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ORIGINAL ARTICLE

# Long-term performance of posterior InCeram Alumina crowns cemented with different luting agents: a prospective, randomized clinical split-mouth study over 5 years

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**Abstract**
*Objectives* This prospective, randomized clinical split-mouth study investigated the 5-year performance of InCeram Alumina posterior crowns cemented with three different luting cements. 4-META- and MDP-based cements were used for adhesive luting. Glass ionomer cement served as control.
*Materials and Methods* Sixty patients were treated with 149 ($n=62$ Panavia F/MDP; $n=59$ SuperBond-C&B/4-META; $n=28$ Ketac Cem/glass ionomer) InCeram Alumina crowns on vital molars and premolars in a comparable position. Follow-up examinations were performed annually up to 5 years after crown placement using the modified United States Public Health Service (USPHS) criteria. Kaplan–Meier survival analysis comprised secondary caries, clinically unacceptable fractures, root canal treatment and debonding. Kaplan–Meier success rate included restorations with minimal crevices, tolerable color deviations (<1 Vitashade), and clinically acceptable fractures. Logistic regression models with a random intercept were fitted.
*Results* The 5-year Kaplan–Meier survival probabilities were: SuperBond-C&B 88.7 %, Panavia F 82.8 %, Ketac Cem 80.1 % with no significant difference ($p=.813$). Endodontical treatment was carried out on 7.4 % of all abutment teeth, and 5.4 % revealed secondary caries. Unacceptable ceramic fractures were observed in 7.4 %. Debonding was a rare complication (1.3 %). The 5 year Kaplan–Meier success rate was 91.6 % for SuperBond-C&B-, 87.4 % for Ketac Cem- and 86.3 % for Panavia F-bonded restorations with no significant difference ($p=.624$). All cement types showed significant marginal deterioration over time ($p<.0001$).
*Conclusions* Posterior InCeram Alumina crowns showed acceptable long-term survival and success rates independent of luting agent used. Ceramic fractures, endodontical treatments and secondary caries were the most frequent failures.
*Clinical relevance* Glass-infiltrated Alumina crowns in combination with adhesive as well as conventional cementation can be considered as a reliable treatment option in posterior teeth.

**Keywords** All-ceramic · InCeram Alumina · Posterior crowns · Luting cements · 4-META · MDP

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## Introduction

Over the last decades, all-ceramic restorations have been accepted as a reliable treatment option even for the posterior region due to their improved physical properties and excellent biocompatibility [1, 2]. Glass-infiltrated aluminum oxide core ceramics (InCeram Alumina, VITA Zahnfabrik, Bad Säckingen, Germany) were introduced to the dental community in 1989 [3]. Densely packed sintered $Al_2O_3$ (80 to 82 wt%) is used as ceramic core material followed by an infiltration with molten glass [4]. The InCeram Alumina ceramic reveals a flexural strength of 500 MPa and is recommended for the fabrication of anterior three-unit fixed dental prostheses (FDPs) and crowns in the anterior as well as in the posterior region [5, 6].

Many authors suggest bonding all-ceramic restorations to tooth structure with adhesive resin cements, because of their high compressive and tensile strengths, low solubility, toughness and favorable esthetic qualities [6, 7]. However, the long-term bond durability at the tooth–resin cement and resin cement–ceramic interfaces still seems to be critical [8–10].

4-META/MMA-TBB (4-methacryloxyethyl trimellitate anhydride/methyl methacrylate) resin cements such as SuperBond-C&B (Sun Medical, Shiga, Japan) have been widely used over the past three decades, not only as a luting cement in restorative dentistry, but also for cementation of orthodontic brackets and splints as part of the treatment for periodontal disease [10]. 4-META/MMA-TBB-containing adhesive cements are characterized by a high bond strength to dentin and restorations, a protection against recurrent caries and an isolation of the pulp from outer stimuli [11–14]. SuperBond-C&B (Sun Medical, Shiga, Japan) consists of long flexible linear polymer chains of high molecular weight and no inorganic fillers, providing this cement with more ductile and shock absorbing properties [15]. MDP-based cements most commonly known as Panavia F (Kuraray, Tokyo, Japan) contain multifunctional phosphoric acid monomethacrylate-modified monomers, and dimethacrylates such as Bis-GMA and inorganic fillers of fine glass and silica [16]. In vitro data demonstrated that both adhesive resin cements were capable to produce a reliable bond to dentin and aluminum oxide ceramics [15].

However, there is some evidence that adhesive cementation may not be necessary for the long-term clinical success of InCeram Alumina posterior crowns [3, 4, 15]. Glass ionomer cements were introduced as dental luting materials in the 1970s [17]. Calcium–aluminum–fluorsilicate and polycarboxylic acid build the basis. The adherence of these cements to the tooth structure is formed by ionic bonds at the tooth cement interface as a result of chelation of the carboxylate groups contained in the acid with the calcium ions in the hydroxyapatite of enamel and dentin [18]. Due to the popularity and ease of application, a glass ionomer cement was chosen as control group in the present study.

The aim of this prospective, randomized clinical split-mouth study over 5 years was to investigate the long-term success of InCeram Alumina posterior crowns cemented with three different luting agents. The null hypothesis was that the long-term performance of glass-infiltrated alumina crowns is independent of the cementation material.

## Material and methods

Sixty adult patients who required at least two full-coverage crowns participated in the study. All patients had to comply with the following criteria: older than 18 years, good oral hygiene, healthy/treated periodontal situation. All abutment teeth were checked for vitality by testing sensitivity to an ice spray-treated foam pellet (Frisco Spray, ad-Arztbedarf GmbH, Frechen, Germany). The study was conducted according to the Declaration of Helsinki and was inspected and approved by an ethics committee (International Ethics Committee Albert-Ludwigs University, Freiburg, Germany, Registration number 59/05). Each patient received an oral and written explanation of the study protocol from the clinical examiner. Informed consent form was obtained from each participant. A randomized split-mouth design and a patient blind data acquisition protocol were used. The patients were assigned by a computer-generated randomization list (simple equal randomization) to allocate each crown with one of the study cements. A total of 149 restorations were inserted in 60 patients. Every patient received at least two adhesively cemented ($n=62$ Panavia F/MDP Kuraray, Tokyo, Japan; $n=59$ SuperBond-C&B/4-META, Sun Medical, Shiga, Japan) glass-infiltrated aluminum oxide all-ceramic crowns (InCeram Alumina, VITA Zahnfabrik, Bad Säckingen, Germany), The position of the two crowns had to be comparable. Twenty-eight of the above-mentioned patients additionally received a third InCeram Alumina crown that was cemented with a conventional glass ionomer cement (Ketac Cem, 3M ESPE, St. Paul, MN, USA). The conventionally cemented crowns ($n=28$) served as a control group. Depending on the extent of sound tooth structure after caries removal, a composite material (Clearfil Core, Kuraray, Tokyo, Japan) was used in combination with a dentin adhesive (Clearfil New Bond, Kuraray, Tokyo, Japan) for build-up of the selected abutment teeth. Fillings were applied under rubber dam. All abutment teeth were prepared by experienced prosthodontists with an occlusal reduction of 1.5–2 mm followed by a circular 1.2-mm-deep chamfer preparation. The gingival tissues were retracted with a retraction cord (Ultrapak, Ultradent, South Jordan, UT, USA) to control bleeding and to expose the preparation margins. Full-arch impressions were taken using a polyether impression material (Permadyne, 3M ESPE, St. Paul, MN, USA). Provisional restorations were fabricated with a silicone key and an acrylic provisional material (TAB 2000, KerrHawe, Orange, CA, USA). The provisional crowns were cemented with eugenol-free temporary cement (TempBond NE, Kerr Corp, Orange, CA, USA). The InCeram Alumina crowns were fabricated using the slip-cast-technique and veneered with a low-fusing veneering ceramic (VITA VM7, VITA Zahnfabrik, Bad Säckingen, Germany) according to the manufacturer's instruction. The fit of the restorations was checked with silicone indicator paste (Fit-checker, GC Dental, Tokyo, Japan) and an explorer. Before cementation, all abutment teeth were cleaned with slurry of pumice using a rotating rubber cup, rinsed with water and subsequently gently air-dried. Super Bond C&B (Sun Medical, Shiga, Japan) and Panavia F (Kuraray, Tokyo, Japan) were used as test cements and Ketac Cem Maxicap (3M ESPE, St. Paul, MN, USA) served as control. The manufacturer's recommendations were followed for all permanent cementation procedure (Table 1). For cementation with Super Bond C&B, the Green Activator (citric acid, $FeCl_3$, Super Bond C&B, Sun Medical, Shiga,

**Table 1** Luting cements, main components and application procedures

| Cement | Main components | Application procedure |
|---|---|---|
| Super Bond C&B (Sun Medical, Shiga, Japan) | PMMA, MMA, 4-META, TBB | Tooth surface: Green Activator (enamel 30 s, dentin 5–10 s)<br>Restoration surface: Red Activator, Porcelain Liner M |
| Panavia F (Kuraray Medical, Tokyo, Japan) | Filler (78 %), MDP, dimethacrylates, initiator | Tooth surface: ED-Primer (30 s)<br>Restoration surface: K-Etchant, Clearfil SE Bond + Porcelain Bond Activator |
| Ketac Cem Maxicap (3M ESPE, St. Paul, MN, USA) | Glass powder, pigments (powder), polycarboxylic acid, tartaric acid, water, conservation agents (liquid) | Activation of the capsule for 2 s, trituration for 10 s and application inside of the crown |

*PMMA* polymethyl-methacrylate, *MMA* methyl-methacrylate, *4-META* 4-methacryloxyethyl trimellitate anhydride, *TBB* tri-*n*-butyl borane, *MDP* 10-methacryloxydecyl di-hydrogen phosphate

Japan) was applied on the tooth structure as follows: enamel, 30 s; dentin, 5–10 s. The Green Activator was then rinsed with water. The entire surface was gently air-dried. The inner surface of the restoration was airborne particle abraded with $Al_2O_3$ (50 μm, 2.8 psi) and cleaned with the Red Activator (phosphoric acid, Super Bond C&B, Sun Medical, Shiga, Japan). The prepared ceramic surface was treated with a surface modifier (Porcelain Liner M, Super Bond C&B, Sun Medical, Shiga, Japan) and dried. Before mixing of the cement, the dispensing dish was cooled in a refrigerator (recommended temperature, 10–16 °C), and taken out just before use. The activated liquid containing four drops of the monomer and one drop of the catalyst V was dispensed into the dispensing dish. One small cup (standard measuring spoon) of the polymer (L-Type Clear, Super Bond C&B, Sun Medical, Shiga, Japan) and the prepared activated liquid was then dispensed into the dispensing dish and stirred lightly with a brush. Immediately after mixing, the cement was applied with a brush to the inner surface of the restoration. All restorations were seated with finger pressure followed by a plastic crown setter (Kronensetz-Instrument 411, Becht, Offenburg, Germany). The excess cement was removed before curing using dental floss and sponge pellets. For Panavia F (Kuraray, Tokyo, Japan) the ED primer II (A liquid and B liquid mixed 1:1) (Panavia F, Kuraray, Tokyo, Japan) was applied on the tooth surface using a sponge pellet. After 30 s, the primer was dried with air flow. Equal amounts of each paste (A/B paste, Panavia F, Kuraray, Tokyo, Japan) were dispensed and mixed thoroughly on a mixing pad for 20 s. The mixed paste was applied with a brush to the inside of the restorations. The restorations were inserted immediately, first using finger pressure and then with a plastic crown setter (Kronensetz-Instrument 411, Becht, Offenburg, Germany). The excess paste was removed with an explorer and sponge pellets before curing. Each section of the crown restoration was light cured for 20 s and then held in position for 3 min. For Ketac Cem Maxicap (3M ESPE, St. Paul, MN, USA) cementation, the abutment and crown restoration was gently air-dried. The Ketac Cem capsule (3M ESPE, St. Paul, MN, USA) was activated for 2 s and triturated automatically for 10 s in a mixing device (Silamat S5, Ivoclar Vivadent, Schaan, Liechtenstein) A thin layer of cement was placed on the inner surface of the restoration. The restorations were inserted without pressure. The excess was removed immediately with an explorer and sponge pellets.

The InCeram Alumina crowns were classified by two independent calibrated investigators according to the modified United States Public Health Service (USPHS) criteria (Table 2) [19, 20] at baseline and after 6, 12, 24, 36, 48, and 60 months post-insertion. These examiners were not involved in patient treatment within this study. The restorations were visually inspected with dental mirror and probe and clinically examined with wax-free dental floss. Pulp vitality was verified with $CO_2$-test. The tooth sensitivity reported by patients was recorded as "normal response" (sensation to cold but no pain), severe response (increased sensitivity causing a patient reflex), and no response. All data was recorded and photographically documented. For statistical evaluation, a Kaplan–Meier survival rate accounting for absolute failures was calculated and graphically depicted [21]. Secondary caries, clinically unacceptable fractures, endodontic complications (necessity of root canal treatment) and loss of crown retention were determined as absolute failures. The Kaplan–Meier success rate comprised relative failures such as clinically acceptable cohesive fractures within the veneering ceramic, slight marginal discoloration (<1 Vitashade), and minimal crevices at the restoration margin. Logistic regression models with a random intercept were fitted for each outcome (secondary caries, marginal adaptation, marginal discoloration, endodontic complications, retention of the crown, ceramic fracture) of the modified USPHS criteria to detect cementation material and time effects using the SAS 9.1.2 procedure PROC GLIMMIX. Following effects were considered: cement, recall, and the interaction between cement and recall. A $p$ value of less than .05 was considered to be statistically significant.

Table 2 USPHS criteria and clinical parameters for classification of all-ceramic full-coverage crowns

| Characteristics | Ratings | Criteria |
|---|---|---|
| Secondary caries | Alpha | No evidence of caries contiguous with the margin of the restoration |
| | Bravo | Caries evident contiguous with the margin of the restoration |
| Marginal adaptation | Alpha | No visible evidence of crevice along margin; no catch or penetration of explorer |
| | Bravo | Visible evidence of crevice and/or catch of explorer; no penetration of explorer |
| | Charlie | Visible evidence of crevice; penetration of explorer |
| Marginal discoloration | Alpha | No discoloration on the margin between the restoration and the tooth structure |
| | Bravo | Superficial discoloration on the margin between the restoration and the tooth structure; does not penetrate in pulpal direction |
| | Charlie | Discoloration has penetrated along the margin of the restorative material in pulpal direction |
| Endodontic complications | Alpha | Vitality negative |
| | Bravo | Percussion positive |
| | Charlie | Endodontic treatment necessary |
| Retention of the crown | Alpha | Bonded |
| | Bravo | De-bonded |
| | Charlie | Lost |
| Fracture of the crown | Alpha | None/Porcelain fracture acceptable |
| | Bravo | Porcelain fracture unacceptable |
| | Charlie | Bulk fracture unacceptable |

## Results

A total of 149 InCeram Alumina crown restorations were inserted in 33 (55 %) female and 27 (45 %) male patients with a mean age of 40.2 years (range 25 to 65). InCeram Alumina crowns were cemented with Panavia F ($n$=62), Super Bond C&B ($n$=59), and Ketac Cem ($n$=28) on premolars (24.2 %) and molars (75.8 %). Of an initial group of 60 patients, 57 could be examined after 6 months, 57 after 12 months, 45 after 24 months, 46 after 36 months, 43 after 48 months, and 53 patients after 60 months (Table 3). The drop-out rate after 60 months regarding restorations was 10.7 % ($n$=16; Super Bond C&B $n$=7, Panavia F $n$=7, Ketac Cem $n$=2), corresponding to a patient drop-out of 11.7 % ($n$=7). The reasons for patient withdrawal were in all cases due to private reasons. One patient died after 48 months and three patients relocated. Three further patients were unable to participate in the clinical examination due to work-related problems.

After 60 months 5 (8.1 %) Panavia F, 2 (3.4 %) Super Bond C&B and 1 (3.6 %) Ketac Cem restoration showed secondary caries. The affected crowns were treated with crown replacement and excluded from further clinical examination. A logistic regression model for secondary caries could not be fitted due to an insufficient number of events. Super Bond C&B, Panavia F, and Ketac Cem cemented restorations revealed a significant increase of marginal discoloration and marginal adaptation over time ($p \leq .0001$), with no difference among the investigated cementation materials (marginal discoloration $p$=.542; marginal adaptation $p$=.3344). One Panavia F (1.6 %) and one Super Bond C&B (1.7 %) cemented restoration showed a Charlie rating in marginal adaptation with visible evidence of marginal crevice and had to be replaced. Endodontical treatment was carried out on 11 (7.4 %) abutment teeth after verification of their non-vitality (14.3 % Ketac Cem ($n$=4), 8.1 % Panavia F ($n$=5), and 3.4 % Super Bond C&B ($n$=2)). Whereas the incidence of loss of vitality was significant ($p$=.0018) over time, no difference could be detected in the occurrence of percussion ($p$=.0911). Type of cementation had no impact on both criteria (negative vitality $p$=.7918; positive percussion $p$=.450). One Panavia F (1.6 %) and one Ketac Cem cemented crown (3.6 %) revealed a debonding. A logistic regression model for debonding could not be fitted due to an insufficient number of events. Clinically unacceptable ceramic bulk fractures and unacceptable cohesive fractures within the veneering ceramic were observed in 7.4 % ($n$=11) of the cemented crowns (8.1 % Panavia F ($n$=5), 6.8 % Super Bond C&B ($n$=4), 7.2 % Ketac Cem ($n$=2)) (Tables 3 and 4; Figs. 4 and 5). The underlying tooth structure was not affected. All InCeram Alumina crowns that failed by clinically unacceptable ceramic bulk or extensive cohesive fracture within the veneering ceramic were replaced. Hence the 5-year Kaplan–Meier survival probabilities accounting for all catastrophic failures (in total $n$=11) were as follows: SuperBond-C&B 88.7 %, Panavia F 82.8 %, and Ketac Cem 80.1 % (Fig. 1). There was no significant difference among the investigated cementation materials ($p$=.813). When only clinically unacceptable fractures were considered as criterion for survival analysis, the 5-year Kaplan–Meier survival rate was 93.7 % for Super Bond C&B, 91.7 % for Ketac Cem, and 89.8 % for Panavia F cementation (Fig. 2). There was no significant difference with respect to the cementation material ($p$=.615).

Clinically acceptable veneering ceramic failures (chipping) were observed in 8 (13.3 %) patients and comparable for all cement types (6.5 % Panavia F ($n$=4), 6.8 % Super Bond C&B ($n$=4), 10.7 % Ketac Cem ($n$=3)). Owing to the limited extension of these cohesive fractures, the restorations could remain in situ. Table 4 shows the distribution of fractures up to 60 months.

After 60 months, the Kaplan–Meier success rate accounting for relative failures such as clinically acceptable veneer

**Table 3** Modified USPHS criteria and clinical evaluation of the InCeram Alumina crowns, cemented with SuperBond-C&B, Panavia F, and Ketac Cem after a follow-up period up to 60 months (number of restorations, USPHS criteria and clinical evaluation in %)

| Recall | | 6 months | | | 12 months | | | 24 months | | | 36 months | | | 48 months | | | 60 months | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| USPHS criteria and clinical evaluation in % | | Super Bond C&B $n=52$ | Panavia F $n=52$ | Ketac Cem $n=25$ | Super Bond C&B $n=52$ | Panavia F $n=51$ | Ketac Cem $n=25$ | Super Bond C&B $n=45$ | Panavia F $n=45$ | Ketac Cem $n=18$ | Super Bond C&B $n=44$ | Panavia F $n=44$ | Ketac Cem $n=20$ | Super Bond C&B $n=42$ | Panavia F $n=43$ | Ketac Cem $n=22$ | Super Bond C&B $n=39$ | Panavia F $n=37$ | Ketac Cem $n=20$ |
| Secondary caries | Alpha | 100 | 100 | 100 | 100 | 100 | 100 | 98 | 100 | 100 | 100 | 100 | 100 | 100 | 95 | 100 | 97 | 92 | 95 |
| | Bravo | – | – | – | – | – | – | 2 | – | – | – | – | – | – | 5 | – | 3 | 8 | 5 |
| Marginal adaptation | Alpha | 98 | 92 | 96 | 94 | 82 | 96 | 98 | 98 | 94 | 75 | 77 | 85 | 55 | 60 | 73 | 51 | 49 | 60 |
| | Bravo | 2 | 6 | 4 | 6 | 18 | 4 | 2 | 2 | 6 | 25 | 23 | 15 | 43 | 40 | 27 | 49 | 51 | 40 |
| | Charlie | – | 2 | – | – | – | – | – | – | – | – | – | – | 2 | – | – | – | – | – |
| Marginal discoloration | Alpha | 98 | 100 | 100 | 94 | 98 | 96 | 91 | 90 | 100 | 82 | 84 | 90 | 74 | 77 | 91 | 49 | 62 | 70 |
| | Bravo | 2 | – | – | 6 | 2 | 4 | 9 | 10 | – | 18 | 16 | 10 | 26 | 23 | 9 | 51 | 38 | 30 |
| | Charlie | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Endodontic complications | Vitality negative | – | 4 | – | 2 | 4 | 4 | 2 | – | 6 | – | 2 | 10 | – | – | – | – | – | – |
| | Percussion positive | – | 4 | – | 2 | 4 | 4 | 2 | – | 6 | – | 2 | 10 | – | – | – | – | – | – |
| | Endodontic treatment necessary | – | 4 | – | 2 | 4 | 4 | 2 | – | 6 | – | 2 | 10 | – | – | – | – | – | – |
| Retention of the crown | Bonded | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98 | 100 | 100 | 100 | 95 | 100 | 98 | 95 | 100 | 100 | 95 |
| | De-Bonded | – | – | – | – | – | – | – | – | – | – | – | 5 | – | – | 5 | – | – | – |
| | Lost | – | – | – | – | – | – | – | 2 | – | – | – | – | – | – | – | – | – | – |
| Fracture of the crown | None | 96 | 100 | 96 | 100 | 92 | 96 | 93 | 96 | 94 | 100 | 100 | 95 | 95 | 96 | 95 | 97 | 97 | 100 |
| | Porcelain fracture acceptable | 2 | – | 4 | – | 4 | 4 | – | – | – | – | – | 5 | 5 | 2 | – | 3 | 3 | – |
| | Porcelain fracture unacceptable | 2 | – | – | – | 4 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | Bulk fracture unacceptable | – | – | – | – | – | – | 7 | 4 | 6 | – | – | – | – | 2 | 5 | – | – | – |

**Table 4** Distribution of fractures and debonding with description of localization and time frame

| Cement/localization/months | | | |
|---|---|---|---|
| Fracture | Super Bond C&B | Panavia F | Ketac Cem |
| Porcelain fracture acceptable (Chipping) | Tooth 46 disto-lingual/ 6 months | Tooth 16 disto-palatal/ 12 months | Tooth 24 mesial/6 months |
| | Tooth 37 mesio-lingual/ 48 months | Tooth 36 disto-buccal/ 12 months | Tooth 25 mesio-occlusal/ 12 months |
| | Tooth 36 disto-buccal/ 48 months | Tooth 26 disto-palatal/ 48 months | Tooth 46 buccal/36 months |
| | Tooth 16 mesio-occlusal/ 60 months | Tooth 16 occlusal-palatal/ 60 months | – |
| Porcelain fracture unacceptable (Chipping) | Tooth 46 disto-lingual/ 6 months | Tooth 46 disto-buccal/ 12 months | – |
| | – | Tooth 36 disto-buccal/ 12 months | – |
| Bulk fracture (clinically unacceptable) | Tooth 46 occlusal/ 24 months | Tooth 46 disto-buccal/ 24 months | Tooth 16 disto-palatal/ 24 months |
| | Tooth 36 bucco-occlusal/ 24 months | Tooth 47 mesio-buccal/ 24 months | Tooth 16 disto-palatal/ 48 months |
| | Tooth 46 disto-buccal/ 24 months | Tooth 36 disto-buccal/ 48 months | – |
| Loss of retention (Debonding) | – | Tooth 26/24 months | Tooth 36/36 months |

failures, minimal crevices at the restoration margin and slight marginal discolorations was 91.6 % for Super Bond C&B-, 87.4 % for Ketac Cem-, and 86.3 % for Panavia F-bonded restorations (Fig. 3). The difference in success rates depending on cementation material was not statistically significant ($p = .624$).

## Discussion

After an observation period of 5 years, acceptable survival rates of 88.7 % for Super Bond C&B-, 82.8 for Panavia F-, and 80.1 % for Ketac Cem-bonded posterior InCeram Alumina crowns were achieved. The Kaplan–Meier survival analysis in the present study included secondary caries, clinically unacceptable fractures, root canal treatment, and debonding as criteria for statistical evaluation. Varying factors are described in the dental literature for survival analyses. As fractures are the most common failure in all-ceramic restorations most clinical studies only consider catastrophic fracture failures in their statistical analyses [6]. When only clinically unacceptable fractures were included, the 5-year survival rates of the present study increased to 93.7 % for SuperBond-C&B, 91.7 % for Ketac Cem, and 89.8 % for Panavia F cementation. These survival probabilities are comparable to the reports on InCeram Alumina crowns mentioned in the literature. Glass-infiltrated alumina crowns achieved survival rates of 92–100 % after 3–5 years [3, 4, 22–25] and 80.5–97.2 % after

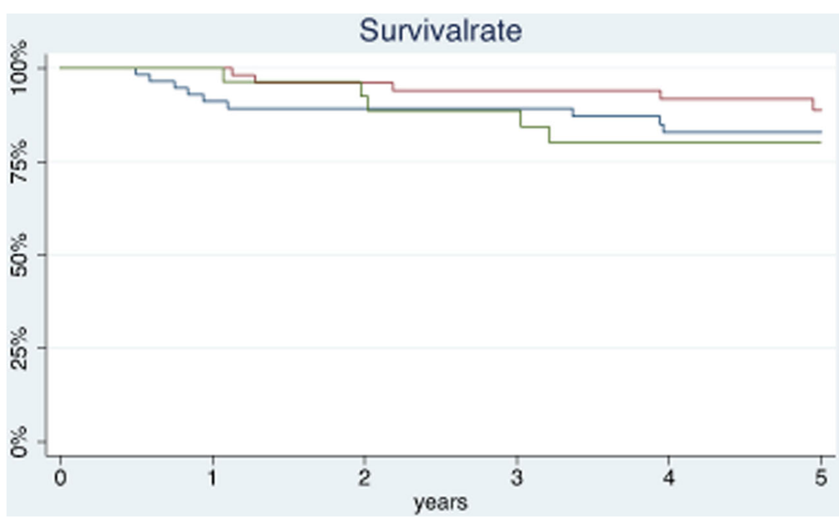


**Fig. 1** Kaplan–Meier survival probability (%) according to cement (SuperBond-C&B: *red*, Panavia F *blue*, Ketac Cem *green*) and time interval of duty (years); all absolute/catastrophic failures were considered

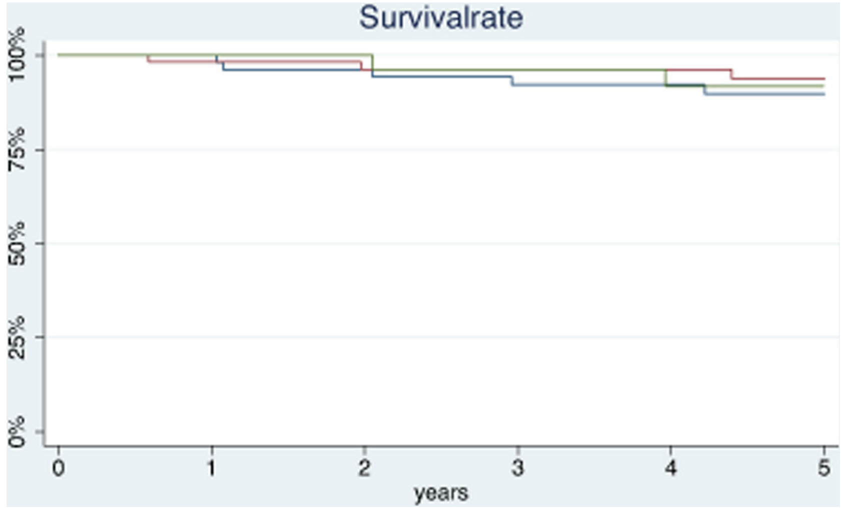


**Fig. 2** Kaplan–Meier survival probability (%) according to cement (SuperBond-C&B *red*, Panavia F *blue*, Ketac Cem *green*) and time interval of duty (years); solely unacceptable fractures were considered

6–15 years [5, 26–29]. Most of the above-mentioned studies describe pooled data with no differentiation between anterior and posterior crowns [6]. As the tooth position has been stated as a key factor for the long-term success of glass-infiltrated aluminous core restorations, lower survival rates for posterior InCeram Alumina crowns can be expected [1, 30]. Significantly inferior survival rates and increased fracture rates of 9.2 to 13 % after 5 to 15 years were described for InCeram crowns on premolars and molars [5, 23, 24]. This augmented risk of fracture failure can be attributed to the high masticatory stresses in the posterior region. Physiologic maximal posterior masticatory forces may vary up to 880 N, depending on gender and age [15, 31, 32]. In the present study, 7.4 % ($n$ = 11) of all cemented InCeram Alumina crowns demonstrated clinically unacceptable ceramic fractures (Figs. 4 and 5). The presently applied surface treatment protocol prior to cementation with alumina abrasion might have increased the risk of fracture failure. In vitro data showed a 20 to 30 % reduction in fracture strength after alumina abrasion of alumina ceramics [33]. Cohesive fracture within the veneering ceramic (chipping) was recorded in 13.3 % ($n$ = 8) patients. Owing to the limited extension of the cohesive fractures, the restorations could remain in situ. Fractures of the veneering material (chipping) were reported as the most frequent technical failure and the incidence in posterior teeth was nearly twice as high as in the anterior area [5, 6]. A complication rate of 28.5 % that was caused by chipping was described for InCeram crowns in a long-term clinical study after 15 years [5]. With an incidence of 1.3 % ($n$ = 2) of all observed alumina crowns, decementation was a rare complication of the presently observed InCeram Alumina crowns. This is in accordance with other studies mentioned in the literature. In an overview article, the mean loss of retention of single crowns was 2 % [34]. After 60 months, 8.1 % ($n$ = 5) Panavia F, 3.4 % ($n$ = 2) Super Bond C&B, and 3.6 % ($n$ = 1) Ketac Cem restoration showed secondary caries. These results are comparable to another clinical long-term study, where caries (6.2 %) was determined as a frequent cause for failures and complications

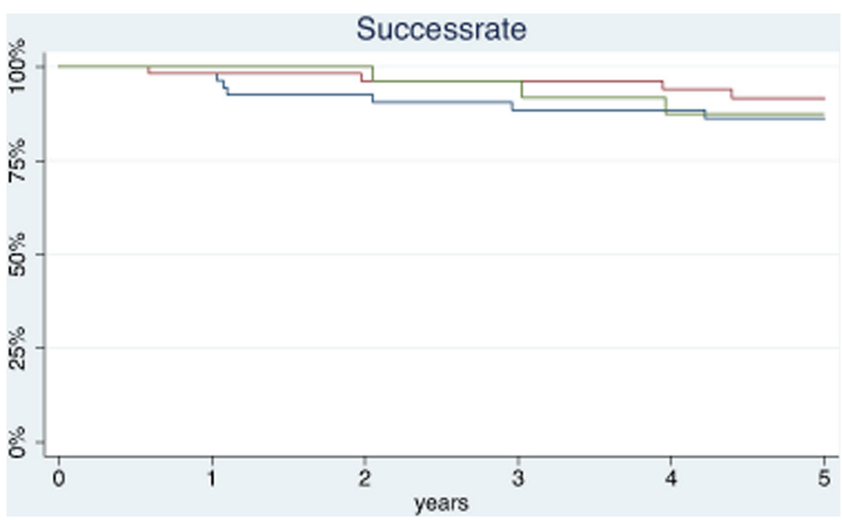


**Fig. 3** Kaplan–Meier success probability (%) according to cement (SuperBond-C&B *red*, Panavia F *blue*, Ketac Cem *green*) and time interval of duty (years); accounting for relative failures

**Fig. 4** Catastrophic failure: bulk fracture of a Panavia F cemented crown after 24 months

[5]. In the present study, 4-META/MMA-TBB and MDP-based resin cements showed no superior performance with respect to secondary caries as compared to a conventional glass ionomer cement.

Severe hypersensitivity that ultimately led to endodontical treatment was noted in 7.4 % ($n=11$) abutment teeth; 14.3 % Ketac Cem ($n=4$), 8.1 % Panavia F ($n=5$) and 3.4 % Super Bond C&B ($n=2$). This incidence is slightly higher than the results of up to 6 % reported in the literature [5, 34]. This may be caused by irritation from cavity preparation and the remaining structure and quantity of dentin, pulpal inflammation, and bacterial microleakage [11]. Full-coverage crown preparations were performed by experienced prosthodontists according to the manufacturer's recommendations. Minimal invasive crown designs, that require less removal of tooth structure evolved with the introduction of novel all-ceramic materials. These preparation designs could have been beneficial for the outcome of this study [35]. Another reason for stimulation of postoperative discomfort after cementation of indirect restorations could be related to the type of cement used. One major drawback of conventional glass ionomer cements is the low setting pH value, which may cause post-operative sensitivity [11, 36]. The etching procedure during

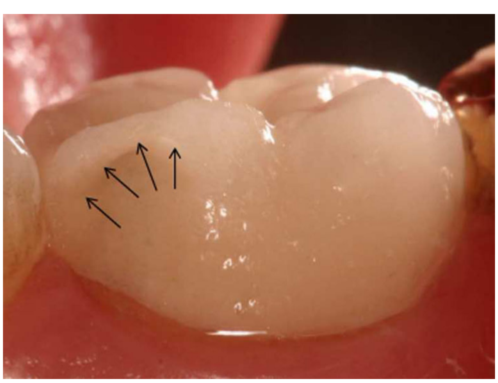

**Fig. 5** Clinically unacceptable chipping of a Super Bond C&B cemented crown after 6 months

adhesive cementation opened the dentinal tubules and stimulated the nerve fibers through a fluid movement and is therefore frequently mentioned as a reason for postoperative hypersensitivity [37]. However, no significant difference between the three types of luting cements was observed. This is in accordance with a preceding study, that showed a similar incidence of postoperative hypersensitivity after cementation of full-crown restorations with a conventional glass ionomer cement and a 4-META resin cement [11].

No clinical longitudinal studies with a comparison of 4-META-, MDP-based resin cement and conventional glass ionomer cement on hypersensitivity are currently available. The incidence of Bravo-rated restoration margins (28.2 %) was within the clinically acceptable range. Several clinical studies on all-ceramic crowns have reported marginal deterioration with an incidence of less than 30 % [22]. Marginal degradation of InCeram Alumina restorations at a rate of 16.5 % was also detected in an observation period over 4 years [38]. Super Bond C&B, Panavia F and Ketac Cem cemented restorations showed an increase of marginal discoloration over time ($p \leq .0001$), with no difference with respect to the different cement materials ($p=.542$). The marginal impairment could be attributed to the degradation of the resin-bonded interfaces, which is extensively reported in the dental literature [39].

With the development of high-strength glass and oxide ceramics recent literature and clinical application of glass-infiltrated ceramics became sparse. All-ceramic systems such as lithium disilicate or zirconia are used increasingly for posterior crown indications. Lithium disilicate ceramics showed promising survival rates of 96.3 % after 4 years for posterior monolithic CAD/CAM single crowns [40] and 97.4 % after 5 years for veneered lithium disilicate single crowns [41]. Porcelain-veneered zirconia single crowns also demonstrated acceptable cumulative survival rates of 88.8–98.1 % after 5 years [42, 43].

At the present, the null hypothesis can be accepted, as the clinical long-term success of InCeram Alumina crowns is independent of luting agent used. Failures and clinical interventions could be attributed to technical reasons such as core and veneer fractures, but also to endodontical complications and secondary caries. Further clinical comparisons are warranted.

## Conclusion

In this prospective, randomized clinical split-mouth trial covering an observation period of up to 5 years, posterior InCeram Alumina crowns showed acceptable long-term survival and success rates. Core fractures, fractures of the veneering material as well as endodontical complications and secondary caries were the limiting factors. Glass-infiltrated Alumina crowns in combination with adhesive as well as with conventional cementation can be considered as a reliable treatment option for posterior teeth.

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