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Original Research

Evaluation of Microgap at the Implant-Abutment Interface with Premachined and Custom Cast Implant Abutments – An *in Vitro* Study

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***ABSTRACT*:**
Purpose: The purpose of this study was to comparatively evaluate the microgap at the implant-abutment interface with premachined and custom cast Co-Cr abutments. **Materials and Methods:** Ten Ti premachined abutments (Group I) and ten custom cast Co-Cr abutments (Group II) were connected to the Ti implants and then embedded in clear autopolymerising acrylic resin blocks. These blocks were vertically sectioned using a water jet powered sectioning equipment. Scanning electron microscopic images of all the samples were obtained. Using pixel counting software, the microgap at the implant- abutment interface at the platform level (A, B, C) and internal connection level (D, E, F) were measured on both right and the left sides for each sample of both test groups. The data were subjected to statistical analysis using non parametric Mann- Whitney U test. **Results:** The mean microgap at the implant-abutment interface at point (IA): 0.774µm for group I and (IIA): 1.888 µm for group II samples. The mean microgap at the implant-abutment interface at point (IB): 0.967µm for group I and (IIB): 1.915 µm for group II samples. The mean microgap at the implant- abutment interface at point (IC): 2.078µm for group I and (IIC): 2.643 µm for group II samples. The mean microgap at the implant-abutment interface at point (ID): 2.313µm for group I and (IID): 6.049 µm for group II samples. The mean microgap at the implant-abutment interface at point (IE): 1.927µm for group I and (IIE): 6.110µm for group II samples. The mean microgap at the implant-abutment interface at point (IF): 2.189µm for group I and (IIF): 6.014µm for group II samples. Non parametric Mann-Whitney U test showed statistically significant difference ($p< 0.05$) between two groups except at point C ($p >0.05$). **Conclusion:** Within the limitation of the study, the mean microgap at the implant-abutment interface at the platform and internal connection level for premachined abutments were significantly lesser compared to that of the custom cast Co-Cr abutments, even though, the microgaps of both the test groups were within the clinically acceptable range.
Key words: Implant-abutment interface, Custom cast Co-Cr abutment, microgap, misfit, Scanning electron microscope(SEM).

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INTRODUCTION

Dental implants are being used increasingly important in the field of oral rehabilitation of partial or completely edentulous patients in both the anterior and posterior regions of the mouth with success rate of more than 90%.[1]

Dental implant system consist of two components, that is, the endosseous implant(s) that is placed during the first surgical phase and the transmucosal abutment(s), which are later secured onto the implant(s) to support single or multi-unit prosthetic restorations.[2] Despite our improved knowledge of the mechanisms of osseointegration, some failures still occur with implant restorations, which can be either mechanical or biological. Most of these failures can be attributed to the screw- joint mechanism between the fixture and abutment. [3,4]

The important factor that avoids abutment screw loosening is screw joint preload. The screw is tightened by applying torque which develops a force within the screw called the “preload. Screw loosening or fracture occurs whenever there is an increase in joint separating forces than the clamping forces that hold the screw joint. Although controlled torque application and altered screw designs have significantly improved performance, they have not eliminated the joint problem entirely[1]. The efficiency of the implant abutment joint depends on several factors such as, component design, connection geometry between implant – abutment, mechanical adjustment between fixture and its set surface on abutments, mechanical and physical component properties and torque application.[5,6]

There are at least 20 different implant abutment interfaces available. These implant-abutment interface determine the joint strength, lateral and rotational stability. Branemark's original external hex connection design and the other similar abutments that followed it were only 0.7 mm in height, and reported screw joint complications and screw loosening ranging from 6% to 48%.[7,8] These were attributed to the short, vulnerable connection design that offered lesser resistance to lateral and rotational forces. To overcome inherent limitations with the external hexagon design, alternate connections have been developed. Currently internal implant-abutment connection geometry is advocated as it could distribute intraoral forces deeper within the implant and protects the retention screws from excess loading and provides a strong and stableinterface.[9,10]

Prosthesis supported by multiple implants has better load distribution and hence lower stress concentration at the implant- abutment interface compared to the single tooth prosthesis. Bending moments becomes more significant in single tooth prosthesis as the load distribution effect is absent.[11]

In regular prosthetic protocols pre-machined components are used to reduce the risk of mechanical complications.[12] Various studies have reported lower micro-gap and misfit values for pre-machined abutments than with cast-on abutments.[13,14]

Although premachined abutments are favored, however, in certain situations, customized abutments are indicated. These custom abutments allow for an individual emergence profile of the reconstruction directly by the abutment.[15,16] Implant abutments can be customized by casting, milling and laser- sintering procedures.Clinicians can restore the implant either with premachined abutments or custom cast abutments and these custom cast abutments can be cast in a variety of alloys such as titanium, gold, palladium, nickel-chromium, cobalt-chromium.[1]

Various techniques for measurement of microgap at the implant – abutment interface have been reported , which include probing with dental explorers, use of periotest device , direct observations of the implant – abutment interface performed by radiography[33,41], scanning electron microscope(SEM)[17,18],scanning laser microscopy (SLM)[19] and optical microscopy(O.M.). 3D micro-tomographic technique, [20] optical coherence tomography.[21]Among the methods to analyze the implant – abutment interface, scanning electron microscopy is a well a well-documented method, which is reported to be an efficient method for this type of analysis.

In light of the above, the aim of the present *in vitro* study was to comparatively evaluate the microgap at the implant – abutment interface with premachined and custom cast Cr-Co abutments using scanning electron microscopy (SEM).

The objectives of the study were to

a) Measure the microgap at platform level of the implant – abutment interface between Titanium implants -premachined titanium abutments (Group I) and Titanium implants - custom cast Co-cr abutments (group II) at various points A,B,C
b) Measure the microgap at internal connection level of the implant – abutment interface between Titanium implants- premachined titanium abutments (Group I) and Titanium implants-custom cast Co-cr abutments (group II) at various points D,E,F
c) Compare the microgap at platform level of the implant-abutment interface between Titanium implants -premachined titanium abutments (Group I) and Titanium implants - custom cast Co-cr abutments (group II) at various points A,B,C using scanning electron microscope (Group I vs. GroupII).
d) Compare the microgap at internal connection level of the implant-abutment interface between Titanium implants -premachined titanium abutments (Group I) and Titanium implants - custom cast Co-Cr abutments (group II) at various points D,E,F using scanning electron microscope (Group I vs. GroupII).

The null hypothesis of the present study was that there would be no significant difference in microgap at the implant-abutment interface with either premachined or customized abutments

MATERIALS AND METHODS

The present *in vitro* study was conducted to comparatively evaluate the microgap at the implant-abutment interface with premachined and custom cast Co-Cr abutments using scanning electron microscope (SEM).

The following materials, instruments, equipment and methodology were employed:

- Titanium dental implant, standard platform, internal hexagon,3.75mm diameter,10mm length (ADIN Dental Implants., Israel)
- Pre-machined titanium abutment, standard platform, internal hexagon (ADIN Dental Implants., Israel)
- Titanium abutment screw for premachined titanium abutment (ADIN Dental Implants., Israel)
- Plastic cylinder internal hex (ADIN Dental Implants, Israel)
- Titanium abutment screw for plastic cylinder (ADIN Dental Implants., Israel)

- Clear autopolymerizing acrylic resin (RR Cold Cure., DPI, India)
- Polyvinylsiloxane impression material (Aquasil, Dentsply, Germany)
  Putty consistency, regular set
  Light body consistency, regular set
- Hex driver and Calibrated Torque wrench (ADIN Dental Implants., Israel)
- Selective Laser Melting machine (SLM) (SLM 125^{HL} Solutions GMbH, Germany)
- Dental surveyor (Saeshin Precision Ind. Co., Korea)
- Sand blasting unit (Delta labs, Chennai, India)
- Water jet powered sectioning machine (Germany)
- High speed lathe (Demco, California, U.S.A)

A stainless steel cuboid block of dimensions 27mm x 27mm x18mm and a stainless steel (Fig.1), perforated metal receptacle of dimensions, 40mmx 50mm x 40mm, were fabricated (Fig.2). The stainless steel receptacle was used as a customized impression tray. On the customized impression tray (stainless steel receptacle) the stainless steel block was centred into the impression material for creating a uniform mold space of standardised dimensions. After setting of the impression material, the stainless steel block was removed from the putty index and the mold space area inspected for accuracy and acceptability. The putty index obtained was used for the purpose of embedding the implant-abutment assembly in the acrylic resin (Fig.3)

One plastic abutment (ADIN Dental Implants, Israel) was then connected to the implant. The fit of the plastic abutment to the implant was checked and later Casting, divesting, and finishing of plastic abutment with Co-Cr alloy was done. So in these fashion, ten custom cast Co-Cr abutments were fabricated.

Twenty titanium implants of 3.75 mm diameter, 10mm length (ADIN Dental Implants, Israel) with standard platform, internal hexagon connection design were used in this study. In the present study, twenty abutments were used. Of these, ten abutments were premachined (ADIN Dental Implants, Israel) and ten abutments were custom cast Co-Cr abutments. The premachined and customized abutments were randomly selected and each was connected tone randomly selected implant by hand torquing the abutment screw with the hex driver.

Based on the type of abutment used, the implant-abutment assemblies were grouped into Group I and Group II. Group I comprised of premachined abutments connected to their respective implants (n=10) and Group II comprised of custom cast Co-Cr abutments connected to their respective implants (n=10)

The Embedding of implant-abutment assembly in the acrylic resin was carried out in two stages, in the first stage the abutment connected to the implant was attached to the surveying mandrel and positioned in the center of the putty index such that the implant was submerged completely in the into the mold space of the putty index except for 1 mm at the crest module. Autopolymerising clear acrylic resin was mixed and poured into the mould space and then allowed to polymerise. The resin block was secured in the custom-made Teflon holding device with the help of a screw. The hex driver was connected to the torque wrench and the abutment screw was torqued to 35Ncm as recommended by the manufacturer. The Teflon holding device resists the rotation of the resin block during torquing of the abutment screw. The abutment screw was retorqued after twenty four hours to prevent screw loosening and to ensure proper adaptation between the implant-abutment interfaces. In the second stage, the abutment over the implant was completely embedded into the auto polymerising resin.

In a similar manner, all the twenty implant-abutment assembly (Group I and Group II) were embedded in the acrylic resin. The embedded implant-abutment assembly test samples were numbered individually and labelled for group I as GI to GI 10 and for group II as GII to GII 10 (Fig 4). The sectioning of test samples was done using water jet sectioning machine.

The resin block was stabilized on the sectioning platform of the water jet powered sectioning machine. Water mixed with abrasive agents was focused on the marked area of sectioning using the nozzle. The test sample was sectioned under 3500 bar pressure by using water and abrasive. The sectioning was done vertically along the long axis of implant-abutment assembly using the reference line marked. Similarly, all the twenty test samples were sectioned (Fig 5) The sectioned test samples were then prepared for SEM analysis.

The implant-abutment interface of each test sample was analysed under Scanning electron microscope (EVO MA 15, CARL ZEISS pvt.Ltd.UK) at 10 kV acceleration voltages.The interface microgap of the implant-abutment assembly of each test sample was measured individually at various points as referred in the schematic diagram (Fig 6). Using an image measuring pixel counting software the images of each test sample were obtained. The microgaps were measured with the linear measuring scale of the software. For each sample, microgap measurement at the implant-abutment interface at the platform and internal connection levels were measured in twelve different points (Fig 7)The basic microgap values at the platform level and internal connection level were measured and tabulated using Microsoft Excel 10 (Microsoft, USA) and the mean and standard deviation were calculated. For each test sample, the mean microgap was calculated for a particular point (at platform level and internal connection level) by averaging the microgap measurements obtained on the right and left sides for that point. From each sample mean, the overall mean microgap at that particular point was calculated.

The data were subjected to statistical analysis using SPSS software for Windows 10.0.5 (SPSS Software Corp., Munich, Germany).

RESULTS

The mean microgap at platform level of the implant – abutment interface between Titanium implants - premachined titanium abutments (Group I) at points A,B,C were 0.774µm, 0.967µm , 2.078µm(TABLE 1)

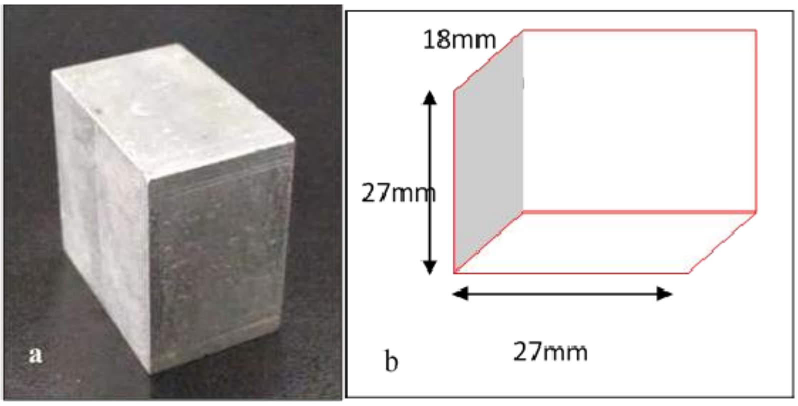
The mean microgap at internal connection level of the implant – abutment interface between Titanium implants – premachined titanium abutments (Group I) at points D, E, F were 2.313µm, 1.927µm, 2.189µm. (TABLE 2)

The mean microgap at platform level of the implant – abutment interface between Titanium implants –custom cast Co-Cr abutments (Group II) at points A, B, C were 1.888µm , 1.915µm , 2.643µm. (TABLE 3)

The mean microgap at internal connection level of the implant – abutment interface between Titanium implants – custom cast Co-Cr abutments (Group II) at points D, E, F 6.049µm , 6.110µm, 6.014µm (TABLE 4)

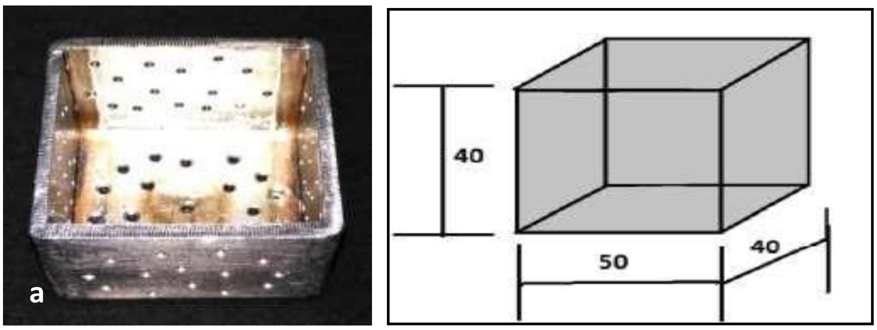
On statistical comparison, the differences in the microgap measurements for both test groups at the platform level and internal connection level were statistically significant except at the point C where it showed significantly lesser values of microgap for the premachined abutments. All the mean values of microgap obtained at the six reference points of the premachined abutments were found to be less than that of custom cast Co-Cr abutments.

FIGURE 1



Custom-made stainless-steel block.
Line diagram of custom-made stainless-steel block

FIGURE 2



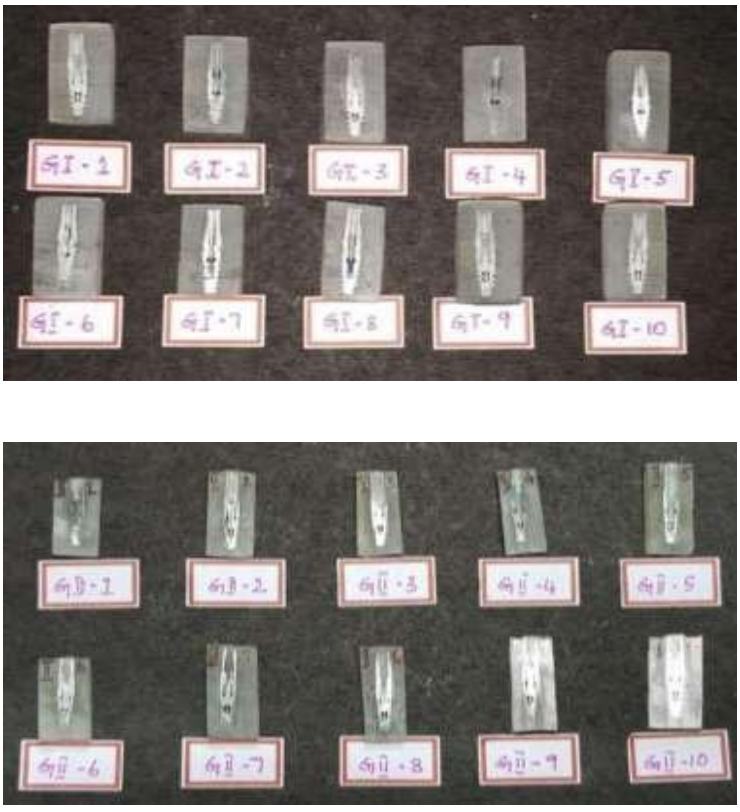
Custom-made stainless steel perforated metal receptacle
Line diagram of custom-made stainless steel perforated metal receptacle

FIGURE 3

Standardized silicone putty index

FIGURE 4: Labelled test samples (Group I and II)

FIGURE 5: **Sectioned samples of Group I and GROUP II**



Schematic CAD diagram showing implant-abutment interface with marked reference points.

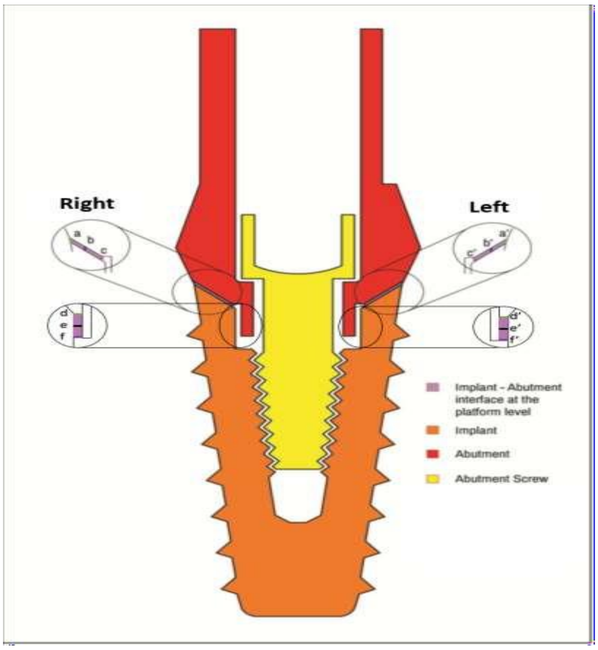
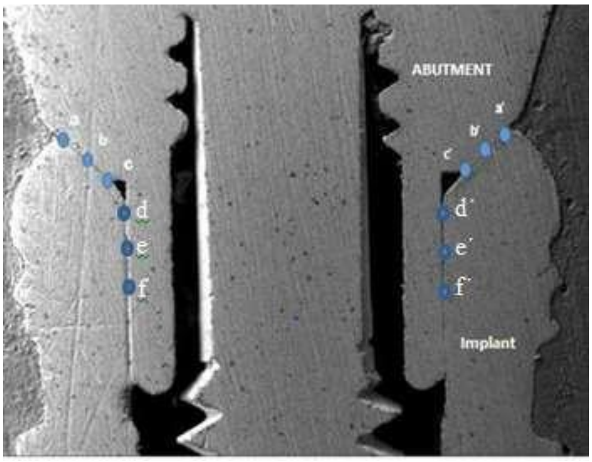
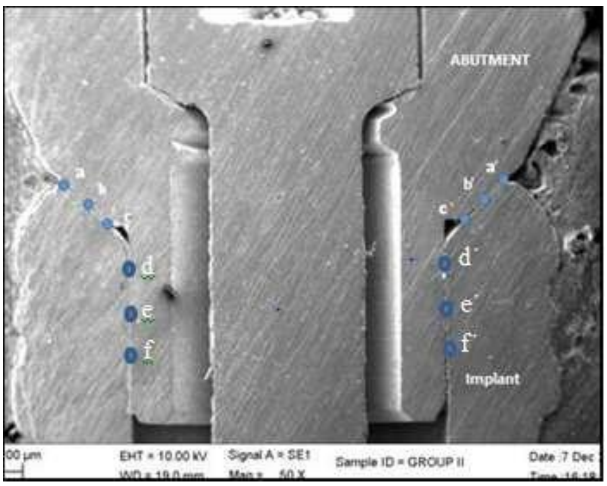


Figure 7



SEM photomicrograph with marked reference points (Group I)



SEM photomicrograph with marked reference points (Group II)

TABLE 1 :
The mean microgap at platform level of the implant – abutment interface between Titanium implants -premachined titanium abutments (Group I) at points A,B,C

S.NO	NO.OF SAMPLES	REFERENCE POINTS (RIGHT &LEFT)	MEAN MICROGAP
1	10	A (a and a')	**0.774µm**
2	10	B (b and b')	**0.967µm**
3	10	C(c and c')	**2.078µm**

TABLE 2:
The mean microgap at internal connection level of the implant – abutment interface between Titanium implants – premachined titanium abutments (Group I) at points D, E, F

S.NO	NO.OF SAMPLES	REFERENCE POINTS (RIGHT &LEFT)	MEAN MICROGAP
1	10	D (d and d')	**2.313µm**
2	10	E (e and e')	**1.927µm**
3	10	F (f and f')	**2.189µm**

TABLE 3 :
The mean microgap at platform level of the implant – abutment interface between Titanium implants – custom cast (Co-Cr) abutments
(Group II) at points A,B,C

S.NO	NO.OF SAMPLES	REFERENCE POINTS (RIGHT &LEFT)	MEAN MICROGAP
1	10	A (a and a')	**1.888µm**
2	10	B (b and b')	**1.915µm**
3	10	C(c and c')	**2.643µm**

TABLE 4:
The mean microgap at internal connection level of the implant – abutment interface between Titanium implants – custom cast (Co-Cr) abutments abutments (Group II) at points D, E, F

S.NO	NO.OF SAMPLES	REFERENCE POINTS (RIGHT &LEFT)	MEAN MICROGAP
1	10	D (d and d')	**6.049µm**
2	10	E (e and e')	**6.110µm**
3	10	F (f and f')	**6.014µm**

DISCUSSION

In recent years, Osseointegrated dental implants have become increasingly important in the field of oral rehabilitation of partial or completely edentulous patients and a successful implant therapy demands a balance between biological and mechanical factors that influence the effectiveness of oral implants.[22]

Implant system consist of two components, the implant that is placed during the first surgical phase, and the abutment is later screwed onto the implant to support the prosthetic restorations[23,2] The mating surfaces of the implant and its abutment form the implant-abutment interface and are considered to be a crucial aspect in the implant design. The design of the fixture-abutment interface may have an impact on the amount of microbial leakage between the two parts [24,11] Several issues have been reported by many authors with abutment misfit and microgaps, including screw loosening,[1] microleakage,[25] abrasion and wear of components, potential for bone loss, and :the micro-pump effect".[26]

Although many studies have shown the importance of implant- abutment fit is available, no standardised, agreed-upon method for measurement of interface gap has been established.[27,13,] Various methods of measuring the interface gap have been reported which include, direct view or measurement of the interface at the margin, cross-sectional measurement after sectioning the impression technique, radiographic appearance, micro- leakage, degree of rotational freedom and the use of an explorer with a visual examination. Many authors recommended that have recommended conducting comprehensive such analysis on sectioned implant-abutment assemblies to enable a more and extensive observation of the adaptation along the implant-abutment interface.

The cross-sectional sectioned view allows greater accuracy in reproducibility of reference points than the circumferential view.[11]

Various studies have reported lower micro-gap and misfit values for pre-machined abutments than with cast-on abutments.[13] However, in certain situations, customized abutments are indicated. Implant abutments can be customized by casting, milling and laser-sintering procedures. Surface irregularities due to customization process can enhance the microgap at the implant-abutment interface. The control of roughness on the mating surfaces at the implant-customized abutment interface could reduce afore mentioned complications by controlling the microgap.[2]

Precision of fit between the implant components play a major role in microgap and micro leakage. Imperfect fit between implant and abutment leading to micro movements of the implant components during function and allow the initiation of pumping effect,[11] causing bacteria to move through the implant-abutment interface. A number of studies evaluated implant-abutment interface using premachined abutments and the microgap ranges from 0 to 150µm.[29,5] Discrepancies greater than 10 microns are reported to result in bacterial colonization and inadequate screw mechanics, which may lead to failures. Currently, studies comparing the implant-abutment interface of internal hexagon connection designs while using premachined versus custom cast abutments by measuring at the interface in vertically sectioned test samples are sparse.

The aim of the present *in vitro* study was to comparatively evaluate the microgap at the implant-abutment interface with premachined and custom cast Co-Cr abutments using scanning electron microscopy (SEM). The null hypothesis of the present study was that there would be no significant difference in microgap at the implant-abutment interface with either premachined or customized abutments.

All the steps discussed in the methodology for test sample preparation were performed by a single operator to avoid operator-based errors. Titanium dental implants of the same dimensions with the internal hexagon design were employed for standardization of the implant fixtures. To avoid mechanical Complications related to external hex implants various internal connections have been developed. Hence, in the present study implants with internal hex.

Studies on fit at the interface in single-implant situations comparing premachined and customized abutments are few. Hence, the implant-abutment interface was assessed on unsplinted single implants in the present study.

In the present study, the microgap was measured along the implant- abutment interface at the platform level and internal connection level after sectioning of embedded implant abutment assemblies. Embedding of implant-abutment assembly done in clear acrylic autopolymerising resin, since it allows easy visualization of implant and its angulation during embedding and sectioning procedures.

The embedding procedure of the assemblies was accomplished in two stages to permit torquing and retorquing of the abutment screws effectively.[30]

In the present study, 35Ncm torque was given using mechanical torque wrench during these procedures in line with manufacturer's recommendations. Retorquing of implant-abutment assembly was done after 24 hours to ensure proper adaptation between implant components and maintenance of preload as recommended by the manufacturer.

Sandblasting of abutment surfaces was done for the mechanical retention within the resin during sectioning procedures. Complete embedding of the implant-abutment involves, complete closure of the abutment screw channel with the autopolymerising resin to prevent loosening of screw threads.

In number of studies, sectioning of the implant-abutment assemblies were carried out by diamond disc in a metallographic cutter,[5] grinder polishing unit with copious water irrigation to avoid clogging of metal debris in the interface region. However, these procedures are technique- sensitive and may result in unevenly cut surface. To avoid this, in the present study, vertical sectioning of test samples was done using water jet sectioning machine. The direction and precise location of sectioning tip can be pre- programmed in the controlling unit to aid in even sectioning of samples. And the size of sectioning tip nozzle can be selected accordingly. Here in this study. 0.76 mm diameter nozzle size was selected to achieve exact sectioned samples. Moreover, with the pressure in the range of 1800-3800 bars along with the abrasive sand particles, clogging of metal debris that can hinder the precise location and measurement of implant- abutment interface gap can be minimized. The other cleaning and polishing procedures followed inthis study were done to obtain well-delineated implant-abutment images during SEM.[5,17,29] The measurement and analysis of microgap at the implant-abutment interface can be done by scanning electron microscopy (SEM), 3D micro-tomographic technique, optical microscopy (O.M.),[31] scanning laser microscopy (SLM),[32] optical coherence tomography[21] and radiography. Of these scanning electron microscopy is efficient method for analysis of the implant-abutment interface and was adopted for obtaining the microgap measurements in this study. The wide range of magnifications possible was well-suited to observe the interface adequately. The measurements were marked on the reference points at the implant-abutment interface at the platform[5]and internal connection level. Pixel-counting software was then used to measure the implant- abutmentmicrogap.[11]

The ideal vertical misfit would be no microgap[36,61] However, previous literature on microgap assessment at the implant-abutment interface have ranged from 0 to 135µm[17,32]

Among the interface gaps observed in studies involving castable or milled abutments, with mean microgap ranging from 1 to 135µm.It was observed very low microgap values for premachined internal and external connection implants, ranging from 2.3µm to5.6µm, corroborating that even premachined abutments can present microgap at the implant-interfaceinterface.[32]

Studies showed interface gaps in sectioned samples of castable external hex implants ranging from 0µm to 15.267µm while using implants and components of the same manufacturer when observed at the most external, middle and most internal points at the platform level of sectioned specimens[18].

The present study also measured the interface gaps at the above mentioned reference points at the interface for internal hex connections using premachined or custom cast Co-Cr abutments after sectioning. The findings of this study reveal much lesser interface gaps in all the areas observed with premachined abutments compared to custom cast Co-Cr abutments. These differences can be attributed to the differences in process of fabrication, polishing procedures.

The average dimension of a microbe is less than 2µm and hence bacterial adhesion and colonization can be assumed in all implant-abutment interface configurations Thus lesser the microgap, lower is the risk of colonization and peri-implant inflammation. Moreover, interface gaps<10 µm have been considered as acceptable with negligible or reduced biological and/or mechanical complications.[59] Though the mean microgap values obtained from both premachined and custom cast Co-Cr abutments were within the clinically acceptable range, the null hypothesis of this study is rejected.

Studies per se evaluating custom cast Co-Cr abutments are very few. It reported that microgap inaccuracies compounded by the multiple fabrication process that compromise the implant-abutment interface fitting.[28]

The results of the present study indicate that the manufacturing technique is also a variable that influences the presence of microgap, probably due to different surface roughness produced by the manufacturing method. The results of the present study were measured on the cobalt- chromium samples which are presumably related to the manufacturing process, in turn, affect the connection misfit and the surface roughness, thereby affecting the microgap.

LIMITATIONS:

The present study had some limitations. Parameters such as mechanical behavior, microbial leakage, cyclic loading and fatigue testing may affect the interface differently and were not part of the present study design. Further, the moist oral environment may also impact these parameters differently than the dry testing conditions employed in the present study. One limitation with evaluating sectioned test samples is that these cannot be used to monitor changes in test conditions where measurements are required before and after testing. Also, the test groups can be expanded to include other customized abutments such as milled and cast-on and/or connection designs. Future studies incorporating the above along with a larger sample size simulating *in vivo* conditions are recommended to add merit to the findings obtained with the present study.

CONCLUSION

In this *in vitro* study, all the mean values of microgap obtained at the six reference points of the premachined abutments were found to be less than that of custom cast Co-Cr abutments with statistically significant difference. Thus, the null hypothesis of this study is not validated, because the present study had revealed that there was a statistically significant difference in the microgap at implant- abutment interface between the premachined abutments and custom cast abutments, but, the microgap values are within the clinically acceptable range.

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