

Original Article

Evaluation of reverse torque values and failure loads of three different abutment designs with internal connections

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ABSTRACT

Background: High percentage of biomechanical complications such as screw loosening in dental implants can be related to implant–abutment (I/A) connection properties which affect the behavior of implant assembly against functional loads in the oral cavity. The aims of the present study were to compare the reverse torque values (RTVs) and failure loads of three abutment types with internal Morse taper connection.

Materials and Methods: In this experimental *in vitro* study, eighteen implants (4.5 mm × 10 mm bone level implants, Implantium, Dentium Co, Seoul, South Korea) were divided into three groups with different abutments: two-piece (TP) abutment, one-piece (OP) abutment, and screw abutment (SA), mounted in stainless-steel blocks according to ISO 14801. After completion the torque/detorque protocol, a compressive load (1 mm/min) was applied at 30° off-axis until failure. Mean reverse torque/tightening torque (RT/TT) values and failure loads were analyzed with one-way ANOVA test and Tukey's honest significant difference ($\alpha = 0.05$). Failure modes were evaluated by radiography and stereomicroscopy.

Results: RT/TT values in the TP group were lower than those in other groups ($P < 0.001$). Highest failure loads were observed in SA group ($P = 0.002$). In radiographic evaluation, all specimens showed deformation in I/A interface.

Conclusion: I/A connections with larger surface areas may lead to higher RTVs (e.g., OP and SA groups). Use of an additional screw and indexed area in TP group did not reduce the bending resistance under static loading.

Key Words: Compressive loading, dental implant–abutment interface, reverse torque

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INTRODUCTION

Although numerous clinical studies have reported high success rates for dental implants, biomechanical complications still occur.^[1] Screw loosening – the most common complication is often related to overload and implant–abutment (I/A) connection design.^[2] Several reasons are involved in screw

loosening like bending moments, connection design, material properties, friction between surfaces, torque sequence, and settling.^[3-6] Screw loosening may cause mechanical complications, such as prosthetic and/or abutment screw fracture, necessitating repair or replacement, which could be exhausting for patients

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and clinicians.^[1] Certain factors, such as connection geometry and abutment insertion torque, contribute to I/A connection stability, especially in single tooth restorations.^[7] Sufficient insertion torque is essential for maximum preload to produce clamping force in the screw joint and to reduce the incidence of failures in the I/A interface.^[8] To maintain connection stability, the unclamping forces induced by functional loading should not exceed the preload clamping force.^[9] It is revealed that high bending moments will result in screw joint instability.^[4] Studies have shown that internal conical I/A connection increases joint resistance to unclamping forces, therefore protects the abutment screw.^[1,10-13] In internal connection system, abutment could be solid (threads are integrated in abutment) or have a separated screw (to permit abutment positional index).^[10,14] Furthermore, they can be selected for cement-retained or screw-retained prosthesis. The preference of these abutments is based on the clinical scenario; however studying the screw joint mechanics and the effects of applied load in I/A interface are valuable for the clinical practice. There exist limited studies to compare the mechanical behavior of one-piece (OP), two-piece (TP) and intermediate abutments' connections in the same system and also varied results. The objectives of this study were to compare reverse torque values (RTVs) and failure loads of three abutment types with internal Morse taper connection. The null hypothesis was that neither RTVs nor failure loads were different among test groups.

MATERIALS AND METHODS

In this experimental *in vitro* study, eighteen implant fixtures (Grade 4 titanium, 4.5 mm × 10 mm bone level implants, Implantium, Dentium Co, Seoul, South Korea) were divided into three groups based on abutment type: TP abutment, OP abutment, and screw abutment (SA) [Figure 1 and Table 1]. Fixture abutments were mounted in a stainless-steel block according to ISO 14801.^[15] Fixtures were tapped into a prepared space within the blocks [Figure 2], which were restrained in a metallic holding device. Abutments were tightened according to the company's recommendation torque by using a digital torque meter (Model BGI, Mark-10 Co, Temecula, USA). After 15 min, a second torque was applied to compensate for the settling effect.^[16] RTVs were recorded for all samples after 15 min using the same torque meter. In the SA group, copings were made

to examine the effect of torquing/detorquing of the prosthetic screw on the abutment screw. Copings were made by using burn-out cylinders that were reinforced with wax (Smooth casting wax, Bego Co, Fort Lauderdale, USA) at the same height as those of the other two groups. Cylinders were cast in base metal alloy (Pors-on 4, DeguDent GmbH, Hanau, Germany) and polished [Figure 3]. Abutment screws in the SA group were tightened and retorqued after 15 min.



Figure 1: Studied groups from left to right: two piece, one piece, screw abutment.

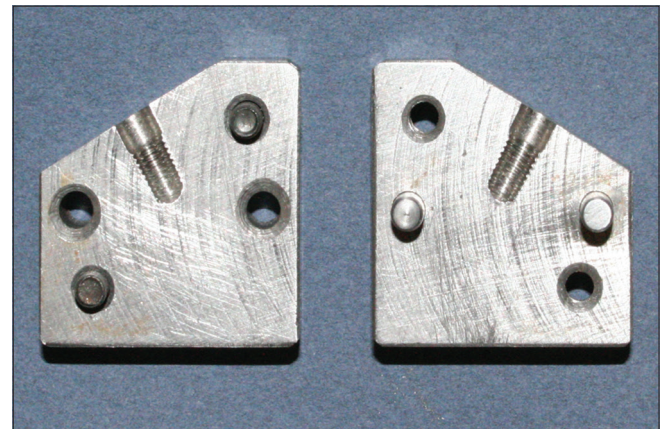


Figure 2: Stainless steel block designed to mount the specimens.



Figure 3: Burn-out cylinder's wax up and casting in screw abutment group.

Prosthetic screws were tightened with 10 Ncm torque according to the company's recommendation, which was repeated after 15 min. RTVs were recorded for prosthetic and abutment screws. To prevent abutment deformation and to ensure accurate load transmission to I/A interface, a cast coping (Wirobond, Bego GmbH, Bremen, Germany) was used during compressive load testing on the TP and OP groups. Compressive load was applied to the specimens at 30° off-axis with a crosshead speed of 1 mm/min in a universal testing machine (UTM, Zwick Z050, ZwickRoell Co, GA, USA) [Figure 4] until failure was evident in the force/displacement curve [Figure 5]. Deviation from linearity in the force/displacement curve indicates plastic deformation; therefore, the point of failure was defined as 0.1 mm of permanent displacement. Failure load data were analyzed by the one-way ANOVA test ($\alpha = 0.05$). Homogeneity of variances was verified by Levene's test. Mean reverse torque/tightening torque (RT/TT) values among groups and

failure loads were analyzed with one-way ANOVA using SPSS software (version 22, IBM Co, New York, USA) and the Tukey's honest significant difference test ($\alpha = 0.05$).

Radiographic investigation of abutment deflection was performed by repositioning I/A assembly in a silicone index [Figure 6]. Radiographs were taken with the beam perpendicular to I/A connection at 5 mm distance (RVG, Carestream Dental LLC). Digital images were saved and the amount of deflection was observed through superimposition of the images before and after loading in the Photoshop program (version 10, Adobe Inc., California, USA) [Figure 7]. Additionally, I/A interfaces were evaluated by stereomicroscope with a magnification of $\times 50$ (SZX12, Olympus Optical Co., LTD, Tokyo, Japan) [Figure 8] and macroscopically through unscrewing the abutments (the abutments could be retrieved in 50% of all specimens by using torque meter). A brand new abutment was torqued in the fixtures in those specimens that abutments could be retrieved. The new I/A connection was investigated for deformation in the implant crest module by using the stereomicroscope

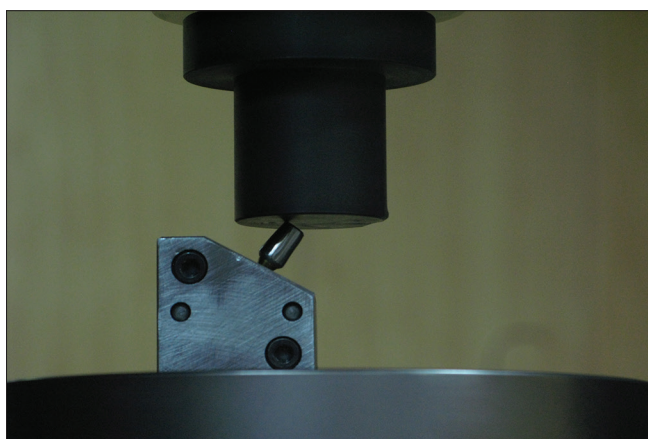


Figure 4: Samples were loaded 30° off axes in the universal testing machine.

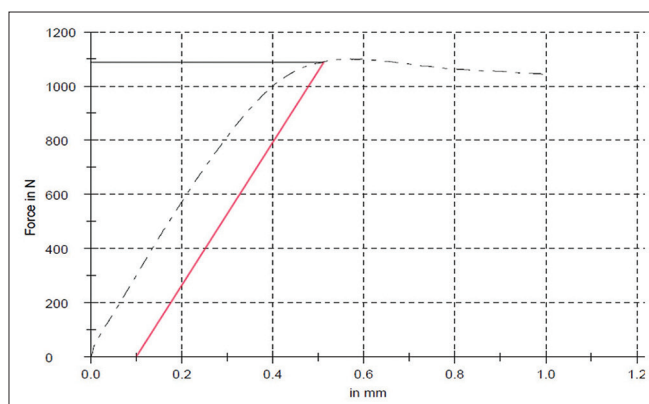


Figure 5: Force/displacement curve and point of failure was recorded for each specimen.

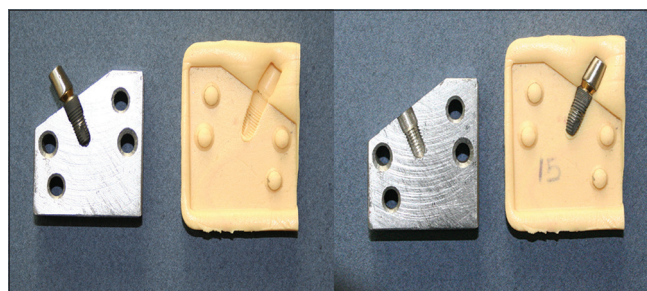


Figure 6: Making silicone indexes (left) for holding implant–abutment assemblies during radiation (right).

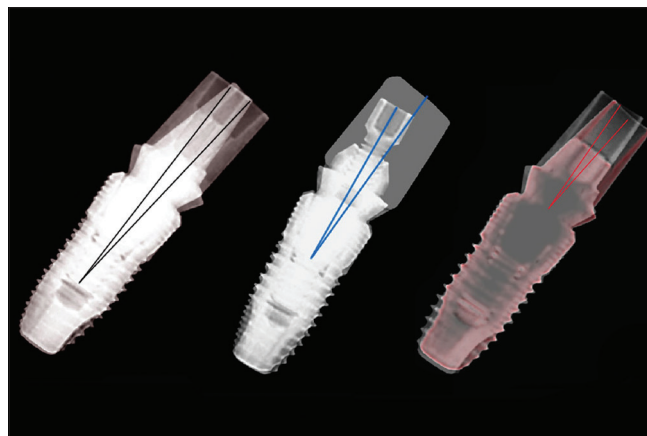


Figure 7: Image superimposition to analyze the amount of deflection.

following the previous protocol. The methodology of the present study was reviewed and verified by an independent statistician.

RESULTS

One-way ANOVA revealed significant difference between tested groups ($P < 0.05$). Thus, there was a

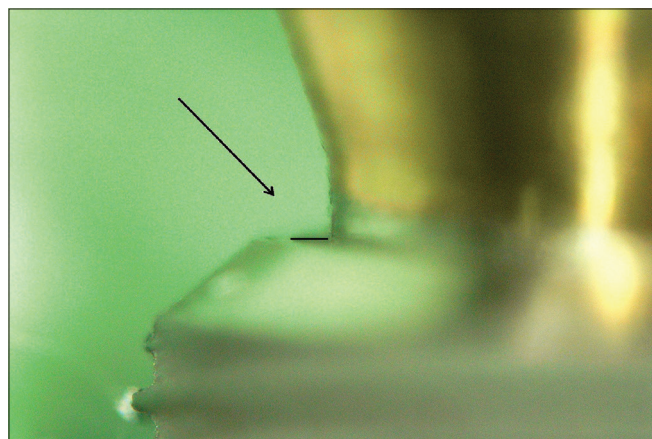


Figure 8: Stereomicroscope view from implant–abutment connection after loading.

Table 1: The properties of the applied materials in the study

Material	Related specification
Wirobond dental alloy	Cobalt-based metal-ceramic alloy According to ISO 22674 free of nickel, cadmium, beryllium, and lead*
Pors-on 4 dental alloy	Palladium-Base alloy for Ceramics It consists of Pd (57.8%), Ag (30%), Zn, Sn, In, Ru According to ISO 1562 extra hard Type 4 [#]
Fixture	SLA surface, internal conical connection, Grade 4 Titanium, 4.5×10 mm bone level**
Combi abutment (one-piece)	4.5 mm diameter (5° vertical angle), 1.5 mm gingival height**
Dual abutment (two piece)	(Hex) 4.5 mm diameter (5° vertical angle), 1.5 mm gingival height**
Screw abutment	With Burnout Cylinder, 4.5 mm diameter (each side tapers by 30°), 1.5 mm gingival height**
Abutment screw	One abutment screw fits all abutments, the material was Ti-4Al-6V ELI alloy with a yield strength of 894 MPa**

*Instruction for use, <https://usa.bego.com>, *Technical Data, www.degudent.com, **Implantium Product Catalog

Table 2: One-way ANOVA results of reverse torque/tightening torque (%) differences among the groups ($P < 0.05$)

	Sum of squares	df	Mean square	F	Significant
Between groups	1070.165	3	356.722	29.483	0.000
Within groups	241.985	20	12.099		
Total	1312.150	23			

statistically significant difference in RT/TT values of experimental groups which is presented in Table 2. All specimens in the TP group showed RT/TT values < 1.0 . Conversely, all but one of the RT/TT values in the OP group were > 1.0 . In the SA group, 50% of RT/TT values were > 1.0 . Furthermore, RT/TT values for all prosthetic screws were < 1.0 . In SA group, when prosthetic screws were detorqued, the RT/TT values of abutment screws became < 1.0 in all specimens. Based on the *post hoc* test, the RT/TT values in the TP group were statistically lower than those in the OP and SA groups ($P < 0.001$), whereas the values in the OP and SA groups were similar [Table 3].

In compressive loading test, ANOVA results indicated significant differences among the groups [Table 4]. According to *post hoc* test, TP and OP groups showed lower failure loads than SA group ($P = 0.002$) without a significant difference between them [Table 3].

In radiographic evaluation, deflection was detected in the conical part of all abutments [Figure 7]. In stereomicroscopic studies, a gap was observed on the same side of the abutment loading between the abutment and fixture platform [Figures 8 and 9]. After loading, unlike the SA group, no abutments in the TP group could be retrieved, and only three abutments were unscrewed in the OP group. In retrieved abutments, deformation was found in the conical part of the abutments.

DISCUSSION

Based on the findings of this study, the RT/TT values and failure loads showed significant differences among the three test groups. Therefore, the null hypothesis was rejected.

Stability of the screw joint is primarily provided by the insertion torque which develops “preload.” Preload is influenced by the magnitude of the torque, the design of the screw head, the number and design of the threads, the composition of the metal, the fit of the components, the surface conditions, and the screw diameter.^[17] The design of the screw head should allow maximum torque to be transferred along the screw stem.^[18] A flat-head screw is common in implant systems and is believed to generate a more favorable stress pattern.^[19] In contrast to the conical-head design, the flat-head screw has less tendency to deform the nonpassive casting, which may blind its misfit.^[20] In the current study, the screw head design in the prosthetic screw and TP group

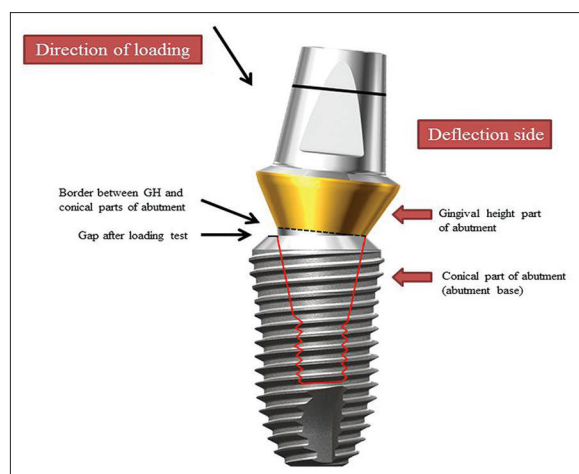


Figure 9: The border between conical part and gingival height of abutment after loading test was not level with the fixture platform because of deformation.

Table 3: Results of reverse torque/tightening torque and mean failure loads (*n*) in studied specimens

Group specimens	Mean±SD	
	RT/TT (%)	Mean failure loads (<i>n</i>)
TP	68.8±6.4 ^a	865.00±101.53 ^a
OP	108.2±12.2 ^b	820.83±369.99 ^a
SA	102.5±13.0 ^b	1706.66±479.27 ^b

Same superscript letters show no significant statistical difference between groups. RT/TT: Reverse torque/tightening torque; TP: Two piece; OP: One piece; SA: Screw abutment; SD: Standard deviation

Table 4: One-way ANOVA results of mean failure load differences among the groups (*P*<0.05)

	Sum of squares	df	Mean square	<i>F</i>	Significant
Between groups	2990108.333	2	1495054.167	11.900	0.001
Within groups	1884554.167	15	125636.944		
Total	4874662.500	17			

was flat. However, in OP and SA groups, the screw was integrated with the conical part of the abutment. Therefore, in TP group, the forces were distributed more evenly along the screw, whereas in OP and SA groups, more stress was localized in the upper parts of the screw stem. Except abutment screw design, test groups were similar in terms of other above factors as mentioned in the methods.

Torque/detorque test

The OP group had the highest RT/TT values, followed by SA and TP group. I/A contact surface area in OP and SA groups was 20.09 mm². In TP group, which had a hexagonal index, the contact surface area was 13.92 mm² (according to system

catalogue information). Less contact surface (31%) in TP group can be a reason for the lower RT/TT values compared to OP and SA groups. Along with this result, Cehreli *et al.*^[14] indicated that the presence of the index area in ITI abutments leads to a lower contact surface area and subsequently, lower RTVs. Also, Ding *et al.*^[21] reported that the initial removal torques of the solid abutment were significantly higher than the synOcta abutment. Recent result confirms the role of friction in preload maintenance. In consistent to the result of present study, Cerutti-Kopplin *et al.*,^[22] de Oliveira Silva *et al.*^[23] and Pintinha *et al.*^[24] revealed higher RTVs in solid conical abutments rather than TP abutments. More I/A conical contact provides more intimate contact which in turn may increase the probability of cold welding and subsequently RTVs,^[10] as occurred in most of OP and SA group specimens (mean RTVs was almost 2%–8% higher than tightening torque values (TTVs)). This phenomenon has been confirmed in solid conical abutments in some studies.^[25–27] Sutter *et al.*,^[25] argued that the precise machining of the mated parts with <10 μm spacing further heightens the security of this interface design. However torque loss has been reported for this kind of abutment in some studies.^[4,22–24] RTVs of TP group in the present study revealed 30% reduction which was similar to Cehreli *et al.*'s^[14] study (36% reduction). Furthermore, Tsuge and Hagiwara^[28] reported a 20% reduction in the RTV of an internal connection TP abutment. In addition, other studies have addressed 15%, 11% and 40% torque loss in indexed TP abutments.^[22–24] Beside less I/A contact surface, it seems that internal indexed feature of the TP group may provide more freedom of movement due to manufacturing tolerance, which may have effect on RTVs. Different results in studies can be attributed to different value and modality of initial torque, connection design, and components tolerance. In the SA group, the detorque value of the abutment screw decreased after detorquing the prosthetic screw. This result may imply that in a similar clinical scenario with prosthetic screw loosening and/or replacement, the abutment screw should be retorqued. Nevertheless, this finding is based on an *in vitro* study and further investigation is recommended.

Loading test

Failure loads in the experimental groups fell within the range of 750–2300 N, which is higher than the common chewing force in the anterior and posterior regions (109 and 250 N, respectively).^[29] Hence, all

test groups displayed sufficient strength to withstand occlusal forces, which is in agreement with studies by Cehreli *et al.*^[14] and Ding *et al.*^[21] However, the applied force in this study was static; multivectoral forces and fatigue processes in the oral condition may modify the result. The mean failure forces in the OP and TP groups were comparable (820.8 vs. 865 N). Cehreli *et al.*^[14] indicated that unlike OP abutments with friction between conical parts, TP abutments are retained mostly by the torque applied on the abutment screw. Nevertheless, it seems that the precise mating of the indexed region in the TP abutment with its counterpart in the implant provides sufficient resistance to torsion and dynamic loads.^[14] In Ding *et al.*'s study,^[21] failure loads at the beginning of plastic deformation of the OP and TP abutments were 1407.6 and 1256.8 N, which are higher than values of similar groups in the present study. Balfour and O'Brien^[30] demonstrated that failure loads were 814 N in a group with a hexagonal internal connection and 587 N in a group with an octagonal internal connection, although a clear definition of failure was not provided. In a study by Möllersten *et al.*,^[31] mean failure loads at the beginning of plastic deformation of seven implant systems were in the range of 137–693 N. The authors related this finding to the connection depth. In this regard, Steinebrunner *et al.*^[32] applied a load-to-fracture protocol and reported greater fracture strength with longer connections (replace 1542 N and Camlog 1467 N). Park *et al.*^[33] also reported similar result in their research. In the present study, the connection depth in the TP group was less than that of the OP or SA group. However, failure loads of the TP and OP groups were comparable, which could be explained by the load resistance of the internal hexagon. Consistent to the present result, Zancopé *et al.*^[34] concluded that the presence of a prosthetic index on Morse taper abutments did not influence the fracture resistance. Moreover, a separate screw in the TP abutment of Astra Tech had no influence on flexural forces in the I/A conical connection compared to the OP abutment, as demonstrated by Norton.^[4] Different failure loads can be linked to different system designs, initial torque and different failure definition in studies. The mean failure load in SA group was significantly higher than OP group which can be attributed to differences in their design and mechanics. The OP abutment in the OP group has more height than the SA in the SA group, which results in a larger lever arm that could make them more susceptible to bending. In the OP group, the loads are

distributed in a single screw joint, whereas two joints exist in the SA group. May be that is because of two screw joints (SA group) offers a more favorable stress distribution; this possibility should be investigated in further studies. In line with the findings of the present study, Ernekli *et al.*^[35] reported different mean failure loads for 20° and 45° uniabutments in the Astra system (1280–157 N, 450–530 N). The only difference between specimens was the amount of taper in the upper part of the components. These findings indicate that the abutment design plays an effective role in load bearing.

Radiographic and macroscopic evaluation

Different failure modes have been reported in the literature, including failure in the first thread of the abutment screw,^[30] bending/breaking of the abutment screw,^[36,37] bending in the concave area above the threads,^[4] and bending in the abutment base.^[21] In the present study, after loading, deformation of the TP abutment (TP group) was less than that of the OP abutments (OP and SA groups), as evidenced by X-ray superimposition [Figure 7]. In other words, deformation in TP abutments occurred in the cervical part of the abutment base and in the threadless part of the abutment screw, which justifies the lack of irretrievability of these abutments after loading.

After retrieving the abutments and fastening a brand new abutment, a gap was observed in I/A connection area; this may indicate distortion in the narrower cervical part of the fixture. Consistent with the result of the present study, Ding *et al.*,^[21] Balfour and O'Brien,^[30] and Strub and Gerds^[36] found deformation in the cervical part of the implants. The relationship between the microgap and loading deformation in the I/A connection deserves further studies. Magnified digital radiographic images revealed that the first thread of the abutment screw was compressed on the bending side and stretched on the opposite side. The upper portion of the abutment screw shaft was not supported by its counterpart in the implant body, which could explain the deformation of this part in the TP group. It seems that the conical part of the abutment endures more force and protects the threads against overload.^[14] In the SA group, the fit between coping and abutment after loading remained intact, and the prosthetic screws did not show any deformation. In retrieved abutments (OP and SA groups), deformation was evident in the abutment base. It seems that the different failure modes in various systems were due to different designs, such as the degree of taper,

connection of the threads with the conical part, and the material used. Irretrievability of the abutment or deformation of the implant crest module can have serious consequences that can complicate reconstruction of the assembly.

As an *in vitro* study, the results of this research cannot be extrapolated to the clinical situation. However, *in vitro* studies can provide useful information about the comparison of failure resistance between implant systems. Moreover, the results can be used to design future studies with similar conditions in the oral environment.

CONCLUSION

Within the limitations of this *in vitro* study, it can be concluded that greater surface area in the I/A connection leads to more adaptation between adjacent surfaces and increased RTV. Separate screw and indexed area in TP abutments did not reduce the bending resistance under static loading in the I/A interface compared to OP abutments. It is recommended that SAs be retorqued in the case of prosthetic screw loosening.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial, in this article.

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