Strength and Mode of Failure of Single Implant All-Ceramic Abutment Restorations Under Static Load

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The strength and mode of failure of three different designs of custom-made all-ceramic implant abutments fabricated by milling of In-Ceram sintered ceramic blocks were compared with the conventional CeraOne system under static load. Four test groups were formed with different locations of abutment screws. In three test groups, In-Ceram crowns were fabricated for placement on the all-ceramic abutments, and in one test group, a veneer porcelain was fired directly on the abutment; crowns in the control group were fabricated using the CeraOne system. Ten-mm-long Brånemark implants were placed into a brass block that allowed loading at a 30-degree angle to the long axis. The test group in which the veneer porcelain was fired directly on the all-ceramic abutments was the weakest, and it showed fractures at a mean value of 236 N. The fracture strength of the three other test groups was dependent on the extension of the crown margin relative to the location of the screw head. The test group that had the screw on the top compressing the entire ceramic abutment showed a mean value of 422 N that was similar to the results that were achieved with the CeraOne system (427 N). The weakest link in the all-ceramic single implant restorations was the abutment screw in which the bending began at approximately 190 N. *Int J Prosthodont 1995;8:265–272.*

The long-term prognosis of endosseous oral implants has been extensively documented for fully and partially edentulous patients.[1-6] Esthetics may be compromised at the cervical third of the suprastructure in the area where the abutment contacts the implant. The abutment must meet biologic, functional, and esthetic requirements. Biologically, the restorative material must be biocompatible and not promote plaque adherence. Functionally, the abutment must provide sufficient strength to endure and transmit forces to the implant and the supporting bone. Esthetically, it should have the anatomically correct contours and replicate the optical properties of a natural tooth including the cervical area corresponding to the crown-root junction. The natural morphology of this area is not cylindrical and varies greatly. The natural tooth allows some light transmission and provides the surrounding soft tissues with a fairly bright background that transmits light through a fiberoptic effect.

On many occasions, conventional titanium abutments fail to meet esthetic requirements. Even when placed subgingivally, a dull greyish background may give the soft tissue an unnatural bluish appearance. Abutment components were modified to allow a more stable screw joint as well as to improve the esthetic result.[1] Based on these modifications, other abutment materials[7] and other tech-

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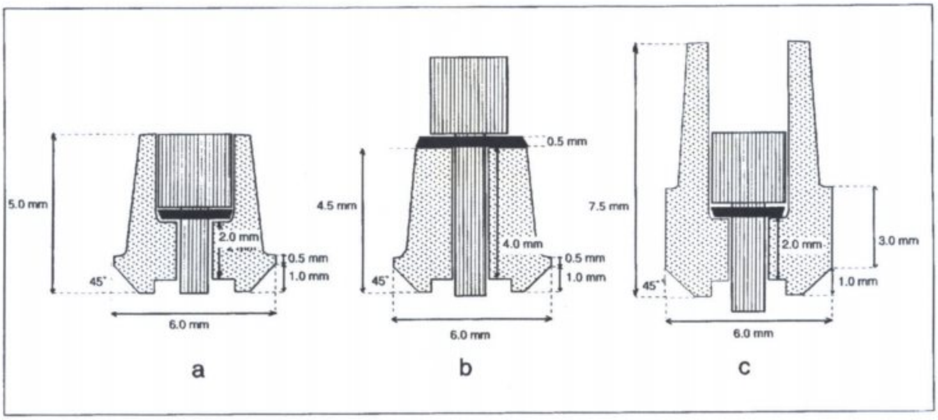


Fig 1 Design of single implant all-ceramic abutments.

niques to secure the abutment screw have been presented.[8] The all-ceramic abutment CeramiCore (not commercially available) was developed for single and multiple units and allows good esthetics and biocompatibility.[9,10] Knode and Sorensen[11] and McGlumphy et al[12] conducted studies comparing the strength of single implant restorations using CeramiCore abutments and traditional metal abutments. In contrast to the latter study, Knode and Sorensen found significant differences between the performance of test and control abutments, although no attempts were made to describe the mode of failure or discuss the relationship of failure to design. Because of the controversy in the literature, further investigations are needed. Furthermore, the mode of failure must be evaluated to propose new designs of all-ceramic abutments.

Before accepting modifications of implant abutments and implant restorations, it is important to carefully evaluate the biologic and mechanical performance and the feasibility of the introduced alterations. The purpose of this study was to evaluate the fracture strength and the mode of failure of different designs of single implant all-ceramic abutment restorations under static load.

Materials and Methods

Twenty-four all-ceramic implant abutments with three different designs were fabricated by milling sintered Al_2O_3 blocks (In-Ceram, Vita Zahnfabrik, Bad Säckingen, Germany) prior to the glass infiltration stage using a copy milling machine (Celay, Mikrona Technologie, Spreitenbach, Switzerland). Titanium impression copings having an internal hexagonal form (DCA 099, Nobelpharma, Göteborg, Sweden) were copied to provide prototypes of identical designs of the cervical portion of the different all-ceramic implant abutments engaging the hexagonal head of the Brånemark implants (SDCA 001, Nobelpharma). The outer surface of the cervical parts diverged by an angle of 45 degrees to reach a maximum diameter of 6 mm, 1 mm above the base. The prototypes of the three different designs of ceramic implant abutments contain a crown portion with 3-degree inwardly sloping axial walls extending cervically to a 0.5-mm-deep rounded shoulder.

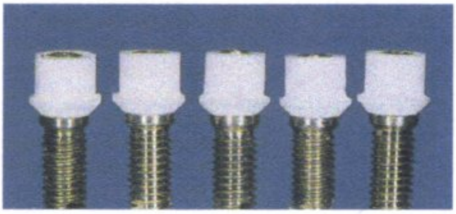


Fig 2 Test abutments retained on implants prior to glass infiltration.

Figure 1 shows two different locations of the abutment screws and three different designs of all-ceramic implant abutments. In design a and c the screw channels house the screw heads, and in b

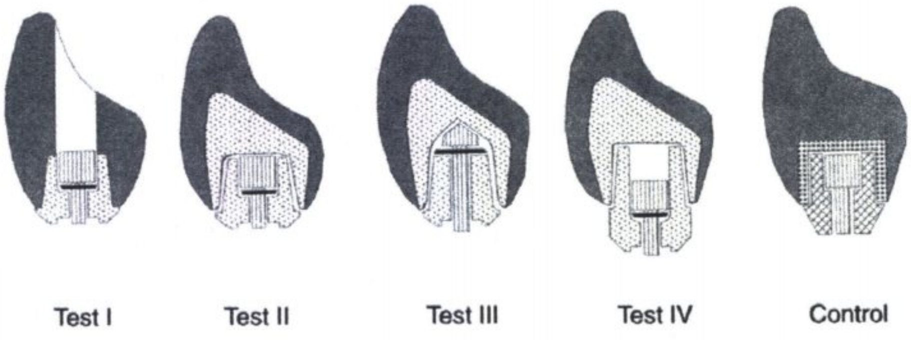


Fig 3 Design of single implant all-ceramic abutment restorations.

the screw head is placed on the top of the abutment. Downward tapering (design a and c) or upward tapering (design b) custom-made metal discs were placed between the screw heads and the all-ceramic implant abutments. The main difference between designs a and c was that on the external surface of the all-ceramic implant abutments in design a, the external rounded shoulder was created at the level below the internal shoulder, whereas in design c the the rounded external shoulder was above the internal shoulder.

Ceramic blocks were milled in the copy milling machine using a high-speed turbine in the wet carving chamber to produce the all-ceramic implant abutments.[13] The stem areas were smoothed using a fine diamond bur in a rotary handpiece prior to glass infiltration in an oven (Inceramat, Vita Zahnfabrik) at 1120 °C for 6 hours (Fig 2). The outer surface of the all-ceramic implant abutments was covered with a mixture of glass and distilled water. After firing, the excess glass was removed by airborne particle abrading using 50 μm Al_2O_3 powder at 3-bar air pressure. The fit between the all-ceramic implant abutments and the implant head was reexamined and improved by wet grinding the contact area using FEPA P 4000 silicon carbide paper mounted on a polishing spinning wheel (K&B Grubbs, Dusseldorf, Germany).

Four test groups were formed containing six specimens each. In test group I, six crowns were fabricated by firing the ceramic veneering material (Vitadur Alpha, Vita Zahnfabrik) directly onto the ceramic implant abutments providing access for the abutment screw (Fig 3–Test I). In each of the other test groups (Test II, III and IV), six impressions were made using a polyether impression material (Impregum, ESPE, Seefeld, Germany), and In-Ceram crowns (Vita Zahnfabrik) were fabricated and luted on the all-ceramic implant abutments using $ZnPO_4$ cement (Harvard R, Berlin, Germany) with finger pressure (Fig 3–Test II, III, and IV). For the control group, all-ceramic crowns (Vitadur Alpha, Vita Zahnfabrik) were fabricated using the CeraOne system (Ceramic cap short, DCB 127, Nobelpharma). The crowns were luted using $ZnPO_4$ on the titanium abutments (1-mm collar, SDCA 121, Nobelpharma) (Fig 3–Control). In all groups three specimens were retained to the implants with gold abutment screws (DCA 118, Nobelpharma) and three with custom-made stainless steel screws using a controlled force of 32

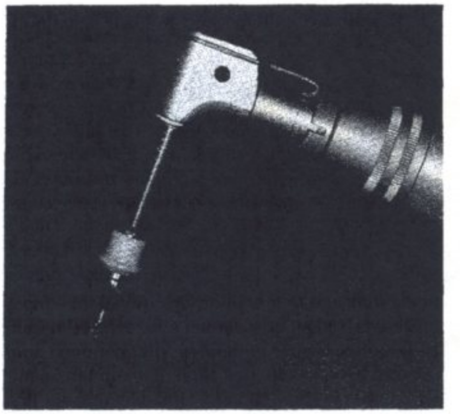


Fig 4 Completed test abutment retained with controlled force of 32 Ncm.

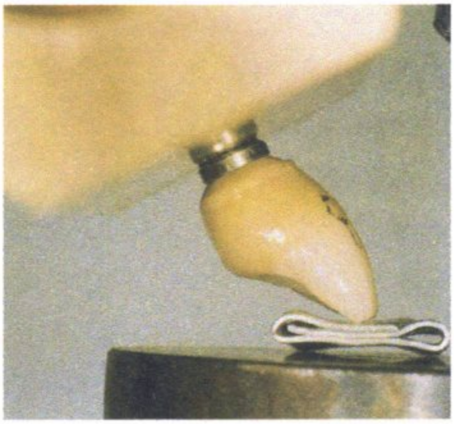


Fig 5 Implant placed in a brass block bearing a test sample of group I ready for loading at a 30 degree angle to the long axis.

Ncm (Torque Controller, Nobelpharma) (Fig 4). The use of stainless steel screws was introduced to examine in vitro the bending properties of a stronger material, Ti and Au being approximately equally weak. The 10-mm-long Brånemark implants were placed in a brass block that allowed loading at a 30-degree angle to the long axis. The incisal edges of the crowns were covered by 0.4-mm-thick tin foil, triple folded, to ensure transmission of the applied static loading forces (Zwick 1445, Ulm, Germany) through their entire lengths (Fig 5). The tests were performed using a crosshead speed of 1 mm per minute (according to ISO 6872), whereby the applied force was graphically recorded on an x-t-recorder (Linseis, Selb, Germany). The graphs show the initial elastic bending of the all-ceramic abutment restorations and the beginning of the irreversible plastic screw bending under the applied forces. The critical force for the beginning of the plastic screw deformation is defined as bending force in this context. Means and standard deviations of the recorded forces for the plastic bending of the abutment screws and the fractures of the ceramic single implant restorations were calculated. The Student's t-test was used to evaluate the differences between test and control groups.

After testing, the specimens were invested into acrylic resin blocks (Technovit 5000–Technovit 4071, Heraeus-Kulzer, Wehrheim, Germany), and they were sectioned buccolingually using a diamond microsaw (Capco, London, England) for microscopic examination.

Results

The results with means and standard deviations of the strength and mode of failure of the different single implant restorations under static load are listed in Table 1 and presented in Fig 6. The statistical analysis revealed differences between the test and control groups for the bending forces of the abutment screws and the fracture strength of the single implant restorations (Table 2).

For the bending forces of the abutment screws, Student's *t* test revealed no significant differences between gold and stainless steel abutment screws in all groups (mean values 195 N and 205 N, $P > .05$). There were some differences between the mean values of the bending forces of the different groups. The mean value of the bending forces of test group III (243 N) was higher than that of test groups I and IV (177 N, 178 N; $P < .05$).

The mean values of the fracture forces in test groups II and III and the control group (373 N, 422 N, and 417 N) are significantly higher than that in test group I (236 N, $P < .05$). There was a significant difference between the fracture force of test groups III and IV.

Discussion

In this study, the strength and mode of failure of different single implant all-ceramic abutment restorations was analyzed and compared with the CeraOne system under static load. The samples of

Table 1 Strength (N) and Mode of Failure of Single Implant All-Ceramic Abutment Restorations Under Static Load

Samples		1		2		3	
		BF	F	BF	F	BF	F
Test group I	g	170	210	180	240	180	240
	ss	180	255	180	180	170	290
Test group II	g	180	365	190	390	200	470
	ss	180	340	170	340	210	330
Test group III	g	200	400	330	450	210	400
	ss	300	500*	210	360	210	440
Test group IV	g	190	215	180	470	180	250
	ss	170	360	170	215	180	250
Control group	g	130	225	230	470*	180	470
	ss	260	455*	230	460*	250	420*

BF = bending force; F = abutment fracture; g = gold screw; ss = stainless steel screw.
*No fracture implant bend.

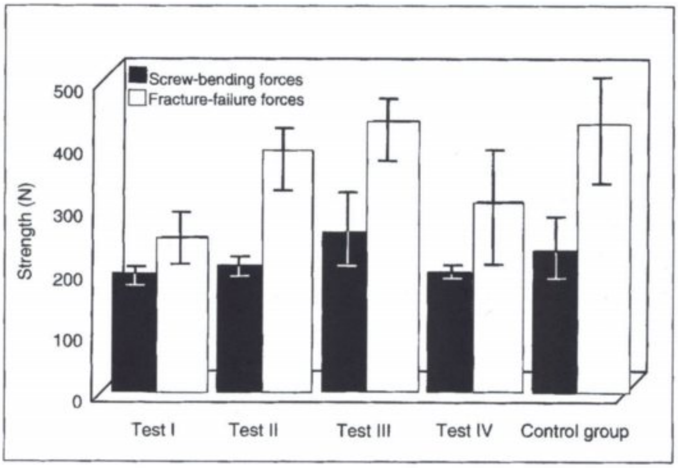


Fig 6 Strength and mode of failure of single implant all-ceramic abutment restorations under static load (means and standard deviations).

Table 2 Student's *t* Test Analysis

Pairs	*t* test value	*P* value
Group III-BF – Group I-BF	2.88	$P < .05$
Group III-BG – Group IV-BF	2.80	$P < .05$
Group II-F – Group I-F	5.18	$P < .001$
Group III-F – Group I-F	7.42	$P < .001$
Control Group – Group I-F	4.31	$P < .01$
Group III-F – Group IV-F	2.79	$P < .05$

BF = bending force; F = failure force.

test group I, consisting of an all-ceramic abutment with a direct porcelain veneer and an occlusal screw hole, provided the weakest restoration. The nature of fractures in this group revealed the presence of tensile stresses around the screw head. Cracks originated from the metal disc outwardly, probably because the incisal part of the crown shifted away from the screw head during loading. Fractures must be expected, because ceramic materials are weak under tension. The presence of an occlusal screw hole weakened the single implant all-ceramic abutment restorations. The fact that the veneering material and the all-ceramic abutment were fused together increased the risk of surface microcracks that can propagate and result in fracture.

Testing the three other all-ceramic abutment groups was designed to specifically evaluate the potential reinforcement provided by a luted crown over the abutment and the influence of the location of the head of the stabilizing screw.

In test group II, the involved abutments are iden-

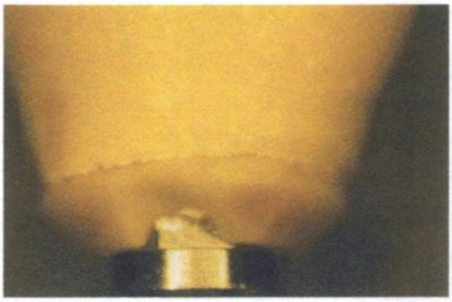


Fig 7 In groups II and III the nature of fracture involved chipping of the ceramic material in the marginal area of the side opposite to the applied force after a small gap between implant head and abutment had formed following bending of the retaining screw.

tical to group I but with a cemented crown instead of a porcelain veneer fired directly on the all-ceramic abutment. The strength of these restorations was significantly higher (373 N) than that of test group I (236 N), revealing the major importance of the cemented crown in reinforcing the abutment.

In test group III, in which the screw head was located on top of the all-ceramic abutment, the strength of the restorations was improved (422 N). One can speculate that the tensile stress around the screw head was eliminated and only compressive forces were applied from the screw head through the disc to the abutment and its margin. In both test groups (II and III), fractures occurred after a gap had formed between the abutment margin and the implant head as a result of the the screw bending (Fig 7). In one test sample in group III, the ceramic margin managed to move away from the hexagonal head without fracturing, and no other fracture occurred before the destruction of the internal threads began.

Test group IV was designed with the margin of the all-ceramic crown located at a higher level than the head of the screw, reducing the strengthening influence. The average fracture strength of this group (293 N) was not significantly greater than that in group I, but significantly less than in groups II and III. Fractures occurring in this group were similar to those in groups II and III (Fig 8a). In one specimen a horizontal fracture occurred, initiated from the screw head outwardly. This probably resulted from the tensile stress not being neutralized by the embracing crown margin that was located at a higher level.

In most of the control group no fracture occurred before implant failure (Fig 8b). In two specimens, however, the ceramic crowns fractured at 225 N and 470 N. The fracture lines involved both the veneer ceramic material and the sintered ceramic core. These incidents indicate that a weak feature of the CeraOne system is that the reinforcing short ceramic core does not follow the external anatomy of the crown. The long ceramic cap that can be modified to the required anatomy would be preferable.

McGlumphy et al[12] compared the amount of static force necessary to cause failures of sintered alumina core abutments (CeramiCore), gold palladium abutments (UCLA type, Implant Innovations, West Palm Beach, FL), and CeraOne. They found that the resistance to failure of all-ceramic abutments may approach that of conventional metal-ceramic abutments.

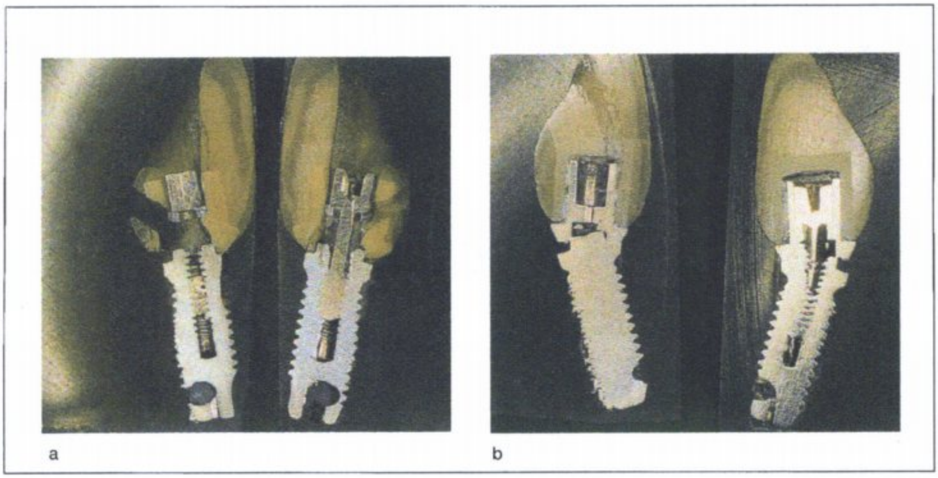
Knode and Sorensen[11] found in a similar study that all-ceramic single implant restorations using all-ceramic CeramiCore abutments are significantly weaker than metal ceramic restorations (UCLA type, Implant Innovations) and the CeraOne (Nobelpharma).

Andersson et al[14] investigated the mechanical strength of three different types of crowns that were placed on CeraOne single tooth abutments (metal ceramic crowns, all-ceramic crowns in which porcelain was fired to prefabricated ceramic copings, all-ceramic crowns made without any copings) and found that the weakest link was the abutment screw. The failure loads of the screws were lower than the failure loads of the crowns (exception of the all-ceramic crowns without any copings).

In the present study, the abutment screw bending force started at 190 N. Between the two types of abutment screws (gold and stainless steel), no significant differences of bending forces were found. Elastic bending of the screw during static loading does not necessarily mean failure of the entire restoration, but the plastic deformation which occurred under loads above 190 N must be considered as a failure.

Jörneus et al[13] analyzed different screw designs in bench situations, and the results were compared with clinical situations. They suggested the use of gold alloy screws with a flat head and high tightening torque (35 N/cm).

The results of the present study show that proper design of the all-ceramic abutments can improve the strength of all-ceramic single implant restorations although ceramics do not possess the flexural strength of metals. It is shown that all-ceramic single implant restorations with a custom-made all-ceramic abutment can reach the level of the



Figs 8a and 8b Sample cross sections. (a) Test Group I: The fracture originated from the metal disk outward revealing the presence of tensile stresses around the screw head, and (b) Control: Extreme bending of the occlusal screw caused implant failure.

strength of the CeraOne system. It must be considered that the weakest link of the system is the abutment screw that is vulnerable to bending.[14] The authors suggest that these types of restorations only be placed in the anterior part of the maxillae and the mandible inasmuch as the average biting forces of canines and incisors are 208 and 155 N.[16] Further data are needed before single implant all-ceramic abutment restorations can be recommended for clinical use.

Conclusions

Four test designs of all-ceramic restorations were compared to a commercially available all-ceramic restorative system. Three screw retention designs using both gold and stainless steel screws were evaluated using a static load to failure. Within the design parameters of the study, the following conclusions may be made:

1. Single implant all-ceramic abutment restorations using custom-made In-Ceram abutment veneered porcelain were shown to be the weakest of all the designs tested.
2. The fracture strength of single implant all-ceramic abutment restorations is dependent on the extension of the crown margin relative to the location of the retaining screw head.
3. If the stabilizing abutment screw is located on top of the ceramic, abutment fracture resistance can be improved.
4. No difference was recorded in the bending properties of stainless steel and gold stabilizing screws.
5. The weakest link of all-ceramic single implant restorations is the abutment screw.

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Literature Abstract

Implant-Supported Prostheses for the Treatment of Adults With Cleft Palate

Posterior pharyngeal flap procedures for repair of cleft palate were not widely performed in the United States until the late 1950's. Therefore, there is a population of adults 40 years of age and older with unrepaired or nonfunctional repaired palates. This article described the use of self-tapping titanium implants for the retention of maxillary prostheses, some with a pharyngeal section added for speech enhancement. Six adult patients (ages 47 to 78 years) with cleft palates were treated with implants. Twenty-three implants were placed, with 21 achieving osseointegration. All patients were treated using a maxillary complete denture or overdenture. Five patients (83%) required the addition of a pharyngeal section to decrease hypernasal speech. **The use of implants in the treatment of persons with cleft palate can provide adequate retention and stability for the prosthetic restoration of oropharyngeal structures, thus improving speech, deglutition, mastication, and esthetics.**

Arcuri MR, LaVelle WE, Higuchi KW, Svec BR. *J Prosthet Dent* 1994;71:375–378. **References:** 5. **Reprints:** M.R. Arcuri, Department of Otolaryngology, University of Iowa Hospitals and Clinics, Iowa City, IA 52242.—*Marina Sauco, DDS, Prosthodontic resident, New York Veterans Administration Medical Center, New York*