. The contamination caused by microleakage found to be present in all the sites. Site B was more contaminated than the other two. This is understood by the higher mean and standard deviation values of Site B when compared with Site A and Site C.

Table 2: Mean and standard deviation of Site A, Site B, and Site C

Paired samples statistics				
	Mean	*n*	SD	SEM
Pair 1				
SBCCP	143.00	15	194.464	50.210
SACCP	0.20	15	0.561	0.145
Pair 2				
SCCCP	14.27	15	24.575	6.345
SACCP	0.20	15	0.561	0.145
Pair 3				
SCCCP	14.27	15	24.575	6.345
SBCCP	143.00	15	194.464	50.210

SACCP: Site A colony count plate, SBCCP: Site B colony count plate, SCCCP: Site C colony count plate, SD: Standard deviation, SEM: Standard error of mean

Table 3: Paired samples correlations

	n	Correlation	Significance
Pair 1			
SBCCP and SACCP	15	0.261	0.347
Pair 2			
SCCCP and SACCP	15	0.048	0.866
Pair 3			
SCCCP and SBCCP	15	0.634	0.011

SACCP: Site A colony count plate, SBCCP: Site B colony count plate, SCCCP: Site C colony count plate

Among Site A and Site C, Site C was more contaminated than Site A and this can be understood by higher mean and standard deviation values of Site C than Site A. A *P* value of all the pairs, i.e., Site A and Site B, Site B and Site C, and Site C and Site A, found to be <0.05. Therefore, it is statistically significant and shows the presence of microleakage at the implant–abutment interface in platform-switched implants.

Microleakage

At the time of reporting, it was revealed that the implant nos. 1, 2, and 5 were completely sterile.

The plates showing no growth but the broth tube showing turbidity were seen in some tubes as indicated. Broths from these tubes were subjected to Gram stain to confirm the growth of *S. aureus* to rule out contamination during the procedure.

Interpretation

Of the total implants subjected to testing, 12 showed leakage while three did not show leakage.

DISCUSSION

Titanium dental implants are uniquely used in the management of patients with edentulous arches, either partial or complete.[12] The dental implants are available in plenty of materials with different platform designs, diameter, body shape, length, and surface coatings.[13] Studies documented that long-term success of implant treatment depends on the marginal bone level changes.[14] Few possibilities for the marginal bone loss are surgical trauma, occlusal overload, microgap, peri-implantitis, biologic width, and implant–abutment connection.[13]

For the preservation of the marginal bone, various advancements have been made through researches. One of the advancements was the use of wider diameter implants and narrow diameter abutments,

Table 4: Paired samples test

Paired samples test								
	Paired differences					t	df	Significance (two-tailed)
	Mean	SD	SEM	95% CI of the difference				
				Lower	Upper			
Pair 1								
SBCCP - SACCP	142.800	194.318	50.173	35.190	250.410	2.846	14	0.013
Pair 2								
SCCCP - SACCP	14.067	24.555	6.340	0.469	27.664	2.219	14	0.044
Pair 3								
SCCCP - SBCCP	−128.733	179.891	46.448	−228.354	−29.113	−2.772	14	0.015

CI: Confidence interval, SACCP: Site A colony count plate, SBCCP: Site B colony count plate, SCCCP: Site C colony count plate, SD: Standard deviation, SEM: Standard error of mean platform-switched concept. This concept was investigated by various investigators. Lazzara and Porter, 2006[3] commented on the advantage of lesser bone loss in platform-switched implants than the regular platform implants.

After the study of Lazzara and Porter on platform-switched implant concept, many researches were carried out to find the benefit of platform-switched implants on crestal bone loss.

Canullo *et al*.[15] through their research have found that bone loss around platform-switched implants to be lesser because the platform-switched implants shift the stress concentration away from the peri-implant bone.

Yun *et al*.[16] conducted a short-term clinical study on marginal bone-level changes around microthreaded and platform-switched implants. They have reported that marginal bone loss was less and also good short-term implant survival rate with microthreaded and platform-switched implants.

A literature search was done on implant platform -switching concept by Cumbo *et al*.[17] They have found the capability of reducing or eliminating crestal bone loss by platform-switched implants.

Guerra *et al*.[18] carried out a multicentered randomized clinical trial between platform-switched and nonplatform-switched implants in the posterior mandible. The findings of the study have found to be favorable for platform-switched implants on the maintenance and even enhancement of crestal bone level.

Chrcanovic *et al*.[19] have stated that the marginal bone loss around platform-switched implants was less than nonplatform-switched implants through literature search.

Liu and Wang[20] studied the beneficial effect of platform-switched implants on preservation of crestal bone. They have detected that microleakage is inevitable because microgap and micromovement at implant–abutment interface are unavoidable. The implant–abutment interface of platform-switched implants shifts the microleakage away from the crestal bone.

A retrospective study was conducted by Nayak *et al*.[21] They have reported that by shifting the platform, the implant–abutment interface will be shifted away from the crestal bone. However, it does not affect the microgap. The fit between the implant and the abutment have found to be more important.

Microgap is found to be one of the most common risk factors for marginal bone loss. It should be taken care for preservation of marginal bone, which determines implant success. Microgap is inevitable when two components fitted together, i.e., implant and abutment. Broggini *et al*.[22] and Enkling *et al*.[23] through their research have found that microgap and microleakage are one of the etiologies for early marginal bone loss. This statement was further strengthened by Tsuge *et al*.[24] They have observed that the microgap is influenced by the design of the implant–abutment interface. Also suggested that microgap can be a source for peri-implantitis through microbial contamination.

Efforts have been made by many studies to measure the microgap between the implant and the abutment. Tsuge *et al*.[24] have reported that both horizontal and vertical discrepancies occur in the implant–abutment marginal fit. The microgap between the implant and the abutment ranges from 2.3 to 5.6 μm. Scarano *et al*.[25] have stated that microgap in screw-retained implant–abutment system is critical for bacterial colonization and the microgap size will be much larger *in vivo* than seen *in vitro*.

The leakage tests have been used in dentistry since long time. There are various leakage tests such as rhodamine dye penetration test and endotoxin penetration test. However, bacterial leakage test was found to be gold standard and most commonly used method to check microleakage in dentistry. Bacterial leakage tests are based on the microgap size between the components and passive as well as active bacterial diffusion into the microgap of assembled test components.[26]

Among the bacterial leakage studies, various pathogens include *Aggregatibacter actinomycetemcomitans*, *Escherichia coli*, and *S. aureus*. Studies use *S. aureus* because of their ease of culture as said in a study by Teixeira *et al*.[27]

Many studies were carried out to reduce the microgap and thereby microbial contamination. Various implant–abutment connection designs such as connection with or without self-inhibition, with mandatory index and combination of cone and index[28] in conjugation with various prosthetic platforms in implant dentistry, which comprise external hexagon, internal hexagon, Morse cone, and platform switching were evolved in an effort to decrease the microgap between the implant and the abutment. The platform switching is mainly indicated for single restoration with reduced prosthetic space for crestal bone and papilla preservation.[29]

Berberi *et al*.[9] studied leakage between the implant–abutment connection among three implant systems using rhodamine B dye penetration. One of the three implant systems were platform switched and they have reported the presence of leakage with platform-switched implant system at the implant–abutment connection.

Screw joint[30] can be defined as the use of screws to connect the implants with the abutments. They are tightened using torque wrench. Application of torque can be achieved either manually or mechanically fabricated tools.[30] Many studies were carried out to analyze the influence of the closing torque values on the microleakage at the implant–abutment connections.

Larrucea Verdugo *et al*.[31] studied the effect of torque values on microleakage at implant–abutment connection. They have found decreased microleakage with increased torque. Application of manufacturer recommended torque found to reduce microleakage.

Gross *et al*.[32] studied the effect of various closing torque values on microleakage with screw retained implant–abutment connections. They found decreased microleakage with increased recommended torque values. Therefore, they decrease the complications of microleakage.

The current study evaluated microleakage at the implant–abutment interface in platform-switched implants. All the implants that were used in this study had in-built platform switching and connected at 30 Ncm torque with abutments by screw retained internal hexagonal connection. The microleakage was assessed using *S. aureus* microorganisms by collecting samples from three different sites – Site A: Walls of the abutments, Site B: Walls of the wells of the implants, Site C: The deepest portion of the wells of the implants. Therefore, a total of 45 samples used, i.e., 15 samples from each site.

The results obtained from the present study indicated that microleakage was present in 12 samples. Three samples out of 15 tested were completely sterile without microleakage at implant–abutment interface in platform-switched implants. Statistically, there was significant contamination in all the sites from which samples were collected due to microleakage at implant–abutment interface in platform-switched implant system.

Connection design used in the present study to evaluate microleakage was internal hexagonal connection and found the presence of microleakage. This is in consistent with the findings of the study done by Nassar and Abdalla[33] where they used similar study protocol. They have stated that microleakage between the implant and abutment is inescapable. The amount of microleakage depends on the design of the implant abutment connection. Added to that internal hexagon showed more microleakage than trilobed internal connection.

Teixeira *et al*.[27] used *S. aureus* and internal hexagon connections similar to the present study and have reported the presence of microleakage with internal hexagonal connections.

D'Ercole *et al*.[34] compared microleakage between internal hexagonal connections and conical connections. They have described more microleakage with internal hexagonal connections than conical connections even when narrow abutments connected to wider platform implants.

A study by Tripodi *et al*.[11] where they compared internal hexagonal implant–abutment connection with other connections and have reported that internal hexagonal connections with more microleakage than the other comparative connection groups. Also found early occurrence of microleakage with internal hexagonal connections than Morse taper implant–abutment connections.

In 2016, Gherlone *et al*.[35] conducted an *in vitro* study to evaluate resistance against bacterial leakage of new conical implant–abutment connection and conventional connections. They also have found the presence of microleakage with internal hexagonal connection.

da Silva-Neto *et al*.[36] have found that the highest microleakage with internal hexagonal connections than external hexagonal connections and Morse-tapered connections.

Studies[11,33,34,36,37] have found the presence of microleakage with internal hexagonal connections. As stated previously, microleakage may cause peri-implant bone loss and peri-implantitis. In spite of that, the use of the internal hexagonal connections with platform-switched implants was proved mechanically beneficial over external hexagonal connections by Freitas-Júnior *et al*.[38] through a three-dimensional finite element analysis and an *in vitro* study.

The present study used screws to connect the implants with the abutments and found the presence of microleakage. This result is similar to the findings of research by Assenza *et al*.[37] They conducted an *in vitro* evaluation of bacterial microleakage in implants with different implant–abutment connections included screwed trilobed connection, cemented connection, and internal conical connection. They have found the presence of more microleakage with screwed implant–abutment connections than the other two groups.

The presence of microleakage in the screw-retained implant–abutment connections of the current study is in accordance with the findings of Scarano *et al*.[25] They have established that microleakage with screw-retained implant–abutment connections were more than cement-retained implant–abutment connections.

D'Ercole *et al*.[34] used screws to connect the narrow diameter abutments with wider diameter implants to check the bacterial leakage at the implant–abutment interface. They have observed that screw-retained abutment connections present more bacterial leakage which coincides with the present study results.

Harder *et al*.[39] evaluated leakage at implant–abutment interface of screw-retained conical connection and screw-retained standard straight connections using endotoxin penetration method. They have detected the presence of endotoxin penetration with both the screw-retained implant–abutment connections.

Berberi *et al*.[9] studied leakage between the implant–abutment connections among three implant systems using rhodamine B dye penetration. All the samples used in their study were screw retained. They have figured out the presence of the leakage of rhodamine B dye in all the three implant systems.

Sahin and Ayyildiz[40] studied the complication of microleakage on screw-retained implant–abutment connections. They have observed that microleakage can provoke screw loosening and that can be appreciated by reduced removing torque values.

The present study analyzed the microbial contamination on abutment as well as implant surfaces, which is similar to the study conducted by Quirynen *et al*.[41] Quirynen *et al*.[41] performed an *in vitro* study using Branemark implant system to evaluate their resistance against bacterial penetration at implant–abutment interface. They assessed the microbial contamination on the abutment and the implant surfaces. They have detected the microbial contamination on the abutments as well as the implants that is in accordance with the present study results.

Even though the platform-switched implants are scientifically proven to prevent crestal bone loss by shifting the stress concentration away from the crestal bone, the researches on microgap and microleakage in the preservation of the crestal bone loss are less. Hence, this study used platform- switched implants and abutments with screw-retained internal hexagonal connections to evaluate the microleakage at the implant–abutment interface. The results of this present study showed the presence of bacterial contamination on the walls of the implant well, deepest portion of the implant well and the abutment surface. This is due to the microleakage at the implant–abutment interface.[41] The microbial contamination in the present study with screw-retained internal hexagonal connections has found to be more on the walls of the wells of the implants than the deepest portion of the wells of the implants. This may be due to the largest mean microgap with flat to flat internal connections and the microgap decreases exponentially from the outer to inner region of internal connections.[42]

Further researches with various internal connection designs using other modes of retention with different closing torque in platform-switched implants should be conducted to check for their promising results in prevention of microleakage.

Clinical implications

- The microgap at the implant–abutment interface is inevitable
- The microleakage at the implant–abutment interface is inescapable
- Microleakage is one of the risk factor for peri-implantitis
- Microleakage may cause screw loosening in screw retained implant–abutment connections.

Limitations of the study

- Intraoral clinical situation is not considered
- Dynamic loading is not considered.

Scope for future studies

- Clinical studies can be done on microleakage at implant–abutment interface
- The surface roughness of implant well can be compared with the abutment surface roughness
- The present *in vitro* study can be designed to include dynamic loading
- Effect of various sealants in reducing or eliminating microleakage at implant–abutment interface
- Effect of various closing torque values on microleakage at the implant–abutment interface
- Effect of various geometries of implant–abutment connections on microleakage at implant–abutment interface.

CONCLUSION

Within the limitations of the study, the following conclusions were made:

1. Platform switched implants with internal hexagonal connections and screw retained abutments presented microleakage at implant-abutment interface.
2. Microleakage at the implant-abutment interface led to the microbial contamination in the implant wells and on the abutment surfaces.

3. Least amount of microbial contamination was present on the abutment surface. The walls of the wells of the implants had the highest microbial contamination.

Finally, it was concluded that, microleakage is present in the platform switched implants with screw retained internal hexagonal connections at the implant-abutment interface.

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Conflicts of interest

There are no conflicts of interest.

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