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ORIGINAL ARTICLE

Fracture behavior of straight or angulated zirconia implant abutments supporting anterior single crowns

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Abstract The aim of the study was to evaluate the influence of artificial aging on the fracture behavior of straight and angulated zirconia implant abutments (ZirDesign™; Astra Tech, Mölndal, Sweden) supporting anterior single crowns (SCs). Four different test groups (n=8) representing anterior SCs were prepared. Groups 1 and 2 simulated a clinical situation with an ideal implant position (left central incisor) from a prosthetic point of view, which allows for the use of a straight, prefabricated zirconia abutment. Groups 3 and 4 simulated a situation with a compromised implant position, requiring an angulated (20°) abutment. OsseoSpeed™ implants (Astra Tech) 4.5 mm in diameter and 13 mm in length were used to support the abutments. The SCs (chromium cobalt alloy) were cemented with glass ionomer cement. Groups 2 and 4 were thermomechanically loaded (TCML=1.2×10^6; 10,000×5°/55°) and subjected to static loading until failure. Statistical analysis of force data at the fracture site was performed using nonparametric tests. All samples tested survived TCML. Artificial aging did not lead to a significant decrease in load-bearing capacity in either the groups with straight abutments or the groups with angulated abutments. The restorations that utilized angulated abutments exhibited higher fracture loads than the restorations with straight abutments (group 1, 280.25±30.45 N; group 2, 268.88±38.00 N; group 3, 355.00±24.71 N; group 4, 320.71±78.08 N). This difference in load-bearing performance between straight and angulated abutments was statistically significant (p=0.000) only when no artificial aging was employed. The vast majority of the abutments fractured below the implant shoulder.

Keywords Zirconia · Zirconium dioxide · Implant abutments · Fracture resistance · Load-bearing capability · Fatigue testing

Introduction

Crestal bone stability and healthy soft tissues are considered essential for the long-term success of implant-supported restorations. Peri-implant tissues are constantly challenged by various hazards. Bacterial plaque [1], loading [2], and prosthetic manipulation [3] are factors that can have adverse effects on implant success. The soft tissue barrier around dental implants serves as a protective seal between the oral environment and the underlying peri-implant bone [4]. The abutment material appears to be of critical importance for the quality of the attachment that forms between the mucosa and the abutment surface [5]. The interface between the peri-implant mucosa and implant abutments made of titanium alloy is comprised of one epithelial and one connective tissue component. The structure and function of this barrier tissue have been described elsewhere [4]. Titanium, gold, base metals, and zirconium or aluminum oxide ceramics are available for

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prosthetic implant-abutment fabrication [5]. In particular, ceramic materials are of increasing importance due not only to their tooth-like color [6] but also to their possible biological advantages. However, there is minimal evidence that zirconium oxide abutments perform better in maintaining stable peri-implant tissues than titanium alloy [7]. Data from animal studies and human histological studies suggest that zirconium oxide abutments may exert a more favorable effect on peri-implant soft tissue health than titanium alloy abutments [4, 5, 8]. Today, the preferred indication for the use of ceramic implant abutments is single-tooth replacement in the aesthetically demanding anterior region of the maxilla [6, 9, 10]. For this application, in vitro investigations have calculated sufficient load-bearing capacities of zirconium dioxide abutments in several different implant systems [11, 12]. In addition, clinical trials have indicated a low fracture risk [13–16]. Because of a clear positive influence on peri-implant soft tissue health, the use of zirconium dioxide abutments seems to be promising not only for single-tooth replacement but also for enlarged indications (e.g., implant–implant- or implant–tooth-supported fixed partial dentures). Nevertheless, only a small number of in vitro and in vivo studies concerning this topic can be found in the literature [17, 18].

The present in vitro study investigated the fracture behavior of zirconium dioxide implant abutments supporting anterior single crowns (SCs). Compared with straight abutments, we hypothesized that the use of angulated abutments would lead to significantly lower load-bearing capacities for implant-supported restorations. Another aim of the study was to evaluate the influence of artificial aging on the load-bearing capacities of straight and angulated zirconium implant abutments in the context of anterior SCs.

Materials and methods

We used four different test groups (n=8). All groups represented an anterior implant-supported SC scenario involving left central incisor replacement. Groups 1 and 2 simulated a clinical situation with an ideal implant position from a prosthetic point of view, allowing for the use of a straight, prefabricated zirconia abutment. Groups 3 and 4 simulated a compromised implant position, requiring an angulated abutment.

All abutments were shortened from occlusal and individualized on the shoulder to recreate realistic clinical conditions. Groups 2 and 4 were subjected to thermal and mechanical artificial aging.

A typodont model of the maxilla was used (KaVo Dental, Biberach, Germany) to simulate adequate clinical dimensions for an anterior SC situation.

For all groups, the left incisors were first removed from the model. The alveolar socket remained empty. An impression (Adisil® blau 9:1, SILADENT Dr. Böhme & Schöps GmbH; Gossar, Germany) was taken from the typodont model, and two casts were poured using a type 4 dental stone (Die-Stone, Heraeus Kulzer GmbH, Hanau, Germany). These casts allowed us to manufacture test models for the two simulated clinical situations (correctly placed implant and angulated implant (Figs. 1 and 2).

For this study, we used Osseo Speed™ Implants (Astra Tech AB, Mölndal, Sweden) with a diameter of 4.5 mm and a length of 13 mm and straight or 20° angulated ZirDesign™ 4.5/5.0 zirconia abutments (Astra Tech AB). Attention was paid to ensure that the position of the implants corresponded to the structure of the dental arch and that the position of the implant shoulder lay 3 mm below the mesial and distal papilla. In groups 1 and 2, the implants were placed axially in the center of the alveolar sockets and fixed with acrylic resin (Pro Base clear, Ivovlar Vivadent, Ellwangen, Germany). In groups 3 and 4, the implants were placed in the center of the alveolar socket but were angulated by 20° in the anterior direction.

Again, impressions were taken with Adisil® blau 9:1 (SILADENT Dr. Böhme & Schöps GmbH), and an appropriate system-specific transfer-coping technique was used after trimming the casts to create a block. Implants could be placed repeatedly into these impressions and mounted in acrylic resin (Palapress Vario; Heraeus Kulzer GmbH, Hanau, Germany). In this manner, 16 test models

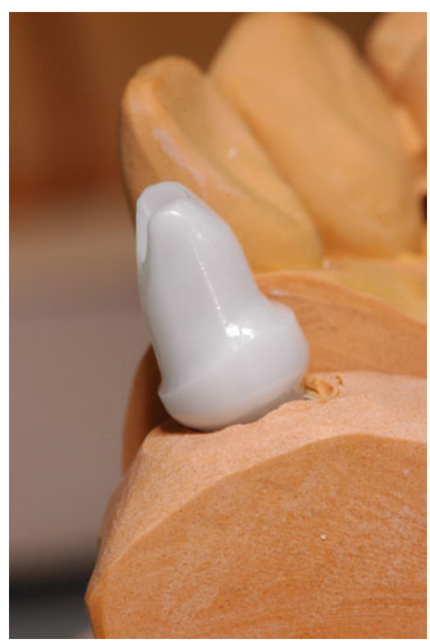

Fig. 1 Master cast for test groups with straight zirconia abutments as prepared for the scanning process

Fig. 2 Master cast for test groups with angulated zirconia abutments as prepared for the scanning process

including straight abutments as well as 16 test models with angulated abutments were fabricated.

The implant abutments were prepared using a parallel drilling device (C.K. Telemaster Mill; C. Hafner GmbH & Co.KG, Pforzheim, Germany) and a high-speed laboratory handpiece under continuous air/water spray treatment. All abutments were prepared by a single operator using special 2° tapered zirconia grinding diamonds (IMAGO® Grind 40 µm; Steco-system-technik GmbH & Co.KG, Hamburg, Germany) for occlusal and circumferential reductions. All abutments had to be reduced in height and were prepared circumferentially to shift the finishing line consistent with the simulated clinical situation. The extent of individualization is shown in detail in Figs. 3 and 4. A preparation aid made from silicone was used to standardize the final dimensions of the individualized abutments.

SCs were manufactured using the computer aided design (CAD)/computer aided manufacturing (CAM) functionality of the KaVo Everest® system (KaVo Dental Gmbh). For both of the simulated clinical situations (straight and angulated abutments), the corresponding master cast was digitized using an optical scanner (KaVo Everest® scan pro). Afterwards, a further scan was performed on the corresponding SCs which were modeled in wax. All data were imported into the CAD software. The cement gap was adjusted to 0.2 mm.

The SC scans served as baseline data and were processed appropriate to mill the actual test SCs from acrylic polymer blanks (Everest® C-Cast, KaVo). These SCs were relined with a light-curing modeling resin (Visio™ -Form, 3 M

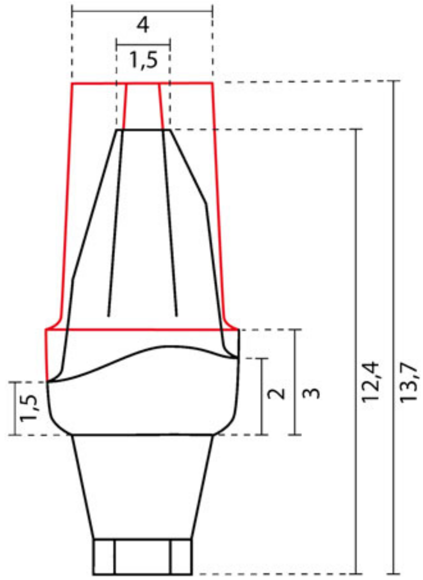

Fig. 3 Dimensions in millimeters of the straight ZirDesign™ abutment before (*red*) and after (*black*) individualization

ESPE AG, Seefeld, Germany) to create the final test specimen. This allowed us to adjust the restorations margins to the finishing line of every implant abutment. The finished resin SCs were finally embedded and cast from a chromium cobalt alloy (Remanium® GM 800+; Dentaurum J. P. Winkelstroeter KG) via the lost wax technique (Fig. 5).

Before cementing the SCs, all abutments were inserted into the implants with a surgical unit (INTRAsurg 200, KaVo) to a torque of 25 Ncm using appropriate screws. The screws were covered with gutta-percha (BeeFill®, VDW

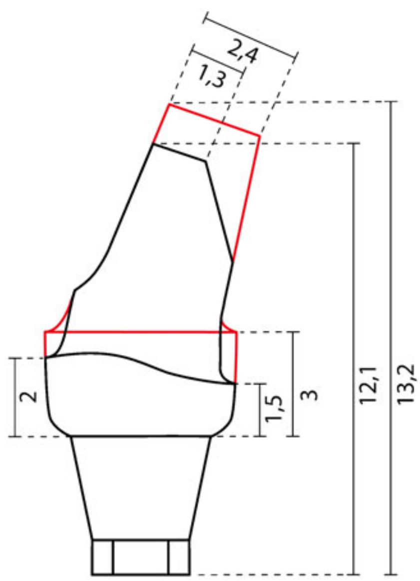

Fig. 4 Dimensions in millimeters of the angulated ZirDesign™ abutment before (*red*) and after (*black*) individualization

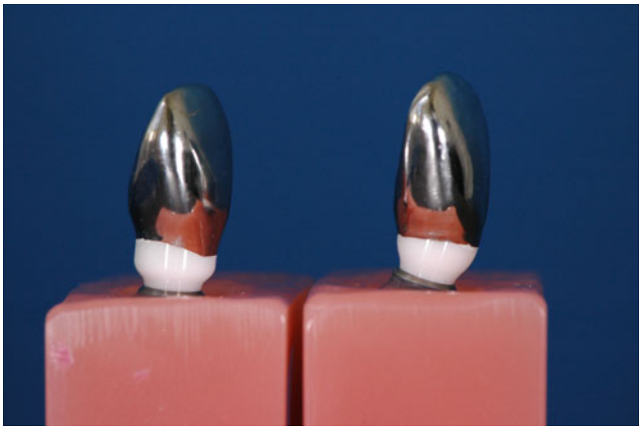

Fig. 5 Lateral view of the test models with cemented SCs made from chromium cobalt alloy (*left* with straight zirconia abutments, *right* with angulated abutments)

GmbH, Munich, Germany) to permit easy access after we had calculated the load-bearing capacity.

The SCs were cleaned with ethanol, dried, and cemented with glass ionomer cement (Ketac Cem; 3 M ESPE gmbH & Co. KG, Seefeld, Germany). The restorations were placed on the prepared samples under finger pressure for 5 min. Excess cement was removed with a sharp instrument. After the cementation procedures and before further processing, all samples were stored in saline solution.

Thermal and mechanical aging was performed in a chewing simulator (SD Mechatronic GmbH, Feldkirchen-Westerham, Germany) with a stainless steel spherical antagonist (diameter, 4 mm) at an angle of 30° and with contact on the palatal surface 2 mm below the incisal edge. The specimens were treated for 1,200,000 cycles at 50 N with a crosshead speed of 10 mm/s downward and 70 mm/s upward. Simultaneously, the samples were subjected to thermocycling for 10,000 cycles at 5–55°C and with a dwell time of 30 s. Due to the transfer time of 5 s, the total duration of each complete cycle was 70 s.

During the aging process, the specimens were maintained in a wet environment (Aqua bidest).

Following artificial aging, the samples were fixed into a metal holder within a universal testing device (Zwick/Roell, Ulm, Germany) with the long axis of the crowns at an angle of 30° to the direction of the load (Fig. 6). A stainless steel spherical antagonist (4 mm diameter) was used to load the samples until failure at a crosshead speed of 0.5 mm/min, with the force transferred to the palatal surface 2 mm below the incisal edge on an interposed polycarbonate foil of thickness 0.5 mm (Duran®; Scheu Dental GmbH, Isarlohn, Germany).

A sudden decrease in force of more than 30% was interpreted as an indication of failure, and the maximum force up to this point was recorded as the force at fracture.

Due to our small sample size, we used nonparametric tests to analyze the force at fracture performance (i.e., Kruskal–Wallis and Mann–Whitney *U*). The level of significance was set to $p<0.05$. For multiple testing, the Bonferroni correction was applied to adjust the level of significance. All fracture pattern data are reported as descriptive statistics. All analyses were performed with SPSS, version 17.0 (SPSS GmbH Software, Munich, Germany).

The implant abutments were unscrewed after removal of the SCs and visually inspected to identify failure modes. The fracture lines were documented on a schematic drawing.

Results

Specimen number 6 of group 3 was excluded from further analysis due to a mistake in adjusting the chewing simulator. On visual inspection, all samples tested survived 1,200,000 cycles of dynamic loading and 10,000 thermal cycles in the artificial oral environment.

Table 1 and Fig. 7 show results from the load-bearing capacity tests. Specimens fractured at failure loads of 194 to 466 N. The highest mean fracture load was measured in the group with angulated abutments without artificial aging (355 N; SD, 24.71 N). The group with straight abutments following artificial aging exhibited the lowest mean load-bearing capacity (268.88 N; SD, 38.99 N). Artificial aging did not lead to a significant decrease of load-bearing capacity in groups with either straight abutments or angulated abutments. The restorations utilizing angulated abutments exhibited higher fracture loads than equivalent restorations with straight abutments. This difference in load-bearing capacity was statistically significant only when no artificial aging was employed.

Each abutment fracture event was accompanied by an audible pop. In nearly all cases, the fractures in the test

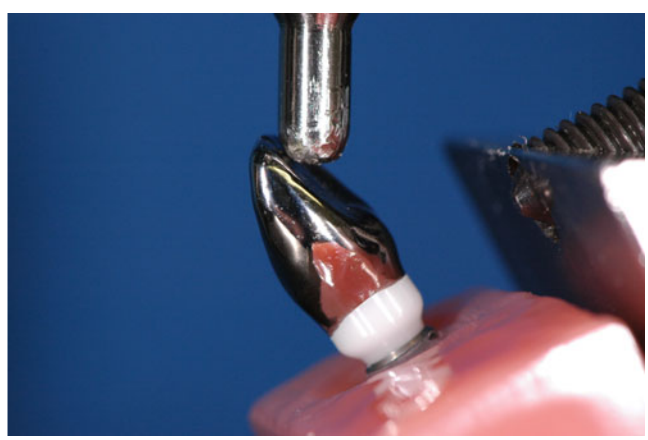

Fig. 6 Static loading of an implant-supported anterior single crown

Table 1 Mean force at fracture with standard deviations in Newtons (N)

Groups	Number	Mean	SD	Median	Minimum	Maximum
1. ZirDesign, straight, nA	8	280.25	30.45	282.50	239.00	319.00
2. ZirDesign, straight, A	8	268.88	38.00	271.50	194.00	324.00
3. ZirDesign, angulated, nA	8	355.00	24.71	353.50	322.00	400.00
4. ZirDesign, angulated, A	7	320.71	78.08	319.00	236.00	466.00

nA no artificial aging, *A* artificial aging

specimens were not visually or tactile-wise detectable after their removal from the static loading assembly. In these cases, fracture patterns could not be evaluated prior to disconnecting the abutment from the implant.

The typical fracture pattern in all different groups is depicted in Fig. 8. A specific fracture pattern was noted. All of the abutments fractured below the implant shoulder. With the exception of two specimens that exhibited solely a horizontal fracture or a secondary horizontal fracture above the implant shoulder, we only observed oblique fracture lines. These oblique fracture lines started from the oral aspect in the region of the internal hexagon, the thinnest portion of the abutment (Figs. 9, 10 and 11).

Discussion

To avoid too much cofactors, our SCs were cast from a cobalt chrome alloy. This procedure is not consistent with clinical practice, but it is a technically and financially less-expensive method for simulating a full coverage restoration in an in vitro setting. Crowns with a zirconia framework and an additional layer of silicate ceramics could have been the weakest link in the test set-up, though not in the main focus of this study. Nevertheless, we are aware of a possible strengthening effect of metal crowns on the overall fracture load and the limiting effect on the study.

A review of the literature uncovered laboratory studies on the fracture resistance of implant abutments made from zirconium dioxide. Researchers highlighted the importance of whether the evaluated samples are zirconium dioxide abutments with a titanium alloy carry base [11, 17, 19, 20] or real, all-ceramic components.

To the best of our knowledge, most of the published investigations on all-ceramic implant abutments made from zirconium dioxide examine simulated single incisor replacements [12, 21–23]. These papers report load-bearing capacities of between 429 and 793 N under load angles that range from 30° to 60°. There seems to exist a strong correlation between measured fracture loads and type of implant-abutment connection [10]. Therefore, it is difficult to compare our values for load-bearing capacities with results from other studies. But to estimate the failure risk associated with implant-supported restorative concepts consistent with their load-bearing capacity as determined in an in vitro setting, it is important to separately consider the forces that can be expected in actual clinical situations. Ferrario et al. [24] measured single-tooth bite forces in healthy young adults and reported results of 150 and 140 N

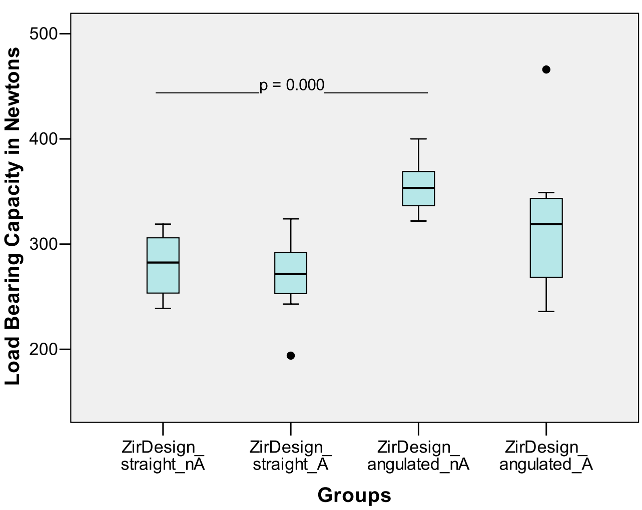

Fig. 7 Box plot diagram of the load-bearing capacities of groups 1 to 4. The *bar* indicates a statistically significant difference. The level of significance was set to $p<0.05$

Fig. 8 Typical fracture mode in group (oblique fracture line starting from the oral aspect in the region of the internal hexagon)

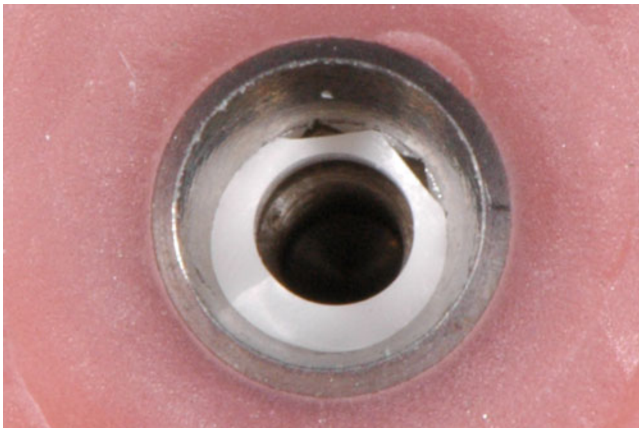

Fig. 9 View into the internal connection area. A typical fracture starting in the region of the internal hexagon, the thinnest portion of the abutment

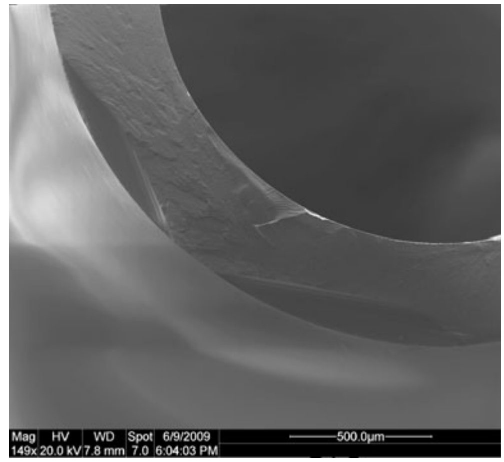

Fig. 11 Higher magnification of the fracture area in the region of the internal hexagon

for the central and lateral incisors, respectively, in men. Higher bite forces are to be expected in subjects with functional disorders, such as bruxism [25]. During static loading, the force was applied slowly with a crosshead speed of 0.5 mm/min. This corresponds to the load in a parafunctional situation rather than to a chewing- or impact-type load.

In this study, the mean fracture loads for all of the restoration groups exceeded the above-mentioned bite forces; however, we note continued uncertainty in predicting the performance of restorations in individuals with functional disorders. We emphasize the need to pay special attention to the occlusal relationship of the lower and upper jaw. Whenever possible, we recommend keeping such restorations free from dynamic occlusion.

It is remarkable that restorations with angulated abutments exhibited higher mean fracture loads than restorations with straight abutments, though statistically significant only without artificial aging. This data leads us to reject our original hypothesis. It is possible that bending forces are lower in the area of the apical hexagon, colocalized with the thinnest portion of the abutment. However, this idea remains speculative. Nevertheless, our findings support the results of studies that confirm the good clinical performance of angulated abutments made from titanium alloys [26–28].

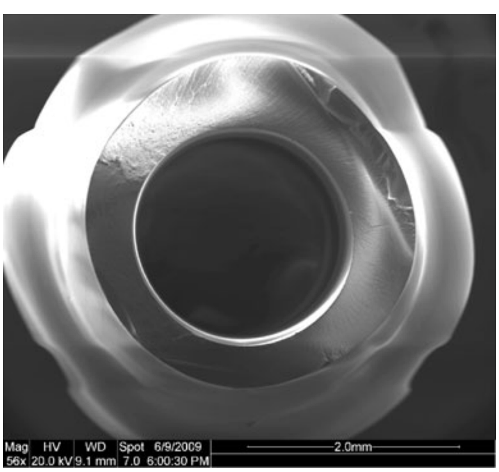

Fig. 10 SEM overview a typical oblique fracture, starting in the region of the internal hexagon, the thinnest portion of the abutment

Clinical failures of dental restorations most commonly result from fatigue [29]. We therefore artificially aged half of the specimens by applying dynamic thermal and mechanical loading with parameters similar to those found in the literature [30]. Dynamic and static loading were performed at an angle of 30° to the long axis of the roots in order to simulate a worst-case scenario. In the present study, artificial aging failed to exert a statistically significant influence on the load-bearing capacity of either straight or angulated abutments.

The most typical fracture pattern was an oblique fracture line below the implant shoulder. This finding, which confirms observations from Adatia et al. [22], indicates that certain grinding procedures above the level of the implant shoulder for the purpose of abutment individualization have no impact on fracture resistance. However, this claim may be valid only for the specific conical type of implant-abutment connection tested in this study.

Conclusion

Within the limitations of this in vitro study, we conclude that compensation for angulated implant positions with an angulated zirconia abutment is possible without reducing the load-bearing capacity of implant-supported SCs.

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Conflict of interests The authors declare that they have no conflict of interest.

References

1. Barboza EP, Caula AL, Carvalho WR (2002) Crestal bone loss around submerged and exposed unloaded dental implants: a radiographic and microbiological descriptive study. Implant Dent 11:162–169
2. Misch CE, Dietsh-Misch F, Hoar J, Beck G, Hazen R, Misch CM (1999) A bone quality-based implant system: first year of prosthetic loading. J Oral Implantol 25:185–197
3. Abrahamsson I, Berglundh T, Lindhe J (1997) The mucosal barrier following abutment dis/reconnection. An experimental study in dogs. J Clin Periodontol 24:568–572
4. Welander M, Abrahamsson I, Berglundh T (2008) The mucosal barrier at implant abutments of different materials. Clin Oral Implants Res 19:635–641
5. Abrahamsson I, Berglundh T, Glantz PO, Lindhe J (1998) The mucosal attachment at different abutments. An experimental study in dogs. J Clin Periodontol 25:721–727
6. Watkin A, Kerstein RB (2008) Improving darkened anterior peri-implant tissue color with zirconia custom implant abutments. Compend Contin Educ Dent 29(238–240):242
7. Linkevicius T, Apse P (2008) Influence of abutment material on stability of peri-implant tissues: a systematic review. Int J Oral Maxillofac Implants 23:449–456
8. Degidi M, Artese L, Scarano A, Perrotti V, Gehrke P, Piattelli A (2006) Inflammatory infiltrate, microvessel density, nitric oxide synthase expression, vascular endothelial growth factor expression, and proliferative activity in peri-implant soft tissues around titanium and zirconium oxide healing caps. J Periodontol 77:73–80
9. Brodbeck U (2003) The ZiReal Post: a new ceramic implant abutment. J Esthet Restor Dent 15:10–23, discussion 24
10. Sailer I, Philipp A, Zembic A, Pjetursson BE, Hammerle CH, Zwahlen M (2009) A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. Clin Oral Implants Res 20(Suppl 4):4–31
11. Butz F, Heydecke G, Okutan M, Strub JR (2005) Survival rate, fracture strength and failure mode of ceramic implant abutments after chewing simulation. J Oral Rehabil 32:838–843
12. Gehrke P, Dhom G, Brunner J, Wolf D, Degidi M, Piattelli A (2006) Zirconium implant abutments: fracture strength and influence of cyclic loading on retaining-screw loosening. Quintessence Int 37:19–26
13. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Scharer P (2004) Experimental zirconia abutments for implant-supported single-tooth restorations in aesthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 17:285–290
14. Henriksson K, Jemt T (2003) Evaluation of custom-made procera ceramic abutments for single-implant tooth replacement: a prospective 1-year follow-up study. Int J Prosthodont 16:626–630
15. Zembic A, Sailer I, Jung RE, Hammerle CH (2009) Randomized-controlled clinical trial of customized zirconia and titanium implant abutments for single-tooth implants in canine and posterior regions: 3-year results. Clin Oral Implants Res 20:802–808
16. Sailer I, Zembic A, Jung RE, Siegenthaler D, Holderegger C, Hammerle CH (2009) Randomized controlled clinical trial of customized zirconia and titanium implant abutments for canine and posterior single-tooth implant reconstructions: preliminary results at 1 year of function. Clin Oral Implants Res 20:219–225
17. Kolbeck C, Behr M, Rosentritt M, Handel G (2008) Fracture force of tooth–tooth- and implant–tooth-supported all-ceramic fixed partial dentures using titanium vs. customised zirconia implant abutments. Clin Oral Implants Res 19:1049–1053
18. Andersson B, Glauser R, Maglione M, Taylor A (2003) Ceramic implant abutments for short-span FPDs: a prospective 5-year multicenter study. Int J Prosthodont 16:640–646
19. Canullo L, Morgia P, Marinotti F (2007) Preliminary laboratory evaluation of bicomponent customized zirconia abutments. Int J Prosthodont 20:486–488
20. Att W, Kurun S, Gerds T, Strub JR (2006) Fracture resistance of single-tooth implant-supported all-ceramic restorations after exposure to the artificial mouth. J Oral Rehabil 33:380–386
21. Aramouni P, Zebouni E, Tashkandi E, Dib S, Salameh Z, Almas K (2008) Fracture resistance and failure location of zirconium and metallic implant abutments. J Contemp Dent Pract 9:41–48
22. Adatia ND, Bayne SC, Cooper LF, Thompson JY (2009) Fracture resistance of yttria-stabilized zirconia dental implant abutments. J Prosthodont 18:17–22
23. Yildirim M, Fischer H, Marx R, Edelhoff D (2003) In vivo fracture resistance of implant-supported all-ceramic restorations. J Prosthet Dent 90:325–331
24. Ferrario VF, Sforza C, Serrao G, Dellavia C, Tartaglia GM (2004) Single tooth bite forces in healthy young adults. J Oral Rehabil 31:18–22
25. Nishigawa K, Bando E, Nakano M (2001) Quantitative study of bite force during sleep associated bruxism. J Oral Rehabil 28:485–491
26. Balshi TJ, Ekfeldt A, Stenberg T, Vrielinck L (1997) Three-year evaluation of Branemark implants connected to angulated abutments. Int J Oral Maxillofac Implants 12:52–58
27. Sethi A, Kaus T, Sochor P (2000) The use of angulated abutments in implant dentistry: five-year clinical results of an ongoing prospective study. Int J Oral Maxillofac Implants 15:801–810
28. Sethi A, Kaus T, Sochor P, Axmann-Krcmar D, Chanavaz M (2002) Evolution of the concept of angulated abutments in implant dentistry: 14-year clinical data. Implant Dent 11:41–51
29. Torbjorner A, Fransson B (2004) A literature review on the prosthetic treatment of structurally compromised teeth. Int J Prosthodont 17:369–376
30. Heydecke G, Butz F, Hussein A, Strub JR (2002) Fracture strength after dynamic loading of endodontically treated teeth restored with different post-and-core systems. J Prosthet Dent 87:438–445