Marginal Adaptation of All-Ceramic Crowns on Implant Abutments

Wael Att, DDS, DR MED DENT;*† Tomas Hoischen, DDS;* Thomas Gerds, DIPL-MATH, DR RER NAT;‡ Jörg Rudolf Strub, DDS, DR MED DENT, PhD*

ABSTRACT

Background: Studies focusing on the marginal accuracy of all-ceramic crowns on implant abutments are in short supply.

Purpose: This study evaluated the marginal accuracy of all-ceramic crowns on different implant abutments.

Materials and Methods: Ninety-six standardized maxillary central incisor crowns (48 alumina and 48 zirconia) were fabricated for each of the six test groups ($n = 16$) (Ti1, titanium abutments–alumina crowns; Ti2, titanium abutments–zirconia crowns; Al1, alumina abutments–alumina crowns; Al2, alumina abutments–zirconia crowns; Zr1, zirconia abutments–alumina crowns; Zr2, zirconia abutments–zirconia crowns). The crowns were adhesively luted using a resin luting agent. The marginal gaps were examined on epoxy replicas before and after luting as well as after masticatory simulation at 200× magnification.

Results: The geometrical mean (95% confidence limits) marginal gap values before cementation, after cementation, and after masticatory simulation were group Ti1: 39(37–42), 57(53–62), and 49(46–53); group Ti2: 43(40–47), 71(67–76), and 64(59–69); group Al1: 57(54–61), 87(85–90), and 67(65–69); group Al2: 66(63–69), 96(90–101), and 75(72–78); group Zr1: 54(51–57), 79(76–82), and 65(63–67); and group Zr2: 64(60–68), 85(80–91), and 75(70–81). The comparison between non-cemented and cemented stages in each group demonstrated a significant increase in the marginal gap values after cementation in all groups ($p < .001$), while the comparison between cemented and aged stages in each group showed a significant decrease in the marginal gap values in groups Al1, Al2, and Zr1 ($p < .0001$). This reduction was not significant for groups Ti1, Ti2, and Zr2 ($p > .05$).

Conclusion: The marginal accuracy of all tested restorations meets the requirements for clinical acceptance.

KEY WORDS: all-ceramic crowns, alumina, implant abutments, marginal accuracy, mastication simulator, zirconia

Implant-supported restorations can be either screw retained or cement retained, or both. The choice of cementation versus screw retention seems to be based mainly on the clinician's preference. Several authors advocate that the screw-retained restoration offers reversibility and more stability and security at the implant-abutment interface.[1,2] On the other hand, some authors have emphasized the advantages of the cement-retained restoration, including its greater versatility for aesthetics and simplicity of the technique.[3] Other advantages include the potential for complete passivity of the cemented restoration and the option to use a variety of materials for reconstruction, including all-ceramic materials.[4] These potential advantages have made cement-retained implant restorations increasingly popular.

Today, high-strength, all-ceramic materials are increasingly being used for the fabrication of implant-supported restorations, especially in the aesthetic area of the dental arch. The most widely used materials are densely sintered high-purity alumina (Al_2O_3) and yttria (Y_2O_3) partially stabilized zirconia (ZrO_2). These high-strength ceramics can be used for the fabrication of implant abutments and superstructures. Both materials show improved optical and mechanical properties and demonstrate differences in their microstructure and

*Department of Prosthodontics, University Hospital of Freiburg, Freiburg, Germany; †The Weintraub Center for Reconstructive Biotechnology, UCLA School of Dentistry, Los Angeles, CA, USA; ‡Institute of Medical Biometrics and Medical Informatics, University of Freiburg, Freiburg, Germany

Reprint requests: Wael Att, Department of Prosthodontics, Dental School, Albert-Ludwigs University, Hugstetter Str. 55, 79106 Freiburg, Germany; e-mail: wael.att@uniklinik-freiburg.de

DOI 10.1111/j.1708-8208.2007.00079.x

mechanism against flaw propagation.[5,6] Y_2O_3 partially stabilized ZrO_2 ceramic has twice the strength of Al_2O_3 ceramic.[5,7] Recent developments in CAD/CAM techniques made it easier to fabricate high-quality, zirconia-based abutments and restorations. The material has a flexural strength of 900 to 1,200 MPa, Vickers hardness of 1,200 Gpa, and Weibull modulus between 10 and 12.[5,7] Because of its shade, the Al_2O_3 ceramic provides certain aesthetic advantages to the more whitish zirconia ceramic.[8] When used as an abutment material, the Al_2O_3 ceramic is easier to prepare, thereby saving time during the definitive abutment preparation, which is usually performed intraorally. Clinical studies have demonstrated that the success rate of alumina abutments was between 93 and 98.1% after observation periods between 1 to 5 years,[9,10] whereas the success rate of zirconia abutments was 100% after an observation period of 4 years.[4]

The restoration of ceramic abutments with all-ceramic crown systems has been described in the literature.[4,8,11] High-quality restorations can be fabricated using Al_2O_3 or ZrO_2 ceramic systems. Although the combination of Al_2O_3- or ZrO_2-based all-ceramic crowns and high-strength ceramic abutments has been demonstrated to have appropriate strength for clinical applicability,[12,13] no clinical data on the long-term success of such restorations are available yet.

In addition to the physical properties and biocompatibility, the marginal fit of any dental restoration is vital to its long-term success. Lack of adequate fit is potentially detrimental to both the tooth and the supporting periodontal tissues. Imperfect restoration margins offer ideal recesses for plaque accumulation followed by adherence of oral bacteria.[14] This may cause traumatic gingival irritations at teeth.[15] Because the soft tissues of teeth and implants behave in the same manner, the marginal fit of crowns on implants is supposed to be an important factor for the implant and prosthetic success.[3,16] The gap between the crown and the abutment can act as a trap for bacteria, and thus, possibly cause inflammatory reactions in the peri-implant soft tissues.[16,17] In vitro evaluations reported mean values between 11 and 67.4 μm for the marginal gaps of metal–ceramic crowns cemented on implant abutments,[18,19] and between 65.9 and 168 μm for all-ceramic crowns cemented on metal implant abutments.[20,21] So far, there are no data about the marginal gap of implant-supported all-ceramic crowns on ceramic abutments.

The aim of the present investigation was to evaluate the marginal accuracy of high-strength all-ceramic crowns on different implant abutments before and after luting, and after thermomechanical fatigue in a mastication simulator.

MATERIALS AND METHODS

Ninety-six implants with a diameter of 4.3 mm and a length of 15 mm (Replace Select®, Nobel Biocare AB, Göteborg, Sweden) were used in this study. The implants were divided into six groups of 16 specimens each. Thirty-two titanium abutments (Esthetic™ Abutment, Nobel Biocare AB) were used for the control groups (Ti1, Ti2), whereas 32 industrially prefabricated Al_2O_3 abutments (Esthetic Alumina Abutment, Nobel Biocare AB) and 32 industrially prefabricated ZrO_2 abutments (Esthetic Zirconia Abutment, Nobel Biocare AB) served as test groups (Al1, Al2, Zr1, Zr2). All abutments were straight and had standard dimensions, a deep chamfer finish line of 0.5 mm depth, and a total height of 9 mm. An incisal reduction of 2 mm (definitive total height of 7 mm) was made for all abutments using diamond rotary cutting instruments (bur no. 379EF 016, Gebr. Brasseler, Lemgo, Germany) with water spray application and the help of a silicone index (Twinduo, Picodent, Wippenfürth, Germany). Then, all abutments were scanned using a mechanical scanner that operates by surface detection (Procera Piccolo scanner, Nobel Biocare AB). Ninety-six copings (48 Al_2O_3 and 48 ZrO_2) were designed (CAD) using the software Procera (Procera CADDesign, version 1.2 Build 23, Nobel Biocare AB) with an overall thickness of 0.6 mm. The data were sent via modem to Nobel Biocare AB where the fabrication of copings took place. After delivery, all copings were tried on and veneered. The Al_2O_3 copings were veneered using Nobel Rondo veneering ceramic (Nobel Biocare AB), whereas the ZrO_2 copings were veneered using Vita VM9 veneering ceramic (Vita Zahnfabrik, Bad Säckingen, Germany). Both veneering ceramics are low-fusing silicate-based porcelains. Forty-eight Al_2O_3- and 48 ZrO_2-based standardized maxillary central incisor crowns were fabricated using a silicone index (height 11 mm, width 8 mm). Afterward, all implants were embedded with autopolymerizing acrylic resin (Technovit® 4000, Heraues Kulzer, Wehrheim, Germany) at an inclination of 135° to the horizontal plane to simulate clinical conditions.[22] Then, groups Ti1, Al1, and Zr1 received Al_2O_3

crowns, whereas groups Ti2, Al2, and Zr2 received ZrO_2 crowns.

All abutments of the test and control group(s) were placed on the implants using titanium screws (Torque Tite®, Nobel Biocare AB) and torqued to 35 Ncm according to the manufacturer's recommendations using the torque control system (Nobel Biocare AB). After 1 minute, the occlusal screws were retightened.

To ensure maximum bond strength between the crowns and the different abutments, the abutment surfaces and the intaglio surfaces of the crowns were tribochemically silicoated with the modified Rocatec method (110 μm grain size Rocatec® Plus, 3M ESPE, Seefeld, Germany) before definitive placement of the crowns. This technique has been shown to result in higher bond strength to non-etchable high-strength ceramics and can be performed clinically.[23] Then, all crowns were definitively placed on the abutments with finger pressure to simulate clinical situation (approx. 3 min) using a resin luting cement (Panavia 21, Kuraray, Tokyo, Japan). The pressure load in this method does not exceed 10 N.[24]

All test specimens were exposed to 1.2×10^6 cycles of thermomechanical fatigue in a computer-controlled dual-axis mastication simulator (Willytech, Munich, Germany) to simulate 5 years of clinical function.[13] The force was applied 3 mm below the incisal edge on the palatal aspect of the crown at a frequency of 1.6 Hz using a 6-mm-diameter ceramic ball (Steatite Hoechst Ceram Tec, Wunsiedel, Germany) with a vertical movement of 6 mm and a horizontal movement of 0.3 mm. The ceramic ball has a Vickers hardness similar to that of enamel. A force of 49 N was chosen to simulate a load within the clinical range.[25,26] During testing, all specimens were subjected to simultaneous thermal cycling between 5 and 55°C for 60 seconds each, with an intermediate pause of 12 seconds, maintained by a thermostatically controlled liquid circulator (Haake, Karlsruhe, Germany).

Replicas of all specimens representing the marginal areas were fabricated in all three stages (before cementation, after cementation, and after exposure to the masticatory simulator). Impressions of the samples were therefore taken with a polyvinyl-siloxane impression material (Dimension® Garant L and Permagum® Putty Soft, 3M ESPE) and were poured in with an epoxy resin (Alpa-Pur, Alpina, Geretsried, Germany). The poured impressions were degassed in a furnace at 60°C for 24 hours until complete polymerization. Afterward, all epoxy replicas were mounted on aluminum sample holders using cyanoacrylate adhesive. The replicas were analyzed with the help of a stereomicroscope (Axioskope, Zeiss, Oberkochen, Germany). A digital camera (3CCD-Iris, Sony, Köln, Germany) was mounted to the microscope and connected to a personal computer (model P 300, Pyramid, Freiburg, Germany). The marginal area of each replica was oriented perpendicularly and orthoradially on the computer monitor. The digital image of the marginal gap (200× magnification) was reproduced on a high-resolution computer monitor and examined by using a special evaluation software (analySIS® 3.0, Soft-Imaging Software GmbH, Münster, Germany). The distance between the external edge of the abutment and the external edge of the crown was defined as the marginal gap (Figure 1). After the first measurements, the replica was moved until the next section of the marginal area appeared in view. For this stage, a special micro-mechanical device was employed. Areas where the crown or the abutment margin could not be precisely detected were excluded from the evaluation. On average, 250 to 300 single measurements were performed for each specimen. The values measured for each specimen were averaged and recorded in a summary table. Based on the averaged marginal gap values, means and confidence intervals for assessing marginal gaps were computed for each group and for all stages (initial, cemented, aged) of the investigation. The logarithmic transformation is an approved method for robust statistical inference on location of data that originate from skewed distributions. It leads to a stabilization

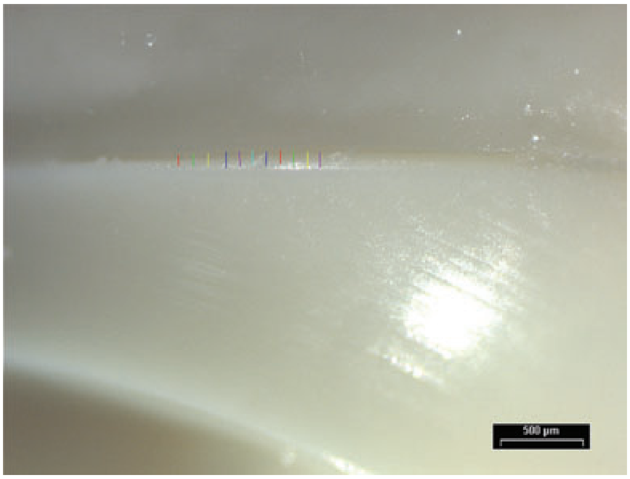

Figure 1 Representative image of the measurement of the marginal gap on a resin replica.

TABLE 1 Results of Marginal Gap Analysis (µm) Before Cementation

Group: abutment-crown (n = 16)	Minimum	Maximum	Mean	Median	Iqr	SD	Geomean	CI 95%
Ti1: Ti–Al_2O_3	35	50	40	39	(36–41)	4.38	39	37–42
Ti2: Ti–ZrO_2	31	59	44	44	(41–47)	7.09	43	40–47
Al1: Al_2O_3–Al_2O_3	43	70	58	57	(54–62)	6.69	57	54–61
Al2: Al_2O_3–ZrO_2	58	77	66	66	(62–69)	5.31	66	63–69
Zr1: ZrO_2–Al_2O_3	45	69	54	54	(49–58)	6.02	54	51–57
Zr2: ZrO_2–ZrO_2	54	88	65	64	(62–65)	7.89	64	60–68

of variance estimators. Therefore, location was estimated by geometric means instead of more familiar arithmetic means. Estimates were supplemented with 95% confidence intervals. Paired *t*-test was implemented to test for differences in marginal gaps within the same groups at different stages, whereas unpaired *t*-test was implemented to compare marginal gaps of test groups Al1 and Zr1 to control group Ti1, and test groups Al2 and Zr2 to control group Ti2. Estimations of confidence intervals and *t*-tests were based also on logarithmically transformed values. The global significance level of 0.05 was achieved by correcting the *p* values according to the Bonferroni–Holm method. All computations were performed with statistical software (R version 2.1.1, R Foundation for Statistical Computing, Boston, MA, USA).

RESULTS

All specimens survived thermomechanical fatigue in the mastication simulator. No screw loosening or abutment and/or restoration fractures were recorded. Summary statistics of marginal gaps in all groups are shown in Tables 1–3. Generally, all groups demonstrated an increase in the marginal gap values after cementation and a decrease in these values after masticatory simulation. The smallest average increase after cementation was recorded in group Ti1 (17.94 µm), followed by group Zr2 (20.93 µm), group Zr1 (24.97 µm), group Ti2 (27.5 µm), group Al2 (29.74 µm), and group Al1 (29.96 µm). After aging, the smallest average decrease in the marginal gap values was observed in group Ti2 (7.34 µm), followed by group Ti1 (7.79 µm), group Zr2 (9.75 µm), group Zr1 (13.81 µm), group Al2 (20.87 µm), and group Al1 (20.52 µm).

The comparison between non-cemented and cemented stages in each group demonstrated a significant increase in the marginal gap values after cementation in all groups ($p < .001$). Also, comparison of the marginal gap between non-cemented and aged stages in each group showed significantly higher values after aging in all groups ($p < .05$). The comparison between cemented and aged stages in each group showed a decrease in the marginal gap values. The decrease was significant in groups Al1, Al2, and Zr1 ($p < .0001$), while it was not significantly different for groups Ti1, Ti2, and Zr2 ($p > .05$).

The marginal gap values of test groups Al1 and Zr1 were significantly larger than those of control group Ti1

TABLE 2 Results of Marginal Gap Analysis (µm) After Cementation

Group: abutment-crown (n = 16)	Minimum	Maximum	Mean	Median	Iqr	SD	Geomean	CI 95%
Ti1: Ti–Al_2O_3	46	78	58	57	(51–65)	9.19	57	53–62
Ti2: Ti–ZrO_2	55	88	72	73	(67–77)	8.34	71	67–76
Al1: Al_2O_3–Al_2O_3	81	95	87	86	(84–92)	4.70	87	85–90
Al2: Al_2O_3–ZrO_2	81	114	96	95	(88–102)	10.57	96	90–101
Zr1: ZrO_2–Al_2O_3	68	91	79	79	(76–82)	5.68	79	76–82
Zr2: ZrO_2–ZrO_2	66	110	86	84	(82–88)	10.53	85	80–91

TABLE 3 Results of Marginal Gap Analysis (μm) After Artificial Aging

Group: abutment-crown (n = 16)	Minimum	Maximum	Mean	Median	Iqr	SD	Geomean	CI 95%
Ti1: Ti–Al_2O_3	39	61	50	52	(45–54)	6.76	49	46–53
Ti2: Ti–ZrO_2	50	78	64	63	(57–73)	9.42	64	59–69
Al1: Al_2O_3–Al_2O_3	62	73	67	67	(64–69)	3.37	67	65–69
Al2: Al_2O_3–ZrO_2	63	85	75	76	(70–78)	5.81	75	72–78
Zr1: ZrO_2–Al_2O_3	58	74	65	64	(62–67)	4.26	65	63–67
Zr2: ZrO_2–ZrO_2	53	91	76	76	(72–81)	8.87	75	70–81

at all stages ($p < .0001$). The comparison between groups Al1 and Zr1 before cementation showed no significant differences ($p > .05$), whereas group Zr1 demonstrated significantly higher values than Al1 after cementation ($p < .01$). No significant differences were found in the marginal gap values between both groups after artificial aging ($p > .05$).

The marginal gap values of test group Al2 were significantly larger than the control group Ti2 before cementation ($p < .0001$), after cementation ($p < .0001$), and after artificial aging ($p < .05$). Similarly, group Zr2 showed significantly larger marginal gap values than group Ti2 before cementation ($p < .0001$), after cementation ($p < .01$), and after artificial aging ($p < .05$). No significant differences were found for comparisons of the marginal gap values between groups Al2 and Zr2 at all stages ($p > .05$).

DISCUSSION

Today, there is no standardized technique available for the examination of the marginal gap of dental restorations. Several techniques to examine the marginal gap such as direct viewing, sectioning, impression taking to make replicas, and explorative and visual examinations have been reported. Important parameters such as consistency of the measuring point, reproducibility of the method used, and the use of sectioning have all been considered.[27] In this study, replica technology was employed to examine the changes in marginal gap values at different stages or between different groups. This technique is less costly and time consuming for the user to create test specimens than other methods (eg, cross-section preparation technique). In addition, the technique allows long-term studies because sacrificing of samples is not required. However, the replica technique does not provide any information regarding the microleakage and disintegration of the cement film.

The microscopic analysis has been performed with a stereomicroscope with 200× magnification. The type of microscopes and magnifications used by investigators for the evaluation of marginal gap varies considerably. Digital microscopes, stereomicroscopes, light microscopes, and electron microscopes have been used with various magnifications.[19,20,28] In an in vitro study, approximately 50 measurements along the margin of a crown yielded clinically relevant information.[29] A consistent estimate for the size of the gap with an overall impact on the measurement error was typically in a range of ±8 μm (SD). In this study, 250 to 300 measurements were made along the complete margin of each abutment. This number is enough to give a consistent estimate for the gap size.

The geometric mean marginal gap values before cementation ranged between 39 μm (group Ti1) and 66 μm (group Al2). The differences in the values between different groups can be attributed to the effect of the fabrication procedure of the crowns. The Procera system creates an enlarged metal die on the basis of the three-dimensional data from the prepared abutment with the use of the subtractive approach. This enlargement takes into account shrinkage associated with sintering the final restoration to achieve its final strength. Powder, which is either alumina or zirconia, is compacted under pressure onto the metal die, creating an oversized block by means of an additive approach. Then, the block is milled away to create the outer contours of the restorations. Finally, the oversized restoration is removed from the die and sintered to make the material as dense as possible and to shrink it to its correct size.[30] The shrinkage, which varies among different materials, creates a marginal gap between the restoration and the abutment and can be usually compensated through veneering. At this stage, the dental laboratory procedures, the manual skills, and the experience of the dental technician have a decisive influence on the size of the marginal gap.[31] Consequently, all restorations employed in the present study were fabricated by the same master technician to ensure that these factors did not change for the individual test groups. Previous literature reported that precementation marginal gaps in the range of 20 to 70 μm are generally acceptable.[32] Hence, the marginal gap values before cementation reported in this study are also within the acceptable limits.

It is well known that the marginal gap generally increases after cementation, which is indeed the clinical situation.[20,27] Thus, to have a correct idea of the marginal gap, it is necessary to evaluate it after cementation. In this study, the geometric mean marginal gap values after cementation ranged between 57 μm (group Ti1) and 96 μm (group Al2). The average increase in the size of the marginal gap after cementation ranged from 17.94 μm (group Ti1) to 29.96 μm (group Al1). The clinically acceptable values defined for marginal gap after cementation were reported to be <120 μm.[18,33] Other studies consider marginal gap between 50 and 100 μm as the clinically acceptable limit.[34,35] The increase in the marginal gap value after cementation can be explained by the volume requirement of the cement used, depending on particle size flow properties and consistency.[36] Film thickness has been reported to play an important role in the bond strength of resin cements. In an in vitro study, 4-point bending strength test of ceramic–cement–ceramic sandwiches with different cement layer thickness (20, 50, 100, and 200 μm) was applied.[35] Bond strength in the 20-μm-thick films was significantly lower than in the thicker ones. The authors concluded that taking into account the physical and clinical properties of resin-based luting agents, a marginal gap in the scale of 50 to 100 μm is ideal for resin cements and seems to optimize performance. For the resin cement used in this study (Panavia), an average film thickness of 30 μm has been reported to be reasonable for optimal performance.[37] Thus, the obtained values are within the mentioned limits, and the increase after cementation seems to be appropriate for optimizing the performance of the resin cement used.

Another factor that may have contributed to increasing the size of marginal gap after cementation is surface treatment prior to cementation. Air abrasion, which is an essential step of the Rocatec method, prior to cementation has been reported to cause marginal defects and widen the gap between the crown and the abutment.[27,38] Therefore, it is always advisable to use careful air abrasion techniques to minimize marginal gap defects.[27] The effect of Rocatec treatment on the marginal gap values obtained in this study after cementation was not examined, and therefore, there is a need to evaluate it in further studies.

Because of inclination of specimens and force application, the force dynamics are different between the palatal and labial aspects of the specimen. Tensile forces are created on the palatal aspect, whereas compressive forces are created on the labial aspect. Therefore, it can be expected that there are differences in the marginal gap values between different aspects of the restoration. This issue was not examined in this study and will be evaluated in a future investigation. The measurement of the marginal discrepancies after artificial aging showed geometrical mean values between 49 μm (group Ti1) and 75 μm (group Zr2). The decrease in the marginal gap values after artificial aging ranged between 7.34 μm (group Ti2) and 20.52 μm (group Al1). Such a decrease can be explained by considering that after artificial aging, a certain degree of degradation of the cement film is occurring.[39] Some portions of the cement film might have been washed out during the aging procedure leading to a clearer image and created the possibility for more precise measurements of the marginal gap. An assessment of the density of the cement seal through microleakage analysis is recommended to provide further information about this issue.

CONCLUSIONS

Within the limits of this study, it can be concluded that marginal accuracy of implant-supported all-ceramic restorations on ceramic abutments meets the requirements for clinical acceptance. More scientific data of the marginal gap of implant-supported all-ceramic restorations must be generated under clinical conditions.

ACKNOWLEDGMENTS

The authors thank Nobel Biocare AB for support of this study. The technical assistance of the dental laboratory Woerner Zahntechnik, Freiburg, Germany, is highly appreciated.

REFERENCES

1. Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated dental implants: the Toronto study. Part III: Problems and complications encountered. J Prosthet Dent 1990; 64:185–194.
2. Jemt T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Branemark implants in edentulous jaws: a study of treatment from the time of prosthesis placement to the first annual checkup. Int J Oral Maxillofac Implants 1991; 6:270–276.
3. Guichet DL, Caputo AA, Choi H, Sorensen JA. Passivity of fit and marginal opening in screw- or cement-retained implant fixed partial denture designs. Int J Oral Maxillofac Implants 2000; 15:239–246.
4. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Scharer P. Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 2004; 17:285–290.
5. Christel P, Meunier A, Heller M, Torre JP, Peille CN. Mechanical properties and short-term in-vivo evaluation of yttrium-oxide-partially-stabilized zirconia. J Biomed Mater Res 1989; 23:45–61.
6. Seghi RR, Denry IL, Rosenstiel SF. Relative fracture toughness and hardness of new dental ceramics. J Prosthet Dent 1995; 74:145–150.
7. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials 1999; 20:1–25.
8. Yildirim M, Edelhoff D, Hanisch O, Spiekermann H. Ceramic abutments – a new era in achieving optimal esthetics in implant dentistry. Int J Periodontics Restorative Dent 2000; 20:81–91.
9. Andersson B, Taylor A, Lang BR, Scheller H, Scharer P, Sorensen JA, Tarnow D. Alumina ceramic implant abutments used for single-tooth replacement: a prospective 1- to 3-year multicenter study. Int J Prosthodont 2001; 14:432–438.
10. Andersson B, Glauser R, Maglione M, Taylor A. Ceramic implant abutments for short-span FPDs: a prospective 5-year multicenter study. Int J Prosthodont 2003; 16:640–646.
11. Ottl P, Piwowarczyk A, Lauer HC, Hegenbarth EA. The Procera AllCeram system. Int J Periodontics Restorative Dent 2000; 20:151–161.
12. Att W, Kurun S, Gerds T, Strub JR. Fracture resistance of single-tooth implant-supported all-ceramic restorations after exposure to the artificial mouth. J Oral Rehabil 2006; 33:380–386.
13. Att W, Kurun S, Gerds T, Strub JR. Fracture resistance of single-tooth implant-supported all-ceramic restorations: an in vitro study. J Prosthet Dent 2006; 95:111–116.
14. Sorensen JA. A rationale for comparison of plaque-retaining properties of crown systems. J Prosthet Dent 1989; 62:264–269.
15. James RA. Periodontal considerations in implant dentistry. J Prosthet Dent 1973; 30:202–209.
16. 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.
17. Ericsson I, Persson LG, Berglundh T, Marinello CP, Lindhe J, Klinge B. Different types of inflammatory reactions in peri-implant soft tissues. J Clin Periodontol 1995; 22:255–261.
18. Keith SE, Miller BH, Woody RD, Higginbottom FL. Marginal discrepancy of screw-retained and cemented metal–ceramic crowns on implants abutments. Int J Oral Maxillofac Implants 1999; 14:369–378.
19. Kersten S, Tiedemann C. Strength and marginal fit of full and partial porcelain crowns on Branemark implants. Clin Oral Implants Res 2000; 11:59–65.
20. Sutherland JK, Loney RW, Syed S. Marginal discrepancy of all-ceramic crowns cemented on implant abutments. J Prosthodont 1995; 4:173–177.
21. Sutherland JK, Loney RW, Jarotskic TJ. Marginal discrepancy of ceramic crowns with redesigned implant components. J Prosthet Dent 1996; 75:540–544.
22. Haraldson T, Carlsson GE, Ingervall B. Functional state, bite force and postural muscle activity in patients with osseointegrated oral implant bridges. Acta Odontol Scand 1979; 37:195–206.
23. Blatz MB, Sadan A, Kern M. Resin-ceramic bonding: a review of the literature. J Prosthet Dent 2003; 89:268–274.
24. Stappert CF, Dai M, Chitmongkolsuk S, Gerds T, Strub JR. Marginal adaptation of three-unit fixed partial dentures constructed from pressed ceramic systems. Br Dent J 2004; 196:766–770, discussion 760, quiz 780.
25. Bates JF, Stafford GD, Harrison A. Masticatory function – a review of the literature. III. Masticatory performance and efficiency. J Oral Rehabil 1976; 3:57–67.
26. Kampe T, Haraldson T, Hannerz H, Carlsson GE. Occlusal perception and bite force in young subjects with and without dental fillings. Acta Odontol Scand 1987; 45:101–107.
27. Naert I, Van der Donck A, Beckers L. Precision of fit and clinical evaluation of all-ceramic full restorations followed between 0.5 and 5 years. J Oral Rehabil 2005; 32:51–57.
28. Besimo D, Bodenschatz V, Guggenheim R, Hassell T. Marginal fit of prefabricated crowns of the Ha-Ti implant system: an in vitro scanning electron microscopic study. Int J Prosthodont 1996; 9:87–94.
29. Groten M, Axmann D, Probster L, Weber H. Determination of the minimum number of marginal gap measurements required for practical in-vitro testing. J Prosthet Dent 2000; 83:40–49.
30. Strub JR, Rekow ED, Witkowski S. Computer-aided design and fabrication of dental restorations: current systems and future possibilities. J Am Dent Assoc 2006; 137:1289–1296.

31. Witkowski S, Komine F, Gerds T. Marginal accuracy of titanium copings fabricated by casting and CAD/CAM techniques. J Prosthet Dent 2006; 96:47–52.
32. Ganz SD, Desai N, Weiner S. Marginal integrity of direct and indirect castings for implant abutments. Int J Oral Maxillofac Implants 2006; 21:593–599.
33. Kokubo Y, Ohkubo C, Tsumita M, Miyashita A, Vult von Steyern P, Fukushima S. Clinical marginal and internal gaps of Procera AllCeram crowns. J Oral Rehabil 2005; 32:526–530.
34. Karlsson S. The fit of Procera titanium crowns. An in vitro and clinical study. Acta Odontol Scand 1993; 51:129–134.
35. Molin MK, Karlsson SL, Kristiansen MS. Influence of film thickness on joint bend strength of a ceramic/resin composite joint. Dent Mater 1996; 12:245–249.
36. Quintas AF, Oliveira F, Bottino MA. Vertical marginal discrepancy of ceramic copings with different ceramic materials, finish lines, and luting agents: an in vitro evaluation. J Prosthet Dent 2004; 92:250–257.
37. Wu JC, Wilson PR. Optimal cement space for resin luting cements. Int J Prosthodont 1994; 7:209–215.
38. Bindl A, Mormann WH. Marginal and internal fit of all-ceramic CAD/CAM crown-copings on chamfer preparations. J Oral Rehabil 2005; 32:441–447.
39. Buchalla W, Attin T, Hellwig E. Brushing abrasion of luting cements under neutral and acidic conditions. Oper Dent 2000; 25:482–487.