Journal of Oral Rehabilitation 2005 **32**; 838–843

Survival rate, fracture strength and failure mode of ceramic implant abutments after chewing simulation

F. BUTZ[*,†], G. HEYDECKE*, M. OKUTAN* & J. R. STRUB* **Department of Prosthodontics, School of Dentistry, University Hospital, Freiburg, Germany and †The Jane and Jerry Weintraub Center for Reconstructive Biotechnology, Division of Advanced Prosthodontics, Biomaterials and Hospital Dentistry, UCLA School of Dentistry, Los Angeles, CA, USA*

SUMMARY **The aim of this study was to compare titanium-reinforced ZrO_2 and pure Al_2O_3 abutments regarding their outcome after chewing simulation and static loading. Forty-eight standard diameter implants with an external hexagon were divided into three groups of 16 implants each and restored with three different types of abutments (group A: ZrO_2 abutments with titanium inserts; group B: Al_2O_3 abutments; group C: titanium abutments). All abutments were fixated on the implants with gold-alloy screws at 32 Ncm torque, and metal crowns were adhesively cemented onto the abutments. The specimens were exposed to 1·2 million cycles in a chewing simulator. Surviving specimens were subsequently loaded until fracture in a static testing device. Fracture loads (N) and fracture modes were recorded. A Wilcoxon Rank test to compare fracture loads among the three groups and a Fisher exact test to detect group differences in fracture modes were used for statistical evaluation ($P < 0{\cdot}05$). All specimens but one of group B survived chewing simulation. No screw loosening occurred. The median fracture loads (±s.d.) were as follows: group A, 294 N (±53); group B, 239 N (±83), and group C, 324 N (±85). The smaller fracture loads in group B were statistically significant. The use of pure Al_2O_3 abutments resulted in significantly more abutment fractures. It is proposed that titanium-reinforced ZrO_2 abutments perform similar to metal abutments, and can therefore be recommended as an aesthetic alternative for the restoration of single implants in the anterior region. All-ceramic abutments made of Al_2O_3 possess less favourable properties.**

KEYWORDS: **dental implants, ceramic implant abutment, fracture strength, failure mode, survival rate, dynamic loading**

Accepted for publication 27 February 2005

Introduction

Natural appearance of replaced single missing teeth in the anterior maxilla is one of the most challenging goals in dentistry (1). Differential treatment modalities include endosseous implants (2, 3). To achieve optimal aesthetics it has been suggested to restore single-tooth implants with all-ceramic abutment-crown combinations (4–6). Bluish appearance of the cervical soft tissues as encountered with metal abutments can be avoided and light transmission is facilitated when using all-ceramic abutments (4). Furthermore, bioadhesive properties (7, 8) are improved and galvanic and corrosive side effects minimized. However, ceramics are sensitive to tensile stresses due their inherent brittleness, and concerns remain regarding the capability of all-ceramic implant restorations to withstand functional forces in the oral cavity.

The first all-ceramic implant abutment (CerAdapt)* consisted of densely sintered aluminium oxide (alumina; Al_2O_3) ceramic (4, 5); it was designed to fit directly on the external hexagon of Brånemark type implants. In a prospective clinical study, Andersson *et al.* (9) reported cumulative clinical success rates of 93% for implant-supported single crowns after a 1-year

---

*Nobel Biocare, Gothenburg, Sweden.

observation period, with no additional failure in the 10 of 34 CerAdapt abutments followed-up for two more years. Cumulative success rates for the titanium abutments in the control during these observations periods were 100%. In a further study on implant supported short-span fixed partial dentures (10), the cumulative success rates after 5 years were 94·7% for CerAdapt and 100% for the titanium abutments in the control group, respectively. Because of increased mechanical strength, it has been suggested to use zirconium dioxide ceramics (zirconia; ZrO_2) instead of alumina as implant abutment material. In a 4-year prospective study, no abutment fractures were observed for experimental zirconia abutments directly screwed onto externally hexed implants (11). However, it has been argued that the ceramo-metal interface is prone to wear and abrasion of the metallic part (12); i.e. the interface between all-ceramic abutments and implants. Rounding of the corners of the external hexagon as a consequence of seating and reseating of ceramic abutments during the fabrication process has been observed (13). Moreover, all-ceramic abutments cannot be machined to the same degree of precision as metal abutments. An imprecise fit between abutment and implant can lead to screw loosening and other clinical problems such as bone loss due to subsequent microbial infection (14).

A zirconia abutment (ZiReal)[†] in which the zirconia is sintered onto a titanium insert that covers the implant platform and hexagon has been developed. The abutment screw seat is located on the zirconia part and the tightened screw compresses the two components, thus additionally protecting the bonding between zirconia and titanium. However, only case reports are available to support the efficacy of this abutment type (15, 16). This study evaluates the ZiReal abutment in a near clinical model under thermo-mechanical fatigue conditions simulating 5 years of clinical service (17). Comparisons with a conventional titanium abutment and the all-ceramic CerAdapt abutment are used to evaluate survival rate, fracture strength and mode of failure after chewing simulation. The null hypothesis to be tested was that there is no difference in (i) survival rate and (ii) load to fracture between the three different implant–abutment combinations.

Materials and methods

Forty-eight implants (Osseotite)[†] with a diameter of 4·0 mm and a length of 13 mm were randomly divided into three groups of 16 implants each (Table 1). The implants were embedded in sample holders[‡] at an inclination of 130° using autopolymerizing resin (Technovit 4000)[§]. The resin covered the implant body up to the first thread. Group A implants received ZiReal abutments, group B, CerAdapt abutments, and group C, titanium abutments (GingiHue)[†]. The abutments in groups A and C were prefabricated and had identical dimensions. The abutments had a 4 mm collar and the retention surface of the abutments was 7 mm in length (Fig. 1). The abutments in group B were customized with a diamond burr under copious water cooling to approximate the dimensions of the prefabricated abutments used in groups A and C. Abutments and implants were assembled using abutment screws with a 24 carat gold coating (Gold-Tite)[†], tightened once with a torque of 32 Ncm (Torque Control)[†].

With the use of a silicon stent, 48 single tooth incisor crowns (14 mm in length) of identical dimensions were waxed and cast in a non-precious alloy (Dentitan)[¶]. The inner surfaces of the crowns and the retention surfaces of the implant abutments were airborne particle abraded (50 µm, 2·5 bar, 15 s), and the crowns were then adhesively cemented to the abutments with chemically polymerizing resin cement (Panavia 21EX)[**]. The specimens were exposed to 1·2 million cycles of thermo-mechanical fatigue in a computer-controlled dual-axis chewing simulator[‡]. A force of 30 N was applied 3 mm below the incisal edge on the palatal surface of the crowns at a frequency of 1·3 Hz using 6 mm diameter ceramic balls (Steatite)[††] as antagonists. The distance of the loading point to the implant shoulder was 14 mm. All specimens were allowed to reach a thermal equilibrium between 5 and 55 °C for 60 s each with an intermediate pause of 12 s, maintained by a thermostatically controlled liquid circulator[‡‡] (Table 2).

Specimens that survived the dynamic loading were examined under a light microscope for crack formation and screw joint stability. Thereafter, surviving

---

[†] Implant Innovations, FL, USA.

[‡] Willytec, Munich, Germany.

[§] Heraeus Kulzer, Wehrheim, Germany.

[¶] Krupp/Austenal, Essen, Germany.

[**] Kuraray, Osaha, Japan.

[††] CeramTec, Wunsiedel, Germany.

[‡‡] Haake, Karlsruhe, Germany.

Table 1. Overview of the implant abutment combinations in the three groups of specimens.

Group	Implant	Abutment	Screw	Crown
A	External Hex/	Ti-reinforced Zirconia (ZiReal)*		
B	4 mm × 13 mm	Alumina (CerAdapt)[†]	Au-Pd (Gold-Tite)*	Non-precious alloy[‡]
C	(Osseotite)*	Titanium (GingiHue)*		

*Implant Innovations, FL, USA.
[†] Nobel Biocare, Gothenburg, Sweden.
[‡] Krupp, Essen, Germany.

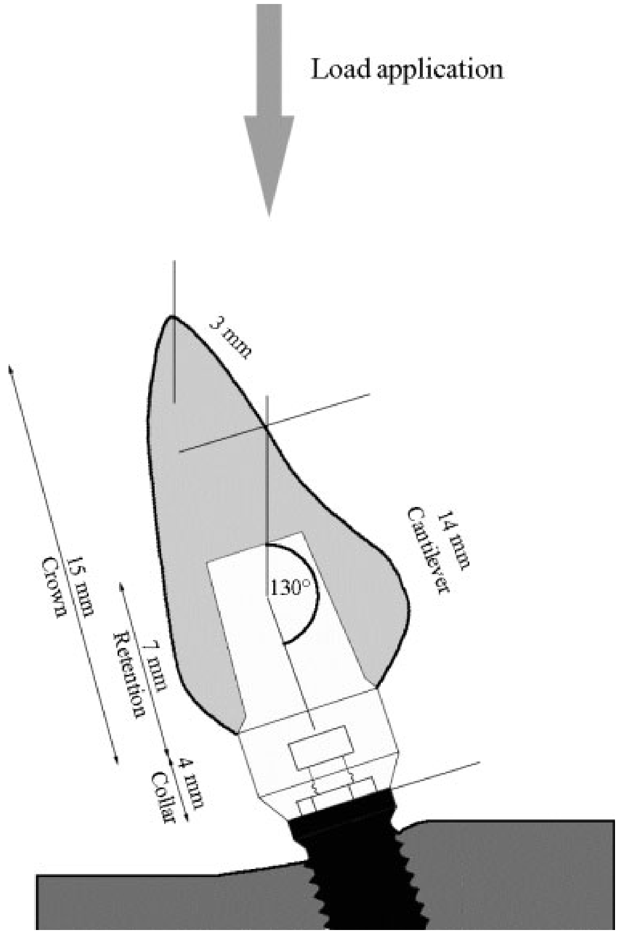

Fig. 1. Schematic drawing of specimen design. The load was applied 3 mm below the incisal edge with an angle of 130° resulting in a distance of 14 mm from the implant platform to the point of loading (= cantilever length).

Table 2. Test parameters of chewing simulation (35)

Cold/hot bat temperature	5 °C/55 °C	Dwell time	60 s
Vertical movement	6 mm	Horizontal movement	0·3 mm
Rising speed	55 mm s^{-1}	Forward speed	30 mm s^{-1}
Descending speed	30 mm s^{-1}	Backward speed	55 mm s^{-1}
Load per sample	30 N	Cycle frequency	1·3 Hz
Kinetic energy	2250 × 10^{-6} J		

specimens were loaded until fracture or deflection of 4 mm in a universal testing machine with a cross-head speed of 1·5 mm min^{-1}[§§]. Loads were applied with an angle of 130°, 3 mm below the incisal edge using a 0·8 mm thick tin foil to ensure even stress distribution (Fig. 1). The fracture loads were recorded and analysed using Zwicktest Xpert software[§§]. The mode of failure was then recorded and classified into screw fracture, abutment fracture, and deflection.

For statistical analysis multiple pair-wise comparisons of the fracture strengths using the Wilcoxon Rank test were performed. Samples that fractured during chewing simulation were assigned the value 'zero' for purposes of statistical evaluation. A Fisher exact test was performed to detect group differences in failure modes. A significance level of $P < 0{\cdot}05$ was used for all comparisons.

Results

All specimens in groups A and C survived chewing simulation, while one in group B failed. In the latter case, the abutment fractured at the screw head level at 9 of 1 200 000 chewing cycles. In the surviving specimens, neither unstable screw joints nor superficial cracks were detected. The results of the fracture strength test are presented as a box plot (Fig. 2). Wilcoxon Rank tests showed significant differences between groups A and B, and groups B and C, respectively ($P < 0{\cdot}05$), but no significant difference ($P = 0{\cdot}36$) was detected between groups A and C.

[§§] Zwick, Ulm, Germany.

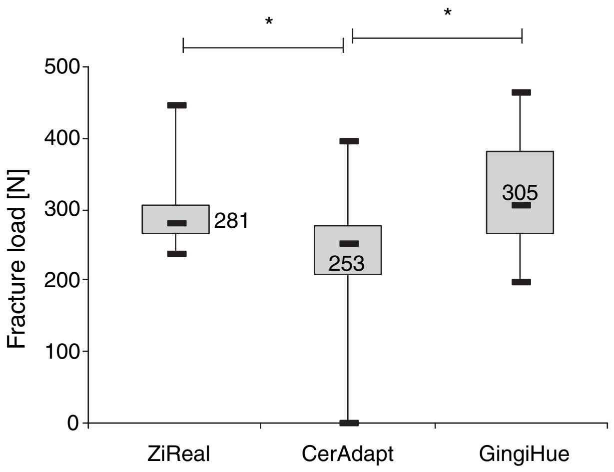

Fig. 2. Fracture loads after artificial aging of specimens. The line in each box represents the median values (group A 281 N, group B 253 N, group C 305 N). *Significant differences ($P < 0{\cdot}05$).

The mode of failure of the three groups is reported in Table 3. In group A, four abutment and two screw fractures occurred; in the remaining 10 specimens, deflection of the abutment-crown assemblies was observed. In group B all failures were abutment fractures, whereas deflection as endpoint event occurred in all specimens of group C. All deflected specimens showed permanent abutment screw bending and slight distortion of the labial implant platform. Fractures of group A and B abutments originated on the lingual side at the screw head level. The fracture lines were perpendicular to the long axis of the implant and did not fully penetrate the abutment. Fisher's exact test revealed a significantly higher rate of abutment fractures for group B as compared with groups A and C ($P < 0{\cdot}05$).

Table 3. Mode and frequency of failures

	Chewing simulation		Static loading		
Group	Survival (*n*)	Failure (*n*)	Deflection* (*n*)	Abutment screw fracture (*n*)	Abutment fracture (*n*)
A	16	0	10	2	4
B	15	1	0	0	16
C	16	0	16	0	0

*Crown abutment deflection of 4 mm without fracture as a result of permanent abutment screw bending.

Discussion

This study used an artificial oral environment to evaluate the pre-clinical efficacy of implant ceramic abutment systems as previously described by Strub and Gerds (18). Parameters for the chewing simulation were adopted from published recommendations on simulation of load (19), cycle frequency (20) and load angle (21). Supplemental thermocycling was performed to simulate moisture and temperature changes as encountered intraorally. The process has been shown to correlate well with the clinical use of a restoration (22).

To minimize the number of variables, all specimens were designed to closely similar dimensions only differing in the abutment type being used. Compatible platform and hexagonal size of standard diameter Brånemark-type and 3i implants allowed for a precise seating of the CerAdapt abutment used in group B on the Osseotite implant. A torque of 32 Ncm has been recommended for the abutment screw used in this study and all three types of abutments (23–25).

The alumina abutments used in group B (CerAdapt) are only provided in one, cylindrical standard form. Consequently, establishing individual crown contours requires customization of the abutment prior to restoration. In this study, the CerAdapt abutments were prepared according to the pre-fabricated size and shape of the titanium-reinforced abutments (ZiReal) and titanium abutments (GingiHue) used in groups A and C, respectively, for means of comparability. Preparation of ceramic abutments is a time consuming procedure. Furthermore, abutment strength may be compromised through the introduction of microcracks during manufacturing or the customization process, possibly explaining the fracture of the one CerAdapt specimen which occurred at an early stage of chewing simulation. ZiReal abutments are available with different emergence profiles, collar and retention heights which reduces the need for adjustments, and therefore the risk of processing related damage (26).

Despite common clinical practice, it was chosen to restore the specimens with complete metal crowns instead of all-ceramic crowns not to obscure the cause of failure; i.e. abutment-related or crown-related. Other authors also favoured this concept (18).

Unlike CerAdapt abutments, ZiReal abutments cannot be veneered with porcelain and the final restoration must be a cement-retained crown. Therefore, loose abutment screws cannot be retightened and, thus, the stability of the abutment screw joint is a most crucial factor for the success of the restoration. Hexagonal screw joint complications, consisting primarily of screw loosening, were reported in the literature to range from 6 to 48% (14). It has been shown that controlled torque application and the use of gold-alloy screws instead of titanium screws reduce failure rates (27, 28). Further, it is believed that the preload of gold-alloy screws can additionally be enhanced by the application of a dry lubricant coating such as 0·76 μm pure gold (25), as confirmed in this study in which no screw loosening occurred during chewing simulation.

Fracture strength after static loading of the artificially aged specimens was significantly higher for ZiReal abutments than for CerAdapt abutments. This may be attributed to the better mechanical properties of zirconium dioxide ceramics compared with alumina ceramics and the unique phenomenon of transformation strengthening (29). Basal reinforcement of the ZiReal abutment by the titanium may also have contributed to increased fracture resistance.

The fracture load values found for the titanium abutments in this study are lower than those reported for implant metal abutment combinations by Strub and Gerds (18) after chewing simulation. This difference may be explained by methodological issues, i.e. in this study the static load measurement was stopped after a deflection of 4 mm, while Strub and Gerds (18) continued until a deviation from the linear slope in the load displacement graph occurred. Yildirim *et al.* (30) found mean fracture load values of 280 N for alumina abutments and 738 N for zirconia abutments on non-fatigued samples. The lower values found in the present study may be attributed to the preceding fatigue loading. Maximal occlusal forces in the anterior region were reported in the range of 150–235 N (31). Loads of these magnitudes were tolerated by specimens of groups A and C but not by specimens from group B.

The specimen that fractured during chewing simulation was included in the statistical evaluation to avoid pre-selection bias. The specimen was assigned the value 0 N because the fracture strength after simulated clinical service was 0 N. This has contributed to the high standard deviation found in group B. If this specimen is excluded from the statistics, the mean fracture strength (±s.d.) for the alumina abutment group changes from 239 N (±83 N) to 255 N (±55 N) as compared with 324 N (±85 N) for the titanium abutments and 294 N (±53 N) for the zirconia abutments. As the median fracture strength value is only minimally affected by excluding the broken specimen from the calculation (252·58 N versus 253·76 N), the Wilcoxon test performed with a significance level of 0·05 still displays significant differences between groups A and B, and groups B and C, respectively. Further, the analysis of the failure mode clearly indicates that group B abutments were more prone to fracture than group A abutments. Therefore, ZiReal abutments may provide a higher degree of functional reliability than CerAdapt abutments.

Meaningful results have been reported in other studies that involved chewing simulation or fatigue loading of implant abutment systems (16, 32–34). However, clinical trials are necessary to validate the results of these investigations as well as the present *in vitro* study.

In conclusion, titanium-reinforced zirconia abutments perform similar to titanium abutments, and can therefore be recommended as an aesthetic alternative for the restoration of single implants in the anterior region. All-ceramic abutments made of alumina yield less favourable properties. The use of gold-coated screws can efficiently prevent screw loosening.

Acknowledgments

The authors want to thank Dr Linda Dubin (UCLA School of Dentistry) for editorial assistance and Dr Thomas Gerds (Department of Medical Biometry, Albert-Ludwigs University, Freiburg) for performing the statistical analysis. This research was partially supported by Implant Innovations.

References

1. Marinello CP, Meyenberg KH, Zitzmann N, Luthy H, Soom U, Imoberdorf M. Single-tooth replacement: some clinical aspects. J Esthet Dent. 1997;9:169–178.
2. Schmitt A, Zarb GA. The longitudinal clinical effectiveness of osseointegrated dental implants for single-tooth replacement. Int J Prosthodont. 1993;6:197–202.
3. Henry PJ, Laney WR, Jemt T et al. Osseointegrated implants for single-tooth replacement: a prospective 5-year multicenter study. Int J Oral Maxillofac Implants. 1996;11:450–455.
4. Prestipino V, Ingber A. Esthetic high-strength implant abutments. Part I. J Esthet Dent. 1993;5:29–36.
5. Prestipino V, Ingber A. Esthetic high-strength implant abutments. Part II. J Esthet Dent. 1993;5:63–68.
6. McLaren EA, White SN. Glass-infiltrated zirconia/alumina-based ceramic for crowns and fixed partial dentures. Pract Periodontics Aesthet Dent. 1999;11:985–994; quiz 996.

7. Abrahamsson I, Berglundh T, Glantz PO, Lindhe J. The mucosal attachment at different abutments. An experimental study in dogs. J Clin Periodontol. 1998;25:721–727.
8. Rasperini G, Maglione M, Cocconcelli P, Simion M. *In vivo* early plaque formation on pure titanium and ceramic abutments: a comparative microbiological and SEM analysis. Clin Oral Implants Res. 1998;9:357–364.
9. Andersson B, Taylor A, Lang BR et al. 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. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Schärer 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.
12. Philipps RW. Science of dental materials. Philadelphia: WB Saunders Co; 1982:502–530.
13. Binon PP. The external hexagonal interface and screw-joint stability: a primer on threaded fasteners. Qintessence Dent Technol. 2000;23:91–105.
14. Binon PP. Implants and components: entering the new millennium. Int J Oral Maxillofac Implants. 2000;15:76–94.
15. Brodbeck U. The ZiReal post: a new ceramic implant abutment. J Esthet Restor Dent. 2003;15:10–23, discussion 24.
16. Strub JR, Butz F, Semsch R. Single-tooth replacement with a new zirconia titanium cylinder implant abutment: a case report. Quintessence Dent Technol. 2003;26:171–178.
17. DeLong R, Douglas WH. Development of an artificial oral environment for the testing of dental restoratives: bi-axial force and movement control. J Dent Res. 1983;62:32–36.
18. Strub JR, Gerds T. Fracture strength and failure mode of five different single-tooth implant-abutment combinations. Int J Prosthodont. 2003;16:167–171.
19. De Boever JA, McCall WD Jr, Holden S, Ash MM Jr. Functional occlusal forces: an investigation by telemetry. J Prosthet Dent. 1978;40:326–333.
20. Bates JF, Stafford GD, Harrison A. Masticatory function – a review of the literature. 2. Speed of movement of the mandible, rate of chewing and forces developed in chewing. J Oral Rehabil. 1975;2:281–301.
21. Kraus BS, Jordan EJ, Abrams LA. The dentition: its alignment and articulation. In: Kraus BS, Jordan EJ, Abrams LA, eds. A study of the masticatory system. Dental anatomy and occlusion. Baltimore: Williams & Wilkins; 1969:223–237.
22. Sakaguchi RL, Douglas WH, DeLong R, Pintado MR. The wear of a posterior composite in an artificial mouth: a clinical correlation. Dent Mater. 1986;2:235–240.
23. Weiss EI, Kozak D, Gross MD. Effect of repeated closures on opening torque values in seven abutment-implant systems. J Prosthet Dent. 2000;84:194–199.
24. Haack JE, Sakaguchi RL, Sun T, Coffey JP. Elongation and preload stress in dental implant abutment screws. Int J Oral Maxillofac Implants. 1995;10:529–536.
25. Drago CJ. A clinical study of the efficacy of gold-tite square abutment screws in cement-retained implant restorations. Int J Oral Maxillofac Implants. 2003;18:273–278.
26. Luthardt RG, Holzhuter M, Sandkuhl O et al. Reliability and properties of ground Y-TZP-zirconia ceramics. J Dent Res. 2002;81:487–491.
27. Jörneus L, Jemt T, Carlsson L. Loads and designs of screw joints for single crowns supported by osseointegrated implants. Int J Oral Maxillofac Implants. 1992;7:353–359.
28. McGlumphy EA, Mendel DA, Holloway JA. Implant screw mechanics. Dent Clin North Am. 1998;42:71–89.
29. Garvie RC, Hannink RH, Pascoe RT. Ceramic steel? Nature. 1975;258:703–704.
30. Yildirim M, Fischer H, Marx R, Edelhoff D. *In vivo* fracture resistance of implant-supported all-ceramic restorations. J Prosthet Dent. 2003;90:325–331.
31. 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.
32. Cibirka RM, Nelson SK, Lang BR, Rueggeberg FA. Examination of the implant-abutment interface after fatigue testing. J Prosthet Dent. 2001;85:268–275.
33. Gratton DG, Aquilino SA, Stanford CM. Micromotion and dynamic fatigue properties of the dental implant-abutment interface. J Prosthet Dent. 2001;85:47–52.
34. Khraisat A, Hashimoto A, Nomura S, Miyakawa O. Effect of lateral cyclic loading on abutment screw loosening of an external hexagon implant system. J Prosthet Dent. 2004;91:326–334.
35. Kern M, Strub JR, Lu XY. Wear of composite resin veneering materials in a dual-axis chewing simulator. J Oral Rehabil. 1999;26:372–378.

Correspondence: Dr Frank Butz, Department of Prosthodontics, School of Dentistry, University Hospital, Hugstetter Str. 55, 79106 Freiburg, Germany.
E-mail: frank.butz@uniklinik-freiburg.de