Six-Year Results of Leucite-Reinforced Glass Ceramic Crowns

Stephan Studer,**, Christian Lehner*, Urs Brodbeck***, and Peter Schärer**

* *Department of Fixed and Removable Prosthodontics and Dental Materials, Center for Dental Medicine, Zürich University, Switzerland*
** *Department of Periodontology, Endodontology and Cariology, Center for Dental Medicine, Basel University, Switzerland*
*** *Private Office, Zürich, Switzerland*

Abstract

A leucite-reinforced glass ceramic material (IPS-Empress®) was developed for clinical use in Zurich. A prospective clinical study of these laboratory-made all-ceramic crowns revealed encouraging result with an estimated 2-year survival rate of 95%. The aim of the present study was to determine the clinical behavior during a longer period of observation with respect to a possible fatigue fracture phenomenon reported for ceramic systems. Crowns were cemented by applying the adhesive technique. The inner crown surface was etched with hydrofluoric acid and silanized. Dentin adhesives and composite cements were utilized. The glass ceramic crowns were evaluated with mirror, probe and apical radiographs using modified US Public Health Service criteria. Crowns recorded as having neither C- nor D-criteria were defined as successful. Kaplan-Meier estimates were calculated with the lower interval of confidence at the 95% level. The patient's drop out rate of 16.9% was relatively low. 142 crowns placed in 59 patients could be evaluated with a mean observation time (± std. dev.) of 5.1 (± 1.5) years. Of the 142 restorations, 14 were judged as failures due to fractures. This resulted in a failure rate of 9.9%. Failures were observed between 1 month and 5.5 years after cementation. The estimated 6-year survival rate for this study group (including the early group) was 89.2%. The clinical behavior of this glass ceramic crown system is judged as satisfactory after six years in function.

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Address for correspondence:
Stephan P. Studer, D.M.D., Two South Montefiore Hospital, University of Pittsburgh Medical Center, Department of Maxillofacial Prosthetic Rehabilitation, 3459 Fifth Avenue, Pittsburgh, PA 15213, USA
Phone: 001-412-648-6080, Fax: 001-412-648-6798

Introduction

Since the introduction of the earliest all-ceramic reinforced crown system, developed by McLean & Hughes (1965), several generations of newer all-ceramic systems compete with the traditional porcelain fused to metal (PFM) crown (Table I). McLean and Hughes' first all-ceramic system (VitaDur N®; Vita, Bad Säckingen, Germany) consisted of a porcelain core material, reinforced with 50% aluminum oxide (Al_2O_3) and veneered with feldspathic porcelain (McLean 1966). The strength of the alumina-reinforced ceramic crown was further increased by the use of a platinum foil (Vita-Twin Foil Jacket®; Vita, Bad Säckingen, Germany), which was bonded by a tin coating to the inner surface of the aluminous dental porcelain (McLean et al. 1976, McLean & Sced 1976). The first shrink-free porcelain system was introduced later and consisted of an opaque aluminous core which was fabricated by injection molding and had to be veneered with classic feldspathic porcelain (Sozio & Riley 1983). The concept of a shrink-free ceramic material was achieved by the addition of magnesium oxide (spinell) to the aluminum oxide for volume control, which allowed a precise marginal fit (Schärer et al. 1988). Unfortunately, this shrink-free all-ceramic system revealed a relatively low flexural strength of 89 ± 13 MPa (Shegi et al. 1990), resulting in unacceptably high failure rates (Linkowsky 1988). Another method for aluminous core fabrication was the slip cast technique, which was derived from industrial technology. It was developed by Sadoun in 1985 (Decrange et al. 1987), and first marketed as In-Ceram® (Vita, Bad Säckingen, Germany). This high alumina core material which possessed porosities was infiltrated by liquid glass particles. The alumina core consisted of a higher proportion of fine-grained crystalline material, so that flexural strength which was three

times higher than that of conventional aluminous cores could be achieved (Shegi et al. 1990). The latest development is the industrial dense sintering of an alumina coping using a highly purified alumina (Andersson & Odén 1993). The mechanically digitized data of the die's surface is transmitted by a computer modem from the dental laboratory to a centralized fabrication place. The pressed alumina coping is shipped back to the dental laboratory for a conventional veneering with feldspathic porcelain (Procera®, Nobel Biocare; Gothenburg, Sweden). However, all the above all-ceramic crowns consist of an aluminous core which possess an esthetically problematic high opacity.

Other research groups developed stronger all-ceramic systems by (1) increasing the cristalline content of conventional feldspathic porcelain with the addition of up to 45 wt% cristalline leucite ($K_2OAl_2O_34SiO_2$), marketed as Optec® (Katz 1989) or (2) by adding fibres in conventional feldspathic porcelain to prevent crack propagation, marketed as Mirage®. All of these systems are fabricated using the refractory die technique. The disadvantage of all these systems is, that the particles are sintered together, which results in microporosities and inhomogeneities between ceramic particles. It is known that these microporosities can initiate crack propagation, leading to early failure of such all-ceramic restorations (McLean 1979).

Therefore, many castable glass ceramic systems have been introduced in which the porosities may be reduced to a minimum by casting the preheated and liquid glass ceramic material using the lost wax technique. Glass ceramics are prepared by controlled crystallization of glasses, described as a ceramming procedure. The ceramming procedure consists of a crystal growth in an amorphous glass matrix which enhances the strength of the ceramic material.

The first dental glass ceramic system was introduced under the trade name Dicor® (Dentsply International, York, PA). This glass ceramic material is based on the growth of fluorine-containing, tetrasilicic mica crystals. It was first reported by Grossman (1973) and later introduced in dentistry for the fabrication of crowns, veneers, inlays and onlays (Adair 1984; Adair & Grossman 1984, Grossman & Walters 1984). Few systems have competed with the original Dicor® glass ceramic. A castable apatite glass ceramic (Cera Pearl®; Kyocera Corp, Kyoto, Japan) was introduced shortly thereafter (Hobo & Iwata 1985a & b). Crystallization of oxyapatite occurs in this castable ceramics after heat treatment at 870° C for one hour. Upon exposure to water, the crystals convert to hydroxylapatite. Another castable glass ceramic containing lithium (Olympus Castable Ceramic®, OCC®; Olympus Optical Co., Tokyo, Japan) was marketed. Mica crystals ($NaMg_3[Si_3AlO_{10}]F_2$) and beta spodumene crystals ($Li_2O.Al_2O_3.4SiO_2$) are produced after the crystallization treatment in order to promote strength (Uryu et al. 1989; Iljima et al. 1991). Unfortunately, in all these castable glass ceramics the casting process is followed by a ceramming procedure which not only enhances the strength, but also results in additional ceramic shrinkage (Schärer et al. 1988), again provoking microporosities and inhomogenities. To overcome this disadvantage, a heat-press technique was developed in 1983 by the Department of Fixed and Removable Prosthodontics and Dental Materials at the Zurich University (Wohlwend 1986; Wohlwend 1987, Lehner & Schärer 1992). This material is previously precerammed by the manufacturer instead of by the dental laboratory (IPS-Empress®; Ivoclar, Schaan, Liechtenstein). With this method, consistent results can be achieved without additional time-consuming crystallization procedures (ceramming) in the dental laboratory. In the laboratory, the material is further processed in a fully adjustable automatic furnace at 1150°C with a pressure of 0.3 to 0.4 MPa, referred to as a "heat-press" technique in the literature (Dong et al. 1992). This heat treatment, which is also required for shading and glazing, allows final maturing of the crystals and improves the mechanical properties (Lüthy 1996).

The initial clinical results of this leucite-reinforced glass ceramic system are encouraging (Studer et al. 1996, Lehner et al. 1997). After 2 years in service, 4 out of 78 crown restorations failed due to fractures, as jugded by using modified US Public Health Service criteria. This resulted in an estimated survival rate of 95% (Lehner et al. 1997). Surprisingly, three out of four failures occurred in the first 2 months, indicating that crown fabrication and cementation are technique-sensitive steps. With respect to a reported fatigue fracture phenomenon for ceramic

Table I All-ceramic systems used as alternatives for porcelain-fused-to-metal crowns.

Material class	Method of strength increase	Product	Reference
Alumina porcelains	Adding aluminum oxide in aluminous core, veneered by feldspathic porcelain	VitaDur N®	McLean & Hughes 1965
	Bonding a tin coated platin foil inside an aluminous core, veneered by feldspathic porcelain	Vita-Twin Foil Jacket®	McLean et al. 1976
	Aluminous core with spinell (MgO) to control shrinkage. Injection molding, veneered by feldspathic porcelain	Cerestore®	Sozio & Riley 1983
	Aluminous core with high proportion of fine-grained crystalin material, infiltrated by glass particles: Slip cast technique	In-Ceram®	Decrange et al. 1987
	Aluminous core with high-purity alumina, industrially dense-sintered, veneered by feldspathic porcelain	Procera®	Andersson & Odén 1993
Feldspathic porcelains	Increased content of cristalline leucite inside feldspathic porcelain	Optec®	Katz 1989
	Fibre reinforcement inside feldspathic porcelain	Mirage®	
Glass ceramics	Casting and ceramming in the dental laboratory with tetrasilicic fluor-mica crystals	Dicor®	Adair 1984, Grossman & Walthers 1984
	with hydroxylapatite crystals	Cera Pearl®	Hobo & Iwata 1985a & b
	with mica and lithium containing ß-spodumene crystals	OCC®	Uryu et al. 1989
	Preceramming by manufacturer, hot pressing in laboratory with leucite crystals	IPS-Empress®	Wohlwend 1986 & 1987

materials (Morena et al. 1986), a longer observation period is necessary in order to determine the clinical behavior more precisely. Consequently, the purpose of this study was to assess the 6-year clinical outcome of this glass ceramic crown system.

Materials and Methods

Study population

Patients were selected for this study based on the following criteria: (1) a high level of oral hygiene, manifested by a papillary bleeding index (PBI) ≤ 20 (Saxer et al. 1977) and (2) an interest in esthetics. Patients with poor oral hygiene, gingivitis (PBI > 20) or periodontitis were excluded from the study. Patients included in this study had a low caries activity, which was manifested that no crown was replaced due to secondary caries. However, no microbiological tests were performed to assess streptococcus mutans or lactobacillus content in saliva. The requirements of the Helsinki Declaration on informed consent were fulfilled by informing the patient that the ceramic material to be used was new and no long-term clinical experience was available at the time of insertion. Patients were asked for his/her written consent. In addition, they all agreed to a recall period of 5 years with at least one recall visit per year. Patients, who did not agree with the consent were treated with a conventional PFM crown.

Treatment method

All patients were treated in the Department of Fixed & Removable Prosthodontics & Dental Material by post-graduate students or, senior lecturers or assistant professors. All had experience with all-ceramic crowns and the adhesive technique. The clinical and technical procedures for Empress crown fabrication are already described elsewhere in detail (Wohlwend & Schärer 1990; Beham 1990, Lehner et al. 1997) and are briefly summarized.

Tooth preparation, impression making, working casts

All abutment teeth were uniformly prepared with a circular shoulder with an internally rounded line angle which was defined as approximately a 90° angle to the axial wall. After gross reduction by diamond burs with an average grain size of 80 µm all surfaces were smoothened with finishing diamond burs, having an average grain size of 40 µm (Uniprep C & B Set®; Intensiv SA, Viganello-Lugano, Switzerland). In most instances the width of the shoulder was approximately 1.0 to 1.2 mm. The occlusal clearance for posterior crowns was 2.0 mm, for anterior crowns 1.5 mm, and therefore similar to what is recommended for porcelain fused to metal restorations with complete porcelain coverage. Full arch impressions were made with polyether material (Permadyne® or Impregum®; Espe, Seefeld, Germany).

Laboratory procedure for the crown fabrication

Basically, two techniques were applied: (1) the stain and glaze technique and (2) the layering technique. Beginning in 1988, crowns were fabricated with several coats of heavily pigmented stain, followed by two separate final glazes to a total thickness of 50 to 60 µm. Beginning in 1990, the layering technique was introduced to our department to achieve better esthetic results and to avoid any risk of surface changes. The layering technique started with a body build up which was heat-pressed by glass ceramic and was restricted to a dentin substructure to avoid any cut back critical for the ceramic structure. Subsequently this build up was veneered by conventional feldspathic porcelain up to a 0.3 mm thickness (Wohlwend & Schärer 1990). Only eighteen crowns were fabricated with the staining technique in the present study. The other crowns were produced by applying the layering technique.

Cementation

Four different luting agents were used for cementation according to each manufacturer's recommendations at time of insertion: (1) Panavia TC® (Kuraray Japan), and two dual cure composite cements: (2) Porcelite® (Kerr Manufactoring Co., Romulus, Michigan, USA) and (3) "VP 891" (Ivoclar, Schaan, Liechtenstein). The latter cement (3) is a modified version of Ivoclar's Dual Cement, a micro filler composite cement with a low viscosity. The dentin bonding agents used in combination with the dual cure composite cements were All Bond II® (Bisco Inc., USA) for cement (2) and "VP 662" (Ivoclar, Schaan, Liechtenstein) for cement (3). Zinc Phosphate (DeTrey, Zurich, Switzerland), without chemical bond to abutment surfaces, served as a control for 14 crowns. The other crowns were luted by the adhesive technique. Moisture was controlled by utilizing retraction cords and cotton rolls during cementation. Excess zinc phosphate cement and Panavia TC® cement was removed after the final set. In the case of the dual cure luting agents (Porcelite® and "VP 891") excess cement was removed by a spongy plastic pellet (Pele Tim®, Voco Chemie, Cuxhaven, Ger-

Table II Criteria for clinical evaluation of all-ceramic crowns, modified according to Ryge & Cvar (1971)

Marginal adaptation	
A:	No catch on probing, no discoloration visible
B:	Probe catches on crown's margin, but no gap Or: gap or chipping on probing, with enamel exposed, but polishable Slight discoloration visible, but polishable
C:	Gap or chipping on probing with dentin or liner exposed Distinct discoloration visible, not polishable, not acceptable
D:	Partial fracture, fracture, luxation or mobile (loose) restoration
Anatomic form	
A:	Correct contour with tight proximal contacts (checked with waxed dental floss) No wear facets on restoration, no wear facets on opposing tooth
B:	Slightly under- or overcontoured, weak proximal contact Small wear facets on restoration, diameter ≤ 2 mm; and/or same on opposing tooth
C:	Distinct under- or over-contoured, missing proximal contact Large wear facets on restoration, diameter ≥ 2 mm; and/or same on opposing tooth
Surface texture	
A:	Smooth glazed or glossy surface
B:	Slightly rough or dull surface
C:	Porous surface, rough, or with deep pores, unevenly distributed pits, cannot be refinished
Color Match	
A:	Restoration hardly detectable, perfect match
B:	Minimal mismatch in shade; 1 shade off (Vita shade guide)
C:	Distinct difference in shade; 1.5 shades off and more

many), a dental probe and waxed dental floss, immediately after the cementation and prior to light curing. Each crown was light cured with an energy density of 550 mW/cm² for at least 4 minutes (mostly Elipar II®; Espe, Seefeld, Germany).

Calibration of operators and dental technicians

All operators were calibrated in the following way: The clinical and technical aspects of all-ceramic crown fabrication were presented and discussed in several seminars and literature reviews (as a part of the post-graduate program) since the introduction of Cerestore® and Dicor® restorations in our department (Soom 1987, Linkowsky 1988, Lehner & Schärer 1992). Clinicians also attended a tooth preparation course using resin teeth. This was supplemented with lectures about the adhesive technique and cementation procedures. Post-graduate students were supervised by senior lecturers and assistant professors.
Laboratory consistency was ensured by having only the same two experienced dental ceramists (A.W. and T.R.), responsible for the crown fabrication of the early group (Wohlwend & Schärer 1990). The first technician, A.W., having developed the IPS-Empress® system (Wohlwend 1986 & 1987), taught and supervised T.R., both working in the same room to maintain the quality level. Further, other ceramists in the Zurich area were instructed in this technique by A.W.

Clinical evaluation at the time of cementation

In addition to the clinical evaluation, using modified US Public Health Service criteria (Ryge & Cvar 1971), photographs of the restorations and the adjacent areas were made in such a way that all aspects of the crowns were visible for assessment (Table II). Radiographs were made to establish the base line information. The periodontal status of all teeth with crowns as well as the adjacent teeth were evaluated by utilizing probing pocket depth (PCP-3; Hu-Friedy, Leimen, Germany), modified sulcus bleeding index (Mombelli et al. 1987) and plaque index (Silness & Löe 1964) immediately after cementation.

Clinical re-evaluation

All patients were recalled during 1996 and 1997. All crowns were re-evaluated, using modified US Public Health Service criteria (Ryge & Cvar 1971) with mirror, probe, radiographs and photographs (Table II). An A-rating was given if the restoration did not require modification and was considered clinically unchanged. A B-rating was assigned if some minor defect was observed, which did not endanger the tooth structure or periodontal tissues, for instance did not provoke secondary caries, irreversible pulpitis or induce loss of attachment. Therefore, restorations with minimal changes which were still clinically acceptable and did not need replacement or even minor repairs were rated a B. C- or D-ratings were assigned if the restoration showed a defect which endangered tooth structure or periodontal tissues. Thus, C- or D-ratings were given if replacement was required or some repair was needed.

Calibration at re-evaluation

Two examiners (S.S. and C.L.) made the recall examinations. The appointments of the first twelve patients were assigned together in order to calibrate each examiner. In addition, photographs were taken and radiographs were used to re-evaluate the restoration scores allowing rejudgment at a different time with both examiners. If there was a disagreement between clinical, radiological and slide assessment, the worst rating was assigned.

Statistical evaluation

Success of the restoration was defined as having either an A- or a B-rating, whereas failure was defined as having either a C- or a D-rating at the time of clinical re-evaluation. Based upon this definition, survival rates with a lower confidence interval of 95% were estimated by a non-parametric survival analysis (Kaplan & Meier 1958). The statistical analysis was performed with the software StatView®, Version 4.1 (Abacus; Berkley, CA, USA).

Results

Seventy-one patients were treated with glass ceramic crowns. At the recall control appointments 59 patients presented with 142 restorations, resulting in a patient drop out rate of 16.9%. 93 crowns were placed in 40 females, and 49 crowns in 19 males. The maxillary incisor crowns predominated this data sample: the

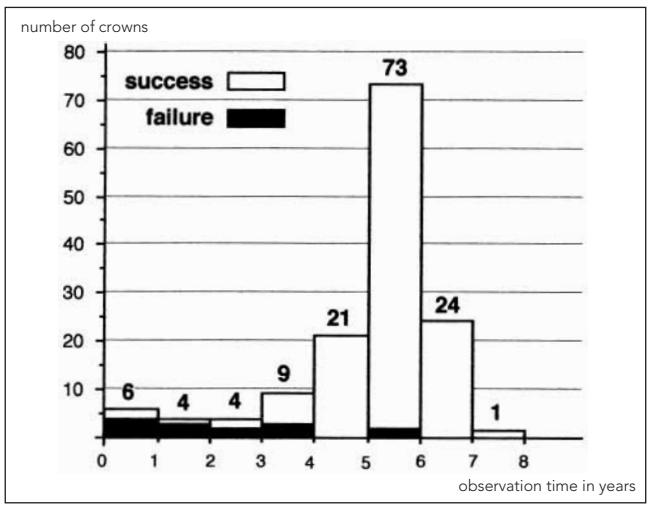

Fig. 1. Distribution of 142 re-evaluated crowns according to the observation time in years, subdivided in 128 successes and 14 failures

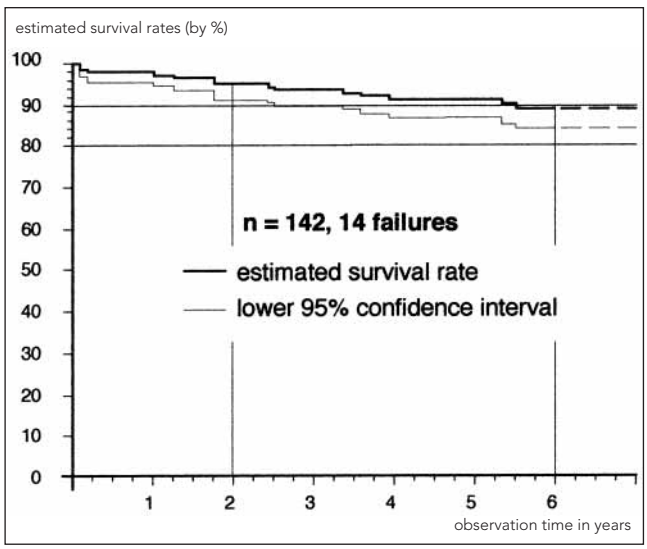

Fig. 2. Estimated survival rates (by percentage) with the lower 95% confidence interval for all 142 restorations according to Kaplan & Meier (1958) with 14 assessed failures

most frequently restored teeth were the incisors with 53 crowns (37%), followed by the molars with 39 units (28%), the premolars with 36 units (25%), and the canines with 14 units (10%).
The mean time in service for all restorations was 5.1 years (SD: ± 1.5 years). The distribution of the observation times for all evaluated crowns at the recall appointments is presented in Figure 1. Fourteen out of 142 crowns failed (either a C- or D-rating) in eleven different patients, between 1 month and 5.5 years in service. All failures occurred due to fractures, resulting in a failure rate of 9.9%. One patient had three failures, and another patient experienced two failures. The remaining nine patients had one failed crown each.
Four out of 14 failures were observed in the first year in function, nine out of 14 failures in the first three years in function. The survival rate of restorations according to KAPLAN-MEIER (1958) using the criteria defined above was estimated to be 91.3% after 5 years in service (Figure 2). The lower confidence interval was 86.6% (Figure 2). The 6-year survival estimate was 89.2% with the lower confidence interval of 83.8%. These intervals were calculated under the assumption of no intra-patient correlation, despite the fact that the 14 failures occurred in eleven different patients. Detailed information for all 14 failed restorations according to patient's gender, their location and time of event is presented in Table III. Of the 14 failures, 2 premolar crowns (6%), 4 incisor crowns (8%), 4 molar crowns (10%) and 4 canine crowns (29%) were involved.

Table III Detailed informations about 14 failures in eleven different patients by absolute numbers and by percentage out of 142 restorations in 59 patients

jaw	luted	failures
maxillary	98 (100%)	10 (10%)
mandibular	44 (100%)	4 (9%)
tooth localisation		
incisor	53 (100%)	4 (8%)
canine	14 (100%)	4 (29%)
premolar	36 (100%)	2 (6%)
molar	39 (100%)	4 (10%)
gender		
male	19 (100%)	3 (16%)
female	40 (100%)	8 (20%)

Discussion

The aim of the present study was to assess the 6-year clinical outcome of a leucite reinforced glass ceramic crown system. The patient drop out rate of 13.2% was in relation to the mean observation time of 5.1 years relatively low. Fourteen out of 142 crowns were failures (9.9%). The 6-year survival estimate of 89.2% is judged as satisfactory. The majority of failures (9 out of 14) were observed during the first three years, starting with three failures until month 2. The predominance of these early failures can be explained by (1) some damage in the material which was initiated during fabrication and/or cementation, or (2) an insufficient cementation technique. Thus, the fabrication and cementation procedures may be technically sensitive. However, only one failed crown was non-adhesively cemented. If the failure rate is calculated per patient, 11 of 59 patients were affected by a fractured crown, leading to a relatively high fracture rate of 18.6%. Therefore, nearly every fifth patient was affected by one failure during a mean observation time of 5.1 years. Two patients experienced more than one crown failure. A re-evaluation of these patients did not reveal any increased bruxism activity, manifested by pronounced wear facets, TMJ-pain, muscle pain, or limited mandibular jaw movements.
The results of our study compare favorably to the survival rates reported for 54 re-evaluated jacket crowns (LEEMPOEL et al. 1985). The long-term assessment in the LEEMPOEL study showed similar results compared to this study with estimated survival rates of 92% after 3 years, 75% after 7 years, which remained at this level until the eleventh year (Table IV).
Surprisingly, there was no significantly increased failure rate for posterior crowns in comparison to incisor crowns in the present data sample. Of the 75 posterior crowns only 6 failures occured (8%) in comparison to the 4 failures of the 53 incisor crowns (8%). Only canine crowns revealed a significantly higher failure rate than crowns placed in other tooth locations (29%). The reasons for this difference remain speculative due to a limited number of only 14 canine crowns. The lack of increased failed posterior crowns is in contrast to many other studies evaluating all-ceramic crowns (Table IV). The platinum twin foil jacket® crown (MCLEAN 1983), Cerestore® crown (LINKOWSKY 1988), Hi-Ceram® crown (HEUSSER, personal communication), Dicor® crown (MOFFA et al. 1988, MALAMENT & GROSSMAN 1990; ERPENSTEIN & KERSCHBAUM 1991, MEIER et al. 1992), as well as the adhesively luted Optec® crown (HANKINSON & CAPPETTA 1994) showed higher fracture rates in the molar region than in the anterior region. For example Dicor® crowns placed on molars demonstrated a fracture range of 28.9% (MEIER et al. 1992) to 64% (ERPENSTEIN & KERSCHBAUM 1991). The same behavior was confirmed for Dicor® crowns by KELSEY et al. (1995) who reported 4-year results of 92 adhesively luted Dicor® crowns. They found 15 fractured crowns, corresponding to a total failure rate of 16.3%, with a failure rate of 22.8% for molar crowns and failure rate of 5.7% for premolar crowns. Better longevity results for posterior crowns were published for the In-Ceram® system (PRÖBSTER 1996).
The estimated 6-year survival rate of 89.2% for the present leucite-reinforced glass ceramic material has to be compared with the standard porcelain fused to metal crown (RÜEGER 1979; LEEMPOEL et al. 1985; KERSCHBAUM et al. 1991). RÜEGER's work demonstrated a favorable outcome after a period of 10 to 13 years. Surprisingly, only 13% of the fixed prosthodontic restorations were lost or in need of repair (RÜEGER 1979). Improved results were reported for porcelain fused to metal (PFM) crowns by LEEMPOEL et al. (1985). They reported estimated survival rates for PFM crowns of 100%, 99% and 95% after 3, 5 and 11 years, respectively. Unfavorable results for single crowns were reported with lower survival rates of 92% and 79% after 5 and 10 years by KERSCHBAUM et al. (1991). Therefore, the latter study assessed a survival rate of conventional single crowns which was more than 4 times worse after ten years in comparison to the study of LEEMPOEL et al. (1985). This difference in the 10-year survival rate may be explained by the environment of dentistry, which lacks a high level of quality control. Consequently, some concerns arise about the long-term behavior of the investigated technically sensitive glass ceramic crown system inside such an environment.
The presented data sample includes the early group of this glass ceramic crown system. Adhesive systems with today's quality were not available at that time. This inefficiency is probably ex-

pressed by the four early failures in the first year in function. The technique of cementation influences the survival rate of all-ceramic restorations. Dicor® crowns which were luted with the adhesive technique demonstrated higher success rates compared to non-adhesive techniques such as the use of zinc phosphate (Erpenstein & Kerschbaum 1991) or glass ionomer cement (Malament & Grossman 1992). Malament & Kerschbaum (1992) reported only a 2.9% failure rate for "bonded" Dicor® crowns in comparison to a 13.6% failure rate of the "non-bonded" group (Table IV). This compares favorably with results obtained for ceramic inlays, cemented either with glass ionomer or with the adhesive technique (Höglund-Åberg et al. 1994): After three years, 15.3% of the glass ionomer cement inlay group were judged as non-acceptable in comparison to only 3.4% of the dual-cured composite resin inlay group. Consequently, glass ceramic crowns which are luted with the latest adhesive technique will probably show better survival rates.

The long-term behavior of the investigated glass ceramic materials should be compared with the cost-effective cusp-protecting amalgam restorations. Martin & Bader (1997) investigated the clinical behavior of cusp-protecting amalgam restorations, gold crowns and PFM crowns in 3655 patients. After 5 years in function the following success rates by percentage were assessed: 72% (2038) for 4-surface cusp-protecting amalgam restorations, 65% (1626) for 5-surface cusp-protecting amalgam restorations, 84% (555) for PFM crowns, and (516) for gold crowns. The 5-year survival estimates resulted in 88% for crowns, which was significantly better than 74% for cusp-pro-

Table IV Clinical studies of all-ceramic crowns with an observation time longer than 1 year in months (m) and years (y)

first author year	# of patients	# and material of restoration	time of observation	failure rate	estimated survival rate	technique of cementation
McLean 1983		Platinum twin	until 7 y	molar crowns: 15.2%	n.i.*	non-adhesive:
		foil jacket® crowns	until 7 y	premolar crowns: 6.4%	n.i.	glass ionomer
			until 7 y	incisor crowns: 2.1%	n.i.	
Leempoel 1985		54 jacket crowns	until 11 y	n.i.	3 y: 92%, 7 y: 75%, 11 y: 75%	non-adhesive
		138 gold crowns	until 11 y	n.i.	3 y: 100%, 7 y: 99%, 11 y: 97%	non-adhesive
		204 porcelain fused to metal crowns	until 11 y	n.i.	3 y: 100%, 7y: 99%, 11y: 95%	non-adhesive
Linkowsky 1988	50	244 Cerestore® crowns:	2 1/4 y	all: 12.5% fractured (28 crowns)	n.i.	non-adhesive:
		103 anterior crowns		anterior: 3% fractured (3 crowns)	n.i.	ZnO-phosphate or
		121 posterior crowns		posterior: 20.6% fractured (25 crowns)	n.i.	glass ionomer
Moffa 1988	71	106 Dicor® crowns	3 y	10.4% replaced (11 crowns)	n.i.	n.i.
Erpenstein 1991	82	159 Dicor® crowns	2 3/4 y	all: 9.4% fractured (15 crowns)	2 y: 86%	non-adhesive:
		85 anterior crowns		anterior: 3.5% fractured (3 crowns)	2 y: 97%	ZnO-phosphate
		60 premolar crowns		premolar: 5% fractured (3 crowns)	2 y: 87%	
		14 molar crowns		molar: 64% (9 crowns)	n.i.	
Iljima 1991	51	69 OCC® crowns	2 y 11 m	all: 4.3% fractured (3 crowns)	n.i.	n.i.
				anterior: 3.5% fractured		
				premolar: 11.7% fractured		
Nahara 1991	26	33 Cera Pearl® crowns	2 y	no fractures	100%	composite cement
Malament 1992	301	985 Dicor® crowns:				
		616 "bonded" crowns	until 4 y	2.9% failures (18 crowns)	n.i.	adhesive**:
		369 "non-bonded" crowns	until 7 y	13.6% failures (50 crowns)	n.i.	non-adhesive: ZnO-phosphate or glass ionomer
Meier 1992		126 Dicor® crowns:	until 4 y	all: 17% fractured (21 crowns)		
		60 anterior crowns		anterior: 10% fractured (6 crowns)	anterior: 2 y: 92%	ZnO-phosphate
		21 premolar crowns		premolar: 9.5% fractured (2 crowns)		
		45 molar crowns		molar: 28.9% (13 crowns)	posterior: 2 y: 86%	ZnO-phosphate
Pröbster 1993		61 In-Ceram® crowns	2.9 y	no fractures	100%	ZnO-phosphate
Hankinson 1994		159 Optec HSP® crowns	until 5 y	all: 6% fractured (9 crowns)	n.i.	adhesive**
		46 anterior crowns		anterior: no fracture until 3 y		
		88 premolar crowns		premolar: 2.3% fractured until 3 y (2 crowns)		
		25 molar crowns		molar: 28% fractured until 3 y (7 crowns)		
Kelsey 1995		92 Dicor® crowns	4 y	all: 16.3% fractured (15 crowns)	n.i.	adhesive **
		35 premolar crowns		premolar: 5.7% fractured (2 crowns)		
		57 molar crowns		molar: 22.8% fractured (13 crowns)		
Sorensen 1995	33	75 IPS-Empress® crowns	1 to 33 m	no fractures	100%	adhesive**
Pang 1995	31	35 In-Ceram® crowns	21 m	8.5% fractured (3 crowns)	n.i.	n.i.
Pröbster 1996		95 In-Ceram® crowns:	4 y 8 m	all failures: 5.3%	n.i.	ZnO-phosphate
		28 anterior crowns		1.1% fractured veneering (1 molar crown)		
		68 posterior crowns		4.2% secondary caries (4 crowns)		
Lehner 1997	34	78 IPS-Empress® crowns	19.7 m	5% fractured (4 crowns)	2 y: 95%	adhesive**
Martin 1997	3655	2038 4-surface complex amalgams	5 y	28% failures		non-adhesive
		1626 5-surface complex amalgams	5 y	35% failures	all amalgams: 5 y: 74%	non-adhesive
		555 porcelain fused to metal crowns	5 y	16% failures		non-adhesive
		516 gold crowns	5 y	16% failures	all crowns: 5 y: 88%	non-adhesive

*: n.i.: no information available, ** adhesive: porcelain etching, silanization, enamel and dentin adhesives, composite cement

tected amalgam restorations. Similar results were published by Robbins & Summitt (1988). They reported a 75% survival rate at 5.7 years and a 50% survival rate at 11.5 years for cusp-protected amalgam restorations. Consequently, the cost-effective amalgam restorations were less favorable than gold crowns, porcelain fused to metal crowns and IPS-Empress® crowns.

Conclusion

1. In this prospective study 142 leucite-reinforced glass ceramic crowns were clinically reevaluated using the modified US Public Health Service criteria. After a mean observation time of 5.1 years, 128 restorations were successful. Fourteen crowns failed due to fractures, resulting in a failure rate of 9.9%.
2. A 6-year survival rate of 89.2% was estimated, which is judged as satisfactory for this all-ceramic system.
3. However, a longer observation period is needed to give a final prognosis in order (1) to exclude a fatigue fracture phenomenon of the glass ceramic material, and (2) to rule out any breakdown of the utilized adhesive system.

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Zusammenfassung

Ein leuzit-verstärktes, glaskeramisches Material (IPS-Empress®) wurde für den klinischen Gebrauch an der Zürcher Schule entwickelt. Eine prospektive klinische Studie über diese laborgefertigten Vollporzellan-Kronen zeigte nach 2 Jahren eine geschätzte Überlebensrate von 95%. Das Ziel dieser Studie war, aufgrund möglicher Ermüdungsphänomene von Keramiksystemen das klinische Verhalten während einer längeren Beobachtungszeit zu bestimmen. Alle Restaurationen wurden mit adhäsiver Technik einzementiert. Die Innenflächen wurden mit Flusssäure angeätzt und silanisiert. Dentinadhäsive und Komposite wurden zur Befestigung verwendet. Mit Spiegel, Sonde und apikalen Röntgenbildern wurden 142 Kronen mittels den United States Public Health Service-Kriterien untersucht. Kronen, die weder mit einem C noch D bewertet worden waren, wurden als erfolgreich definiert. Eine Kaplan-Meier-Schätzung wurde mit einem unteren Vertrauensintervall von 95% berechnet. Die Patienten-Drop out-Rate war mit 16,9% relativ klein, so dass 142 Kronen von 59 Patienten bei einer mittleren Beobachtungszeit (± Standardabweichung) von 5,1 (± 1,5) Jahren evaluiert werden konnten. Von den 142 Restaurationen wurden 14 als Misserfolge aufgrund von Frakturen bewertet, was einer Misserfolgsrate von 9,9% entsprach. Die Misserfolge traten zwischen 1 Monat und 5,5 Jahren nach der Zementierung auf. Die geschätzte 6-Jahres-Überlebensrate betrug 89,2% für diesen Datensatz, der die Frühgruppe beinhaltete. Das klinische Verhalten dieses glaskeramischen Kronensystems ist nach 6 Jahren Beobachtungszeit zufriedenstellend.

Résumé

Une céramique vitreuse renforcée par de la leucite (IPS-Empress®) a été mise au point à l'Institut de Médecine dentaire de l'Université de Zurich en vue d'une application clinique. Une étude prospective concernant ce type de couronnes entièrement en céramique et fabriquées au laboratoire a révélé des résultats encourageants avec un taux de survie estimé à 95% après 2 ans. Le but de la présente étude était de déterminer leur comportement durant une période d'observation plus longue et concernant surtout les fractures de fatigue, bien connus pour les systèmes céramiques. Les couronnes ont été scellées avec une méthode d'adhésion. Leur intrados a été mordancé à l'acide fluorhydrique, puis silanisé. Des adhésifs dentinaires et des ciments en composite ont été utilisés pour le scellement. L'évaluation des couronnes a été réalisée à l'aide du miroir, de la sonde et de radiographies apicales, suivant les critères modifiés du US Public Health Service. Les couronnes qui ne remplissaient ni le critère C ni le D ont été considérées par définition comme étant un succès. Les estimations selon Kaplan-Meier ont été calculées avec in intervalle de confiance inférieur situé au niveau de 95%.
Le taux de «drop out» de patients a été relativement modéré, autour de 17%. 142 couronnes chez 59 patients ont pu être examinées après un temps d'observation moyen (± déviation standard) de 5,1 (± 1,5) ans. Parmi les 142 restaurations, 15 ont été jugées comme étant des échecs à cause de fracture, ce qui représente un taux de 9,9%, entre 1 mois et 5,5 ans après scellement. Le taux de survie estimé sur 6 ans était de 89,2% pour le collectif (y inclus le groupe précoce). Au bout de 6 ans, le comportement clinique de ce système de couronnes en céramique vitreuse renforcée peut donc être considéré comme étant satisfaisant.

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