Comparison of Fracture Resistance and Fit Accuracy of Customized Zirconia Abutments with Prefabricated Zirconia Abutments in Internal Hexagonal Implants

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ABSTRACT

Background: Customized zirconia abutments are increasingly applied for the fabrication of esthetic implant restorations aimed at imitating the natural situation. These abutments are individually shaped according to the anatomical needs of the respective implant site.

Purpose: This study sought to compare the fracture resistance and fit accuracy of prefabricated and customized zirconia abutments using an internal hexagonal implant system (TSV®, Zimmer, Carlsbad, CA, USA).

Materials and Methods: Two zirconia abutment groups were tested: prefabricated zirconia abutments (ZirAce, Acucera, Seoul, Korea) and customized zirconia abutments milled by the Zirkonzahn milling system. Twenty zirconia abutments per group were connected to implants on an acrylic resin base with 30-Ncm torque. The fracture resistance of zirconia abutments was measured with an angle of 30° at a crosshead speed of 1 mm/min using the universal testing machine (Z020, Zwick, Ulm, Germany). Marginal and internal gaps between implants and zirconia abutments were measured after sectioning the embedded specimens using a digital microhardness tester (MXT70, Matsuzawa, Tokyo, Japan).

Results: The customized abutments were significantly stronger (1,430.2 N) than the prefabricated abutments (1,064.1 N). The mean marginal adaptation of customized abutments revealed a microgap that was increased (11.5 µm) over that in prefabricated abutments (4.3 µm).

Conclusion: Within the limitations of this study, the customized abutments are significantly stronger than prefabricated abutments, but the fit is less accurate. The strength and fit of both abutments are within clinically acceptable limit.

KEY WORDS: CAD/CAM, fit, fracture resistance, internal connection implant, zirconia

INTRODUCTION

Titanium abutments in dental implants have the advantages of preventing galvanism or corrosion at the fixture-abutment interface and promoting health of the gingiva.[1,2] However, in the anterior region, the darker shade of metal abutments causes esthetic problems indicated by grayish discoloration, especially in cases with thin gingiva. To overcome such disadvantages, ceramic abutments using aluminum oxide have been developed and adopted in clinical practice. These abutments have the advantages of optical translucency, shade, and good fit with the implant fixture. However, the mechanical property of aluminum oxide is sometimes not strong

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enough to endure masticatory forces, resulting in fracture. Thus, stronger dental ceramic material remains in demand.[3,4]

With high fracture strength, abrasion resistance, and biocompatibility, clinical applications of zirconia include all ceramic crowns, post and cores, orthodontic brackets, and, more recently, implant abutments.[5–9] The zirconia-type material that has received the most attention due to its superior mechanical properties is yttrium oxide partially stabilized zirconia (Y-TZP).[10,11] Dental restorations using Y-TZP have been made available with the recently developed computer-assisted design/computer-assisted manufacturing (CAD/CAM) systems.[12,13] In CAD/CAM technology using zirconia, a uniform ceramic green-body blank of zirconia is fabricated, the restoration is milled to a magnified size, and the size is adjusted after shrinkage during sintering. With the superior physical properties of zirconia and the efficiency of the CAD/CAM system, esthetic restorations are increasingly fabricated. Zirconia prostheses using CAD/CAM technology are rapidly replacing conventional dental ceramic restorations.[14,15] As zirconia is also being used for implant abutments, many researchers are investigating this topic.

Yildirim and colleagues[16] compared the abutment fracture strength in an external hexagonal connection system and reported that zirconia abutments were more than twice as resistant to fracture as alumina abutments, with a fracture strength of 737.6 N for the zirconia abutment and 280.1 N for the alumina abutment. Kohal and colleagues[9] studied the fracture strength of titanium, alumina, and zirconia abutments when restored with alumina and zirconia prostheses and reported that zirconia abutments had higher fracture strength than alumina abutments. Both groups studied prefabricated zirconia abutments used in an external hexagonal connection system.

Prefabricated zirconia abutments are uniform, standardized, easy to use, and have an excellent fit. However, if the position or angulation of the fixture is not appropriate or if the height of the surrounding soft tissue is insufficient, it is difficult to use prefabricated zirconia abutments. Such difficulties may be overcome by fabricating customized zirconia abutments with a CAD/CAM system, and investigations on their fracture resistance and fit accuracy at the implant-abutment interface are urgently needed. Therefore, the purpose of this study was to investigate the fracture resistance and fit accuracy of customized zirconia abutments fabricated with a CAD/CAM system using an internal hexagonal implant system and to evaluate clinical applications of zirconia abutments.

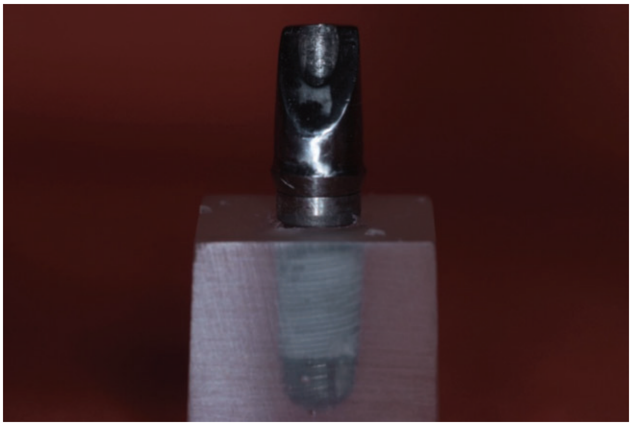

Figure 1 Prepared titanium master abutment connected to Zimmer implant with internal hexagon.

MATERIALS AND METHODS

A master abutment representing the standardized abutment for a maxillary central incisor was created to fit an implant fixture (TSV®, Zimmer, Carlsbad, CA, USA) with an internal hexagonal connection (Figure 1). The titanium abutment (Hex-Lock®, Zimmer) was prepared on a surveyor so that the abutment was 10 mm in height, tilted 6° laterally, and angled 20° labially, and the screw hole was positioned labially. The cervical margin was placed 1 mm above the implant. Twenty prefabricated commercially available zirconia abutments (ZTSV47, Shinwon Dental, Seoul, Korea) made of (Y,Nb)-TZP (ZirAce, Acucera, Seoul, Korea) were also used for comparison (Table 1). Prefabricated ZirAce

TABLE 1 Composition of Zirconia Used in This Study (wt%)

Chemical Composition	ZirAce	ICE Zircon
ZrO_2	70.7	>91.2
Al_2O_3	14.2	0.25 ± 0.10
Y_2O_3	7.6	5.15 ± 0.20
Nb_2O_5	7.5	
HfO_2		<3.0
SiO_2		≤0.02
Fe_2O_3		≤0.01
Na_2O		≤0.04

Figure 2 Prefabricated ZirAce abutment.

abutments had a diameter of 4.5 mm at the platform and 5.5 mm at the height of contour. They had a convergence of 3.75° from the height of contour toward the incisal edge and were 7.57 mm in length. The outer diameter and the length of the internal hexagonal connection were 2.69 mm and 1.5 mm, respectively. Each abutment was connected to the implant fixture and prepared using diamond burs (102R, SF102R, Shofu Inc., Kyoto, Japan) in a high-speed dental handpiece under water cooling to simulate the shape of a master titanium abutment. The dimensions and anatomic form were standardized by using a silicone form guide. After preparation, all abutments were cleaned with distilled water in ultrasonic cleaner and then steam autoclaved (Figure 2).

Twenty customized zirconia abutments were fabricated by grinding green-stage zirconia blocks (ICE Zircon, Zirkonzahn, Gais, Italy) with a manual copy-milling machine (Zirkonzahn) using a master titanium abutment as a model (Figure 3). Green-type zirconia was used to create the abutment because it can be used to create the abutment in its softest form, and subsequently, it was subjected to a sintering process to obtain the final abutment. The milled abutments were sintered at 1,500°C in the sintering oven (Zirkonzahn); the temperature rose from 20 to 1,500°C over 3 hours and was maintained at 1,500°C for 2 hours according to the manufacturer's recommendation. After fabrication, the abutments were inspected under a microscope to assess the precision of the fit and confirm the absence of any structural defects.

Implant fixtures were mounted in a self-cured resin base of 10 mm × 10 mm × 15 mm in size using a surveyor so that only the upper 3 mm was exposed and perpendicular to the base. The zirconia abutments were connected to the implant fixtures with 30-Ncm torque using a torque wrench. The holes were filled with gutta percha and light cure-type composite resin (Filtek Z350®, 3M, St. Paul, MN, USA) and light cured for 20 seconds. The 20 specimens were randomly divided into two groups: 10 abutments were included in the "fracture resistance group" and 10 samples were included in the "fit accuracy group."

The fracture resistance of zirconia abutments was measured using the universal testing machine (Z020, Zwick, Ulm, Germany). A metal jig was fabricated to hold the specimen in a position so that the long axis of the implant fixture was tilted in a 30° angulation.[16–21] After placing the specimen in the jig, a semicircle-shaped rod 6 mm in diameter was used to place loading at 1 mm lingual to the incisal edge of the zirconia abutment. To prevent lateral displacement of the specimen or the slippage of the rod, a rubber dam sheet was placed between the metal rod and the specimen. The speed of the universal testing machine was set at 1 mm/min, and the load was placed until fracture of the zirconia abutment (Figure 4). The fracture resistance was measured for 10 specimens in each group and statistically analyzed. In addition, the pattern of the fractured zirconia specimen surfaces was studied and analyzed.

Figure 3 Customized zirconia abutment milled by the Zirkonzahn system.

Figure 4 Thirty-degree loading of the abutment with a universal testing machine.

The specimens in the fit accuracy group were then embedded in a plastic mould (10 mm × 20 mm × 25 mm) with clear acrylic resin (Orthojet®, Lang Dental, Wheeling, IL, USA). The specimens were sectioned in the longitudinal axis using a diamond saw (ISOMET low speed saw, Buehler, Lake Bluff, Germany). The sectioned surface of each specimen was polished sequentially to a SiC paper of 1,200 grit. Finally, the surfaces were highly polished with alumina powder (1-µm particle size) mixed with water. Using an ultrasonic cleaner, alumina powder and debris on the surface between the screw threads or implant fixture and at the abutment connection were removed. The sectioned surface of each specimen was examined at ×100 magnification with a microscope in a digital microhardness tester (MXT70, Matsuzawa, Tokyo, Japan), and the resolution of the microscope was 0.1 µm. The gap between the implant fixture and the abutment was measured at the three measuring point by one investigator (Figures 5–7). The marginal gap was measured at the area at a distance of 100 µm from the top of the fixture along the bevel of the implant. The internal gap between the zirconia abutment and the implant fixture was measured at the center in the vertical and horizontal directions. The fracture resistance, the marginal, the internal vertical, and the internal horizontal gaps were compared between the two zirconia abutments by independent *t*-test using the SPSS® software (version 12.0, SPSS Inc., Chicago, IL, USA) at a confidence level of $p < .001$ and $p < .01$.

RESULTS

The mean fracture resistance of prefabricated ZirAce abutments was 1,064.1 N and that of the customized

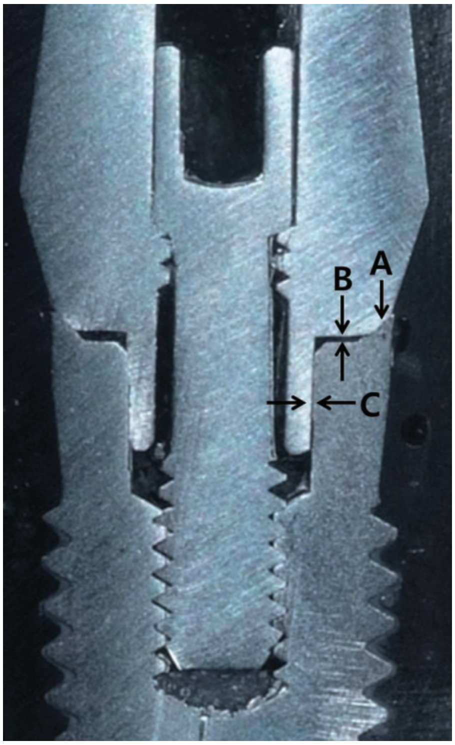

Figure 5 Cross-sectional view of titanium master abutment-implant assembly. Measuring points of marginal (A), horizontal (B), and vertical (C) gaps between the master titanium abutment and implant.

Zirkonzahn abutments was 1,430.2 N (Table 2). The customized Zirkonzahn abutments were significantly stronger compared with the prefabricated ZirAce abutments ($p < .001$). With regard to the failure mode of the abutments, all specimens except for one prefabricated abutment were fractured obliquely along the body and separated at the junction of the internal hex and platform ledge (Figure 8). The one prefabricated abutment was fractured at the internal surface of the zirconia abutment in contact with the abutment screw head.

The marginal and internal fit between the zirconia abutment and the implant is seen in Tables 3 and 4, and Figure 9. The marginal gap and horizontal gap of the

TABLE 2 Fracture Strengths (N) of Zirconia Abutments (*n* = 10)

	Prefabricated Abutment	Customized Abutment
Mean	1,064.1	1,430.2
SD	155.6	219.7

SD = standard deviation.

Figure 6 Cross-sectional view of prefabricated ZirAce abutment.

Figure 7 Cross-sectional view of customized Zirkonzahn abutment.

customized abutments were greater than those of the prefabricated abutments ($p < .01$). However, the vertical gap at the horizontal ledge showed no difference between the two abutments.

DISCUSSION

The use of zirconia abutment was introduced recently because of its high fracture resistance compared with alumina and other dental ceramics. However, the literature addressing the effect of impact force on zirconia abutments is inconclusive, and the mechanical strength of the abutments has been difficult to assess due to the lack of relevant information in the majority of articles. The physical properties of raw stock zirconia, the types of implant-abutment connection, and fabrication and experimental methods have been known to significantly influence the strength and precision of zirconia abutments.

The metal-free zirconia abutments are often recommended for externally connected implant systems rather than those that are internally connected. Yildirim and colleagues[16] tested zirconia abutments with an external hex implant connection (Nobel Biocare, Göteborg, Sweden) and reported that the mean fracture load of zirconia abutments restored by glass-ceramic crowns was 737.6 N (±245.0) under 30° loading. Kerstein and Radke[22] reported that mean fracture loads of Procera and Atlantis abutments connected on external hex implants without restoration under 40° loading were 740 N (±96) and 831 N (±69), respectively. The Procera zirconia abutments were computer-milled by scanning the technician-created wax abutment, while Atlantis abutments were created using computer-design techniques after scanning the master cast. Metrologic inspection of the two

TABLE 3 Mean Value (SD) for Marginal, Vertical, and Horizontal Gap (μm) between Implant and Abutment (n = 10)

	Marginal Gap	Vertical Gap	Horizontal Gap
Prefabricated abutment	4.3 (2.9)	106.5 (13.5)	19.3 (12.6)
Customized abutment	11.5 (9.0)	105.0 (36.6)	28.8 (14.3)

SD = standard deviation.

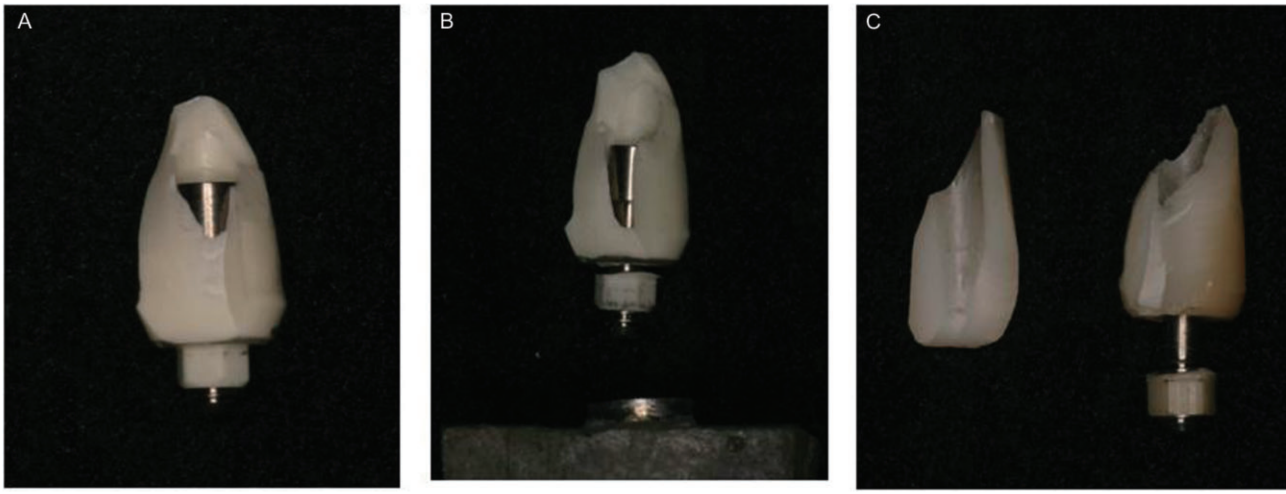

Figure 8 Modes of failure. *A*, Body fracture with a sound hexagonal structure in the prefabricated abutment. *B*, Body fracture with a hexagonal structure fracture in the prefabricated abutment. *C*, Body fracture with a hexagonal structure fracture in the customized abutment.

customized zirconia abutments revealed no significant differences in the interface features. Therefore, their respective significant strength differences were thought to be a result of the raw stock zirconia material that each company uses in its abutment fabrication process.

The mean failure load of the customized Zirkonzahn abutments (1,430.2 ± 219.7 N) was greater than the prefabricated ZirAce abutments (1,064.1 ± 155.6 N) in this study. The main reason for the superior load-bearing capacity of the customized Zirkonzahn abutments lies in the difference of raw stock zirconia material. ICE Zirkonzahn had more ZrO_2 content than ZirAce. While ZirAce contained 70.7% zirconia, ICE Zirkonzahn contained 91.2% zirconia, and this difference in composition most likely accounts for the difference in strength.[23,24] The flexural strengths of ICE Zirkonzahn and ZirAce were 1,138 and 916 MPa, respectively, whereas Weibull moduli, which are related to the flaw-size distribution,[22] of ICE Zirkonzahn and ZirAce were 14.32 and 33, respectively.[25,26] However, the ZirAce (Y,Nb)-TZP/Al_2O_3 composite was reported to have a high fracture toughness of 12 $MPam^{1/2}$, which is higher than that of other commercial zirconia material, which ranges from 7 to 10 $MPam^{1/2}$. As the fracture toughness means the resistance of a material against a propagating crack,[27] it has been reported that ZirAce abutments can prevent low-temperature degradation due to its high fracture toughness.[23,28]

The type of connection between the abutments and implants significantly influenced the strength

TABLE 4 Statistical Analysis of Prefabricated Zirconia Abutment and Customized Zirconia Abutment

		Mean	N	SD	*t*	*p*
Fracture strength (N)	P	1,064.1	10	155.6	−4.561***	.001
	C	1,430.2	10	219.7		
Marginal gap (μm)	P	4.3	10	2.9	−2.388***	.000
	C	11.5	10	9.0		
Vertical gap (μm)	P	106.5	10	13.5	0.161	.874
	C	105.0	10	36.6		
Horizontal gap (μm)	P	19.3	10	12.6	−2.967**	.008
	C	28.8	10	14.3		

**$p < .01$, ***$p < .001$.
P = prefabricated abutment; C = customized abutment; SD = standard deviation.

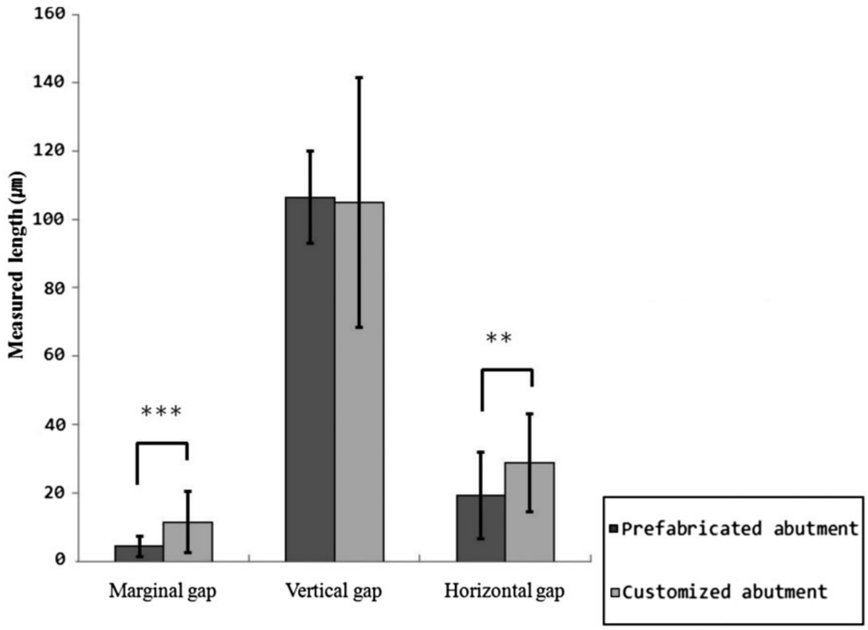

Figure 9 The marginal, vertical, and horizontal gaps between the zirconia abutment and implant.

of zirconia abutments. The advantage of internal implant-abutment connections is that they are more stable, and forces are more widely distributed along the interface compared with the external hex design.[29] However, Sailer and colleagues[17] concluded that one-piece internally connected zirconia abutments were weaker than one-piece externally connected or two-piece internally connected zirconia abutments with metallic insert. The mean fracture loads of the unrestored zirconia abutments were 480.9 N (±82.8) for external connection (Nobel Biocare) and 292.0 N (±218.4) for internal connection (Straumann, Basel, Switzerland) under 30° loading. They also proved that the zirconia abutment groups with restorations did not show higher bending moments than those without restorations. Our investigation, as well as the study by Adatia and colleagues,[18] did not include a full veneer crown in the experimental model. Other authors[16] included crowns over the zirconia abutments and found that a crown may act to shield the abutment from the effects of the load, thereby allowing a larger load to be applied before failure is noted.

While there have not been many studies regarding one-piece zirconia abutments with internal connections, there have been numerous studies on Astra Tech system with conical seal design implant connections. Adatia and colleagues[18] reported that the mean fracture loads of unrestored zirconia abutments on Astra implants were between 429 (±140) and 576 (±120) N, depending on the preparation amount of between 0 and 1.0 mm under 30° loading. Margin preparation of the zirconia abutments up to 1.0 mm with irrigation did not adversely affect the fracture strength of abutment assemblies. Nothdurft and colleagues[19] evaluated the effects of thermomechanical loading on the failure load of zirconia abutments on Astra implants. The restored angulated abutments exhibited a mean fracture load of 355.0 N (±24.7) under 30° loading, and thermomechanical aging did not lead to a significant decrease in load-bearing capacity of zirconia abutments. However, Mitsias and colleagues[20] reported that the fracture load of zirconia abutments on Astra implants restored with metal crowns was 690 N (±430) under 30° static loading, while the reliability of the zirconia abutments for 50,000 cycles of fatigue test dropped considerably from 93% at 175 N to 18% at 300 N.

Gehrke and colleagues[21] performed cyclic loading tests using Cercon zirconia abutments fixed on Xive implants. The Xive system is characterized by a 1.5-mm-high and 2.5-mm-wide internal hex, a wide platform on the top of the implant, and a parallel socket above and below the hex. Cercon zirconia abutments restored with spherical caps exhibited a maximum fracture load of 672 N during 30° static loading and 403.2 N at 10,000 cycles runout point, and 268.8 N at an 800,000 to 5 million cycles runout point during cyclic loading. They concluded that Cercon zirconia abutments could safely be used in the incisor region of the maxilla and mandible, while caution was recommended in the molar regions.

Hjerppe and colleagues[24] compared unrestored, custom-made Zirkonzahn abutments with prefabricated, commercially available zirconia abutments using two types of implant systems (i.e., Astra and Xive). The fracture loads in Astra groups varied from 511 to 624 N under 45° loading, and there were no significant differences among the Astra groups. However, they reported higher fracture load of 1,099 N (± 207) in the Zirkonzahn-Xive modified abutments compared with 412 N (±79) in prefabricated Xive abutments. These stronger abutments were relatively short and had more zirconia material by volume than the others due to the abutment design. Our findings were consistent with those of Hjerppe and colleagues, and the mean fracture load of the customized Zirkonzahn abutments was greater than that of the prefabricated ZirAce abutments.

The abutment-implant connection of Zimmer implants has a 44° internal bevel with a 1-mm ledge and a 1.5-mm-high and 2.5-mm-wide internal hex. Studies on fracture strength of zirconia abutments of Zimmer implant systems have been scarce. The analysis of the failure mode of the two tested zirconia abutments revealed that the crack initiated from the oral aspect in the region of the internal hex, at the thinnest portion of the abutment. As the cervical portion of ceramic abutments represents the area of highest torque that leads to crack initiation, further improvements in the design and/or strength of implant-abutment connections of zirconia abutments are needed to enhance the resistance of the restorative system.

In this study, the volume of zirconia was greater because the amount of abutment reduction was less. In addition, the understructure of zirconia abutments is stronger due to the characteristic of the abutment-implant connection. These are probably the reasons why the fracture resistance was higher than in other investigations. The fracture resistance of a zirconia abutment should be within a safety range of 370 N for the anterior region[30] and 1,000 N for the posterior region[31] of the maxilla and mandible to ensure a favorable clinical prognosis of zirconia abutments. However, cyclic fatigue patterns and stress corrosion failure may occur intraorally in clinical situations. As a rule of thumb, the endurance limit for fatigue cycling that can be applied to dental ceramics is approximately 50% of the maximum fracture resistance.[21] In this study, the fracture resistance of zirconia abutments was greater than 1,000 N, and if the 50% fatigue resistance rule is applied to zirconia abutments of Zimmer implant systems, 500 N is an adequate fatigue strength to be used on anterior teeth. The two tested zirconia abutments have the potential to withstand physiological occlusal forces in the anterior region.

The long-term clinical success of zirconia abutments can be influenced significantly by marginal discrepancies. Poor marginal adaptation increases plaque retention and changes the distribution of the microflora, which can induce the onset of peri-implant disease.[32] Studies on the comparison of microgaps between implant-abutment interfaces demonstrated varying results because of the differences in machining tolerances of implant systems as well as measuring methods (e.g., scanning electron microscope analysis or cross-section methods).[33] Byrne and colleagues[34] reported that the mean external gap between the Ti abutment and Nobel Biocare implant ranged from 36 to 86 µm using a cross-section method. However, Yüzügüllü and Avci[35] reported that the mean marginal discrepancy for zirconia abutments in external hex implants was 2.53 (±0.48) µm by scanning electron microscopy analyses. These differences in results between the two studies may be due to differences in measuring points and methodology.

Kanno and colleagues[36] found a marginal gap at the fixture top of the Astra Tech implant of approximately 0.94 µm (±1.21) using cross-section methods. Whereas Hjerppe and colleagues[24] reported that the horizontal discrepancies between Astra and customized Astra zirconia abutments and the implant replica were 4.9 µm (±2) and 10.7 µm (±11.1), and the vertical discrepancies in Xive and customized Xive abutments were 1.5 µm (±0.5) and 7.5 µm (±5.8). The mean marginal gaps in this study were 4.3 µm (±2.9) for prefabricated ZirAce abutments and 11.5 µm (±9.0) for customized Zirkonzahn abutments. The prefabricated ZirAce abutment performed significantly better than the customized Zirkonzahn abutment in terms of marginal fit, which is consistent with the results of Hjerppe and colleagues. Possible causes of poorer fit include a 20% sintering shrinkage, the scanning process, compensatory software design, and milling. Hoyer and colleagues[37] stated that the marginal gap between implant and abutment under dynamic loading after 500,000 cycles was consistently in the range of 0 to 30 µm, which are clinically acceptable. Therefore, the marginal and internal fit of both abutments were within clinically acceptable range.

The fact that the marginal gap between the implant and abutment was larger in the customized copy-milled abutments did not seem to affect the mechanical strength of the implant-abutment system. However, fretting wear between the titanium implant and the zirconia abutment occurs when repeated loading and unloading cause cyclic stresses that induce surface or subsurface breakup, resulting in the loss of material. This wear must be taken into account when fabricating customized zirconia abutments in dental laboratories.

The limitations of the present study were as follows. (1) The customized abutment was copy-milled using the master titanium abutment. Therefore, the dimensions of the two experimental abutment designs were not identical, which could possibly affect the fracture strength results. It would be more ideal to have a prepared, prefabricated abutment copy-milled into the customized abutment. (2) The gap dimensions were measured using the cross-section technique. As a result, the precision was measured at only three defined areas per assembly, and this may not represent the complete fit. Cross sectioning might also cause damage to the specimens.

CONCLUSIONS

Within the limitations of this study, the customized Zirkonzahn abutments showed higher fracture resistance than the prefabricated ZirAce abutments. Both types of zirconia abutments demonstrated failure loads that exceeded maximum human bite force. However, the marginal fit of the customized abutments was not necessarily as satisfactory as that seen with prefabricated abutments.

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