

## An 18-year retrospective evaluation of glass-infiltrated alumina crowns

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**Objective:** To evaluate the long-term performance of conventionally luted In-Ceram crowns with a maximum follow-up period of 18.6 years. **Method and Materials:** Eighty patients (39 females and 41 males) were treated at the University of Göttingen with a total of 272 In-Ceram restorations (163 anterior and 109 posterior). All participated in a clinical follow-up examination (mean observational period,  $13.5 \pm 3.6$  years). Time-dependent crown survival (in situ criteria) and success rates (event-free restorations) were calculated according to Kaplan-Meier and analyzed in relation to the crown position (anterior vs posterior crowns) using a Cox regression model. **Results:** Forty-three complete failures (overall survival, 80.5%) were recorded; 73.4% remained event-free after 15 years. Of the 163 anterior restorations, 18 crowns failed (9 fractures and 9 biologic reasons), resulting in a survival rate of 87.5% after 15 years (success rate, 82.7%). The remaining complete failures (10 fractures, 8 biologic reasons, and 7 changes of treatment plan) were recorded for posterior crowns (survival rate, 68.3%; success rate, 56.9%). Cox regression revealed a significant difference in survival ( $P = .00523$ ) and success rates ( $P = .000297$ ) of anterior and posterior crowns. **Conclusion:** The survival and success rates of anterior In-Ceram crowns at 15 years are comparable to those published for metal-ceramic crowns. Significantly lower survival rates and an increased rate of complications should be expected if In-Ceram crowns are placed on premolars and molars. Chipping of the veneering material was the most frequent technical complication in the posterior area. (*Quintessence Int* 2011;42:625–633)

**Key words:** all-ceramic, aluminous core restorations, clinical performance, retrospective study, single crowns

All-ceramic crown restorations have been used as an alternative to metal-ceramics in the anterior region for many years. Early all-ceramic systems exhibited high failure rates by fracture, especially if used for posterior crowns.<sup>1–3</sup> Therefore, the need for increased crown strength has directed the development of new all-ceramic systems. In 1989, glass-infiltrated aluminum oxide core resto-

rations (In-Ceram Alumina, Vita Zahnfabrik) were introduced.<sup>2</sup> The high-strength ceramic core is fabricated by sintering a densely packed slurry (80 to 82 wt%) of pure  $Al_2O_3$ , followed by infiltration with molten glass.<sup>3,4</sup> Glass and alumina phases for In-Ceram all-ceramic crowns are interpenetrating; thus, crack propagation should be effectively limited. Unlike most high-strength industrial ceramics, this material system can be processed in a regular dental laboratory.<sup>5</sup> Due to their improved load-bearing capacity, these restorations could be used for conventionally cemented all-ceramic crowns and anterior three-unit fixed partial dentures (FPDs). Although In-Ceram has been extensively investigated in vitro over the past 20

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years, limited clinical performance data have been published.<sup>5-7</sup>

Clinical results for In-Ceram single crowns have been published on only short- and midterm bases. A recently published systematic literature review identified 12 relevant publications with a total of 1,724 In-Ceram alumina crowns observed over mean observational periods ranging from 20.8 to 40.6 months.<sup>1-12</sup> The reported crown survival rates were between 86.5% and 100.0%; however, most short-term studies had small sample sizes, which were insufficient to monitor fracture (survival rates ranging from 98.4% to 100.0%), and most of the crowns included were followed-up for relatively short periods. Clinical results on a midterm basis (mean follow-up times, > 3 years) have been published in 10 clinical studies. They cover a total of 1,603 single crowns with mean follow-up periods ranging from 3.2 to 4.2 years. The reported survival rates range from 90.0% to 98.5%.<sup>13</sup>

In a systematic review based on these midterm clinical results, a meta-analysis demonstrated that In-Ceram crowns placed on anterior teeth demonstrate survival rates comparable to those seen for metal-ceramic crowns.<sup>13-17</sup> However, lower survival rates have to be expected if this type of crown is used on premolars and molars.<sup>13</sup> Nevertheless, long-term evaluations with mean follow-up periods of more than 10 years are available for metal-ceramic crowns and are still rare for all-ceramic crowns.<sup>18-22</sup>

To date, only one study for a monolayered material (Dicor) with an observational period of more than 10 years has been published.<sup>21</sup> Long-term clinical data for bilayered all-ceramic materials, which are supposed to show different clinical failure patterns than monolayered materials, are still lacking. Long-term data for a bilayered material would be helpful in understanding how these all-ceramic dental materials fail. This knowledge would be especially helpful in research on more recently introduced bilayered materials such as zirconia-feldspathic ceramics.

The purpose of this study was to retrospectively evaluate the survival and complication rates of bilayered glass-infiltrated alumina crowns (In-Ceram) in a university setting over a follow-up period of up to 18

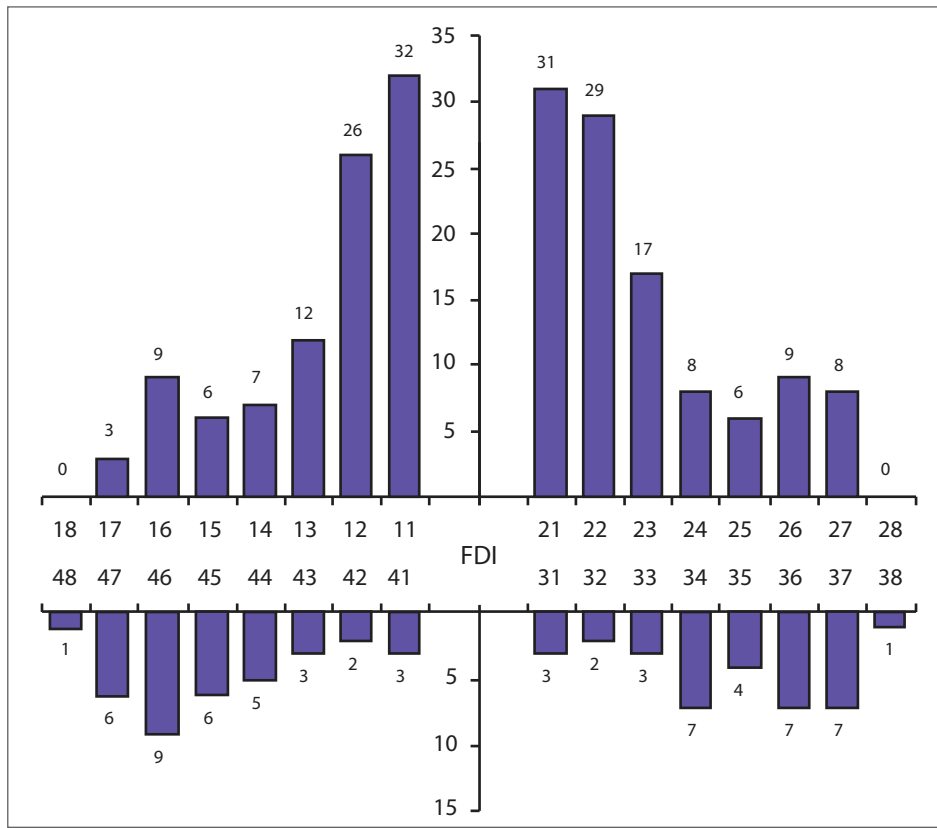
years. This investigation hypothesizes that the position of the crown in the mouth will influence the survival and technical complication rates of In-Ceram single crowns.

## METHOD AND MATERIALS

This study involved a retrospective assessment of patient records and clinical follow-up examination. All patients who had been restored with In-Ceram alumina crowns by faculty members of the Prosthetic Department of the Georg-August University in Göttingen, Germany, between 1991 and 1999 were asked to participate in the study. Inclusion criteria were conventionally cemented single-tooth restorations on natural teeth and antagonists either restored with fixed restorations or intact natural dentition.

Consequently, implant-borne and splinted restorations were excluded as well as crowns made from modifications of the In-Ceram material (In-Ceram Spinell and In-Ceram zirconia) and restorations without an antagonist. A total of 113 patients fulfilled these criteria.

Initial contact was made in writing, and follow-ups were conducted by telephone. Only patients who attended the follow-up examination were included in the study. All participants were examined by one of two prosthodontists. An initial examination was performed to ensure calibration of the examiners. Patients received a complete intraoral examination, wherein intraoral photographs recorded the current state of their all-ceramic crowns. The evaluation of the In-Ceram crowns included: (1) core fracture, (2) fissures and chipping of the veneering ceramics, (3) secondary dental caries, (4) loss of retention, and (5) biologic complications (for example, endodontic or periodontal treatments). Radiographs were taken for an additional analysis of crown margins, secondary dental caries, and the potential requirement of periodontal treatment. Crown survival was defined according to in situ criteria, including all restorations that remained in function during the observational period. A restoration was defined as successful if it remained event-



**Fig 1** Distribution of the included In-Ceram restorations.

free during the evaluation period without any clinical intervention.

Of the 113 patients who fulfilled these inclusion criteria, 80 (39 females and 41 males) participated in a clinical follow-up examination between March 2009 and February 2010. They were included in the study. The study design was approved by the Human Research Ethics Committee at the University of Göttingen, Germany. All complications leading to a replacement of a crown (technical and biologic complications) were defined as total failures.

The survival time of a restoration was defined as the period between the day of cementation and the final follow-up appointment or, in the case of a failure, the appointment scheduled to address the failure as documented in the patient's file. A restoration was defined as successful if it survived event-free without any clinical intervention. The time-dependent survival rates of the restorations (in situ criteria) and success

rates (no intervention) of the crowns were calculated according to Kaplan-Meier.<sup>23</sup>

Different observations in one and the same patient (several crowns per patient) were dependent. This dependence was allowed for by an adjusted variance estimation in the Cox regression model. Thus, for the analysis of the data, a marginal model was applied.<sup>24</sup> Univariate Cox regression was performed for the tooth position as an influence factor. A level of significance of < 5% was accepted to determine a statistically significant influence.

## RESULTS

The mean observational period for the 272 In-Ceram restorations (163 anterior crowns and 109 posterior crowns) was 13.5 ± 3.6 years with a maximum follow-up time of 18.6 years (Fig 1). Forty-three complete

<b>Table 1 Distribution of complete failures and complications</b>			
	<b>Anterior (n = 163)</b>	<b>Posterior (n = 109)</b>	<b>Total (n = 272)</b>
<b>Type of complete failure</b>			
Technical (core fracture and veneer fracture)	9	10	19
Biologic (caries, periodontal, and endodontic)	9	8	17
Change of treatment plan	0	7	7
Total	18	25	43
<b>Type of complication</b>			
Loss of retention	1	3	4
Minor chipping	5	7	12
Endodontic treatment	7	2	9
Caries	5	12	17
Total	18	24	42

Four restorations with complications transitioning to complete failures in the course of the study (three anterior crowns and one posterior crown).

failures leading to a loss of the restoration were recorded. An overall survival rate (Kaplan-Meier according to the in-situ criteria) of 80.5% after 15 years was calculated (10-year survival rate according to Kaplan-Meier, 91.5%). Of the 43 failures, 19 were due to technical reasons (core fracture and extensive veneer fracture) and 17 were caused by biologic reasons (secondary caries, endodontic failures, and periodontal reasons). In addition, seven posterior restorations had to be removed due to a change in the prosthetic treatment plan.

An additional 42 restorations required a clinical intervention during the observational period to maintain function. The most frequent complications were caries lesions (n = 17) followed by chipping of the veneer porcelain (n = 12) that required intraoral polishing. Caries lesions were treated with a composite filling to maintain the restoration (Table 1). Endodontic treatment was necessary for nine restorations, and four losses of restorations were recorded. Over the duration of the study, four restorations began with complications and continued to complete failures.

Restorations that remained event-free were rated as successful. Based on this criterion, the success-rate (Kaplan-Meier) was 73.4% after an observational period of 15 years. The corresponding success rate after

10 years was 86.4%. Of the 163 anterior crowns, 18 failed during the observational period, resulting in a survival rate (Kaplan-Meier according to the in situ criteria) of 87.5% after 15 years. Nine anterior crowns failed due to biologic reasons (endodontic/periodontal problems or caries). In addition, nine crowns were replaced due to a fracture of the alumina core or an extensive fracture of the veneering ceramics (Fig 2). The remaining complete failures (n = 25) were recorded for posterior In-Ceram crowns, and their survival rate after 15 years was 68.3%. The most frequent types of failures for posterior crowns were fractures of the core or extensive fractures of the veneering material (n = 10) (Fig 3), followed by biologic reasons (caries, periodontal problems, and endodontic failures) (n = 8). Furthermore, seven posterior restorations had to be removed due to changes of the prosthetic treatment plan (Table 1).

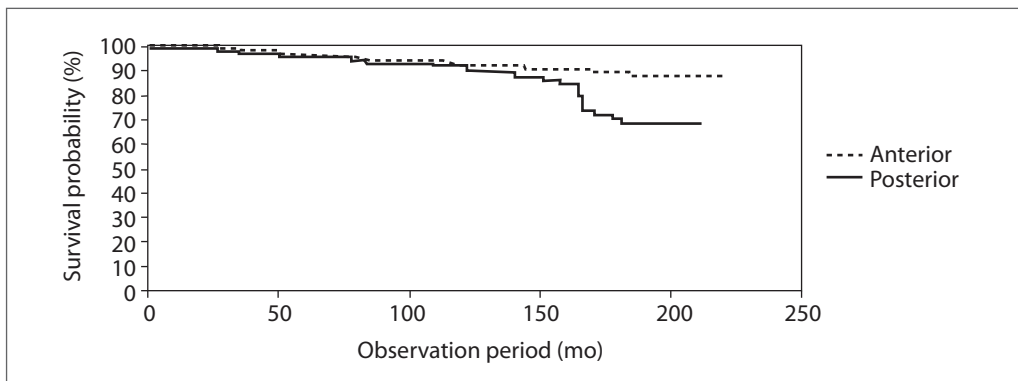
The Cox regression revealed a significant difference ( $P = .005232$ ) in the survival rates (in situ criteria) of anterior crowns compared to posterior crowns (Fig 4). Based on these findings, the hypothesis was confirmed. Of 163 anterior restorations, 18 complications were recorded that required a clinical intervention to maintain function. The most frequently required intervention was endodontic treatment (n = 7), followed by a



**Fig 2** Clinical example of core fracture of anterior crown leading to replacement of restoration.



**Fig 3** Extensive fracture of veneering ceramics that led to replacement of restoration.



**Fig 4** Time-dependent crown survival rates (Kaplan-Meier) in relation to crown position (anterior crowns = incisors + canines, posterior crowns = premolars + molars).

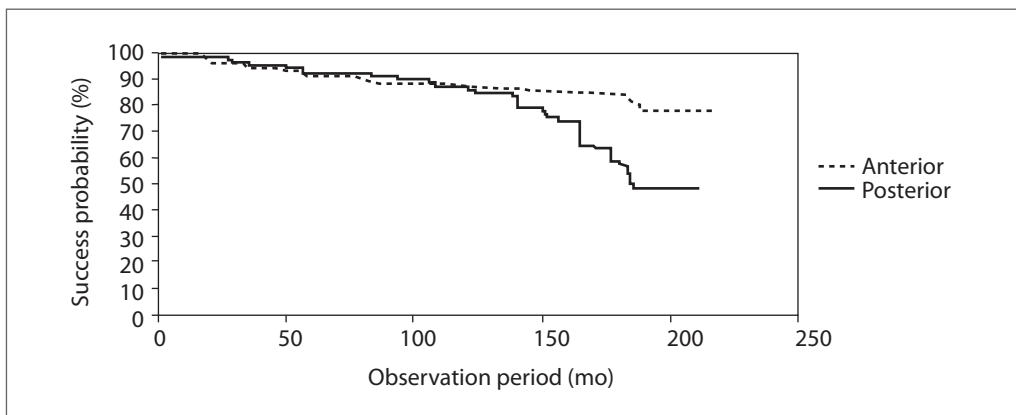
**Fig 5** Clinical documentation of four anterior crowns that remained event-free for an observational period of 11 years.



polishing of minor chippings of the veneering porcelain (n = 5) (see Table 1). Other complications included recementation of a single crown (n = 1) and the treatment of secondary caries (n = 5) with composite fillings. During the course of the study, three restorations with complications failed com-

pletely. Nonetheless, 130 of the 163 anterior restorations remained event-free during the observational period of this study.

The success rate (event-free restorations) of anterior restorations was 82.6% after 15 years (86.6% after 10 years) (Fig 5). In the 109 posterior crowns, 24 complica-



**Fig 6** Time-dependent success rates (Kaplan-Meier) in relation to crown position (anterior crowns = incisors + canines, posterior crowns = premolars + molars).

tions leading to a clinical intervention were observed: 12 complications were caused by caries and two endodontic treatments were rated as biologic complications. Ten interventions were caused by technical reasons (seven had chipping of the veneering porcelain, while three had loss of retention) (see Table 1).

Only one restoration with a complication resulted in a complete failure during the course of the study. Thus, a total of 48 restorations showed a complication or complete failure. Of the 109 investigated posterior restorations, 61 remained event-free, resulting in a success rate (according to Kaplan-Meier) of 56.9% after 15 years (85.9% after 10 years). A comparison of the success rates for anterior and posterior In-Ceram crowns using the Cox regression model showed a significant difference ( $P = .000297$ ) (Fig 6).

## DISCUSSION

The overall survival rate for anterior and posterior In-Ceram crowns after the 15-year study period was 80.5%. Clinical data on the clinical performance of glass-infiltrated aluminous core restorations with a similar observational period have not yet been published. Long-term clinical data of all-ceramic crowns with an observational

period of up to 14 years are available for only glass-ceramic crowns. In a study with adhesively luted glass-ceramic crowns, an overall survival rate of 76% after 14 years was calculated.<sup>21</sup>

In this study, only fractured crowns were counted as failures. Thus, this evaluation revealed a high incidence of technical failures for glass-ceramic restorations. In the present study, only 19 of 43 complete failures were due to material fractures. Based on the different survival criteria, the long-term survival of conventionally luted In-Ceram crowns seemed to be higher than was reported for adhesively luted glass-ceramic crowns and feldspathic porcelain crowns.<sup>21,22</sup> The results of the present study can also be compared to long-term data (mean observational period, 10 years) for metal-ceramic crowns.

Despite some differences in terms of study and sample characteristics, survival definitions, and types of material, there is a general similarity of the reported survival proportions. Most studies on the clinical performance of metal-ceramic single crowns reported a survival of more than 80% for up to 10 years.<sup>14,16</sup> Only a few studies have reported survival data for mean observational periods exceeding 10 years. In a retrospective study covering 1,037 full crown restorations, a survival rate (in situ criteria) of 78% after 18 years was reported. In this study, biologic failures (66%) occurred

more often than technical failures. The most frequent technical reasons for failures were porcelain fracture and loss of retention.<sup>19</sup> In another long-term retrospective evaluation of 50 patients with 100 porcelain-fused metal single crowns, an overall survival rate of 78% after 20 years was reported.<sup>18</sup> Based on the same survival criteria, the glass-infiltrated core restorations evaluated in the present study revealed similar survival rates after an observational period of 15 years. In studies of metal-ceramic crowns, biologic reasons were the most common reason for failures.<sup>14–16,19</sup> In the present study, the failures were accounted nearly equally on technical and biological reasons. This differs from the results of earlier studies on the clinical performance of all-ceramic crowns, wherein a core fracture was the most frequent reason for complication (85% of the losses).<sup>13</sup>

In the present study, 19 of the 43 complete failures were caused by a core fracture or an extensive fracture of the veneering material. After 5 years, Goodacre et al<sup>15</sup> calculated a mean fracture incidence of 13% for all-ceramic crowns. The aluminous core restorations evaluated in the present study revealed a mean fracture rate of 7% after a mean observational period of 13.5 years. In comparison to conventional ceramics, this indicates the improved mechanical strength of the glass-infiltrated aluminous core leads to a reduction in technical failures.

Smales and Hawthorne<sup>20</sup> reported a success rate (event-free restorations) of 81% after 15 years for porcelain-fused-to-gold crowns. These findings agree with the results of another retrospective study reporting a 20-year success rate of 75% for metal-ceramic crowns.<sup>18</sup> The overall-success rate in the present study was 73.4% after 15 years. This indicates a slightly increased complication rate that was basically due to technical complications. Indeed, 28.5% of the complications associated with In-Ceram crowns were caused by chipping of the veneering material. This percentage is higher than the technical complication rates for metal-ceramic crowns.<sup>13,18,19</sup> A loss of retention was identified in three restorations, leading to a complication rate of 1.3%. This is well within the range documented in other studies, where the mean loss of retention

was determined to be 2%.<sup>15</sup> With a mean rate of 1.75%, the incidence of endodontic treatments is also within the range reported in literature.<sup>15</sup> In accordance to the results of long-term clinical studies of porcelain-fused-to-metal restorations, caries was determined as a frequent cause for failures and complications.<sup>13,15</sup>

The survival rate for anterior crowns after 15 years was 87.5% compared to 68.3% for posterior crowns. Only 56.9% of the posterior restorations remained event-free after an observational period of 15 years (82.7% for anterior restorations). When analyzing the survival and success rates of the restorations according to their position in the mouth, it became evident that glass-infiltrated alumina crowns performed better in the anterior region, with significant differences in the time-dependent survival ( $P = .005232$ ) and success rate ( $P = .000297$ ). These results mark a difference in the clinical performance of glass-infiltrated alumina crowns compared to metal-ceramic restorations. Two studies evaluating the clinical performance of metal-ceramic crowns showed no significant differences in the survival rates of anterior or posterior metal-ceramic crowns.<sup>17,19</sup> The survival rate of the anterior In-Ceram restorations is equivalent to the survival rate reported for metal-ceramic restorations after 15 to 20 years in retrospective studies with the same survival criteria.<sup>18,19</sup> Compared to these findings, the clinical performance of posterior In-Ceram crowns is obviously reduced. When comparing the reasons for failure or a clinical intervention, a clear difference between anterior and posterior restorations can be seen. In the anterior area, 8.6% of the failures or clinical interventions had a technical origin related to the restorative material used. In the posterior area, this share was nearly twice as high (15.6%). As expected for a bilayered material, a chipping of the veneering material was the most frequent technical complication; it was predominantly determined in the posterior area.

The data of the present investigation describe the tooth position as a key factor for the long-term success of glass-infiltrated aluminous core restorations. They support the findings of a systematic review on the failure and complication rates of single crowns.<sup>13</sup> In this systematic review, the authors conclude

that all-ceramic crowns used for anterior teeth demonstrate high survival rates comparable to those of metal-ceramic crowns. The survival rates of In-Ceram and glass-ceramic crowns used for posterior teeth were decreased and significantly lower than those documented for metal-ceramic crowns. Although this review is based only on the results of midterm studies, it provides a good estimation of the long-term results for glass-infiltrated aluminous core restorations reported in the present study.

When interpreting the results of the present study, the inherent limitations of a retrospective study should be considered. A typical problem of retrospective studies is the availability of consistent analyzable data; however, this did not apply to the present retrospective study, as the clinical findings had been recorded in the Department of Dental Prosthetics since 1989 according to a standardized procedure. It can therefore be assumed that the recorded data are representative and comparable. Another limitation of retrospective studies that include follow-up examinations is that inferences can only be generalized to the population segment that participated in the study.<sup>8</sup> Of the 113 patients contacted, 33 did not participate. This led to a response rate of 70.8%. This response rate is well in the range of data published for other long-term retrospective studies with a clinical follow-up examination and an observational period of 15 to 20 years.<sup>18,19</sup> Patients gave multiple reasons for not participating. Most frequently, they moved out of the area, had a severe disease, or had died. Only a small group of patients ( $n = 8$ ) chose a private practitioner for maintenance. Nevertheless, a possible selection bias toward patients who were satisfied with the entire treatment may result. In such an instance, the group would represent a positive selection of the complete sample. This selection bias could result in a positive overestimation of the survival and success rates. Nevertheless, considering the preconditions of this study, the results were achieved under typical clinical conditions with a diverse group of well-trained dentists. Due to the long follow-up period and the large number of teeth and restorations involved, the present study provides valuable data on the long-term clinical behavior of bilayered all-ceramic restorations.

## CONCLUSION

The following conclusions were drawn based on the results of this retrospective assessment of 272 all-ceramic In-Ceram crowns:

- The survival and success rates of In-Ceram single crowns are significantly influenced by the position of the restoration in the mouth. Anterior restorations showed a higher survival probability than posterior In-Ceram crowns.
- In the anterior area, failures were caused equally by biologic and technical reasons. In the posterior area, most failures and clinical interventions were due to technical reasons (core fracture and chipping of the veneering material).
- The long-term survival and success rates of anterior glass-infiltrated aluminous core restorations are equivalent to the long-term survival rates published for metal-ceramic restorations.

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