Survival of Ceramic Computer-aided Design/Manufacturing Crowns Bonded to Preparations with Reduced Macroretention Geometry

Andreas Bindl, Dr Med Dent[a]/Björn Richter, Dr Med Dent[b]/Werner H. Mörmann, Dr Med Dent, Prof[c]

Purpose: Adhesive cementation reduces the need for macroretentive preparation for crowns. This study investigated the survival and clinical rating of monolithic computer-aided design/manufacturing (CAD/CAM) ceramic crowns bonded to preparations with reduced macroretention, hypothesizing that adhesion would compensate for reduced retention geometry. ***Materials and Methods:*** Two-hundred eight posterior CAD/CAM-generated crowns from feldspar block ceramic were adhesively bonded in 136 patients in three preparation groups: classic (100% stump height, n = 70); reduced (reduced stump height or irregular stump, n = 52); and endo (absent stump but pulp chamber retention cavity, n = 86). Crowns were examined at baseline and after 55 ± 15 months using modified USPHS criteria. Plaque and bleeding of gingiva around the crowns were assessed. ***Results:*** Cumulative Kaplan-Meier survival of crowns on premolars/molars was: classic = 97.0%/94.6%; reduced = 92.9%/92.1%; and endo = 68.8%/87.1%, confirming the hypothesis for classic, reduced, and endo molars as well as for classic and reduced premolars. A significant difference was found between classic and endo premolar crowns, rejecting the hypothesis for endo preparation on premolars. Plaque and bleeding indices were significantly lower for crowned teeth than for controls. ***Conclusion:*** The survival of classic and reduced crowns was rated adequate for premolars and molars. Endo preparation appeared acceptable for molar crowns but inadequate for premolar crowns. *Int J Prosthodont 2005;18:219–224.*

The increasing demand for esthetic and metal-free restorations led to the development of a computer-aided design/manufacturing (CAD/CAM) system for the fabrication of ceramic inlays, onlays, and veneers.[1] This CAD/CAM technique is popularly considered clinically proven[2] and was further developed to include the fabrication of all-ceramic monolithic posterior crowns.[3] A preliminary report on clinical experiences with 19 bonded posterior CAD/CAM "endo" crowns with reduced macroretentive preparation appeared promising, as only one failure occurred after 28 months of clinical monitoring because of recurrent caries.[4]

Functional dentin adhesives enable a strong bond between dentin and resin-based cementation material,[5] while etching feldspathic ceramic with hydrofluoric acid effects a micromechanical etch pattern that provides high bond strength between ceramic and a resin-based cementation layer.[6] It appears that adhesive cementation reinforces the ceramic and compensates for the risk of ceramic fracture.[7,8] The reinforcement of the ceramic is explained by the strong adhesion between ceramic, resin-based cementation material, and dentin.[9] The concept of adhesive cementation of ceramic restorations is based on sound clinical evidence.[10–12]

Nonadhesive cementation of all-ceramic crowns requires a pronounced macromechanical retention, as

[a]*Research Associate and Director, Clinic of the Division of Aesthetic and Computer Restorations, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental and Oral Medicine, University of Zurich, Switzerland.*

[b]*Research Associate, Division of Aesthetic and Computer Restorations, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental and Oral Medicine, University of Zurich, Switzerland.*

[c]*Professor and Director, Division of Aesthetic and Computer Restorations, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental and Oral Medicine, University of Zurich, Switzerland.*

Correspondence to: *Dr Andreas Bindl, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental and Oral Medicine, University of Zurich, Attenhoferstrasse 8a, Zurich CH-8032, Switzerland. Fax: + 41 1-261 33 29. e-mail: andreas.bindl@zzmk.unizh.ch*

provided by the geometry of the prepared dental hard tissue, whereas adhesive cementation reduces the need for fricative macroretention.[13] Therefore, the restoration of minimal or absent macroretentive preparations with extensive dentin- or enamel-bonded ceramic coverage is of particular clinical interest.[10] Crown preparations have been classified according to available dental hard tissue into classic, reduced, and endo types,[8] hence the hypothesis that bonding complete crowns to preparations with reduced macroretentive geometry (eg, reduced and endo preparations) will achieve survival rates similar to the classic crown stump preparation.

The purpose of the present study was to investigate the survival rate and clinical quality of CAD/CAM-generated posterior crowns on different preparation types after a service time of up to 7 years.

Materials and Methods

Patients

In March 1995, treatment with CAD/CAM-generated posterior monolithic crowns began as part of a clinical prospective study at the authors' clinic (Division of Aesthetic and Computer Restorations, Department of Preventive Dentistry, Periodontology and Cariology, approval 6/95 and 7/02; StV 02/10 of the Ethics Committee of the Center for Dental and Oral Medicine, University of Zurich, Switzerland). The inclusion criterion for participation in the study was the presence of stable occlusal relations with at least pairs of three molars or premolars in antagonistic contact on either side. Patients with a history of temporomandibular disorders or with insufficient hygiene compliance were excluded.

Crown Preparation, Fabrication, and Bonding

Previous restorative and base materials, as well as carious dentin, were completely removed. The preparation type was determined by the morphology of the remaining healthy dentin. Where a stump height of at least 3.0 mm and a convergence angle of 6 degrees could be realized, a classic stump preparation was performed, with a shoulder width of 1.0 to 1.2 mm. Where a stump height of less than 3.0 mm and a defect-oriented surface existed, a reduced preparation was performed. An endo preparation was chosen for endodontically treated teeth with complete loss of the clinical crown.[4]

A total of 208 crowns—63 premolars (33 classic, 14 reduced, 16 endo) and 145 molars (37 classic, 38 reduced, 70 endo)—were included in the study. Eighty-four crowns (15 classic, 30 reduced, 39 endo) were directly fabricated at chairside using feldspathic block ceramic (Vitablocs Mk II, Vita) with a CAD/CAM unit (CEREC 2, Sirona) in a single appointment; 124 crowns (55 classic, 22 reduced, 47 endo) were indirectly fabricated in two appointments using a heavy-body/light-body impression (Permadyne, 3M/ESPE) and articulated casts. Between appointments, preparations were treated with provisional crowns (Pro Temp, 3M/ESPE). Optical impressions were taken of the preparations using the CEREC 3D camera (Sirona) either directly in the mouth or from the casts. The individual crowns were then designed and machined. After machining, the external crown surfaces were smoothed using a rotating instrument (031F, Girrbach) with a 60-µm-grain-size diamond coating. Static occlusion of crowns fabricated directly at chairside was adjusted directly in the mouth of the patient using finishing diamonds (40 µm) until even static contacts were achieved throughout the dental arch. Then, dynamic occlusion was adjusted until premature and balancing contacts were eliminated. CAD/CAM crowns fabricated indirectly via working models were adjusted in the same way in an articulator (Artex AR, Girrbach). The crowns were either polished using flexible disks (Sof-Lex, 3M Dental) or individually stained and glazed (Akzent Kit, Vita).

Dentin was adhesively pretreated using a self-etching primer and adhesive (Syntac Classic, Ivoclar Vivadent). Bonding agent (Heliobond, Ivoclar Vivadent) was then brushed onto the preparation, and a penetration time of 20 seconds was allowed. The bonding agent was blown out to prevent pooling and was light-cured from the occlusal aspect for 60 seconds at 750 mW/cm^2 (Heliolux DLX, Ivoclar Vivadent). Prior to insertion of the crowns, the internal surface was etched (60 seconds) with hydrofluoric acid 4.9% (Ceramics-Etch, Vita). The etching gel was sprayed off with water for 20 seconds and dried. Silane agent (Monobond S, Ivoclar Vivadent) was applied and blown dry after an exposure time of 60 seconds. Bonding agent (Heliobond) was applied to allow wetting and chemical bonding with silane, blown out thin, and protected against light until seating. The crowns were seated using resin-based posterior composite (Tetric, Ivoclar Vivadent) as the luting material. The resin composite was light cured by irradiation through the crown walls at 750 mW/cm^2 (Heliolux DLX) for 4 minutes for classic as well as reduced preparations, and 6 minutes for endo preparations. Excess luting material at the margins was leveled out and smoothed abrasively by means of 8-µm oscillating files (Proxoshape P2, Intensiv) and flexible disks (Sof-Lex, 3M).

Clinical Examination

Baseline examination was carried out by applying United States Public Health Service (USPHS) criteria[14] modified to suit the demands of rating bonded ceramic crowns.[15] From May to September 2002, 172 patients whose crowns had been in service for more than

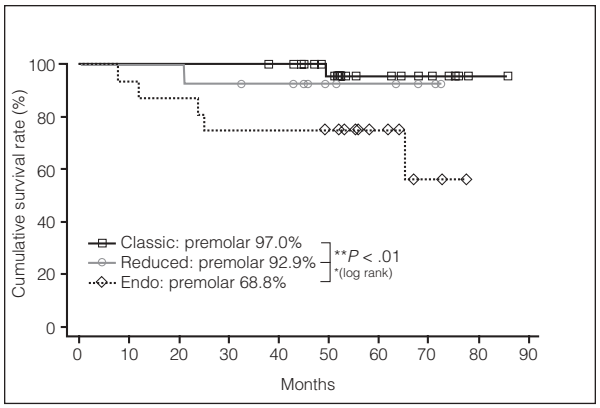

Fig 1a Cumulative survival rate[19] of all-ceramic CAD/CAM crowns bonded to classic (control), reduced, and endo preparations on premolars. Service times of crowns were 60 ± 14 months on classic preparations, 55 ± 14 months on reduced preparations, and 52 ± 15 months on endo preparations (**P < .01 = significant difference).

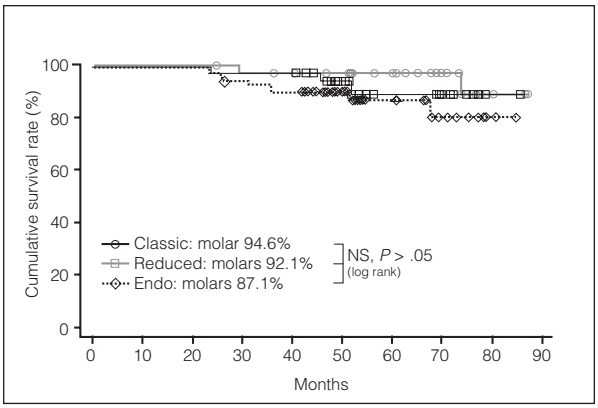

Fig 1b Cumulative survival rate[19] of all-ceramic CAD/CAM crowns bonded to classic (control), reduced, and endo preparations on molars (service times as in Fig 1a; *NS* = nonsignificant difference).

36 months were invited for follow-up examination. One hundred thirty-six patients (79 female, 57 male) with 208 crowns attended the follow-up. Two clinicians assessed the crowns independently. The examiners had previously trained on other clinical cases until ratings were equal. If differences occurred, the examiners discussed them and agreed on a common result. In addition, Plaque[16] and Papillary Bleeding Indices[17] were recorded for six sites (mesiobuccal, buccal, distobuccal, distolingual, lingual, mesiolingual) on crowned teeth and on Ramfjörd[18] control teeth. Ramfjörd control teeth included nonrestored and restored teeth.

Statistical Analysis

The statistical unit in calculating the survival rate was the crown. Crown failure was defined as fracture of the ceramic or adhesive loss of the crown. The service time and event were entered into a statistics program (StatView 4.02, Abacus Concepts), and the Kaplan-Meier[19] cumulative survival rate was calculated for premolars and molars. The log-rank test was used to detect statistically significant differences in survival rates between crowns on premolars and molars, and between crowns on the three different preparation types. Plaque and bleeding indices for CAD/CAM crowns were compared with those for the Ramfjörd control teeth using the paired *t* test. The number of single ratings A, B, C, and D was expressed as a percentage of the total number of ratings per criterion and crown type. Between baseline and follow-up examinations, the shift from A to lesser ratings for integrity of crown, marginal adaptation, proximal contact, and balancing contacts of the three crown types was analyzed using the McNemar test.[20]

Results

The cumulative survival rate of premolar/molar crowns was 97.0%/94.6% on classic preparations, 92.9%/92.1% on reduced preparations, and 68.8%/87.1% on endo preparations (Fig 1). A statistically significant difference ($P < .010$) was discerned between the premolar crowns on endo preparations and premolar crowns on classic preparations (Fig 1a).

A mean service time of 55 ± 15 months was calculated for the 208 CAD/CAM-generated crowns in 136 patients. By preparation type, the following service times were obtained: 60 ± 14 months for crowns on classic preparations, 55 ± 14 months for crowns on reduced preparations, and 52 ± 15 months for crowns on endo preparations. Of the 70 crowns on classic preparations, 3 crowns fractured (2 molars, 1 premolar), 5 crowned teeth needed endodontic treatment because of irreversible pulpitis (the crowns stayed intact), and 3 crowns were lost because of vertical root fractures. One crown was lost because of the necessity of creating a new prosthesis. Of the 52 crowns on reduced preparations, 4 fractured (3 molars, 1 premolar), and 3 were lost because of vertical root fractures. Of the 86 endo crowns, 14 were lost because of adhesive failure (9 molars, 5 premolars), and 5 crowns were lost because of vertical root fractures, periodontal disease, or interradicular osteitis (Table 1).

All fractured crowns exhibited a similar fracture pattern. The crown broke completely in two, with one of the crown fragments still adhering to the preparation. In all fractured crowns and all debonded endo crowns, examination showed that a loss of adhesion of the resin to dentin had occurred. The internal surface of the

Table 1 Failure of Bonded All-Ceramic CAD/CAM Crowns on Premolars (PM) and Molars (M) with Three Preparation Types

Type of failure	Time of failure (mo)		
	Classic	Reduced	Endo
Fracture of ceramic	M: 74, 30 PM: 50	M: 46, 24, 52 PM: 21	–
Pulpitis	M: 61, 41, 25, 37, 61	–	–
Loss of adhesion	–	–	M: 24, 27, 24, 36, 52, 26, 32, 36, 68 PM: 8, 24, 12, 25, 66
Vertical root fracture	M: 57*, 57* PM: 38*	M: 51* PM: 33*, 46*	M: 45*, 53*
Interradicular osteitis	–	–	M: 55*
Periodontitis	–	–	M: 78*, 79
Removal of crown†	M: 66	–	–

*Endodontically treated teeth.
†Tooth needed as a retainer.

Table 2 Percentage of USPHS Criteria* Ratings for Bonded All-Ceramic CAD/CAM Crowns with Three Preparation Types

Clinical criteria/ preparation type	Baseline				Follow-up				Statistical significance†
	A	B	C	D	A	B	C	D	
Marginal adaptation									
Classic	45	55	0	0	28	72	0	0	$P < .001$
Reduced	69	31	0	0	40	60	0	0	$P < .001$
Endo	52	48	0	0	19	81	0	0	$P < .001$
Integrity of crown									
Classic	100	0	0	0	88	2	0	10	$P < .010$
Reduced	100	0	0	0	87	0	0	13	$P < .010$
Endo	100	0	0	0	78	0	0	22	$P < .001$
Anatomic form									
Classic	86	14	0	0	78	22	0	0	NS
Reduced	80	20	0	0	80	20	0	0	NS
Endo	84	16	0	0	79	21	0	0	NS
Secondary caries									
Classic	100	0	0	0	100	0	0	0	NS
Reduced	100	0	0	0	100	0	0	0	NS
Endo	100	0	0	0	100	0	0	0	NS
Surface texture									
Classic	97	3	0	0	90	10	0	0	NS
Reduced	87	13	0	0	78	22	0	0	NS
Endo	94	6	0	0	87	13	0	0	NS
Color/translucency of crown									
Classic	74	26	0	0	74	26	0	0	NS
Reduced	58	42	0	0	49	51	0	0	NS
Endo	58	42	0	0	57	53	0	0	NS
Proximal contact									
Classic	91	9	0	0	74	21	5	0	$P < .001$
Reduced	89	11	0	0	80	20	0	0	NS
Endo	94	6	0	0	81	16	3	0	$P < .001$
Occlusal contact									
Classic	100	0	0	0	100	0	0	0	NS
Reduced	100	0	0	0	100	0	0	0	NS
Endo	100	0	0	0	100	0	0	0	NS
Balancing contact									
Classic	91	9	0	0	67	33	0	0	$P < .001$
Reduced	89	11	0	0	67	33	0	0	$P < .001$
Endo	94	6	0	0	64	36	0	0	$P < .001$
Sensitivity									
Classic	100	0	0	0	92	0	0	8	NS
Reduced	100	0	0	0	100	0	0	0	NS
Endo	100	0	0	0	100	0	0	0	NS

*Modified for bonded crowns.[15]
†McNemar test.
NS = nonsignificant difference.

Table 3 Plaque[16] and Bleeding[17] Indices on Teeth with Bonded All-Ceramic CAD/CAM Crowns at Follow-up

Index/ preparation type	Crowned teeth	Control teeth*	Ratio of crowned to control teeth
Plaque			
Classic	0.41 ± 0.24	0.55 ± 0.20	75 ($P < .001$)†
Reduced	0.48 ± 0.24	0.60 ± 0.21	80 ($P < .010$)†
Endo	0.53 ± 0.25	0.63 ± 0.21	84 ($P < .050$)†
Bleeding			
Classic	0.09 ± 0.14	0.12 ± 0.07	75 (NS, $P > .050$)†
Reduced	0.08 ± 0.12	0.11 ± 0.08	72 ($P < .050$)†
Endo	0.10 ± 0.12	0.13 ± 0.11	77 (NS, $P > .050$)†

*Ramfjörd teeth served as controls.[18]
†Paired *t* test.
NS = nonsignificant difference.

ceramic was always covered with adhesive luting resin composite. In the case of the debonded endo crowns, probing demonstrated that the adhesive resin composite was completely hardened. At follow-up examination, significant simultaneous shifts from A to lesser ratings were seen for the three crown types for the criteria integrity of crown, marginal adaptation, proximal contact, and balancing contacts (Table 2). Plaque accumulation and bleeding tendency on/around teeth bearing CAD/CAM crowns were equal to or significantly better ($P < .050$) than at Ramfjörd control teeth (Table 3).

Discussion

The novel aspect of this study was the adhesive cementation of monolithic CAD/CAM crowns on preparations with reduced macroretention geometry while the classic preparation served as a control. Although crowns on reduced and endo preparations were essentially attached by adhesively bonding the ceramic to the dentin, there were no significant differences in survival between these two and the classic preparation on molars or between classic and reduced preparations on premolars. The clinical quality as well as plaque and bleeding were the same for crowns on all preparations on premolars and molars.

The loss of adhesion of endo crowns—as in the case of fractures of crowns on classic and reduced preparations as well—was diagnosed as being due to the failure of adhesion to dentin, as scratching with a scaler always showed that the resin-based luting material still adhering to the crown's internal surface was completely hard. The failure rate of endo crowns on premolars was higher than that on molars. This may be explained by the fact that the surface available for adhesive bonding was larger on molars than on premolars. The ratio between crown basis and crown height might cause higher leverage for premolar than for molar endo crowns. Also, in the clinical situation, the operator could not assess the structure and thus suitability for adhesive bonding of the dentin surface available in each individual case. It was not possible to definitively identify sclerotic dentin; adhesion to sclerotic dentin is poorer than to nonsclerotic dentin. Sclerotic dentin is characterized by an adsorption of peritubular dentin, precipitation of mineral crystals in the dentin tubules, and lower permeability.[21] The hybrid layer is therefore thinner and less homogeneous on sclerotic than on nonsclerotic dentin, causing reduced adhesion.[21,22]

Bonding all-ceramic crowns to reduced preparations as well as to endo preparations demonstrates clinical advantages because adhesive buildups and endodontic treatment for post buildups can be avoided. By the use of endo crowns, it is possible to avoid screw and post anchorage, which is accompanied by the risk of root fractures.[23] Based on the loss of adhesion reported here, the adhesion of the resin-based luting material to the dentin of endo preparations appears limited. Further investigations should be conducted to determine whether other adhesive systems or a dual-curing or solely chemically curing resin-based luting material could produce a higher retention rate of endo crowns. In addition, creating slight macroretentions or undercuts in the lateral walls of the pulp chamber should be considered. Nonvital premolars with complete crown loss should, however, be restored with a post buildup.

The crowns were machined completely from monolithic feldspathic block ceramic without any reinforcing framework. In this study, it was not possible to provide a control group of core crowns (ie, metal-ceramic crowns) because the patients requested metal-free restorations. Survival rates for metal-ceramic crowns of 96.5% after 5 to 10 years[24] and of 100% up to 5 years[25] have been documented and seem to cover the same range of success as the adhesive CAD/CAM crowns on classic and reduced preparations in the present study. Ceramic crowns with a core of high-

strength ceramic,[26,27] as well as bonded heat-pressed crowns, have shown similar survival rates.[10,28,29]

The block ceramic used for all three types of crowns in the present study has a comparatively low flexural strength of 121 MPa and a comparatively high Weibull modulus (23.6), which indicates a lower fracture probability compared to conventionally processed feldspathic ceramic.[30] Compared to conventional cementation materials, resin-based luting materials have significantly higher fracture resistance values.[31] Thus, the ceramic is supported by a material with good physical properties and is adhesively bonded to dentin. For these reasons, adhesively bonded all-ceramic crowns can withstand markedly higher masticating forces than can conventionally cemented all-ceramic crowns.[31,32] Despite these properties, 7 of the 208 crowns in this study fractured completely. The main reason may be inadequate adhesion between resin-based luting material and dentin. The observation that the internal surfaces of the fractured crowns were always coated with resin-based luting material substantiates this assumption.

The hypothesis that crowns adhesively bonded to three different types of preparations would exhibit comparable survival rates could be accepted for molar and premolar crowns, but not for premolar endo crowns.

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