Clinical Evaluation of 209 All-Ceramic Single Crowns Cemented on Natural and Implant-Supported Abutments with Different Luting Agents: A 6-Year Retrospective Study

Roberto Sorrentino, DDS, MSc, PhD;* Luigi Galasso, MD, DDS;† Stefano Tetè, MD, DDS;‡ Giorgio De Simone, DDS;§ Fernando Zarone, MD, DDS‖

ABSTRACT

Background: The Procera AllCeram™ system (Nobel Biocare AB, Göteborg, Sweden) is a valid alternative to metal–ceramic restorations. However, limited long-term data of its use for single crowns on natural and implant-supported abutments are available.

Purpose: The present study aimed at evaluating the clinical performances of Procera AllCeram single crowns in both anterior and posterior regions of the oral cavity either on natural tooth or implant abutments over a period of 6 years.

Materials and Methods: Two hundred nine single crowns were fabricated and used in 112 patients. Zinc phosphate and resin luting agents were used to cement the restorations. The crowns were evaluated according to the California Dental Association's quality assessment system.

Results: Three crowns were lost at follow-up. Of the 206 restorations, which completed the 6-year follow-up, 9 crowns were affected by mechanical complications and 7 crowns failed. All surviving crowns were ranked as either excellent or acceptable. Cumulative survival and success rates of 95.2 and 90.9%, respectively, were recorded.

Conclusions: Within the limitations of the present study, Procera AllCeram crowns proved to be a reliable clinical option to restore both anterior and posterior missing teeth either on natural or implant abutments. The resin cement used in the present study performed better than the zinc phosphate luting agent.

KEY WORDS: all-ceramic crowns, anterior crown, implant prosthodontics, observational study, posterior crown, Procera AllCeram, prosthesis, resin cement, retrospective study, zinc phosphate cement

INTRODUCTION

Metal–ceramic crowns have represented a standard in terms of long-term survival for many years. However, the presence of metal frameworks is to be considered a limiting factor for the final esthetic result. Owing to patients' increasing demand for esthetics, all-ceramic restorations have become a widespread treatment option: as interference with the natural transmittance of light is unlikely, such restorations are characterized by a much more natural appearance. Feldspathic porcelain usually provides optimal biocompatibility, esthetics, and mechanical resistance to compressive forces, but it frequently fractures under shear loads because of its low tensile strength. In order to make all-ceramic crowns suitable for all intraoral sites, various innovative all-ceramic-based restorative systems have been developed in recent years.[1–4] Available pieces of evidence indicate the effectiveness of different all-ceramic systems for several clinical applications.[5]

The ceramic core can be produced by slip casting or machine milling, usually combined with a computer-aided design/computer-aided manufacturing

*Research fellow, University "Federico II" of Naples, Italy; †private practitioner, Naples, Italy; ‡professor and chair, University "G. D'Annunzio" of Chieti-Pescara, Italy; §research fellow, University "Federico II" of Naples, Italy; ‖professor and chair, University "Federico II" of Naples, Italy

Reprint requests: Dr. Roberto Sorrentino, Via Generale Giovanni De Bonis, 75-80123 Naples, Italy; e-mail: errestino@libero.it

DOI 10.1111/j.1708-8208.2009.00251.x

(CAD/CAM) method.[6] Core systems using a ceramic core are characterized by high-fracture toughness.[7] Particularly, densely sintered, high-purity alumina was reported to have significantly higher flexural strength than glass-infiltrated pre-sintered alumina.[4]

The Procera system (Nobel Biocare AB, Göteborg, Sweden and Procera™ Sandvik AB, Stockholm, Sweden) is today one of the most evidence-based validated systems to produce alumina and zirconia restorations for natural abutments and different implant platforms. Nevertheless, few long-term evaluations of its use for single crowns on natural and implant-supported abutments are available. Procera AllCeram is a leucite-free porcelain containing more than 99.9% alumina. The purity of the aluminum oxide and the sinterization process contribute to reduce porcelain failure.[3,8,9] Moreover, such ceramics is provided with optimal mechanical resistance to fracture and allowed to obtain a natural appearance of the restorations because of its translucency and opalescence.

As for the adaptation of crowns to the periodontal tissues, the range of acceptability for crown marginal gaps has been stated to be 40 to 100 μm[10]; restorations realized with the Procera system show a marginal gap ranging between 60 μm and 80 μm, which can be considered clinically acceptable.[11,12]

Survival rates for all-ceramic restorations were reported to range from 88% to 100% after 2 to 5 years, and from 84% to 97% after 5 to 14 years of clinical service.[4,13–16] When used for both anterior and posterior teeth, the survival rates at 5 years of densely sintered alumina crowns (94.9%) and reinforced glass–ceramic crowns (93.7%) were similar to those obtained for metal–ceramic crowns.[17] As to Procera AllCeram crowns, the cumulative survival rate was 100% in the anterior region and 98.8% in the posterior region after 5 and 7 years of clinical service; clinical success was achieved irrespective of the tooth position.[18] Success rates of 100 and 98.3% on natural tooth and implant-supported abutments, respectively, were found using anterior Procera AllCeram single crowns after 4 years of function.[19]

For all-ceramic prostheses that use ceramic frameworks, it has been reported that, similarly to metal–ceramic restorations, fracture of the veneering porcelain and/or ceramic coping remains the most commonly reported primary complication affecting longevity and sometimes requiring remaking of the restoration.[20] Fractures are expected as a consequence of fatigue after a long-term service; moreover, an improperly designed core requiring the application of an excessively thick layer of veneering porcelain may result in a higher incidence of failure. Nevertheless, recently, it was hypothesized that the thickness of the incisal veneering porcelain could affect the failure load of metal–ceramic crowns but not that of all-ceramic crowns.[21]

Besides providing retention of prostheses, the cementation techniques as well as the mechanical properties of luting agents affect the fracture strength and leakage of all-ceramic crowns.[22] To date, adhesive luting systems are recommended for the cementation of all-ceramic prostheses, however, because of multistep clinical luting procedures, the adhesion actually achieved could be strongly affected by different intraoral variables particularly in the posterior region. Consequently, cements with less-complicated luting procedures, just like the zinc phosphate cement, might minimize the influence of oral conditions and could be useful in achieving a sufficient adhesion.[23]

Some dentists are better trained and feel more comfortable with using zinc phosphate cement because of its simplicity of use. The removal of cement excess is perceived as being easier with zinc phosphate than with resin cement. Moreover, adhesive bonding could be considered a drawback if it is needed to retrieve the prosthesis.[24]

Zinc phosphate cement sets through an acid-base reaction that can exacerbate surface flaws in ceramics because of the increased acidity of the cement. Resin cement sets through a photo- or chemically initiated polymerization; this results in improved strength, fracture toughness, and wear resistance. Consequently, non-acid-base cements are recommended to improve success rates with glass- and alumina-based ceramic restorations.[25,26]

Bonding procedures have been shown to increase the clinical success of all-ceramic restorations: clinical data suggest that higher success rates can be achieved when ceramics can be bonded to teeth.[5] Different luting agents influenced the fracture resistance of Procera AllCeram copings: resin luting cements resulted in significantly higher fracture resistance values than zinc phosphate and glass ionomer cements.[23]

Although fracture strengths were well above natural chewing forces irrespectively to the cementation technique, the adhesive bonding cementation significantly

increased fracture strength and improved marginal seal of alumina crowns.[22] The use of resin cements reduced microleakage on all ceramic prostheses, whereas zinc phosphate cements resulted in the highest percentage of extensive microleakage.[27,28] Lower microleakage was observed for the aluminum oxide blasting plus silane treatment.[29] The use of a silane coupling agent could reduce the stress at the flaw tips, restricting the propagation of cracks within the Procera AllCeram copings.[23]

As regards the mode of fracture, it was proved that Procera AllCeram copings cemented with either zinc phosphate or glass ionomer cements exhibited severe fracture of copings while Procera AllCeram copings cemented with a resin cement showed minimal fracture without any loss of coping. The retention of resin cement on the internal surface of the copings could explain the difference in the mode of fracture.[23]

It was also demonstrated that luting agents together with the background shade may influence the final color of the restoration. In particular, the zinc phosphate cement was proved to be less translucent than the resin cement.[30]

The present study aimed at assessing the clinical performance of Procera AllCeram single crowns supported by either natural teeth or implants, and cemented with a resin cement or a zinc phosphate cement over a period of 6 years.

MATERIALS AND METHODS

Four dentists at the Department of Prosthetic Dentistry of the University "Federico II" of Naples and in their private practice made 209 Procera AllCeram (Nobel Biocare AB and Sandvik AB) single crowns in 112 patients (Table 1) over a period of 12 months.

Patients were selected for the retrospective evaluation on the basis of the following inclusion criteria[31]:

- Age above 18 years with at least one tooth in need of crowning
- Extensive loss of tooth structure indicating full veneer crowns or crowns needing replacement (ie, secondary caries and fracture)
- Good oral hygiene
- Low caries activity
- Vital or sufficient endodontically treated tooth with no pathological signs on the X-ray and without clinical symptoms of inflammation
- No history of previous periodontal flap surgery
- Periodontal pocket depth less than 3 mm
- No tooth mobility
- Lack of excessive parafunctional activity leading to an extensive loss of tooth structure, abfraction lesions, or cracks
- Sufficiently treated remaining teeth or treatment during study therapy

Conversely, the following exclusion criteria were adopted[31]:

- Addiction to alcohol or drugs
- Psychologically unstable patients
- Patients with acute symptoms of functional disorders with the necessity of functional pretreatment before prosthodontic therapy

TABLE 1 Crown Distribution According to the Anatomic Site

Crowns per patient	Patients	Maxillary					Mandibular					Total crowns
		CI	LI	CAN	PREM	MOL	CI	LI	CAN	PREM	MOL	
1	69	19	9	11	13	6	—	—	1	2	8	69
2	22	13	10	2	11	3	—	—	1	1	3	44
3	7	—	1	—	8	4	—	—	—	4	4	21
4	8	10	11	3	6	1	—	—	—	1	—	32
5	1	2	2	1	—	—	—	—	—	—	—	5
6	2	4	4	4	—	—	—	—	—	—	—	12
7	1	2	2	2	—	—	—	—	—	—	1	7
8	1	1	1	1	4	1	—	—	—	—	—	8
11	1	—	—	1	2	2	—	—	1	3	2	11
Total	112	51	40	25	44	17	0	0	3	11	18	209

CAN, canines; CI, central incisors; LI, lateral incisors; MOL, molars; PREM, premolars.

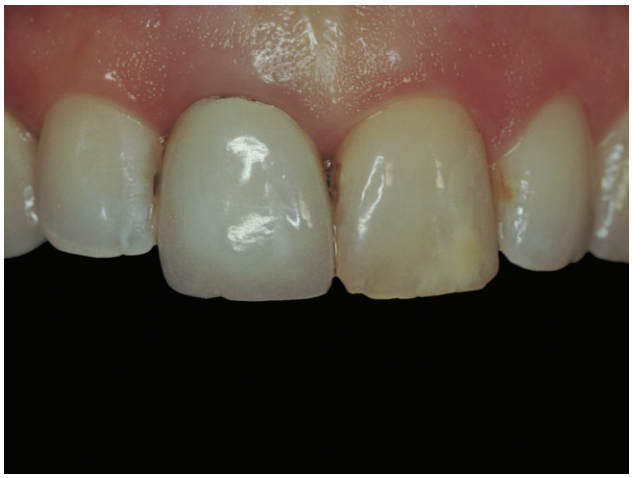

Figure 1 Case 1: Incongruous prosthetic crown in region 11 and discromic crown in region 21.

- Patients with systemic life-threatening diseases (physical status corresponding to group IV or higher of the American Society of Anesthesiologists classification[32])

The crowns had been realized on 128 natural tooth abutments (Figures 1 and 2) and on 81 implant-supported abutments (Figures 3–6); the implants used in the present study were both non-submerged (Institut Straumann AG, Waldenburg, Switzerland) and submerged (Nobel Biocare AB) implants. The number of crowns received by each patient ranged from 1 to 11 (Table 2). Crown location was not related to gender, age, or other factors.

Seventy-three female and 39 male patients were included in the present retrospective study; their age ranged from 18 years to 69 years. All patients were in good general health; 16 of them were smokers while 31 showed occlusal parafunctional habits; the smokers had received no implants. Before being included in the study, the patients signed a written consent form.

The prostheses were distributed as follows: 69 patients had received 1 single crown ($n = 69$; 36 on natural tooth abutments and 33 on implant-supported abutments), 22 patients had been provided with 2 single crowns ($n = 44$; 24 on natural tooth abutments and 20 on implant-supported abutments), 7 patients had

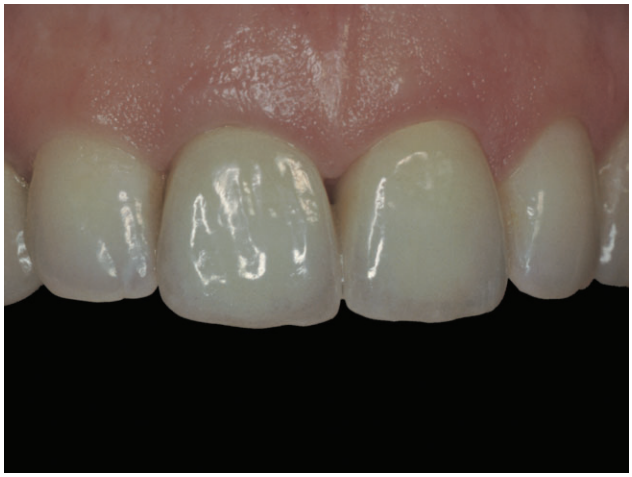

Figure 2 Case 1: Procera AllCeram crowns in regions 11 and 21 at the 6-year follow-up.

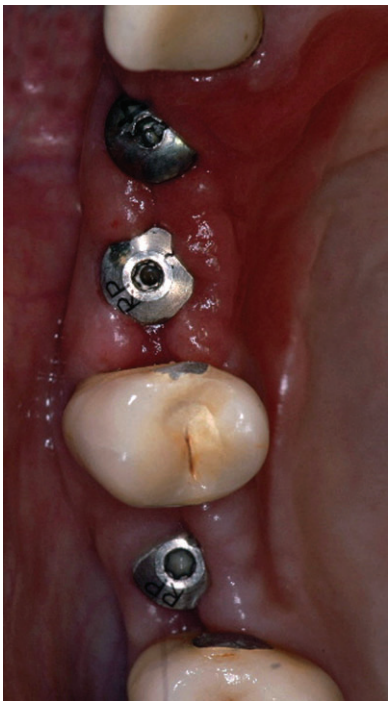

Figure 3 Case 2: Postsurgical site in maxillary left emiarch.

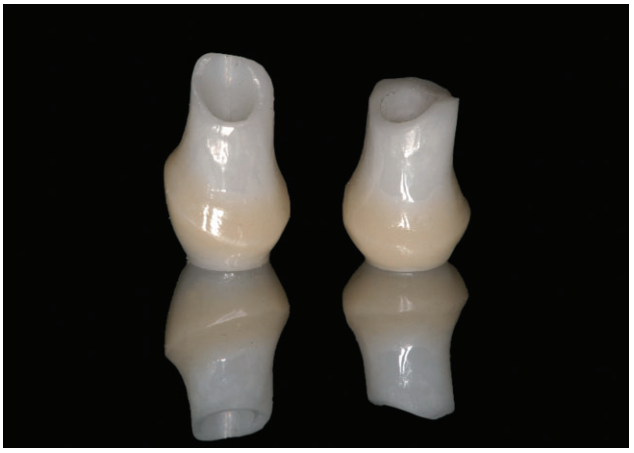

Figure 4 Case 2: Aluminum oxide abutments.

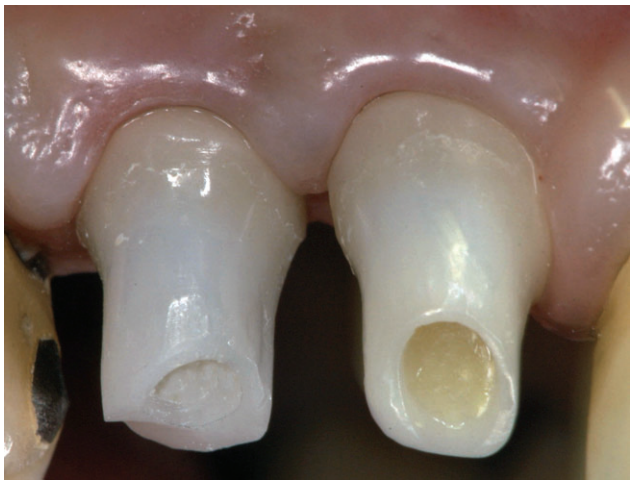

Figure 5 Case 2: Aluminum oxide abutments set onto non-submerged implants in regions 23 and 24.

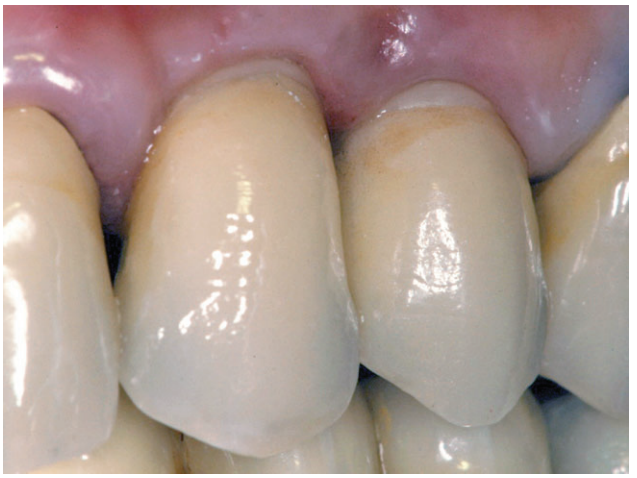

Figure 6 Case 2: Marginal adaptation of all-ceramic crowns in regions 23 and 24 at the 6-year follow-up.

received 3 single crowns ($n = 21$; 13 on natural tooth abutments and 8 on implant-supported abutments), 8 patients had been provided with 4 single crowns ($n = 32$; 20 on natural tooth abutments and 12 on implant-supported abutments), 1 patient had received 5 single crowns ($n = 5$; 5 on natural tooth abutments and none on implant-supported abutments), 2 patients had been provided with 6 single crowns ($n = 12$; 12 on natural tooth abutments and none on implant-supported abutments), 1 patient had received 7 single crowns ($n = 7$; 4 on natural tooth abutments and 3 on implant-supported abutments), 1 patient had been provided with 8 single crowns ($n = 8$; 8 on natural tooth abutments and none on implant-supported abutments), and 1 patient had received 11 single crowns ($n = 11$; 6 on natural tooth abutments and 5 on implant-supported abutments).

Seven patients provided with two single crowns received one crown on a natural tooth abutment and one crown on an implant-supported abutment. As regards maxillary sites, 51 crowns had been realized to restore central incisors, 40 on lateral incisors, 25 on canines, 44 on premolars, and 17 on molars. As to mandibular sites, 3 crowns had been used to restore canines, 11 on premolars, and 18 on molars.

After performing the conventional procedures to obtain a good oral hygiene, a first impression was taken with an irreversible hydrocolloid (Neocolloid, Zhermack, Badia Polesine, Italy) in order to pour the study cast and realize the resin temporary crowns. The casts of both dental arches were mounted into an articulator.

As to the restorative procedures involving natural teeth, the tooth preparation of each crown was performed following the Procera clinical protocol. A general 1 to 1.5 mm overall reduction was performed, except for the incisal margins that were reduced to 2 mm. A 1 mm moderate chamfer circumferential shoulder preparation was performed with rounded internal line angles. The preparation margins were set 0.8 mm deep in the gingival sulcus. The shoulders were prepared using fine diamond burs, and eventual

TABLE 2 Crown Distribution According to the Type of Abutment

	Maxillary					Mandibular					Total
Abutment	CI	LI	CAN	PREM	MOL	CI	LI	CAN	PREM	MOL	crowns
Tooth	32	24	16	25	11	—	—	2	7	11	128
Implant	19	16	9	19	6	—	—	1	4	7	81
Total	51	40	25	44	17	0	0	3	11	18	209

CAN, canines; CI, central incisors; LI, lateral incisors; MOL, molars; PREM, premolars.

irregularities were smoothed by means of hand chisels. The buccal surface of the teeth was prepared following two different planes of preparation, according to the anatomy of the teeth, while the palatal surface was prepared rounding the transition surfaces. Fine carbide finishing burs were used to smooth the axial walls.

As regards the restorative procedures onto implant abutments, aluminum oxide Procera abutments were used on submerged implants whereas titanium abutments were used on non-submerged implants. Although light transmission is going to be blocked by metal structures, the choice of seating all ceramic crowns onto titanium abutments aimed at evaluating the soft tissue response induced by alumina restorations around a non-submerged implant platform. Both the resin abutments for the Procera scanning procedures and the titanium abutments were prepared in the dental laboratory according to the clinical needs of each patient.

The Procera custom abutments were realized according to the respective technique.[10,13–15,19] On the contrary, fine diamond burs were used to customize the titanium abutments. The buccal surface of the abutments was prepared following two different planes of preparation, according to the anatomy of the crowns. The main features of the implant-abutment preparation geometry were the same as previously described for the preparation of natural tooth abutments.

All the resin temporary crowns were realized by the same dental technician using autopolymerizing resin (Jet Kit, Lang Dental MFG. CO., Wheeling, IL, USA). The same resin was put into the temporary crowns in order to fit them intraorally on the prepared teeth; they were smoothed with soft rubbers and polishing cups by means of a 10× surgical stereomicroscope (Zeiss OpMil, Zeiss, Oberkochen, Germany) to obtain an optimal marginal adaptation between the crowns and the soft periodontal tissues. All the temporary crowns were cemented with eugenol-free temporary cement (Temp Bond NE, Kerr Co., Orange, CA, USA); residual provisional cement was removed by means of pumice slurry applied with a rotary bristle brush and rubber cup under water irrigation. Such resin crowns were worn by patients for 3 weeks.

After the healing period, the temporary crowns were removed and the tooth preparations refined under the control of a 10× surgical stereomicroscope (Zeiss OpMil, Zeiss). One-step precision impressions were taken by using polyether materials (Permadyne Penta H, Permadyne Penta L, 3M ESPE, Seefeld, Germany) with custom autopolymerizing acrylic resin trays (SR-Ivolen, Ivoclar Vivadent AG, Schaan, Liechtenstein) made by the technician at least 24 hours before the impression; a thin layer of an adhesive specific for polyethers was applied over the internal surface of such trays (polyether adhesive, 3M ESPE). Then, the impressions were sent to a dental technician laboratory and poured using an extra-stone plaster type IV (Fuji Rock, GC, Tokyo, Japan) after 5 hours in order to allow an elastic return of polyethers. The resin temporary crowns were re-adapted using an autopolymerizing resin intraorally; the same finishing and polishing procedures previously described were followed, and the temporary crowns were cemented with eugenol-free temporary cement.

The previously described Procera protocol was adopted in order to make the aluminum oxide shells. Two weeks later, the alumina copings were realized and checked for a 0.6 mm thickness; they were carefully seated onto their abutments, and the final positional impressions were taken by using the same materials and procedure as previously described. The clinicians selected the shade of the final restorations according to the patients' needs.

All the final restorations were realized by the same dental technician. The porcelain veneering of the alumina copings was realized in a dental technician laboratory by using a ceramic material specifically developed for aluminum oxide copings (Procera AllCeram Ceramics, Ducera Dental GmbH, Rosbach, Germany), characterized by a special adaptation to the coefficient of thermal expansion of the aluminum oxide framework ($7.0\ \mu m/[m \times K]$). The thickness of the veneering ceramics ranged between 1 mm and 2 mm. The inner surface of the copings was silanized before cementation (Silane Primer, Kerr Co.).

The final all-ceramic crowns were tried in, checked up, and cemented by means of two different kinds of luting agents: a resin cement (RelyX Luting Cement, 3M ESPE) and a zinc phosphate cement (De Trey Zinc, Dentsply, York, PA, USA). Approximately, half of the crowns were cemented with zinc phosphate cement, and the other half with resin cement. As to natural tooth abutments, 62 crowns were cemented with zinc phosphate cement and 66 crowns were cemented with resin cement (Table 3). As regards implant-supported

TABLE 3 Natural Tooth-Supported Crown Distribution According to Luting Agent

	Maxillary					Mandibular					Total
Cement	CI	LI	CAN	PREM	MOL	CI	LI	CAN	PREM	MOL	crowns
Zinc phosphate	16	12	8	12	5	—	—	1	3	5	62
Resin	16	12	8	13	6	—	—	1	4	6	66
Total	32	24	16	25	11	0	0	2	7	11	128

CAN, canines; CI, central incisors; LI, lateral incisors; MOL, molars; PREM, premolars.

restorations, 38 crowns were cemented with zinc phosphate cement and 43 crowns were cemented with resin cement (Table 4).

The prepared teeth were isolated with rubber dam, and the cementation procedure was performed at room temperature strictly following the manufacturer's instructions. The same cementation protocol was used for metal abutments, ceramic abutments, and tooth structure. Auto-mixing capsules were used for the resin cement. Differently, the zinc phosphate cement was mixed on a glass plate. For each portion, 1.2 g powder was mixed with 0.5 mL liquid. The powder was divided into six portions (two 1/16, one 1/8, and three 1/4 portions). First, one 1/16 portion was mixed for 10 seconds, then the second 1/16 portion was mixed for 10 seconds, followed by the 1/8 portion for another 10 seconds. A 1/4 portion was then added and mixed for 15 seconds followed by another 1/4 portion, also mixed for 15 seconds. The final 1/4 portion was then added and mixed for 30 seconds. Thus, a total mixing time of 1 minute and 30 seconds was used.[23]

The luting agent was inserted into the crowns, and the patients were requested to hold the crowns under occlusal compression until luting cement set. After 5 minutes, excess cement was removed as described for the temporary luting agent; the occlusion was refined as needed, and any adjusted crown surfaces were polished with pumice paste and rubber caps. As for the implant-supported crowns, standardized periapical radiographs (Irix 70, Trophy, London, U.K.) were taken to verify the seating of the restorations.

Cementation time was considered the baseline to record data. The patients were recalled for follow-up visits at 1 month after the cementation of the crowns, at 6 months, and then every 12 months until a whole observational period of 72 months. The function, esthetics, and marginal adaptation of the restorations were evaluated. The periodontal status was analyzed by means of a 4-point periodontal probing (ie, mesial, buccal, distal, and palatal probing) and evaluation of the following periodontal parameters:

- Gingival Index (GI), describing the color and inflammation of gingival tissue[33]; GI is made up of four levels:
  1. GI 0 – normal healthy gingiva
  2. GI 1 – slight inflammation, slight color change, edema, no spontaneous bleeding
  3. GI 2 – moderate inflammation, moderate color change, edema, bleeding on probing
  4. GI 3 – serious inflammation, serious color change, serious edema, spontaneous bleeding
- Plaque Index (PI), describing the quantity of dental plaque at the cervical region[33]; PI is made up of four levels:
  1. PI 0 – no dental plaque

TABLE 4 Implant-Supported Crown Distribution According to Luting Agent

	Maxillary					Mandibular					Total
Cement	CI	LI	CAN	PREM	MOL	CI	LI	CAN	PREM	MOL	crowns
Zinc phosphate	9	8	4	9	3	—	—	—	2	3	38
Resin	10	8	5	10	3	—	—	1	2	4	43
Total	19	16	9	19	6	0	0	1	4	7	81

CAN, canines; CI, central incisors; LI, lateral incisors; MOL, molars; PREM, premolars.

TABLE 5 Clinical Outcomes

	Abutment		Cement		Restoration support				
	Tooth	Implant	Zinc	Resin	Tooth-zinc	Tooth-resin	Implant-zinc	Implant-resin	Total
Loss at follow-up	0.96% ($n=2$)	0.48% ($n=1$)	0.96% ($n=2$)	0.48% ($n=1$)	0.96% ($n=2$)	— ($n=0$)	— ($n=0$)	0.48% ($n=1$)	0.48% ($n=3$)
Failures	1.45% ($n=3$)	1.94% ($n=4$)	2.43% ($n=5$)	0.96% ($n=2$)	0.96% ($n=2$)	0.48% ($n=1$)	1.46% ($n=3$)	0.48% ($n=1$)	3.39% ($n=7$)
Complications	2.43% ($n=5$)	1.94% ($n=4$)	3.89% ($n=8$)	0.48% ($n=1$)	2.43% ($n=5$)	— ($n=0$)	1.46% ($n=3$)	0.48% ($n=1$)	4.37% ($n=9$)

2. PI 1 – dental plaque to be pointed out only with dental plaque-revealing substances
3. PI 2 – dental plaque to be pointed out at a glance
4. PI 3 – plentiful dental plaque

- Bleeding on probing, probing in the depth of the pocket until a slight resistance is met,[34] evaluated with a yes–no score.

The clinical evaluations of the single crowns were performed according to the California Dental Association's[35] quality evaluation system; the restoration surface and color, anatomical form, and marginal integrity were evaluated with the California Dental Association system, ranging between not acceptable, acceptable, good, and excellent. The structural integrity of the crowns was evaluated by means of surface probing with a sharp dental explorer under a 10× surgical stereomicroscope. Chipping or cracking of the veneering porcelain was defined as minor cohesive fracture of the veneering porcelain that did not impair function.[19,24]

The patients' satisfaction score was assessed, ranging between not acceptable, acceptable, good, and excellent.

RESULTS

During the 6-year observational period, three crowns (1.4%) were lost at follow-up after 20, 31, and 34 months respectively (Table 5).

Of the 206 restorations that completed the 6-year follow-up, 16 crowns (7.8%) showed different kinds of mechanical complications (see Table 5), such as porcelain chipping at intraoral try-in or at cementation time, crown fracture during function, or loss of retention. The latter occurred only in restorations luted with zinc phosphate cement, whereas none of the crowns cemented with a resin luting agent showed such a problem.

As to the mechanical complications (Table 6), the following occurrences were noticed: three crowns fractured at trial (one later on cemented on tooth abutment

TABLE 6 Mechanical Complications

	Abutment		Cement		Restoration support				
	Tooth	Implant	Zinc	Resin	Tooth-zinc	Tooth-resin	Implant-zinc	Implant-resin	Total
Fracture at trial	0.48% ($n=1$)	0.96% ($n=2$)	1.46%* ($n=3$)	— ($n=0$)	0.48%* ($n=1$)	— ($n=0$)	0.96%* ($n=2$)	— ($n=0$)	1.46% ($n=3$)
Fracture at cementation	0.48% ($n=1$)	0.48% ($n=1$)	0.96% ($n=2$)	— ($n=0$)	0.48% ($n=1$)	— ($n=0$)	0.48% ($n=1$)	— ($n=0$)	0.96% ($n=2$)
Porcelain chipping	0.48% ($n=1$)	0.48% ($n=1$)	0.48% ($n=1$)	0.48% ($n=1$)	0.48% ($n=1$)	— ($n=0$)	— ($n=0$)	0.48% ($n=1$)	0.96% ($n=2$)
Loss of retention	0.96% ($n=2$)	— ($n=0$)	0.96% ($n=2$)	— ($n=0$)	0.96% ($n=2$)	— ($n=0$)	— ($n=0$)	— ($n=0$)	0.96% ($n=2$)

*The type of cement refers to the final cementation and not to the try-in phase.

TABLE 7 Cumulative Survival and Success Rates

	Abutment		Cement		Restoration support				
	Tooth	Implant	Zinc	Resin	Tooth-zinc	Tooth-resin	Implant-zinc	Implant-resin	Total
Cumulative survival rate (%)	97.6	97.6	96.7	98.6	98.1	99.5	98.6	99.1	95.2
Cumulative success rate (%)	95.2	95.7	92.6	98.1	95.7	99.5	97.1	98.6	90.9

with zinc phosphate cement, and two later on cemented on implant abutment with zinc phosphate cement), two crowns fractured at cementation (one cemented on tooth abutment with zinc phosphate cement and one cemented on implant abutment with zinc phosphate cement), two crowns were interested by porcelain chipping (one cemented on tooth abutment with zinc phosphate cement and one cemented on implant abutment with resin cement), and two crowns lost retention (both of them cemented on tooth abutments with zinc phosphate cement).

Failure occurred in seven restorations (3.4%) that were considered non-repairable, three on natural tooth abutments (1.5%) and four on implant-supported crowns (1.9%) (see Table 6).

The survival rate was 97.6% for crowns supported by either natural tooth or implant abutments. As to the luting agents, the survival rates were 96.7 and 98.6% for crowns cemented with zinc phosphate and resin cement, respectively (Table 7).

The success rates were 95.2 and 95.7% for crowns supported by natural tooth and implant abutments, respectively. As to the luting agents, the success rates were 92.6 and 98.1% for crowns cemented with zinc phosphate and resin cement, respectively (see Table 7). The survival and success rates of the different combinations between the type of support and the type of cement are reported in Table 7.

Irrespectively of either the type of support or cement, cumulative survival and success rates at 6 years of 95.2 and 90.9%, respectively, were recorded (see Table 7).

Over the observational period, the color and surface characteristics of 199 restorations were considered excellent, while 7 restorations (five on natural tooth abutments and two on implant support) were judged acceptable (Table 8). As to the anatomic form, all the 206 crowns were judged excellent (Table 9). The marginal integrity was considered excellent in 203 restorations while three crowns (two on natural tooth abutments and

TABLE 8 California Dental Association Rating for Color and Surface Characteristics (Natural Tooth-Supported Crowns/Implant-Supported Crowns)

Rating	1 month (n = 209)	6 months (n = 209)	1 year (n = 209)	2 years (n = 208)	3 years (n = 206)	4 years (n = 206)	5 years (n = 206)	6 years (n = 206)
Not acceptable	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Acceptable	1/1	2/1	3/2	4/2	4/2	5/2	5/2	5/2
Excellent	127/80	126/80	125/79	123/79	122/78	121/78	121/78	121/78

TABLE 9 California Dental Association Rating for Anatomic Form (Natural Tooth-Supported Crowns/Implant-Supported Crowns)

Rating	1 month (n = 209)	6 months (n = 209)	1 year (n = 209)	2 years (n = 208)	3 years (n = 206)	4 years (n = 206)	5 years (n = 206)	6 years (n = 206)
Not acceptable	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Acceptable	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Excellent	128/81	128/81	128/81	127/81	126/80	126/80	126/80	126/80

TABLE 10 California Dental Association Rating for Marginal Integrity (Natural Tooth-Supported Crowns/Implant-Supported Crowns)

Rating	1 month ($n = 209$)	6 months ($n = 209$)	1 year ($n = 209$)	2 years ($n = 208$)	3 years ($n = 206$)	4 years ($n = 206$)	5 years ($n = 206$)	6 years ($n = 206$)
Not acceptable	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Acceptable	0/0	0/0	0/0	1/1	1/1	1/1	2/1	2/1
Excellent	128/81	128/81	128/81	126/80	125/79	125/79	124/79	124/79

TABLE 11 Gingival Index (GI) Score (Natural Tooth-Supported Crowns/Implant-Supported Crowns)

Score	1 month ($n = 209$)	6 months ($n = 209$)	1 year ($n = 209$)	2 years ($n = 208$)	3 years ($n = 206$)	4 years ($n = 206$)	5 years ($n = 206$)	6 years ($n = 206$)
GI 0	119/68	122/75	125/80	125/80	126/79	126/78	124/79	124/78
GI 1	8/11	6/6	3/1	2/1	0/1	0/2	2/1	2/2
GI 2	1/2	0/0	0/0	0/0	0/0	0/0	0/0	0/0
GI 3	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0

TABLE 12 Plaque Index (PI) Score (Natural Tooth-Supported Crowns/Implant-Supported Crowns)

Score	1 month ($n = 209$)	6 months ($n = 209$)	1 year ($n = 209$)	2 years ($n = 208$)	3 years ($n = 206$)	4 years ($n = 206$)	5 years ($n = 206$)	6 years ($n = 206$)
P1 0	113/70	121/77	124/76	125/79	123/78	123/78	123/77	121/77
P1 1	14/11	7/4	4/5	2/2	3/2	3/2	3/3	5/3
PI 2	1/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
PI 3	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0

TABLE 13 Bleeding on Probing (BoP) Evaluation (Natural Tooth-Supported Crowns/Implant-Supported Crowns)

Index	1 month ($n = 209$)	6 months ($n = 209$)	1 year ($n = 209$)	2 years ($n = 208$)	3 years ($n = 206$)	4 years ($n = 206$)	5 years ($n = 206$)	6 years ($n = 206$)
BoP +	4/6	1/0	1/1	0/0	0/0	0/0	0/0	0/0
BoP −	124/75	127/81	127/80	127/81	126/80	126/80	126/80	126/80

TABLE 14 Patients' Satisfaction Score (Natural Tooth-Supported Crowns/Implant-Supported Crowns)

Score	1 month ($n = 209$)	6 months ($n = 209$)	1 year ($n = 209$)	2 years ($n = 208$)	3 years ($n = 206$)	4 years ($n = 206$)	5 years ($n = 206$)	6 years ($n = 206$)
Not acceptable	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Acceptable	2/3	0/1	0/0	0/0	0/0	0/0	0/0	0/0
Good	4/2	3/3	1/0	1/0	1/2	1/2	3/2	3/2
Excellent	122/76	125/77	127/81	126/81	125/78	125/78	123/78	123/78

one on implant support) were judged acceptable (Table 10). As to the periodontal parameters evaluated in the present study, 202 crowns scored 0 while 4 crowns (2 on natural tooth abutments and 2 on implant support) scored 1 for the GI (Table 11). Moreover, 198 restorations scored 0 while 8 restorations (five on natural tooth abutments and three on implant support) scored 1 for the PI (Table 12). None of the sites around the crowns was positive to the bleeding on probing (Table 13).

As regards the satisfaction score, 201 crowns were considered excellent by the patients while 5 crowns (three on natural tooth abutments and two on implant support) were considered acceptable (Table 14).

DISCUSSION

In the present study, the use of the Procera system confirmed either the clinical or the esthetical advantages reported in the literature. The CAD/CAM technology allowed the dental technician to reduce the laboratory working time, if compared with the conventional procedures needed to realize metal frameworks. The increasing patients' demand for esthetics in anterior regions was satisfied with both natural tooth abutments and implant-supported restorations. Similarly, the mechanical properties required by function in posterior sites were proved by the optimal clinical performances of the restorations.

The overall survival and success rates of alumina single crowns noticed in the present study were consistent with data published in scientific literature.[4,7,13,14,17–20] The reliable mechanical performances of alumina in withstanding occlusal static and dynamical loads were confirmed, particularly in anterior regions.

During the 6-year observational period, three crowns (one maxillary central incisor and one maxillary premolar cemented on natural tooth abutments, and one maxillary premolar cemented on an implant abutment) were lost at follow-up after 20, 31, and 34 months, respectively. Until these crowns were controlled, they satisfied all the periodontal and functional parameters assessed.

In the present study, 128 single crowns had been cemented onto natural tooth abutments: 32 onto maxillary central incisors, 24 onto maxillary lateral incisors, 16 onto maxillary canines, 25 onto maxillary premolars, 11 onto maxillary molars, 2 onto mandibular canines, 7 onto mandibular premolars, and 11 onto mandibular molars. Of these, 2 were lost at follow-up, 5 were interested by mechanical complications, and 3 failed. The mechanical complications affected one maxillary central incisor (porcelain chipping), one maxillary premolar (fracture at trial), one mandibular premolar (fracture at cementation), and two mandibular molars (loss of retention). The failures interested one maxillary premolar, one maxillary molar, and one mandibular molar. The mechanical complications affected solely crowns luted with zinc phosphate cement, while the failures interested two crowns luted with zinc phosphate (maxillary premolar and molar) and one crown luted with resin cement (mandibular molar). The crowns cemented on natural tooth abutments that survived the whole observational period without any complication were considered satisfactory both by the clinicians and the patients.

As regards implant-supported restorations, 81 single crowns had been cemented onto implant abutments: 19 onto maxillary central incisors, 16 onto maxillary lateral incisors, 9 onto maxillary canines, 19 onto maxillary premolars, 6 onto maxillary molars, 1 onto mandibular canines, 4 onto mandibular premolars, and 7 onto mandibular molars. Of these, 1 was lost at follow-up, 4 were interested by mechanical complications, and 4 failed. The mechanical complications affected one maxillary central incisor (fracture at trial), one maxillary canine (fracture at trial), one maxillary premolar (porcelain chipping), and one mandibular molar (fracture at cementation). The failures interested one maxillary premolar, one mandibular premolar, and two mandibular molars. The mechanical complications affected three crowns luted with zinc phosphate cement (maxillary central incisor, canine, and premolar) and one crown luted with resin cement (mandibular molar), while the failures interested three crowns luted with zinc phosphate cement (maxillary premolar, mandibular premolar, and molar) and one crown luted with resin cement (mandibular molar). The crowns cemented on implant abutments that survived the whole observational period without any complication were considered satisfactory both by the clinicians and the patients.

In two crowns, minor cohesive fractures of the veneering porcelain were observed; as after accurate intraoral trimming and polishing such fractures did impair neither function nor esthetic, the restorations were not considered as failed.

As regards the failures, five out of seven unrestorable fractures were likely because of the excessive occlusal parafunctional forces exhibited by patients who were affected by severe bruxism; such a condition allowed the parafunctional loads to exceed the tensile strength of the veneering porcelain. In three cases, the fractures interested the aluminum oxide core: this occurred mainly in mandibular molars where the occlusal loads are particularly high.

Porcelain chipping and fractures affecting anterior restorations occurred in regions well known to be high tensile stress concentration areas, just like the incisal margin of maxillary central incisors and the cusp of maxillary canines, because of the occlusal functions of guidance.

Loss of retention affected only two mandibular molars luted with zinc phosphate cement onto natural tooth abutments; such an occurrence was probably because of the limited height of the abutments, which did not provide adequate retention.

No significant differences were evidenced for the type of restorative support in relation to the clinical outcomes of the restorations. Conversely, the resin cement performed better than the zinc phosphate cement on both tooth and implant support. This trend was noticed either in crowns that underwent mechanical complications or in crowns that failed.

Although there is still no consensus about the luting agent to be used with all-ceramic restorations, the resin cement used in the present study proved to be easy to use and reliable for the medium-term success of the restorations. Conversely, zinc phosphate cement caused a few losses of retention; besides its proved easy-handling characteristics, the limited tensile strength of zinc phosphate might play an important role in the genesis of mechanical complications, particularly in posterior sites. As for the durability of the luting agent, no differences were noticed in the performance of either the zinc phosphate or the resin cement on metal abutments, ceramic abutments, and tooth structure.

As to the periodontal parameters evaluated in the present study, a slight soft tissue inflammation was observed in four restorations, particularly during the first month after cementation. A small amount of plaque was evidenced by means of dental plaque-revealing substances on eight restorations. Such an occurrence was likely because of the patients' fear of damaging the restorations; in these cases, the problem should be eliminated through an increase in the patients' motivation toward oral hygiene.

The color of seven restorations was considered acceptable but not excellent, likely because of the fact that the patients provided with these crowns were heavy smokers.

CONCLUSIONS

Within the limitations of the present study, on the basis of the results of the retrospective evaluation of 209 Procera AllCeram single crowns, the following conclusions were drawn:

- The Procera AllCeram crowns showed good clinical reliability in the medium term in both anterior and posterior oral sites.
- Of 206 restorations completing the follow-up period of 6 years, 9 crowns (4.37%) experienced mechanical complications.
- Of 206 restorations completing the follow-up period of 6 years, 7 crowns (3.39%) failed because of unrestorable fractures; in 3 cases the fractures involved the alumina core.
- Cumulative survival and success rates of 95.2 and 90.9% were found, respectively, after 6 years of clinical service.
- The crowns provided excellent esthetics and color stability in the medium-term observational period.
- Healthy soft tissues were observed around both natural tooth abutment and implant-supported restorations.
- No significant differences were evidenced for the type of restorative support in relation to the clinical outcomes of the restorations.
- The resin cement performed better than the zinc phosphate cement on both tooth and implant support.

ACKNOWLEDGMENTS

We wish to thank Mr. Ugo Castaldo and Mr. Giuseppe Zuppardi for their dental laboratory support.

REFERENCES

1. McLean JW. The future for dental porcelain. In: McLean JW, ed. Dental ceramics: proceedings of the first international symposium on ceramics. Chicago, IL: Quintessence, 1984:13–40.

2. Neiva G, Yaman P, Dennison JB, Razzoog ME, Lang BR. Resistance to fracture of three all-ceramic systems. J Esthet Dent 1998; 10:60–66.
3. Tinschert J, Zwez D, Marx R, Anusavice KJ. Structural reliability of alumina-, feldspar-, leucite-, mica- and zirconia-based ceramics. J Dent 2000; 28:529–535.
4. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and systems with clinical recommendations: a systematic review. J Prosthet Dent 2007; 98:389–404.
5. Della Bona A, Kelly JR. The clinical success of all-ceramic restorations. J Am Dent Assoc 2008; 139(Suppl):8S–13S.
6. Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part I. Pressable and alumina glass-infiltrated ceramics. Dent Mater 2004; 20:441–448.
7. Yilmaz H, Aydin C, Gul BE. Flexural strength and fracture toughness of dental core ceramics. J Prosthet Dent 2007; 98:120–128.
8. Andersson M, Oden A. A new all-ceramic crown: a densely-sintered, high-purity alumina coping with porcelain. Acta Odontol Scand 1993; 51:59–64.
9. Russell MM, Andersson M, Dahlmo K, Razzoog ME, Lang BR. A new computer-assisted method for fabrication of crowns and fixed partial dentures. Quintessence Int 1995; 26:757–763.
10. Andersson M, Razzoog ME, Oden A, Hegenbarth EA, Lang BR. Procera: a new way to achieve an all-ceramic crown. Quintessence Int 1998; 29:285–296.
11. Sulaiman F, Chai J, Jameson LM, Wozniak WT. A comparison of the marginal fit of In-Ceram, IPS Empress and Procera crowns. Int J Prosthodont 1997; 10:478–484.
12. May KB, Russell MM, Razzoog ME, Lang BR. Precision of fit: the Procera AllCeram crown. J Prosthet Dent 1998; 80:394–404.
13. Fradeani M, D'Amelio M, Redemagni M, Corrado M. Five-year follow-up with Procera all-ceramic crowns. Quintessence Int 2005; 36:105–113.
14. Oden A, Andersson M, Krystek-Ondracek I, Magnusson D. Five-year clinical evaluation of ProceraAllCeram crowns. J Prosthet Dent 1998; 80:450–456.
15. Odman P, Andersson B. Procera AllCeram crowns followed for 5 to 10.5 years: a prospective clinical study. Int J Prosthodont 2001; 14:504–509.
16. Wolfart S, Bohlsen F, Wegner SM, Kern M. A preliminary prospective evaluation of allceramic crown-retained and inlay-retained fixed partial dentures. Int J Prosthodont 2005; 18:497–505.
17. Pjetursson BE, Sailer I, Zwahlen M, Hämmerle CHF. A systematic review of the survival and complication rates of all-ceramic and metal–ceramic reconstructions after an observation period of at least 3 years. Part I: single crowns. Clin Oral Implants Res 2007; 18(Suppl 3):73–85.
18. Zitzmann NU, Galindo ML, Hagmann E, Marinello CP. Clinical evaluation of Procera AllCeram crowns in the anterior and posterior regions. Int J Prosthodont 2007; 20:239–241.
19. Zarone F, Sorrentino R, Vaccaro F, Russo S, De Simone G. Retrospective clinical evaluation of 86 Procera AllCeram anterior single crowns on natural and implant-supported abutments. Clin Implant Dent Relat Res 2005; 7(Suppl 1):S95–S103.
20. Segal BS. Retrospective assessment of 546 all-ceramic anterior and posterior crowns in a general practice. J Prosthet Dent 2001; 85:544–550.
21. Shirakura A, Lee H, Geminiani A, Ercoli C, Feng C. The influence of veneering porcelain thickness of all-ceramic and metal ceramic crowns on failure resistance after cyclic loading. J Prosthet Dent 2009; 101:119–127.
22. Blatz MB, Oppes S, Chiche G, Holst S, Sadan A. Influence of cementation technique on fracture strength and leakage of alumina all-ceramic crowns after cyclic loading. Quintessence Int 2008; 39:23–32.
23. Al-Makramani BM, Razak AA, Abu-Hassan MI. Evaluation of load at fracture of Procera AllCeram copings using different luting cements. J Prosthodont 2008; 17:120–124.
24. Soderholm KJ, Mondragon E, Garcea I. Use of zinc phosphate cement as a luting agent for Denzir trade mark copings: an in vitro study. BMC Oral Health 2003; 3:1.
25. Fleming GJ, Narayan O. The effect of cement type and mixing on the bi-axial fracture strength of cemented aluminous core porcelain discs. Dent Mater 2003; 19:69–76.
26. Diaz-Arnold AM, Vargas MA, Haselton DR. Current status of luting agents for fixed prosthodontics. J Prosthet Dent 1999; 81:135–141.
27. Gu XH, Kern M. Marginal discrepancies and leakage of all-ceramic crowns: influence of luting agents and aging conditions. Int J Prosthodont 2003; 16:109–116.
28. Albert FE, El-Mowafy OM. Marginal adaptation and microleakage of Procera™ AllCeram crowns with four cements. Int J Prosthodont 2004; 17:529–535.
29. Osorio AB, Camacho GB, Demarco FF, Powers JM. Microleakage in full-crown all-ceramic restorations: influence of internal surface treatment, silane application, alumina system and substrate. Int J Prosthodont 2007; 20:123–124.
30. Barath VS, Faber FJ, Westland S, Niedermeier W. Spectrophotometric analysis of all-ceramic materials and their interaction with luting agents and different backgrounds. Adv Dent Res 2003; 17:55–60.
31. Encke BS, Heydecke G, Wolkewitz M, Strub JR. Results of a prospective randomized controlled trial of posterior ZrSiO(4)-ceramic crowns. J Oral Rehabil 2009; 36:226–235.
32. Wolters U, Wolf T, Stutzer H, Schroeder T. ASA classification and perioperative variables as predictors of postoperative outcome. Br J Anaesth 1996; 77:217–222.

33. Loe H. The Gingival Index, the Plaque Index and the Retention Index Systems. J Periodontol 1967; 38:610–616.
34. Esposito M, Hirsch JM, Lekholm U, Thomsen P. Biological factors contributing to failures of osseointegrated oral implants. (I). Success criteria and epidemiology. Eur J Oral Sci 1998; 106:527–551.
35. California Dental Association. Quality evaluation for dental care: guidelines for the assessment of clinical quality and professional performance. Los Angeles, CA: California Dental Association, 1997.