Fracture Strength and Precision of Fit of Implant-Retained Monolithic Zirconia Crowns

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New monolithic zirconia materials can be used to fabricate full-contour fixed dental prostheses with the computer-aided design/computer-aided manufacturing (CAD/CAM) method. The aim of this study was to examine the fracture strength and precision of fit of screw-retained monolithic zirconia crowns made directly on implants or by cementing on prefabricated titanium (Ti) bases. Monolithic screw-retained implant crowns (n = 6) were produced by CAD/CAM method using partially (PSZ) and fully stabilized (FSZ) zirconia. Industrially produced zirconia crowns were used as a reference. A lateral incisor study model was made onto an implant replica. Crowns were produced either directly on the implant or through cementing on a prefabricated titanium base (PSZ+Ti, FSZ+Ti). The crowns were tightened to implant replicas with a torque of 35 Ncm. The gap between the replica and the abutment or crown was measured from ×400 scanning electron microscope images for precision of fit. Mechanical testing until failure was completed with a universal testing machine with loading angle of 45°. Statistical analysis was performed (analysis of variance). Mean (±SD) failure loads were 259 ± 23 (PSZ), 140 ± 13 (FSZ), 453 ± 25 (PSZ+Ti), 439 ± 41 (FSZ+Ti), and 290 ± 39 (Procera). Mean (±SD) gap values were 2.2 ± 0.2 (PSZ), 2.5 ± 1.0 (FSZ), 7.0 ± 1.0 (PSZ+Ti), 7.7 ± 1.6 (FSZ+Ti), and 6.7 ± 1.7 (Procera). Monolithic zirconia crowns with a Ti base clearly show higher fracture strengths than the crowns fixed directly on the implant surface. Better marginal fit can be achieved with direct zirconia crowns than with crowns on a titanium base or industrially produced zirconia crowns.

Key Words: zirconia, titanium base, fracture strength, implant, marginal fit

INTRODUCTION

Implant-supported single crowns are currently the treatment of choice for replacing missing teeth in the intact dentitions of adult patients. Survival rates of implant-supported single-crown restorations are demonstrably high after 5 years of observation.[1,2] Crowns on implants can be screw retained or cemented on abutments, and both have shown acceptable clinical outcomes.[3,4]

Titanium abutments have been a standard in clinical use for many years. As an abutment material, titanium has good mechanical properties and biocompatibility.[5,6] However, with growing esthetic demands, the use of all-ceramic materials has become an option for crowns and abutments. Esthetic challenges can be numerous, especially in patients with thin gingival biotype and high lipline. This is because the titanium structures can lead to a grayish appearance showing through gingival tissues.[7]

Studies on more esthetic zirconia abutments have shown successful results, and zirconia appears to be a suitable treatment option in the anterior region to support single crowns.[8–11] New monolithic zirconia materials can be used to fabricate full-contour fixed dental prostheses with the computer-aided design/computer-aided manufacturing (CAD/CAM) technique. These materials were developed because chipping of the veneering porcelain has been shown to be a clinical problem.[12,13]

To minimize possible biological problems with excess cement and to make possible reparations of implant-supported fixed dental prostheses easier, fixation of prosthetic crowns directly on the implant surface without a separate abutment has become an attractive and cost-effective treatment alternative. In addition, CAD/CAM techniques can provide more accurate superstructures than those fabricated on conventionally produced casts.[14,15] Monolithic zirconia crowns can be screw retained directly on the implant surface or cemented extraorally on prefabricated titanium bases. The purpose of the titanium bases is to make the implant-abutment connection more durable compared with zirconia abutments and simultaneously have the advantage of esthetic properties of zirconia underneath the peri-implant soft tissues.[16–18]

The gap between the implant and the prosthetic component allows bacterial leakage despite the size of the gap and connection type of the implant abutment.[19,20] Marginal gap sizes depend on the materials used. Previous studies have shown that the marginal gap sizes of prefabricated titanium

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Figure 1. Lateral incisor study models on replicas: partially stabilized zirconia (PSZ) direct, PSZ + titanium (Ti) base, fully stabilized zirconia (FSZ) direct, FSZ + Ti base, Procera.

abutments are smaller than gaps of custom-made zirconia abutments.[21] Gap sizes up to 7 times larger have been reported in implant-zirconia abutment connections compared with implant-titanium abutment connections.[22]

The aim of this study is to evaluate the fracture strength of monolithic screw-retained zirconia implant crowns made directly on implants and to compare these with the crowns that are cemented on prefabricated titanium bases. The study hypothesis is that crowns on titanium bases have higher fracture strength than monolithic zirconia crowns fitted directly on the implant surface.

Another aim is to evaluate the precision of fit of these crowns on flat-top implants and to compare the fit of titanium bases on implants. Thus, another study hypothesis is that the marginal gap between the flat-top implant surface and titanium bases is smaller than the gap between the flat-top implant surface and custom-made monolithic zirconia crowns.

Materials and Methods

Thirty implant crowns or crown-titanium base combinations were tested with 6 specimens in each group. Partially stabilized zirconia (PSZ; Prettau, Zirkonzahn, Taufers, Italy) and fully stabilized zirconia (FSZ; Prettau Anterior, Zirkonzahn) materials were used to produce custom-made screw-retained monolithic zirconia crowns using CAD/CAM (Zirkonzahn). Crowns were produced either directly on the implant replica (PSZ and FSZ) or through cementing (Multilink Implant, Ivoclar Vivadent, Schaan, Liechtenstein) them on a prefabricated (Zirkonzahn) titanium base (PSZ+Ti and FSZ+Ti). Industrially produced screw-retained zirconia crowns were used as a reference (Procera, Nobel Biocare, Kloten, Switzerland; Figure 1). For the experiment, a study model was made in which an implant replica (height = 14.0 mm, Ø = 4.0 mm) with an external fixation design (ad. modum Brånemark, Nobel Biocare) was placed between the Frasaco (Tettnang, Germany) canine and incisor. The lateral incisor crowns were milled according to the manufacturer's guidelines. The external shape of the crowns was identical.

Prefabricated titanium bases and the direct zirconia crowns were connected to the implant replicas with a titanium screw. These were then tightened to a torque of 35 Ncm with a calibrated torque wrench (Nobel Biocare). The crowns in PSZ+Ti and FSZ+Ti were silanized (Monobond S) and cemented (Multilink Implant, Ivoclar Vivadent) on the prefabricated titanium bases. Two replica/crown combinations from each group were gold sputtered and analyzed with a scanning electron microscope (SEM) (Jeol 5500, Jeol, Tokyo, Japan) for precision of fit. From each specimen, the distopalatal, palatal, and mesiopalatal sites were measured. The gap between the replica and the abutment or crown was measured from ×400 SEM images.

All specimens were cemented to an acrylic block to a height just below the implant replica collar. The axis of the replica was vertically aligned.

All crowns were subjected to static mechanical testing with a universal testing machine (model LRX, Lloyd Ltd, Fareham, UK). The incisal edges of the crowns were covered with thin, folded aluminum foil to prevent force peaks during load transmission and loaded at a 45° angle to the long axis to simulate the bite forces in the anterior region at a speed of 1.0 mm/min until failure. Statistical evaluation was performed using 1-way analysis of variance. Tukey test was used for the pairwise comparisons. The level of significance was set at .05. The failure mode was evaluated visually.

The methodology was reviewed by an independent statistician.

Results

PSZ+Ti and FSZ+Ti crowns had the highest fracture strength. There was no statistically significant difference between these groups. Maximal failure loads of monolithic FSZ crowns were significantly lower than that those of PSZ and commercial zirconia crowns fabricated directly on the implant. The means and standard deviations for all groups are shown in the Table.

Visual evaluation of fractured specimens showed that crowns on titanium bases demonstrated bending until fracture of the implant screw during loading. In these groups (PSZ+Ti and FSZ+Ti), the crowns remained intact, and the connection between the crown and abutment was flawless. The maximal fracture strength was measured at the fracture of the screw. Monolithic zirconia crowns that were fabricated directly on the implant replicas showed more catastrophic failures.

PSZ and FSZ crowns, which were fabricated directly on implant replicas, had a mean marginal gap of 2.2 ± 0.2 and 2.5 ± 1.0 μm (Figure 2b and c). The marginal gaps between the titanium bases and implant replicas were significantly greater ($P < .05$). Industrially produced Procera crowns had statistically significantly greater marginal caps ($P < .05$) than custom-made PSZ and FSZ crowns. The mean marginal gaps are shown in the Table and Figure 3.

The results were reviewed by an independent statistician.

Discussion

This study was conducted to evaluate the fracture strength and marginal fit of implant-retained monolithic zirconia crowns fitted directly on the implant surface or cemented on prefabricated titanium bases. There is a lack of studies about

Table

Summary of results of fracture loads (N) and marginal gaps (μm)*

Crown Type (group)	Fracture Load, N (SD)†	Marginal Gap, μm (SD)
PSZ direct	259 (23)[a]	2.2 (0.2)[a]
PSZ+Ti-base	453 (25)[b]	7.0 (1.0)[b]
FSZ direct	140 (13)[c]	2.5 (1.0)[a]
FSZ+Ti-base	439 (41)[b]	7.7 (1.6)[b]
Procera direct	290 (39)[a]	6.7 (1.7)[b]

*PSZ indicates partially stabilized zirconia; FSZ, fully stabilized zirconia.
†Different superscript letters indicate statistically significant differences (Tukey, $P < .05$).

these applications, although they are already used widely in clinical settings.

To be clinically successful on implants, both the crown's and the abutment's mechanical strength should exceed maximal biting forces. In the anterior area, the maximal bite forces reported in the literature are 108 to 299N.[23,24] In this study, monolithic PSZ and FSZ crowns on a titanium base demonstrated noticeably higher fracture strength than maximal bite forces in the anterior region, and the load-bearing capacity was in the same range as previously reported for similar constructions.[16,25] Also, CAD/CAM PSZ screw-retained crowns and industrially produced Procera crowns showed fracture strengths that could bear the maximal bite forces. Only FSZ direct crowns fracture loads were below the maximal bite forces reported in the literature. More transparent fully stabilized zirconia material (FSZ) has shown a lower flexural strength than PSZ in a previous in vitro study as well.[26] As the crowns on titanium bases had a higher fracture strength than the monolithic zirconia crowns fitted directly on the implant surface and the industrially produced Procera crowns, the first study hypothesis regarding the mechanical strength was accepted.

The crowns on prefabricated titanium bases showed no fractures during loading but did display bending and final fracture of the titanium screw. Similar failure modes have been reported in previous studies as well with fracture or bending of the titanium screw.[17,25,27] When zirconia abutments or abutment-crown combinations are mechanically tested, the typical area of failure is around the head of the prosthetic screw or in

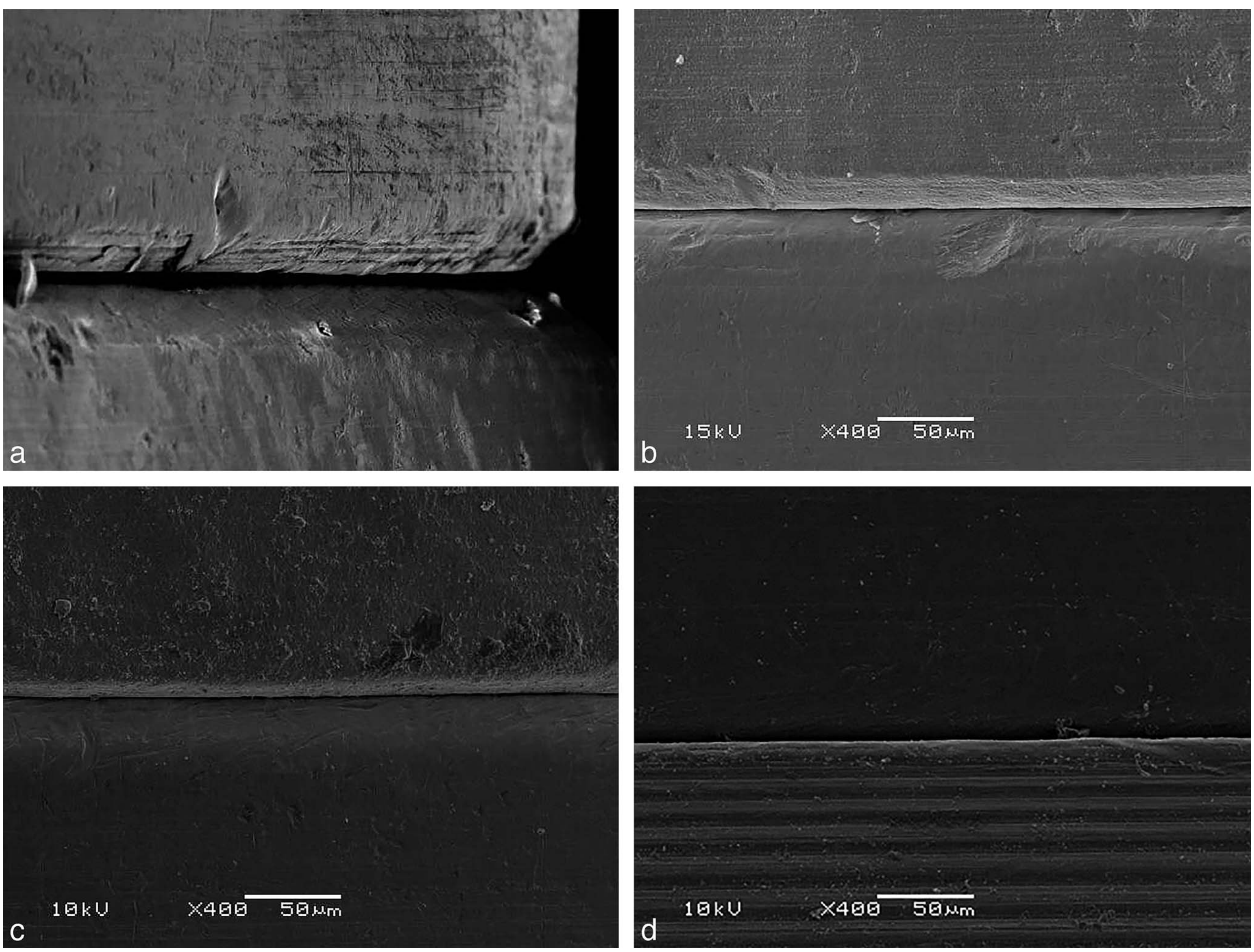

Figure 2. Scanning electron microscope images (×400) of the gap between implant replica and different zirconia crowns. (a) Industrially produced Procera crown. (b) Fully stabilized zirconia direct. (c) Partially stabilized zirconia direct. (d) Titanium base.

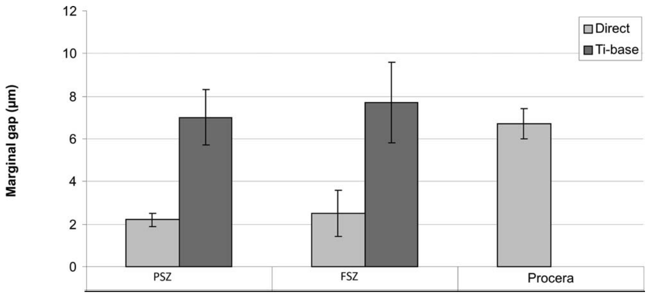

Figure 3. Illustration of marginal gaps (μm) of partially (PSZ) and fully stabilized zirconia (FSZ) crowns made directly on an implant replica or through cementing on a titanium base. Industrially produced zirconia crown (Procera, Nobel Biocare) is shown as a reference.

the internal connection part of the abutment.[9,16] These results could be seen in the present study as well, although the failure modes were evaluated visually and no fractographic analysis was done.

When 2 pieces are fitted together, there can always be some discrepancy in the surfaces and micro gaps between the parts. Explanations for gaps between implant and abutment or crown can be the processing method, type of coping material, hardness of the blanks, improper tightening of the screw, and therefore distortion of the abutment material and the misfit of the 2 connecting parts due to improper impression.[28,29] Butignon et al[30] studied the marginal fit of zirconia, titanium, and gold-alloy abutments on implants before and after cyclic loading. They found that the cyclic loading did not significantly affect the marginal fit, which shows that the screw joint can resist the bending load up to certain point.

For titanium bases on implants, the mean marginal gaps reported in this study were 7.0 to 7.7 μm (SD = 1.0, 1.6). A marginal gap of 8.4 μm (SD = 5.6) has been reported in previous studies for prefabricated titanium bases.[22] Differences depend on the implant connection and abutment design. Baldassarri et al[22] showed that there was no statistically significant difference in the mean marginal gap of zirconia abutments compared with zirconia abutments with titanium insert; however, the type of titanium insert used was different than in the present study.

Gaps between implant and zirconia abutment have been reported to vary between 0 and 2 μm[21] and 5.7 and 11.8 μm[22] depending on the study. In the present study, the results were similar to those of Alikhasi et al.[21] The marginal fit on the implant was better in custom-made CAD/CAM crowns compared with industrially produced zirconia crowns and crowns on titanium bases. Therefore, the second study hypothesis regarding marginal fit was rejected.

The purpose of this study was to investigate the mechanical strength and marginal fit of implant-retained monolithic zirconia crowns, although, there are some limitations. In the present in vitro study, implant replicas were used instead of implants, and the acrylic blocks into which the replicas were cemented did not have the elasticity of human bone. A static loading test of the implant crowns was conducted, and no chewing simulation or aging process to simulate oral conditions was used. Aging conditions induce the process of phase transformation in zirconia from tetragonal to monoclinic and can reduce mechanical properties.[31] Chewing simulation with zirconia crowns could initiate crack development and show the mechanical behavior of these materials in fatigue. In addition, in the present study, airborne-particle abrasion was not used when cementing the zirconia crowns on titanium bases. This did not seem to affect the results, since no debonding of the titanium bases was seen. Despite these limitations, the present study provides valuable information about fracture strength and marginal fit of monolithic zirconia implant crowns.

The present study focused on implant crowns in the esthetic zone. Future studies should include crowns in more load-bearing areas. Furthermore, the number of specimens could be increased, and the crowns should be examined using cyclic loading instead of loading until failure.

Conclusions

Monolithic zirconia crowns with a titanium base are mechanically stronger than the monolithic zirconia crowns fixed directly on the implant surface. Adequate marginal fit can be achieved with all crown types, but the marginal gap is significantly smaller with individual zirconia crowns fabricated directly on implant replicas.

Abbreviations

CAD/CAM: computer-aided design/computer-aided manufacturing
FSZ: fully stabilized zirconia
PSZ: partially stabilized zirconia
SD: standard deviation
SEM: scanning electron microscopy

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Note

The authors have no conflict of interest.

References

1. Zembic A, Bösch A, Jung RE, Hämmerle CH, Sailer I. Five-year results of a randomized controlled clinical trial comparing zirconia and titanium abutments supporting single-implant crowns in canine and posterior regions. *Clin Oral Implants Res*. 2013;24:384–390.
2. Torabinejad M, Anderson P, Bader J, et al. Outcomes of root canal treatment and restoration, implant-supported single crowns, fixed partial dentures, and extraction without replacement: a systematic review. *J Prosthet Dent*. 2007;98:285–311.
3. Vigolo P, Mutinelli S, Givani A, Stellini E. Cemented versus screw-retained implant-supported single-tooth crowns: a 10-year randomized controlled trial. *Eur J Oral Implantol*. 2012;5:355–364.

4. Lops D, Bressan E, Chiapasco M, Rossi A, Romeo E. Zirconia and titanium implant abutments for single-tooth implant prostheses after 5 years of function in posterior regions. *Int J Oral Maxillofac Implants*. 2013;28: 281–287.

5. de Avila ED, Avila-Campos MJ, Vergani CE, Spolidório DM, Mollo FA Jr. Structural and quantitative analysis of a mature anaerobic biofilm on different implant abutment surfaces. *J Prosthet Dent*. 2016;115:428–436.

6. Mitsias ME, Silva NR, Pines M, Stappert C, Thompson VP. Reliability and fatigue damage modes of zirconia and titanium abutments. *Int J Prosthodont*. 2010;23:56–59.

7. Park SE, Da Silva JD, Weber HP, Ishikawa-Nagai S. Optical phenomenon of peri-implant soft tissue. Part I. Spectrophotometric assessment of natural tooth gingiva and peri-implant mucosa. *Clin Oral Implants Res*. 2007;18:569–574.

8. Mühlemann S, Truninger TC, Stawarczyk B, Hämmerle CH, Sailer I. Bending moments of zirconia and titanium implant abutments supporting all-ceramic crowns after aging. *Clin Oral Implants Res*. 2014;25:74–81.

9. Hjerppe J, Lassila LV, Rakkolainen T, Närhi T, Vallittu PK. Load-bearing capacity of custom-made versus prefabricated commercially available zirconia abutments. *Int J Oral Maxillofac Implants*. 2011;26:132–138.

10. Cooper LF, Stanford C, Feine J, McGuire M. Prospective assessment of CAD/CAM zirconia abutment and lithium disilicate crown restorations: 2.4 year results. *J Prosthet Dent*. 2016;116:33–39.

11. Zembic A, Philipp AO, Hämmerle CH, Wohlwend A, Sailer I. Eleven-year follow-up of a prospective study of zirconia implant abutments supporting single all-ceramic crowns in anterior and premolar regions. *Clin Implant Dent Relat Res*. 2015;17:e417–e426.

12. Pjetursson BE, Sailer I, Makarov NA, Zwahlen M, Thoma DS. All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (FDPs)? A systematic review of the survival and complication rates. Part II: multiple-unit FDPs. *Dent Mater*. 2015;31:624–639.

13. Sax C, Hämmerle CH, Sailer I. 10-year clinical outcomes of fixed dental prostheses with zirconia frameworks. *Int J Comput Dent*. 2011;14:183–202.

14. Prasad R, Al-Kheraif AA. Three-dimensional accuracy of CAD/CAM titanium and ceramic superstructures for implant abutments using spiral scan microtomography. *Int J Prosthodont*. 2013;26:451–457.

15. de França DG, Morais MH, das Neves FD, Barbosa GA. Influence of CAD/CAM on the fit accuracy of implant-supported zirconia and cobalt-chromium fixed dental prostheses. *J Prosthet Dent*. 2015;113:22–28.

16. Alsahhaf A, Spies BC, Vach K, Kohal RJ. Fracture resistance of zirconia-based implant abutments after artificial long-term aging. *J Mech Behav Biomed Mater*. 2017;66:224–232.

17. Elsayed A, Wille S, Al-Akhali M, Kern M. Comparison of fracture strength and failure mode of different ceramic implant abutments. *J Prosthet Dent*. 2017;117:499–506.

18. Cosgarea R, Gasparik C, Dudea D, Culilc B, Dannewitz B, Sculean A. Peri-implant soft tissue colour around titanium and zirconia abutments: a prospective randomized controlled clinical study. *Clin Oral Implants Res*. 2015;26:537–544.

19. Passos SP, Gressler May L, Faria R, Özcan M, Bottino MA. Implant-abutment gap versus microbial colonization: clinical significance based on a literature review. *J Biomed Mater Res B Appl Biomater*. 2013;101:1321–1328.

20. Jansen VK, Conrads G, Richter EJ. Microbial leakage and marginal fit of the implant-abutment interface. *Int J Oral Maxillofac Implants*. 1997;12: 527–540.

21. Alikhasi M, Monzavi A, Bassir SH, Naini RB, Khosronedjad N, Keshavarz S. A comparison of precision of fit, rotational freedom, and torque loss with copy-milled zirconia and prefabricated titanium abutments. *Int J Oral Maxillofac Implants*. 2013;28:996–1002.

22. Baldassarri M, Hjerppe J, Romeo D, Fickl S, Thompson VP, Stappert CF. Marginal accuracy of three implant-ceramic abutment configurations. *Int J Oral Maxillofac Implants*. 2012;27:537–543.

23. Helkimo E, Carlsson GE, Helkimo M. Bite force and state of dentition. *Acta Odontol Scand*. 1977;35:297–303.

24. Lujan-Climent M, Martinez-Gomis J, Palau S, Ayuso-Montero R, Salsench J, Peraire M. Influence of static and dynamic occlusal characteristics and muscle force on masticatory performance in dentate adults. *Eur J Oral Sci*. 2008;116:229–236.

25. Rosentritt M, Hagemann A, Hahnel S, Behr M, Preis V. In vitro performance of zirconia and titanium implant/abutment systems for anterior application. *J Dent*. 2014;42:1019–1026.

26. Sulaiman TA, Abdulmajeed AA, Donovan TE, Vallittu PK, Närhi TO, Lassila LV. The effect of staining and vacuum sintering on optical and mechanical properties of partially and fully stabilized monolithic zirconia. *Dent Mater J*. 2015;34:605–610.

27. Sghaireen MG. Fracture resistance and mode of failure of ceramic versus titanium implant abutments and single implant-supported restorations. *Clin Implant Dent Relat Res*. 2015;17:554–561.

28. Karataşli O, Kursoğlu P, Capa N, Kazazoğlu E. Comparison of the marginal fit of different coping materials and designs produced by computer aided manufacturing systems. *Clin Oral Implants Res*. 2012;23: 12–18.

29. Chochlidakis KM, Papaspyridakos P, Geminiani A, Chen CJ, Feng IJ, Ercoli C. Digital versus conventional impressions for fixed prosthodontics: a systematic review and meta-analysis. *J Prosthet Dent*. 2016;116:184–190.e12.

30. Butignon LE, de Almeida Basilio M, Santo JS, Arioli Filho JN. Vertical misfit of single-implant abutments made from the different materials under cyclic loading. *Int J Oral Maxillofac Implants*. 2016;31:1017–1022.

31. Basílio Mde A, Cardoso KV, Antonio SG, Rizkalla AS, Santos Junior GC, Arioli Filho JN. Effects of artificial aging conditions on yttria-stabilized zirconia implant abutments. *J Prosthet Dent*. 2016;116:277–285.