

# Marginal Accuracy of Three Implant–Ceramic Abutment Configurations

Marta Baldassarri, MS, PhD<sup>1</sup>/Jenni Hjerpe, DDS, PhD<sup>2</sup>/Davide Romeo, DDS, PhD<sup>3</sup>/  
Stefan Fickl, DDS, PhD<sup>4</sup>/Van P. Thompson, DDS, PhD<sup>5</sup>/Christian F. J. Stappert, DDS, MS, PhD<sup>6</sup>

**Purpose:** Microgaps at the implant-abutment interface allow for microbial colonization, which can lead to peri-implant tissue inflammation. This study sought to determine the marginal accuracy of three different implant–zirconium oxide (zirconia) abutment configurations and one implant–titanium abutment configuration.

**Materials and Methods:** Three combinations of implants with custom-made zirconia abutments were analyzed ( $n = 5/\text{group}$ ): NobelProcera abutments/titanium inserts on Replace Select Tapered TiUnite implants (Nobel Biocare) (NP); Encode abutments/NanoTite Tapered Certain implants (Biomet 3i) (B3i); Astra Tech Dental Atlantis abutments/Biomet 3i NanoTite Tapered Certain implants (At). Five custom-made Encode titanium abutments/NanoTite Tapered Certain implants (Ti) were used as a control group. All abutments were fabricated with computer-aided design/computer-assisted manufacture. One-hundred twenty vertical gap measurements were made per sample using scanning electron microscopy (15 scans  $\times$  4 aspects of each specimen [buccal, mesial, palatal, distal]  $\times$  2 measurements). Analysis of variance was used to compare the marginal fit values among the four groups, the specimens within each group, and the four aspects of each specimen. **Results:** Mean ( $\pm$  standard deviation) gap values were  $8.4 \pm 5.6 \mu\text{m}$  (NP),  $5.7 \pm 1.9 \mu\text{m}$  (B3i),  $11.8 \pm 2.6 \mu\text{m}$  (At), and  $1.6 \pm 0.5 \mu\text{m}$  (Ti). A significant difference was found between B3i and At. No difference resulted between NP with the other two groups. Gap values were significantly smaller for Ti relative to all zirconia systems. For each ceramic abutment configuration, the fit was significantly different among the five specimens. For 12 of the 15 ceramic abutment specimens, gap values sorted by aspect were significantly different. **Conclusions:** The implant–titanium abutment connection showed significantly better fit than all implant–zirconia abutment configurations, which demonstrated mean gaps that were approximately three to seven times larger than those in the titanium abutment system. INT J ORAL MAXILLOFAC IMPLANTS 2012;27:537–543.

**Key words:** custom abutment, dental implant, marginal accuracy, titanium, zirconium oxide

<sup>1</sup>Assistant Research Scientist, Department of Periodontology and Implant Dentistry, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York, New York.

<sup>2</sup>Visiting Scholar, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York, New York; Research Assistant, Department of Biomaterials Sciences, University of Turku, Turku, Finland.

<sup>3</sup>Resident and Scholar, Department of Periodontology and Implant Dentistry, New York University College of Dentistry, College of Dentistry, New York, New York.

<sup>4</sup>Associate Professor, Department of Periodontology, Julius-Maximilians-University, Würzburg, Germany.

<sup>5</sup>Professor and Chairman, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York, New York.

<sup>6</sup>Principal Investigator, Department of Periodontology and Implant Dentistry, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York, New York; Professor and Director of Implant Periodontal Prosthodontics, Department of Periodontics, University of Maryland School of Dentistry, Baltimore, Maryland; Associate Professor, Department of Prosthodontics, Albert-Ludwigs-University, Freiburg, Germany.

Excellent esthetics is critical for anterior dental restorations. Ceramic implant abutments are preferable to metal, since they provide better translucency and reduce the risk of an unnatural dark or grayish appearance through the tissues, especially in patients with a thin gingival biotype.<sup>1–3</sup> Zirconium oxide (zirconia) is commonly used for ceramic implant abutments because of its high fracture toughness,<sup>4–6</sup> low thermal conductivity, low corrosion potential, high biocompatibility, and favorable interaction with soft and hard tissues.<sup>7,8</sup>

The first two authors contributed equally to this work.

**Correspondence to:** Dr Christian Stappert, Department of Periodontics, University of Maryland School of Dentistry, Baltimore, MD 21201. Fax: +410-706-7201. Email: c.stappert@umaryland.edu

Many different types of zirconia abutments are available on the market for two-stage implant systems. However, limited information is available on the size of the implant-abutment marginal gap, which can offer a niche for oral bacteria.<sup>9–16</sup> A preliminary clinical study identified moderate and high levels of eight periodontal pathogens in 43 implant-abutment interface areas.<sup>11</sup> The presence of bacteria at the implant-abutment gap has been associated with chronic tissue inflammation<sup>9,10</sup> and resorption of peri-implant alveolar bone.<sup>17,18</sup>

Bacterial adhesion might also be influenced by the material used for implant abutments. In vivo studies of microbial colonization on titanium and zirconia disks showed that zirconia had significantly lower probability of colonization.<sup>19,20</sup> In recent years, several implant companies have introduced anatomically shaped, custom-made zirconia abutments to be used in unusual interdental spaces or challenging occlusal or esthetic conditions and for individual soft tissue modifications.

In addition to biologic issues, it has been shown that marginal misfit between an implant and an abutment is able to cause screw loosening and facilitates the risk of abutment fracture.<sup>21,22</sup> In fact, marginal misfit results in the transmission of high stresses to the alveolar bone and dental implant components.<sup>23,24</sup>

The purpose of the present study was to determine the vertical marginal accuracy of three different anatomically shaped custom-made zirconia abutment–implant combinations. Custom-made titanium abutments were used as a control group. The null hypothesis of this work was that there is no significant difference in the vertical marginal accuracy of three implant–zirconia abutment connections.

## MATERIALS AND METHODS

Twenty samples, each one comprising a titanium dental implant and a screw-retained abutment, were included in this study. Four different implant-abutment combinations were used ( $n = 5$  samples per configuration):

- **NP:** custom-made Nobel Procera zirconia abutments (Nobel Biocare) with titanium inserts on Replace Select Tapered TiUnite implants ( $4.3 \times 13$  mm, lot 671546) (Nobel Biocare)
- **B3i:** custom-made Encode zirconia abutments and NanoTite Tapered Certain implants ( $4$  mm/ $3$  mm  $\times$   $15$  mm, lot 879900) (Biomet 3i)
- **At:** custom-made Atlantis zirconia abutments (Astra Tech Dental) and NanoTite Tapered Certain implants ( $4$  mm/ $3$  mm  $\times$   $15$  mm, lot 879900)
- **Control group (Ti):** custom-made Encode titanium abutments (Biomet 3i) and NanoTite Tapered Certain implants ( $4$  mm/ $3$  mm  $\times$   $15$  mm, lot 879900)

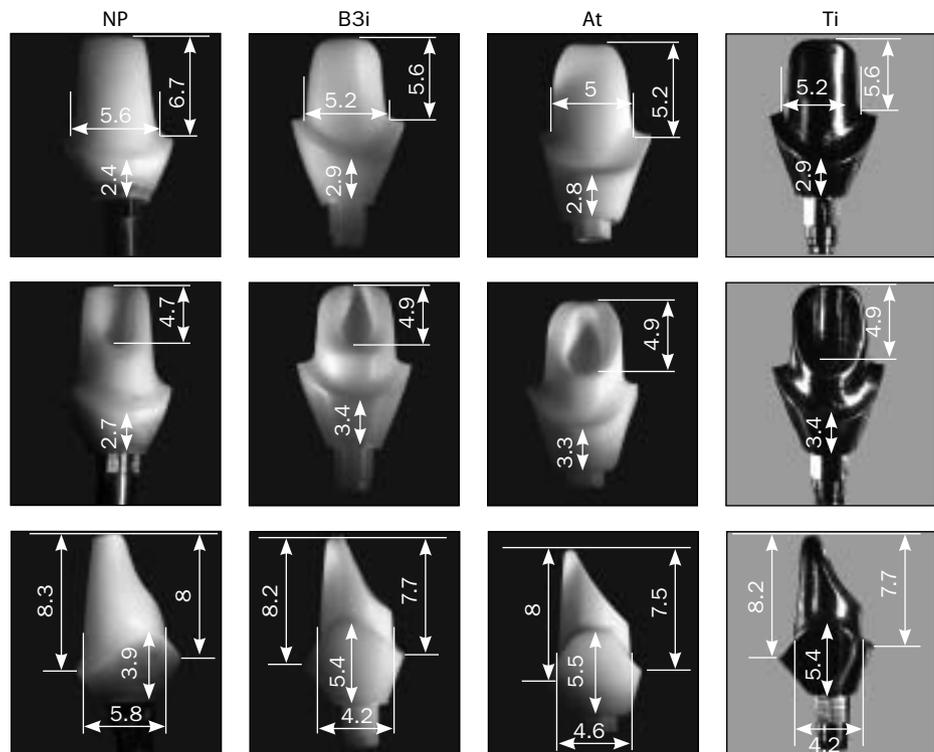
All abutments were fabricated with computer-assisted design/computer-aided manufacture (CAD/CAM) based on a master cast of the maxillary dentition that was missing the right central incisor. An anatomically shaped wax-up of a central incisor crown,  $12$  mm high and  $9.5$  mm wide, was created on an implant analog mounted onto the master cast. The crown wax-up was duplicated. A thickness of  $1.5$  to  $2$  mm was taken into account for an all-ceramic crown in the mesiodistal and faciolingual directions; based on those dimensions, the crown wax-up was cut back to generate a custom-made abutment that would allow for ideal crown size and support. The abutment wax-up was duplicated, and copies were adjusted to each implant-abutment system. Because of variations in the scanning and design processes of the different CAD/CAM systems, dimensional discrepancies occurred among the specimens of the three test groups (Fig 1). The Ti (control) group was generated from the same CAD file used for the custom-made Encode zirconia abutments.

The abutments of each group were screwed onto the dental implants using a torque of  $32$  Ncm for the Nobel Procera zirconia specimens (torque ratchet, Nobel Biocare) and  $20$  Ncm for the Encode zirconia, Encode titanium, and Atlantis zirconia abutments, following the manufacturers' guidelines. After the abutments were secured, four areas were defined<sup>25</sup> along the implant-abutment interface: buccal, mesial, palatal, and distal. The boundaries of each aspect were marked with fine notches on the implant shoulder using a turbine and a diamond bur under a stereomicroscope. All implant-abutment configurations were cleaned with ethanol and rinsed in distilled water.

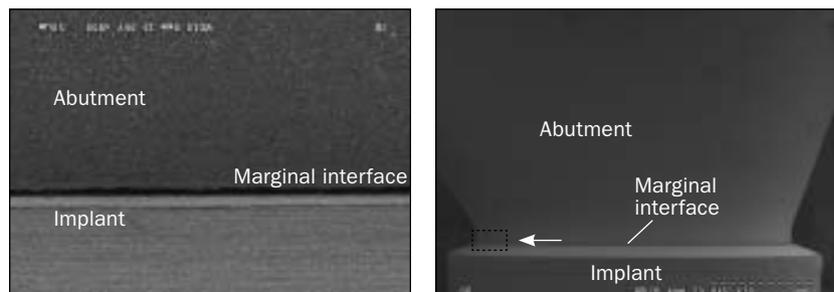
Each specimen was gold sputtered (K650 sputter coater, Quorum Technologies), and scanning electron microscopy (SEM) (S-3500N, Hitachi Instruments) was used to image the implant-abutment gap at the marginal interface. To ensure that all the specimens were appropriately positioned in the SEM and the measurements of the vertical gap were accurate, each sample was mounted on a holder with the implant-abutment interface parallel to the SEM detector. For each aspect of each specimen, the marginal fit was imaged by obtaining 15 scans in a clockwise direction using  $800\times$  magnification (Fig 2). For each scan, two measurements of the marginal gap were made with image analysis software (Quartz PCI, version 5.5, Quartz Imaging Corporation). Thus, for each side of each specimen, 30 measurements were recorded, and a total of 120 values was obtained per specimen.

One-way analysis of variance ( $\alpha = .05$ ) was performed with SigmaPlot (version 11.0) to compare gap values among groups. The same approach was used to compare among samples of the same configuration and among aspects of the same specimens.

**Fig 1** Dimensions (mm) of the investigated abutments imaged with polarized reflected light microscopy. NP = Nobel Procera zirconia abutment; B3i = Encode zirconia abutment; At = Atlantis zirconia abutment; Ti Encode titanium abutment.



**Fig 2** Implant-abutment marginal interface on one aspect. Thirty SEM images were obtained on each aspect of each specimen, with the camera capturing images in a clockwise direction (arrow).



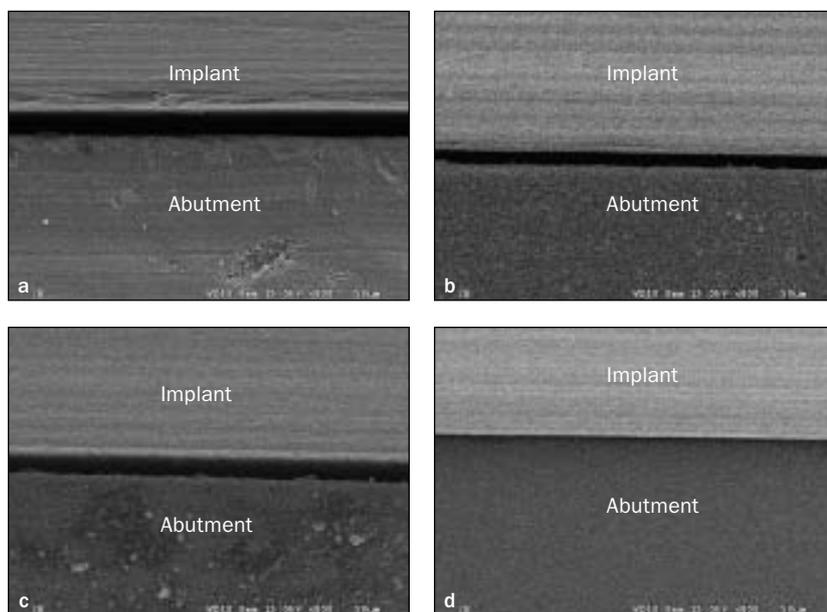
## RESULTS

The overall marginal gap of the three implant–zirconia abutment configurations ranged from 1.5 to 34.3  $\mu\text{m}$ . The marginal gap ranged from 1.5 to 34.3  $\mu\text{m}$  for the NP group, 2.2 to 11.4  $\mu\text{m}$  for the B3i group, 7.8 to 21.5  $\mu\text{m}$  for the At group, and 1 to 3.5  $\mu\text{m}$  for the Ti (control) group. Mean values ( $\pm$  standard deviations [SDs]) were  $8.4 \pm 5.6 \mu\text{m}$  (NB),  $5.7 \pm 1.9 \mu\text{m}$  (B3i),  $11.8 \pm 2.6 \mu\text{m}$  (At), and  $1.6 \pm 0.5 \mu\text{m}$  (Ti). Representative SEM images of the implant-abutment marginal gap for each configuration are shown in Figs 3a to 3d. The marginal gap sizes of the Ti group were significantly smaller than those seen in each implant–ceramic abutment configuration ( $P < .05$ ). Gap values of the NP system were not significantly different from those of the At ( $P = .06$ ) and B3i

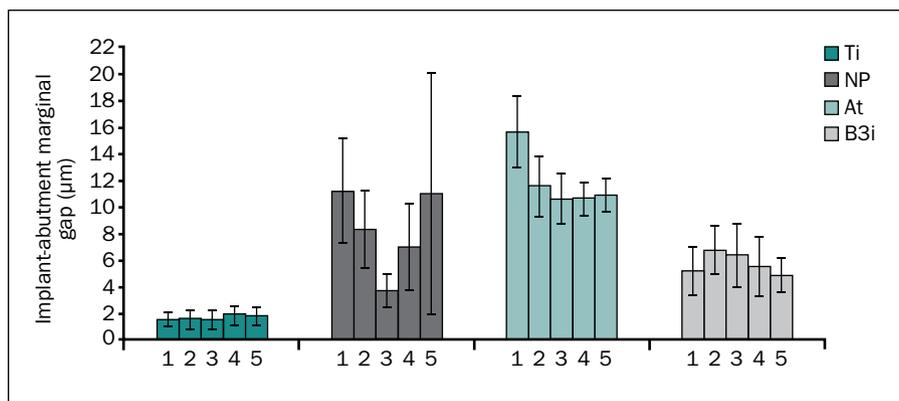
groups ( $P = .1$ ). However, a significant difference was found between the gaps of the B3i and At configurations ( $P < .01$ ).

For all specimens of each group, the means and SDs of marginal gap values are shown in Fig 4. No significant difference was found among the samples of the control group ( $P > .05$ ). For all the implant–ceramic abutment systems, marginal gap values were significantly different among samples ( $P < .01$ ).

Table 1 shows the mean ( $\pm$  SD) marginal gaps measured on each aspect (palatal, mesial, buccal, distal) of each specimen. When gap values were compared among aspects, a statistically significant difference was found for all but three samples ( $P < .05$ ): B3i specimen no. 1 ( $P = .65$ ) and At samples no. 3 ( $P = .81$ ) and no. 5 ( $P = .72$ ).



**Figs 3a to 3d** SEM images of the marginal gap on each implant-abutment configuration. (a) NP; (b) B3i; (c) At; (d) Ti (WD [working distance] 10.0 mm, magnification × 800).



**Fig 4** Means and standard deviations of marginal gaps per specimen of each combination.

## DISCUSSION

In this work, the marginal fit of three custom-made implant–zirconia abutment combinations was investigated. Several techniques have been reported for evaluation of the marginal gap between implants and abutments. The marginal gap has been previously measured from either a cross section of the implant-abutment configuration<sup>26,27</sup> or from the outer aspect circumferentially of the abutment.<sup>15,28,29</sup> The latter method—measurement of the marginal gap from the outer aspect—was applied in the present study.

A technique to measure the gap size accurately was developed so that it was possible to determine whether there were differences in the three implant-abutment configurations, among samples of the same system, and also among specific locations within each sample (ie, palatal, mesial, buccal, distal). The B3i configuration showed a significantly smaller marginal gap than the

At model and less variability than the NP specimens. For almost all specimens, the marginal fit was different for each specific aspect, with no correlation between gap values and location within each sample.

The custom-made implant–titanium abutment (control) system from Biomet 3i showed marginal gaps that ranged from 1 to 3.5 µm. The marginal gaps in the Ti group were significantly smaller and less variable than those seen with the three ceramic abutment configurations. Zirconia abutments are milled before sintering, which results in ceramic shrinkage of approximately 20% to 25%.<sup>30,31</sup> Thus, the sintering phase might increase the marginal gap of implant–ceramic abutment configurations. Although zirconia has been shown to have less risk of bacterial colonization compared to titanium,<sup>19,20</sup> the larger marginal gap of implant–zirconia abutment systems might increase the likelihood of bacterial colonization compared to that seen with metal abutment–implant configurations.

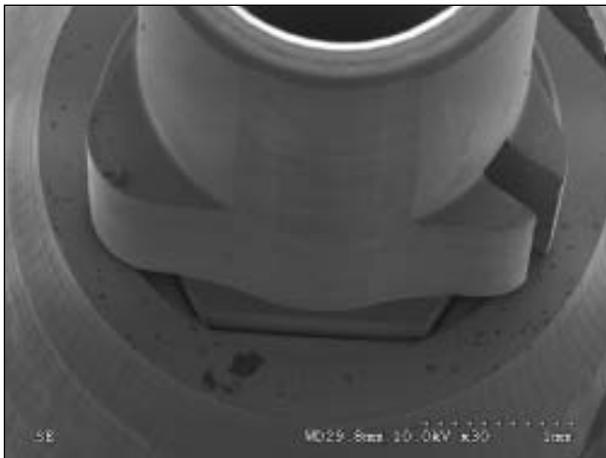
**Table 1 Mean ( $\pm$  SD) Marginal Gap Values (in microns) of the Investigated Abutment-Implant Combinations**

Configuration/ sample no.	Palatal	Mesial	Buccal	Distal
<b>Nobel Biocare/zirconia abutment</b>				
1	10.5 $\pm$ 0.9	8.3 $\pm$ 1.1	16.8 $\pm$ 3.0	8.9 $\pm$ 2.1
2	10.6 $\pm$ 1.7	7.0 $\pm$ 2.2	10.0 $\pm$ 2.6	6.1 $\pm$ 1.4
3	3.7 $\pm$ 1.2	3.3 $\pm$ 0.6	3.8 $\pm$ 1.4	4.3 $\pm$ 0.9
4	8.3 $\pm$ 3.6	4.5 $\pm$ 2.4	8.9 $\pm$ 1.5	6.4 $\pm$ 2.3
5	23.5 $\pm$ 8.5	4.7 $\pm$ 2.9	6.7 $\pm$ 1.2	8.4 $\pm$ 2.5
<b>Biomet 3i/zirconia abutment</b>				
1	3.5 $\pm$ 0.5	5.3 $\pm$ 1.4	7.2 $\pm$ 0.7	4.7 $\pm$ 0.8
2	8.3 $\pm$ 0.8	7.0 $\pm$ 1.0	4.3 $\pm$ 1.1	6.9 $\pm$ 0.9
3	3.6 $\pm$ 0.4	6.0 $\pm$ 1.3	8.3 $\pm$ 1.4	7.9 $\pm$ 1.6
4	3.3 $\pm$ 0.6	6.9 $\pm$ 1.6	7.5 $\pm$ 0.9	4.0 $\pm$ 0.9
5	3.6 $\pm$ 0.7	4.7 $\pm$ 0.6	5.8 $\pm$ 0.8	5.7 $\pm$ 0.9
<b>Atlantis/zirconia abutment</b>				
1	15.2 $\pm$ 1.2	18.4 $\pm$ 2.1	14.8 $\pm$ 2.3	14.2 $\pm$ 2.1
2	11.0 $\pm$ 1.3	14.2 $\pm$ 1.9	11.3 $\pm$ 2.2	10.3 $\pm$ 1.1
3	10.8 $\pm$ 2.6	10.5 $\pm$ 1.2	10.9 $\pm$ 1.2	10.5 $\pm$ 1.6
4	9.9 $\pm$ 0.8	10.8 $\pm$ 0.8	11.3 $\pm$ 1.1	10.7 $\pm$ 1.4
5	11.1 $\pm$ 1.0	10.8 $\pm$ 1.1	11.1 $\pm$ 1.3	10.9 $\pm$ 1.0
<b>Biomet 3i/titanium abutment</b>				
1	1.6 $\pm$ 0.3	1.5 $\pm$ 0.4	1.5 $\pm$ 0.4	1.6 $\pm$ 0.4
2	1.5 $\pm$ 0.4	2.0 $\pm$ 0.5	1.4 $\pm$ 0.5	1.3 $\pm$ 0.4
3	1.6 $\pm$ 0.6	1.8 $\pm$ 0.3	1.7 $\pm$ 0.3	1.1 $\pm$ 0.3
4	1.3 $\pm$ 0.3	2.1 $\pm$ 0.6	2.0 $\pm$ 0.4	1.9 $\pm$ 0.4
5	2.0 $\pm$ 0.3	1.6 $\pm$ 0.5	1.8 $\pm$ 0.5	1.8 $\pm$ 0.3

The variable shrinkage percentage of zirconia during sintering might lead to slightly distorted abutment dimensions.<sup>30</sup> This might explain why the marginal gap was significantly different for the ceramic specimens within the same configuration but not for the titanium abutment samples. Also, the variability in shrinkage percentage could randomly affect the contact surface of the abutment in the specific locations, explaining why differences were found among aspects of the same ceramic abutment configuration.

A different marginal fit for each ceramic abutment configuration was found in this work. The abutment scanning process is different for each abutment brand, leading to specific abutment sizes. Thus, the present results might have been a consequence of both different shrinkage percentages and brand-related scanning and milling techniques. Specifically, the Biomet 3i configuration showed a significantly better marginal fit than the Atlantis, suggesting that the first one is less

susceptible to microbial leakage and has better bio-mechanical stability.<sup>22–24,26,32</sup> No significant difference was observed between the NP and the B3i configurations. However, NP samples showed higher variability than B3i and At, similar to what was reported in a study by Baixe et al.<sup>26</sup> In that study, of four implant-zirconia abutment configurations, Procera Esthetic Abutments (Nobel Biocare) had a mean marginal fit of  $1.8 \pm 3.2 \mu\text{m}$ , as measured from the outer to the inner region of the implant-abutment interface on cross sections. However, the outer aspect showed marginal gap values up to  $18.9 \mu\text{m}$ . Similar to the present results, Procera Esthetic abutments showed the highest variation in marginal fit among the specimens, with a range of  $0.25$  to  $18.9 \mu\text{m}$ .<sup>26</sup> The higher variability might be related to the metal internal connector of this abutment system (Fig 5). This metal connector is retained mechanically to the zirconia abutment and can allow for micromovement.



**Fig 5** SEM image showing the base of a Nobel Procera zirconia abutment with its internal metal insert. The internal metal connector is retained mechanically to the zirconia abutment (WD [working distance] 29.8 mm, magnification  $\times 30$ ).

For the B3i system (2.2 to 11.4  $\mu\text{m}$ ), gap values were consistent with those of a previous study by Canullo,<sup>28</sup> which observed a vertical gap ranging from 3.7 to 7.0  $\mu\text{m}$  for custom-made titanium/zirconia two-component abutment assemblies. Hjerppe et al<sup>29</sup> found a similar range, with vertical gaps of 1.5 to 7.5  $\mu\text{m}$  for custom-made zirconia abutments.

The B3i configuration showed a better vertical fit compared to the NP and At configurations. Jansen et al tested 13 implant-abutment configurations and observed microbial leakage in all systems, concluding that a good marginal fit of the implant components can reduce microbial leakage but not prevent it.<sup>15</sup> Bacterial adhesion was addressed in other studies.<sup>13,14,16</sup> Coelho et al concluded, using toluidine blue in the internal screw of each implant system as a marker, that the seal between the implant and the abutment could not be maintained in any of the studied implant-abutment configurations.<sup>12</sup> The average diameter of a microbe is less than 2.0  $\mu\text{m}$ .<sup>11</sup> Therefore, microbial leakage and adhesion of bacteria to the marginal gap area can be assumed to occur in all implant-abutment configurations. However, it is expected that a wider microgap increases microbial colonization and enhances the risk of peri-implant tissue inflammation.

Radiographic methods, laser and photogrammetric methods, and SEM have been used to measure the marginal gap of implant-abutment assemblies.<sup>33,34</sup> For the measurements in the present study, SEM imaging was employed to visualize the vertical gap at the implant-abutment interface. Previous investigators obtained approximately 50 measurements along the margin of crown restorations, which is said to be sufficient to yield clinically relevant information about average marginal fit.<sup>35</sup> Thus, it can be assumed that

the results of the present study, in which 120 measurements per sample were taken into account, provides clinically valuable insights.

The null hypothesis of the present study was rejected, since there were significant differences in the marginal fit of implant–ceramic abutment configurations.

## CONCLUSIONS

The control group configuration, which featured a titanium abutment attached to a titanium implant, exhibited a more consistent fit among specimens and the smallest implant-abutment gaps ( $\leq 3.5 \mu\text{m}$ ). All zirconia abutments connected to titanium implants demonstrated significantly higher marginal discrepancies. Among the implant–zirconia abutment combinations, the configuration with an extended internal ceramic connection (Encode abutment/NanoTite Tapered Certain implant, Biomet 3i) showed the most reliable fit. The consequences of implant-abutment marginal fit discrepancies and risk of microbial leakage must be evaluated further in clinical investigations.

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