

RESEARCH AND EDUCATION

## Differences in micromorphology of the implant–abutment junction for original and third-party abutments on a representative dental implant



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Implants are considered the treatment of choice for many patients with partial or complete edentulism because of the prostheses' long-term survival rates, predictability of implant-supported prostheses, and overall patient satisfaction.<sup>1-7</sup> However, this has also resulted in increasing patient and clinician expectations, which justifies the shift in implant research toward reporting the medium- to long-term success of implant-supported restorations and, more importantly, the complications encountered during service.<sup>8</sup>

The abutment is the critical interface between the fixed dental prosthesis and the dental implant, and the stability of the implant–abutment junction is essential for long-term success of implant-supported restorations.<sup>9,10</sup> Parameters that play an important role in the stability of this connection include design, precision of fit, materials used, and screw geometry, amount of friction, preload, and antirotational elements.<sup>10-14</sup> Misfit and microgaps in the implant–abutment junction have

### ABSTRACT

**Statement of problem.** Evidence for micromorphology and precision of fit of third-party prosthetic components compared with the original manufacturer's components is lacking.

**Purpose.** The purpose of this in vitro pilot study was to evaluate the micromorphological differences among different commercial brands of zirconia, titanium, and gold abutments for dental implants in terms of tight surface contact.

**Material and methods.** The following abutments (n=3 per type) were preloaded on Straumann Bone Level implants according to the manufacturer's instructions for zirconia (Zr, Zr2, Zr3), titanium (Ti and Ti2), and gold (Gold 1, Gold 2). The micromorphology of the implant–abutment units was investigated by using scanning electron microscopy (original magnification ×10 to ×500) after microtome sectioning. After we calibrated, the length of the areas with tight contact (TC) (discrepancy ≤3 μm) was calculated at the level of conical connection (CC), lower internal connection (LIC), and screw threads (STs). The interexaminer agreement was assessed by using intraclass correlation coefficient(s) (ICC). One-way ANOVA was used for the overall comparison of the Zr groups, and the Student paired *t* test was used for pairwise comparisons of the abutments of the same group. After we adjusted for multiple comparisons, the significance level for the overall and pairwise comparisons of Ti and Gold groups was set at a *P* value of .008 and a *P* value of .003 for the Zr groups.

**Results.** Major differences were found among the different abutment types in terms of design and extent of surface contact. The TC showed significant differences among the abutments of Zr group, depending on the side and level of evaluation (Zr1 > Zr2 > Zr3 on the left side for CC; Zr1, Zr2 > Zr3 on the right side for CC, and, Zr2 > Zr3 on the right side for LIC; *P*<.003). In Ti group, no significant differences were found (*P*>.008). The Gold and Gold 2 groups had significantly greater contact on the left side of CC (*P*<.008).

**Conclusions.** A difference in design of the abutments was apparent. The tight surface contact was significantly different among the examined abutments or abutment screws and the respective area of the inner surface of the implants. (J Prosthet Dent 2019;121:143-50)

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## Clinical Implications

Differences in micromorphology between the original and compatible abutments may lead to complications or compromise long-term clinical performance. Due to the current scarcity of evidence about compatible abutments and lack of relevant clinical studies, the use of original prosthetic components may still be the safest option for clinicians.

been reported to be linked to reduction of friction,<sup>15-17</sup> screw loosening,<sup>18-19</sup> microleakage,<sup>20</sup> and adverse or premature component wear.<sup>21-23</sup>

Development of more reliable internal connections and progress in material science and precision manufacturing have improved abutment design and more reliable alloys for the abutment screws,<sup>24-27</sup> significantly reducing the incidence of technical complications.<sup>27-29</sup> However, increasing competition and growing use of computer-aided design and computer-aided manufacturing (CAD-CAM) technologies in dentistry have led to the introduction of so-called "compatible" prosthetic components, the use of which is increasing but with unknown consequences for the longevity of the prostheses. Research of the risks and implications of the use of such components is limited.<sup>12</sup>

The purposes of the present in vitro study were to provide a 2-dimensional (2D) depiction of different commercially available zirconia, titanium, and gold abutments for dental implants and to investigate their micromorphological differences in terms of tight surface contact (TC) between the abutment-abutment screw and the inner surface of the implant. The null hypothesis was that no significant differences in TC would be found along the interfaces among the different abutment types.

## MATERIAL AND METHODS

Seven different commercially available abutments were grouped according to material (Table 1) and preloaded to 35 Ncm according to the manufacturer's instructions for dental implants with a diameter of 4.1 mm and a length of 8 mm (Bone Level Implant; Straumann AG). All specimens of the same type had the same lot number. All implant-abutment units were cleaned with ethanol, air dried, embedded in slow-setting autopolymerizing acrylic resin (ScandiPlex; Scan-Dia), and mounted on a microscope-slide from 2 sides with adhesive under vacuum pressure and sectioned by using a microtome system with 800- to 4000-grit (IsoMet 4000; Buehler). Sectioning was conducted axially at the widest diameter of the implant. A marking on each side of each implant

**Table 1.** Groups of abutments: Zr, Ti, and Gold

Group	Zr	Ti	Gold
Type	Cares; Straumann AG (Zr1)	Variobase; Straumann AG (Ti1)	Straumann Gold; Straumann AG (Gold 1)
	Atlantis; Dentsply Sirona (Zr2)	KISS; Bluesky Bio (Ti2)	Gold UCLA; Bluesky Bio (Gold 2)
	Aadva Zr; GC (Zr3)		

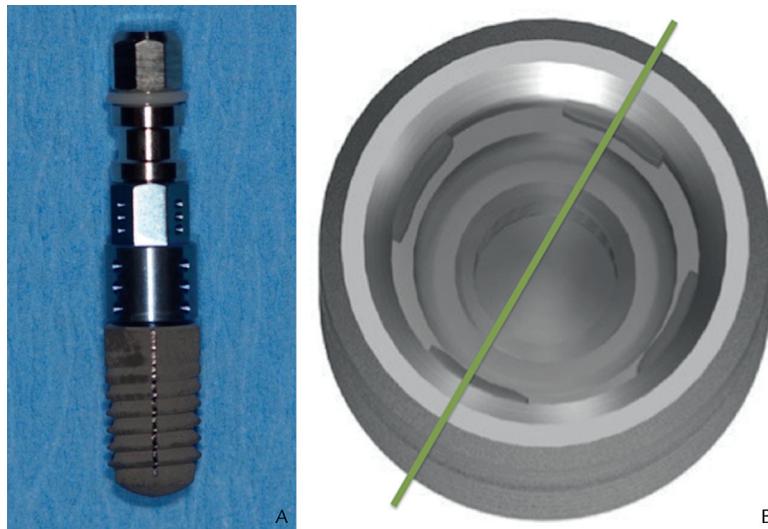
identified the ideal position (Fig. 1) for sectioning, thus eliminating the need for calibration measurements.<sup>8</sup> The sectioned specimens were cleaned in an ultrasonic bath (Sonorex RH; Bandelin) for 15 minutes and then with steam and were then air dried and prepared for scanning electron microscopy (SEM).

All sections of the implant-abutment units were investigated by using a variable pressure SEM (SU1510; Hitachi) at original magnification  $\times 10$  to  $\times 500$ . Precision measurements were conducted by 2 calibrated, independent examiners (G.F., M.L.), using photographic editing software (Image J; National Institutes of Health). The total length of linear TC (discrepancy of  $\leq 3 \mu\text{m}$ ) on the left and right sides of the slice were calculated in millimeters in 3 different parts of the implant-abutment junction (Fig. 2): the conical connection (CC), defined as the area of the inner conus of the implant; the lower internal connection (LIC), defined as the straight area of the inner implant surface below the conus; and screw threads (ST), defined as the area of contact between the abutment screw and the internal implant threads. An absence of TC in these areas may reflect deficiencies in the design or difference in the machining tolerances and production precision. Furthermore, the specific design of the abutments and abutment screws was observed, and the areas with TC were examined for surface anomalies and microcracks.

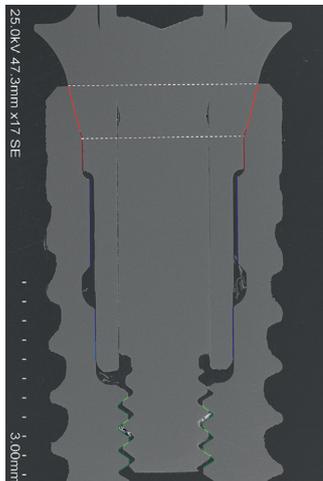
The intraclass correlation coefficient (ICC) with a 2-way mixed effect absolute agreement model for average measurements was used to control interexaminer agreement. The overall comparison of the measurements for Zr group was done by using 1-way ANOVA, and the different pairs of abutment types within each group were analyzed by using the Student paired *t* test. After adjusting for multiple comparisons, the significance levels of overall comparison and pairwise comparisons of Ti and Gold groups were adjusted as  $.05/6=.008$ , whereas comparisons for the zirconia group were adjusted as  $.05/(6 \times 3)=.003$ .

## RESULTS

ICC ranged from .957 to .999 for the 7 types of abutments, indicating excellent inter-rater agreement (Table 2). The morphological observations in Zr group abutments Zr1 and Zr2 presented TCs at CC, whereas Zr3 group presented no contacts. Zr1 showed TCs at the



**Figure 1.** A, Laser markings on both sides of implant indicate ideal positions for vertical sectioning, as directed by internal connection. B, Position of vertical slice of implant-abutment unit in center of connection at maximum diameter.



**Figure 2.** Tight contact measurements. White dotted lines indicate internal conical connection area (CC). Red/blue/green lines indicate tight contacts of screw threads. Darker red/blue/green lines indicate no tight contact.

lower half of LIC for some specimens. A minor “flat-to-flat” contact at the transition zone between CC and LIC was observed in Zr3 group (Fig. 3). The abutment screw-to-abutment connection was similar for the Zr1 and Zr2 groups, with a flat-to-flat surface engagement that was different from the Zr3 group, which presented a tapered interface with little contact (Fig. 3). The screw threads appeared to be similar in terms of engagement for all 3 ceramic abutments.

In group Ti, the abutments presented with extended TC at CC on all 3 specimens. Deeper in the implant body, Ti2 had a clear distance from the implant walls, contrary to Ti1, which in parts appeared close to the inner implant walls, with one Ti1 specimen showing some minor TC at

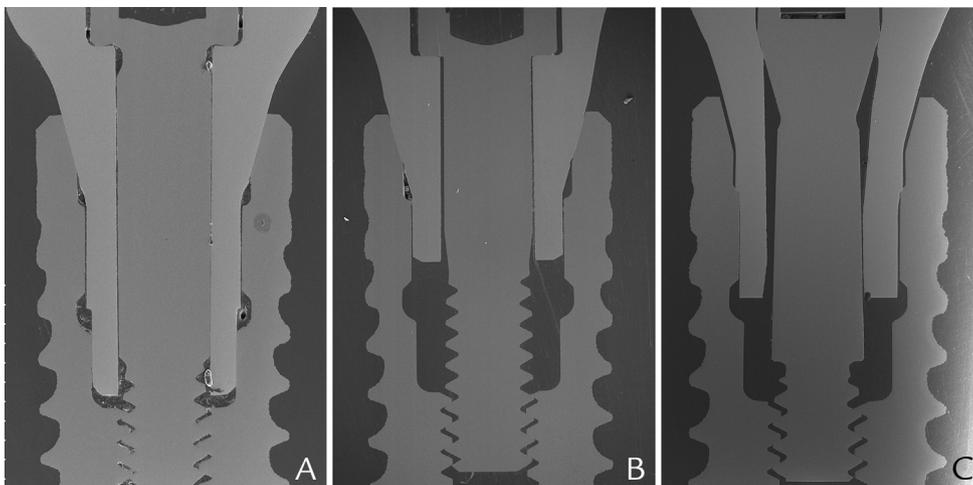
**Table 2.** Intraclass correlation coefficient for measurements of 2 examiners (two-way mixed effects, absolute agreement for average measures)

Abutment Type	Intraclass Correlation Coefficient
Zr1	.998
Zr2	.996
Zr3	.957
Ti1	.990
Ti2	.989
Gold 1	.982
Gold 2	.999

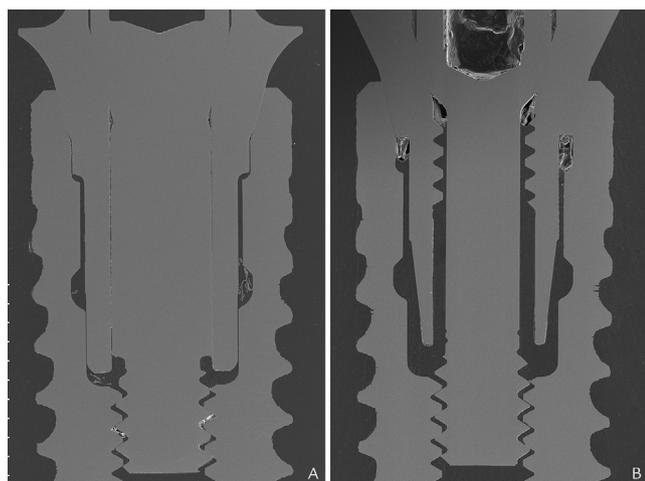
LIC level (Fig. 4). The head of the abutment screw had a tapered type of contact for both types of the tested titanium abutments, with the Ti1 screw head showing obvious, more extensive contact, whereas the screw threads seemed to have similar engagement with the internal threads of the implant body (Fig. 4).

In the Gold group, like the titanium specimens, the shapes of Gold 1 and Gold 2 were significantly different. Both of the abutment types showed extended contact at the CC level. Gold 1 extended deep into the implant body and was close to the inner implant walls, whereas Gold 2 was clearly not in contact along the LIC (Fig. 5). The screw heads of both abutment types had extended tapered contact with the respective abutment, whereas the threads of the Gold 1 screw had better engagement with the implant threads than the Gold 2 screw did (Fig. 5).

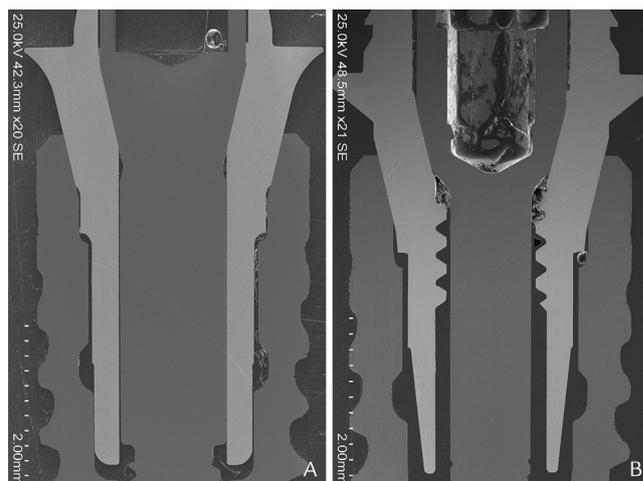
The results of the statistical comparison of the measurements of TC are presented in Table 3. For Zr group at CC area, significant differences were noted for both the left and right sides. Zr1 abutment presented with significantly more TC than Zr2 only at the left side of CC, whereas Zr3 had no contact at all apart from the



**Figure 3.** A, Cross-section of Zr1 abutment (original magnification  $\times 17$ ). B, Cross-section of Zr2 abutment (original magnification  $\times 16$ ). C, Cross-section of Zr3 abutment (original magnification  $\times 16$ ).



**Figure 4.** A, Cross-section of Ti1 abutment (original magnification  $\times 17$ ). B, Cross-section of Ti2 abutment (original magnification  $\times 17$ ).



**Figure 5.** A, Section of Gold 1 abutment (original magnification  $\times 20$ ). B, Section of Gold 2 abutment (original magnification  $\times 21$ ).

flat-to-flat minor contact, and the difference was significant for both Zr1 and Zr2 on both the left and right sides (Fig. 6). At LIC level, no significant differences were found among the zirconia abutments, except for the right side of Zr2 abutments, which had significantly less contact than Zr3 abutments. All Zr3 abutments had some minor contact in the LIC area, but in Zr1 samples, only 1 specimen had some contact on the right side, and only 1 Zr2 abutment had some contact on the left, both of which increased the mean values of measurements for the respective abutment types in this area. At the ST level, the overall and pairwise comparison resulted in no statistically significant differences. All abutment types in this group demonstrated similar TC of the screw threads on the left side, with the Zr1 screw having the greatest engagement, whereas on the right side Zr2 had the highest TC with the implant (Fig. 7).

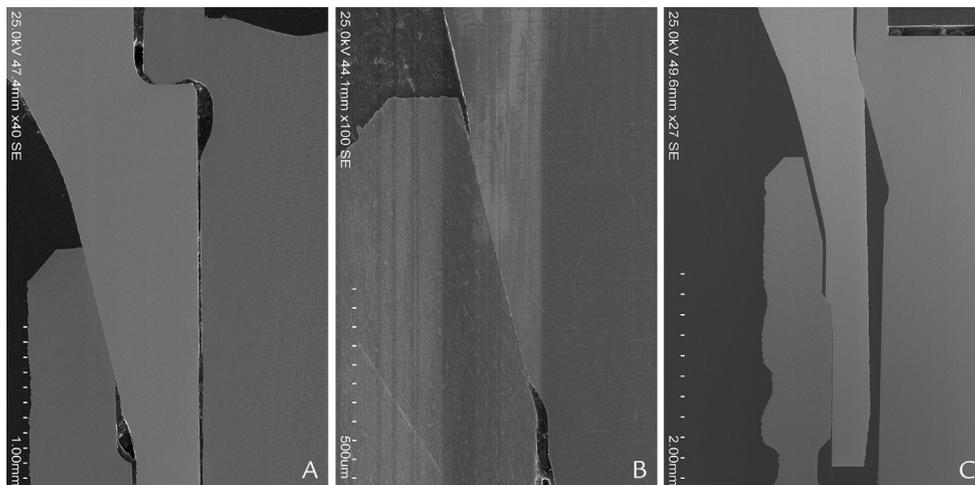
For the Ti group at the CC level, both abutments had extended TC. Ti1 had a mean TC of 83% on the left and 85.9% on the right, whereas Ti2 had 100% and 99.6% TC, although the differences in TC were not statistically significant (Fig. 8). At the LIC level, the abutments of this group had no TC apart from 1 Ti1 abutment that had some minor contact on the right side. The difference was not statistically significant. At the ST level, the abutment screw of Ti1 had greater engagement than Ti2 did on both sides (0.39 mm on the left and 0.32 on the right compared with 0.30 mm and 0.26 mm, respectively), and these differences were not statistically significant (Fig. 9).

For the Gold group at the CC level, Gold 2 had a more extended contact than the original abutment, and the difference was statistically significant on the left side. Contact was found on 97.9% of the total conical area on

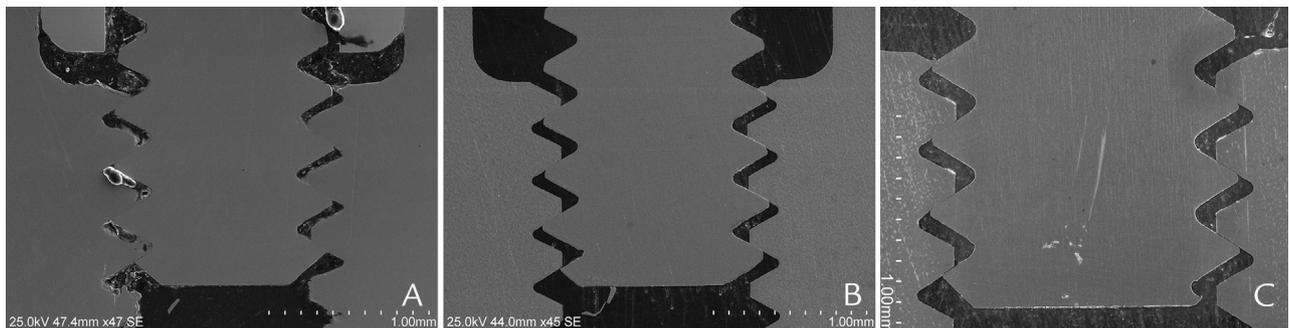
**Table 3.** Surface contact of sliced implant–abutment units per group

	TC-CC		TC-LIC		TC-STs	
	Left	Right	Left	Right	Left	Right
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD
<b>Zr group</b>						
Zr1	0.91 ±0.02 <sup>a</sup>	0.92 ±0.03 <sup>a</sup>	0.00 <sup>a</sup>	0.25 ±0.43 <sup>ab</sup>	0.42 ±0.02	0.41 ±0.04 <sup>a</sup>
Zr2	0.69 ±0.05 <sup>b</sup>	0.56 ±0.11 <sup>a</sup>	0.28 ±0.49 <sup>a</sup>	0.00 <sup>a</sup>	0.40 ±0.05	0.44 ±0.02 <sup>a</sup>
Zr3	0.00 <sup>c</sup>	0.00 <sup>b</sup>	0.26 ±0.06 <sup>a</sup>	0.10 ±0.02 <sup>b</sup>	0.41 ±0.02	0.36 ±0.04 <sup>a</sup>
<b>Ti group</b>						
Ti1	0.71 ±0.01 <sup>a</sup>	0.73 ±0.01 <sup>a</sup>	0.03 ±0.04 <sup>a</sup>	0.01 ±0.02 <sup>a</sup>	0.39 ±0.03 <sup>a</sup>	0.30 ±0.09 <sup>a</sup>
Ti2	0.85 ±0.05 <sup>a</sup>	0.84 ±0.05 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	0.32 ±0.08 <sup>a</sup>	0.26 ±0.18 <sup>a</sup>
<b>Gold group</b>						
Gold 1	0.71 ±0.03 <sup>a</sup>	0.75 ±0.08 <sup>a</sup>	0.02 ±0.03 <sup>a</sup>	0.03 ±0.05 <sup>a</sup>	0.41 ±0.04 <sup>a</sup>	0.38 ±0.08 <sup>a</sup>
Gold 2	0.84 ±0.03 <sup>b</sup>	0.86 ±0.03 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	0.27 ±0.04 <sup>a</sup>	0.23 ±0.04 <sup>a</sup>

TC-CC, tight contact at conical connection level; TC-LIC, tight contact at lower internal connection area; TC-STs, tight contact at screw threads level. Values are mean ±SD. Values with same superscript letters not significantly different for pairwise comparisons using Student *t* test (Zr group, *P* > .008; groups Ti and Gold, *P* > .003)



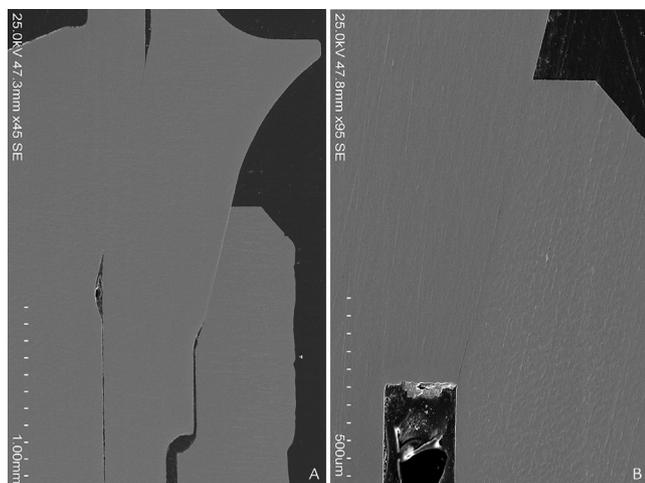
**Figure 6.** A, Zr1 abutment. Contact area on left side at level of CC (original magnification ×40). B, Zr2 abutment. Contact area on left side at level of CC (original magnification ×100). C, Zr3 abutment. Left side of slice at level of CC (original magnification ×27). CC, conical connection.



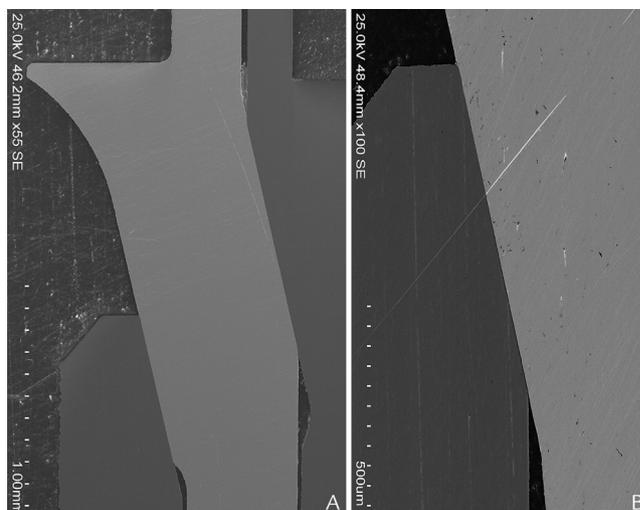
**Figure 7.** A, Contact area of abutment STs of Zr1 abutment (original magnification ×47). B, Cross-section at level of STs of Zr2 abutment (original magnification ×45). C, Contact area at STs of Zr3 abutment (original magnification ×47). STs, screw threads.

the left and 98.3% on the right for Gold 2 abutment, whereas the Gold 1 abutment covered 85.8% of the left and 88% of the right areas with the 3- $\mu$ m discrepancy threshold (Fig. 10). At the LIC level, Gold 2 had no contact with the inner surface of the implant on this level,

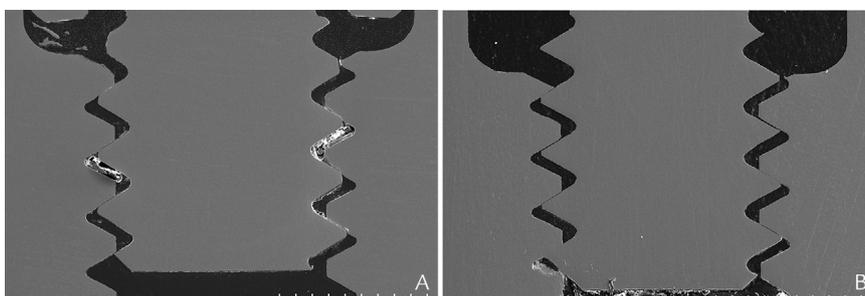
whereas, similar to Ti, 1 Gold 1 specimen was found to have some minor contact. The difference in TC at LIC was not statistically significant. At the ST level, no significant differences were found between the threads of the 2 abutment types (Fig. 11).



**Figure 8.** A, Ti1 abutment. Contact area on right side at level of CC (original magnification  $\times 45$ ). B, Right side of CC for Ti2 abutment (original magnification  $\times 95$ ). CC, conical connection.



**Figure 10.** A, Contact area of left side at level of CC of Gold 1 abutment (original magnification  $\times 55$ ). B, Contact area of left side of CC of Gold 2 abutment (original magnification  $\times 100$ ). CC, conical connection.



**Figure 9.** A, Cross section of screw threads of Ti1 abutment (original magnification  $\times 45$ ). B, Screw threads of Ti2 abutment (original magnification  $\times 45$ ).

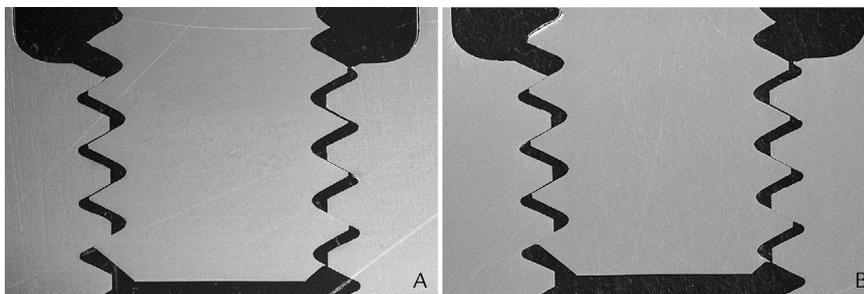
## DISCUSSION

The present study demonstrated major differences in micromorphology of the different abutment types of the same material and also significant differences in terms of tight surface contact at the investigated interfaces. Thus, the null hypothesis that there were no significant differences was rejected. Because the purpose of the investigation was to provide a representation of the design and fit of original and compatible abutments of different materials for implants with a conical connection, only abutments within the same material group were compared.<sup>12</sup> Differences in shape and dimensions among different abutment types might have resulted from patent protection,<sup>9</sup> but it should be noted that all original abutments extended much deeper than the compatible abutments, with a fit closer to that which was defined as TC.

For the specific implant type, the major contact areas seemed to be the upper CC and the engaged STs. The TC found at the LIC level was minimal, and the Zr3 specimen was the only abutment type, where all specimens

presented with some minor contact. However, even minor premature contact between abutment and inner surface of the implant may hinder the full seating of the abutment. This seemed to be the case for the Zr3 abutments, where a minor contact on the upper part of the lower internal connection appeared to prevent the full engagement of the abutment. Considering the potential impact of the extent of contact on long-term stability of implant restorations, long-term clinical outcomes of prostheses with such abutments may be questionable.

Although precise fit of the abutment is essential for restoration longevity,<sup>12</sup> it is difficult to define an acceptable threshold for establishing a TC due to lack of evidence for this subject.<sup>7</sup> In the current investigation, TC was defined as interfaces that had microgaps less than  $3\ \mu\text{m}$  to ensure reproducibility, as the interexaminer agreement was significantly lower when this threshold was  $<3\ \mu\text{m}$ . However, this is still a very low value, and choosing higher thresholds may offer different results.



**Figure 11.** A, Cross-section of screw threads of Gold 1 (original magnification  $\times 45$ ). B, Cross-section of screw threads of Gold 2 abutment (original magnification  $\times 45$ ).

Loosening of abutment screws is the most commonly encountered technical complication,<sup>19,26</sup> thus the engagement of the screw threads is essential for the implant–abutment connection as the preload is applied through them.<sup>14</sup> However, the screws of different commercially available abutments possess different physical and chemical properties depending on the alloy used. Consequently, the preload and screw removal torque values have been shown to have critical differences.<sup>17</sup> Also, as the original screws cannot be used with compatible abutments because they usually do not match,<sup>10</sup> the use of such components could potentially lead to different clinical behavior in the long term. In this investigation, engagement of the threads did not seem to present major differences; small but significant differences were found only on the right side between Zr2 and Zr3 abutments (Fig. 7) and between Gold 1 and Gold 2 abutments (Fig. 11).

The screw head contact area is also essential for the connection of the abutment to the implant.<sup>11,27</sup> The present investigation showed that this area varied between flat-to-flat and tapered configurations. Although taper was not measured in this study, one can expect that the taper-shaped screw head would have a more extensive contact than a flat one. It was recently demonstrated that the flat-to-flat configuration of screws of abutments connected to Straumann Tissue Level implants showed significant flattening and wear after cyclic loading contrary to the screws with a beveled shape,<sup>7</sup> which could prove to be the weak link of the connection in the long term.

Another parameter which could influence long-term stability is the settling of the abutment on the implant (embedment relaxation), a phenomenon observed due to the reduction of friction between the surfaces of the implant and the abutment.<sup>11</sup> As the 2 surfaces are held together initially by the preload of the abutment screw, functional forces gradually bring the components closer, potentially leading to screw loosening.<sup>15,16</sup> The impact of settling is increased when the initial fit of the components is deficient.<sup>11</sup> Further in vitro testing will be required to investigate the implications of the differences

in fit observed in this study with regard to settling of the abutment and related complications.

Full zirconia abutments, rather than those with titanium inserts, were chosen to be tested because the aim was to investigate the connection for different types of materials and because a titanium abutment group was already included in the study. Furthermore, 1-piece zirconia abutments appeared to have no complications in clinical studies,<sup>26</sup> contrary to the results of certain in vitro studies.

Minimal data were available before the study to estimate the expected variation to provide a sample size calculation. Hence, the results of this pilot investigation must be explored with caution. Three specimens of each abutment type were chosen to address the possible errors introduced by the machining process. It was noteworthy that individual variation between specimens of the same kind appeared much higher than initially anticipated, which may imply that the sample size was too low, potentially limiting the power of the statistical analysis. Nevertheless, this pilot study will help with future studies of this topic, with larger sample sizes. Another factor that may impact the results is the specimen processing for SEM analysis. Detailed polishing and cleaning were used to minimize this problem. Furthermore, laser markings were used to facilitate and increase the accuracy of the slicing process, which minimized potential errors in creating a slice precisely to the desired position.

To the best of our knowledge, this was the first study to investigate these parameters. Future studies should measure the TC of abutments before and after cyclic loading with larger sample sizes to define the effect of settling of the components, their wear, and the possible reduction of torque.

## CONCLUSIONS

Within the limitations of this in vitro pilot study, the following conclusions were drawn:

1. The design and tight surface contact between the examined abutments or abutment screws and the

respective area of the inner surface of the implants showed significant differences.

- There was significant diversity in the extent of TC among the different compatible abutments investigated.

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