Five-Year Follow-up of Implant-Supported Y-TZP and ZTA Fixed Dental Prostheses. A Randomized, Prospective Clinical Trial Comparing Two Different Material Systems

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Purpose: The aim of this study was to evaluate the clinical performance of two- to five-unit implant-supported all-ceramic restorations and to compare the results of two different all-ceramic systems, Denzir (DZ) and In-Ceram Zirconia (InZ). ***Materials and Methods:*** Eighteen patients were treated with a total of 25 two- to five-unit implant-supported fixed dental prostheses. Nine patients were given DZ system restorations and 9 were given InZ system restorations. The restorations were cemented with zinc phosphate cement onto customized titanium abutments and were evaluated after 1, 3, and 5 years. ***Results:*** At the 5-year follow-up, all restorations were in function; none had fractured. However, superficial cohesive (chip-off) fractures were observed in 9 of 18 patients (11 of 25 restorations). Sixteen units in the DZ group (9 of 13 restorations) and 3 in the InZ group (2 of 12 restorations) had chip-off fractures. The difference between the two groups regarding frequency of chip-off fractures was statistically significant ($P < .05$ at the FDP level and $P < .001$ at the unit level). ***Conclusion:*** The results suggest that all-ceramic implant-supported fixed dental prostheses of two to five units may be considered a treatment alternative. The DZ system, however, exhibited an unacceptable amount of veneering porcelain fractures and thus cannot be recommended for the type of treatment evaluated in this trial. Poor compatibility or problems with the bond mechanisms between the veneer and framework could not explain the chip-off fractures. Stress distribution, as well as other factors concerning the veneering porcelain, need to be evaluated further. *Int J Prosthodont 2010;23:555–561.*

All-ceramic fixed dental prostheses (FDPs) were introduced as a treatment alternative in the mid-1960s. Owing to the high fracture rates of early restorations, however, it was not until the development of new high-strength ceramic framework materials, often referred to as oxide ceramics, that the use of all-ceramic FDPs could be recommended for use in both anterior and posterior regions. Zirconia-based restorations have been suggested as the most successful all-ceramic system for FDPs for the future because of a low fracture rate, possibly due to the unique crack inhibitory material properties of yttria-stabilized tetragonal zirconium dioxide polycrystals.[1] The results of laboratory studies on oxide ceramics show promising results for zirconia, and the success rates of published clinical studies, although of limited follow-up time, are approaching those of porcelain-fused-to-metal FDPs.[2–9]

The survival rates of all-ceramic implant-supported single crowns (ISCs) are reportedly high. In a review article, the survival rate for ISCs was 94.5% after 5 years. Metal-ceramic ISCs showed a survival rate of 95.4%, compared to 91.2% for all-ceramic ISCs.[10] Unfortunately, not enough information is available comparing metal-ceramic and all-ceramic ISCs.

Clinical studies so far have only concerned FDPs supported by natural teeth. When teeth are lost, implants can be used to replace the natural abutments. Today, implant-supported FDPs have become an increasingly more common treatment alternative. Few clinical studies on all-ceramic FDPs supported by dental implants, however, have been published, and none with a follow-up of more than 1 year.[11,12] Results from a laboratory study comparing tooth- and implant-supported all-ceramic restorations favored implant support. Loads at fracture were significantly higher in the group of all-ceramic FDPs supported by implants compared to the group supported by tooth analogs.[13]

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However, at the 12-month follow-up of the patients in the present study, problems with chipping of the veneering porcelain were noted, similar to several clinical reports on tooth-supported zirconia-based restorations.[6,7,11,14] Therefore, it is important to report on the long-term results for tooth- and implant-supported zirconia-based restorations and to evaluate the cause of the veneer fractures.[1]

The aim of the present study was to evaluate the clinical performance of implant-supported all-ceramic FDPs composed of two different material systems after 5 years.

Materials and Methods

Twenty-five implant-supported all-ceramic FDPs were fabricated for 18 patients. Nine patients received 12 FDPs of a zirconia-toughened alumina (In-Ceram Zirconia, Vita Zahnfabrik [InZ]) and nine received 13 FDPs of a yttria-stabilized tetragonal zirconia polycrystal material (Denzir, Decim [DZ]). The span of the FDPs was two to five units, and the total number of units was 31 and 35 in the DZ and InZ groups, respectively.

A total of 320 individuals who regarded themselves as in need of prosthetic treatment responded to an advertisement in a local newspaper. After a short preliminary interview, followed by panoramic radiographic examination, 18 patients (12 women, 6 men; age range: 37 to 70 years) who were partially dentate met the inclusion criteria, which were indications for one or more two- to five-unit implant-supported FDPs and satisfactory oral hygiene. The FDPs were to be supported by two or three implants. Exclusion criteria consisted of bone dimensions insufficient for implant placement, deep occlusion, and diagnosed bruxism. Customary anamnestic information regarding general health, allergies, and smoking habits was collected. However, these factors were not regarded as reasons for exclusion. None of the 18 patients were excluded. The patients were informed about the protocol of the study, the risks of and alternatives to the proposed treatment, and gave their informed consent. An extended warranty for the restorations was offered in case of failure. Ethical approval of the study was obtained from the Regional Ethics Committee, Lund University.

One clinician at the Department of Oral and Maxillofacial Surgery, Malmö University Hospital, performed the surgical treatment for all patients. Two clinicians at the Department of Prosthetic Dentistry performed the prosthetic treatment of 11 and 7 patients with 16 FDPs (7 InZ, 9 DZ) and 9 FDPs (5 InZ, 4 DZ), respectively.

Dental implants (Astra Tech standard or ST, Astra Tech) were placed according to the surgical instructions of the manufacturer in a single-stage surgical procedure. The healing time before prosthetic treatment was a minimum of 3 months in the mandible and 6 months in the maxilla, according to a standard protocol. Patients were subsequently divided into two groups of nine, one group with DZ FDPs and one with InZ. Patients were randomized to the two groups by drawing lots.

Full-arch impressions were taken using a polyether impression material (Impregum, 3M ESPE) in disposable trays (SOLO, Davis) to allow use of the open-tray technique. Impressions of the opposing arch were taken using alginate in rigid standard stainless steel trays (Svedia, Svedia Dental Industri), and interocclusal registrations were taken in centric relation using aluminium wax (Alminax, Associated Dental Product, Kemdent Works). Preparable titanium abutments (Profile BiAbutment, Astra Tech) were used. The supporting implant abutments were prepared with a cervical shoulder depth of 1.2 mm and slightly rounded inner angles. The preparations allowed a minimum occlusal thickness of 1.7 mm and minimum buccal, approximal, and lingual/palatal thicknesses of 1.5 mm. The desired angle of convergence was 15 degrees. The preparations were performed using a parallelometer with a standardized cutting instrument to ensure achieving the necessary dimensions.

All laboratory procedures were carried out at a dental laboratory (DP Nova) that had been authorized by the manufacturers of the material systems. The clinicians responsible for the treatment inspected and measured the thickness of the inner constructions and connectors. The minimum acceptable diameter of the connection between crown and pontic was 3 mm for anterior and premolar replacements. In cases of molar replacement, the minimum diameter for the pontic connectors was set at 4 mm. For FDPs with no pontics, the minimum diameter between connecting abutments was set at 3 mm. The frameworks were inspected clinically and examined radiographically from the occlusal and buccal aspects to detect any possible flaws. Any frameworks exhibiting visible pores, other defects, or not giving adequate support to the veneering porcelain were to be remade. After inspection and approval, the frameworks were veneered with porcelain, as recommended by the manufacturer at the time of the study, and fired accordingly in calibrated furnaces. Esprident Triceram (Dentaurum) veneering porcelain was used for DZ FDPs and Vitadur Alpha (Vita Zahnfabrik) for InZ.

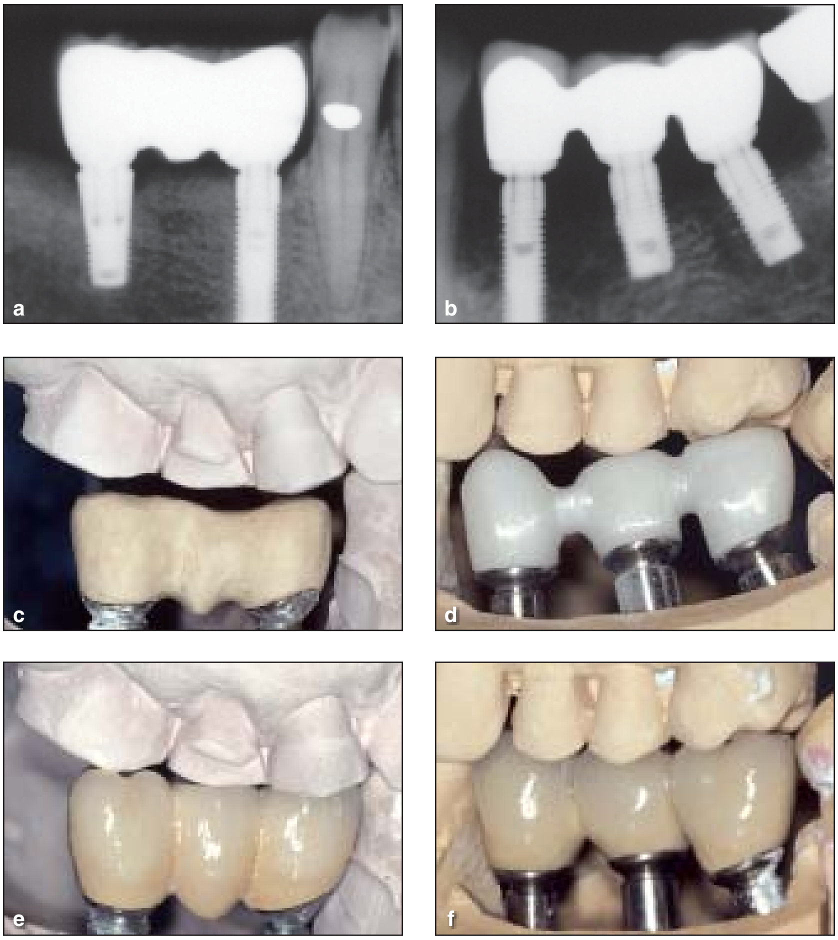

Fig 1 Examples of **(a and b)** radiographs, **(c and d)** frameworks, and **(e and f)** definitive FDPs of the **(a, c, and e)** InZ and **(b, d, and f)** DZ all-ceramic systems.

To avoid creating microcracks and flaws in the material during removal, no temporary cementation was performed, and the completed FDPs were fit, adjusted, and cemented permanently with zinc phosphate cement (De Trey zinc crown and bridge Fixodont Plus, Dentsply) in one sitting. The occlusion was checked using GHM Hanel single-sided occlusion foils (Hanel GHM Medizinal) and, if necessary, adjusted using fine-grit diamond burs (Two striper VF grit, Abrasive Technology) in a high-speed turbine handpiece cooled with copious water spray and polished with rubber points (Identoflex, Identoflex) and a polishing paste (Temrex Diamond, Temrex). Patients were scheduled for final check-ups 1 to 2 weeks after cementation (Fig 1). Follow-up examinations were performed after 6, 12, 36, and 60 months by two calibrated dentists who were not responsible for the treatment. Examinations were performed blindly and the examiners were not aware of which material system each patient had received. The follow-up examinations included registrations of the surface, anatomical form of the restoration, occlusion and articulation, marginal integrity, pocket depth, bleeding on probing, and mobility.

The surface of the restoration was rated as excellent, acceptable, retrievable, or not acceptable according to a slightly modified California Dental Association quality assessment system (Table 1).[15] A fracture was registered as cohesive when veneering porcelain was present on the surface to such an extent that it was easily detected visually. If no remnants of veneering porcelain were detected visually, the fracture was registered as adhesive. Fractured surfaces were polished if necessary.

A restoration was regarded as a success if all registrations were Romeo (excellent) or Sierra (acceptable). A restoration remaining in situ with or without modification was regarded as surviving.

Differences in the amount of fractures were calculated using the Fisher exact probability test. The statistical method was chosen after consultation with a statistician.

Results

At the five-year follow-up, all FDPs were in use and all patients were fully satisfied with their treatment. None of the FDPs had fractured through the framework, but

Table 1 Surface According to the Modified California Dental Association Protocol

Romeo (excellent)	Surface of the restoration is smooth, no irritation of adjacent tissue
Sierra (acceptable)	Surface of the restoration is slightly rough or pitted, can be polished but is unnecessary
Tango (retrievable)	Surface is grossly irregular, not related to anatomy, and not subjected to correction; can be polished
Victor (not acceptable)	Surface is fractured or there are gross porosities in the material that cannot be corrected by polishing, anatomical form functionally insufficient

Fig 2 Example of a chip-off fracture.

superficial (chip-off) fractures were observed in 9 of 18 patients (Fig 2). The chip-off fractures were limited in size and could be polished. Consequently, there was no need for replacement of any of the FDPs, resulting in a 100% survival rate for both groups. Table 2 denotes the details on placement of the FDPs and location of chip-off fractures.

The amount of fractures differed substantially between the two material systems in respect to the number of patients, FDPs, and units affected, resulting in significantly different success rates for the two material systems. Seven of nine patients in the DZ group showed chip-off fractures, whereas two patients in the InZ group showed such fractures. Nine DZ FDPs (69%) and two InZ FDPs (17%) showed chip-off fractures. Sixteen units (52%) in the DZ group and three units (9%) in the InZ group were affected. The success and survival rates from baseline to the 5-year follow-up are shown in Figs 3a and 3b. The differences were statistically significant for results at both the FDP ($P < .05$) and unit level ($P < .001$).

Three of the 16 fractures (19%) in the DZ group were judged to be adhesive. None of the fractures in the InZ group were adhesive.

Discussion

There are many ways to describe the clinical outcome of a treatment modality, but to enable comparisons between different material systems, it is important to use some type of standard. Survival is one such standard and has been defined as when the restoration remains in situ with or without modification during the entire observation period.[9] In that respect, it could be concluded that all restorations in the present study survived.

However, the results show a significant range between not only the survival and success rates within each material system investigated, but also the success rates between the two systems. Therefore, in spite of the fact that all patients were fully satisfied with their treatment and none of the complications resulted in a need for replacement, a discussion regarding the importance of the discrepancy between survival and success is recommended.

The results from this study are in agreement with other studies on tooth-supported all-ceramic FDPs that have shown acceptable survival rates and few complete fractures of the framework but have indicated problems with chipping of the veneering porcelain. Studies have shown varying frequencies of such fractures, ranging from 6% to 25%.[4,6,7,14] The present study found 17% of InZ FDPs showing chip-off fractures, a number comparable to the aforementioned studies, resulting in a 5-year success rate of 83%. Corresponding results for DZ FDPs, however, found 69% showing chip-off fractures and, thus, a 5-year success rate of only 31%.

The incidence of veneer fractures has been reported to be higher for all-ceramic FDPs compared to metal-ceramic FDPs—the gold standard. One review article found an estimated rate of chipping of 13.6% after 5 years for all-ceramic FDPs, compared to 2.9% for metal-ceramic FDPs.[9] The frequencies of framework fractures were also significantly higher in the all-ceramic group. However, when zirconia was used as the framework material, the reasons for failure were not fractures of the framework. The results from the present study are in accordance with these previous studies.

The FDPs in this study were implant-supported, a factor that must be considered when discussing success and survival rates since the biomechanical support differs between tooth- and implant-supported restorations. The complication rates for implant-supported FDPs have been reported to be higher than for tooth-supported FDPs. A comprehensive review article comparing tooth- and implant-supported FDPs found that both types of restorations show high survival rates, but 38.7% of implant-supported FDPs had complications after 5 years, compared to 15.7% of tooth-supported FDPs. The most common complications for tooth-supported FDPs were biologic. For implant-supported

Table 2 Placement of FDPs, Material System, and Location of Fractures

Patient no.	Restoration no.	Material system	FDP*				
1	1	DZ	25 ▶(C)	26			
	2	DZ	44	45			
	3	DZ	35 ■ (C)	36 ▶ (C)			
2	4	InZ	33	34	35		
3	5	InZ	22	23	24 ● (C)	25	26 ▶ (C)
4	6	DZ	24	25 ● (C)			
5	7	DZ	16 ▶ (C)	17			
6	8	DZ	36 ■ (A)	37 ■ (A)			
7	9	DZ	35 ■ (C)	36 ▶ (A)			
	10	DZ	44 ■ (C)	45 ▶ (C)	46		
8	11	InZ	44	45			
	12	InZ	34	35	36		
9	13	DZ	11	12	13	14	
	14	DZ	25	26			
10	15	DZ	14	15			
11	16	InZ	44	45	46		
12	17	InZ	35	36 ● (C)			
13	18	InZ	35	36	37		
	19	InZ	44	45	46		
14	20	DZ	35 ▶ (C)	36 ■ (C)	37 ▶ (C)		
15	21	DZ	34	35 ▶ (C)	36 ▶ (C)		
16	22	InZ	46	46	47		
17	23	InZ	24	25			
18	24	InZ	34	35	36		
	25	InZ	45	46	47		

Dark gray = abutment tooth; light gray = pontic; ▶ = chip-off fracture noted after 12 months; ■ = chip-off fracture noted after 36 months; ● = chip-off fracture noted after 60 months; A = adhesive; C = cohesive.
*FDI tooth-numbering system.

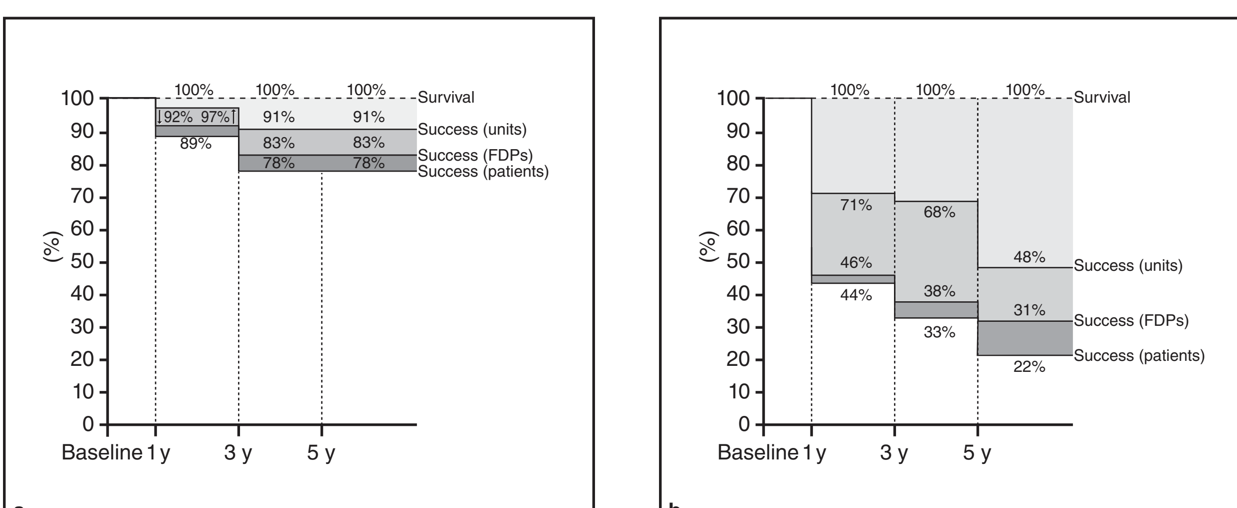

Fig 3 Survival and success for **(a)** InZ and **(b)** DZ material groups.

FDPs, however, technical complications in the form of ceramic fractures or chipping were the most frequent.[16] Another comprehensive review found similar differences as seen in the present study.[17]

Although chipping rarely impairs function or esthetics or leads to replacement of the restoration, it is an important factor to discuss. Several theories concerning the causes of veneer fractures have been presented. Factors such as design of the framework, the bond between the framework and veneer, mechanical properties, and handling of the veneering porcelain have been suggested to be of importance. However, no evidence favoring any of these theories has been put forward.

A well-designed framework will support the veneering porcelain during functional loading and provide conditions for mainly compressive forces instead of tensile forces within the porcelain. Since the compressive strengths of vitreous porcelains are more than 10 times higher than their tensile strength, the veneering porcelain is susceptible to tensile forces, and therefore it is important to design the framework to avoid such forces.[18] The present study was initiated when computer-aided design/computer-assisted manufacturing (CAD/CAM) technology did not provide full possibilities for individual design of the framework or adaptation to the opposing dentition, as modern systems do. With CAD/CAM, the technique used for manufacturing DZ FDPs, there is an inherent risk that the shape is insufficient regarding veneer support. If the software of the CAD system limits the possibilities for the dental technician to give the restoration an optimal shape and the porcelain layer is too thick, loads will lead to high tensile forces within the porcelain and risk resulting in veneer fractures. The technique involved in manufacturing InZ, however, yields few limitations in designing the framework. This could be one explanation for the differences in veneer fractures. It does not, however, provide the full explanation for the veneer fractures found in the present study, since the frameworks were checked before veneering, and no obvious differences were noted.

It has been suggested that the quality of the bond between the framework and veneer is of importance. A ceramic laminate will always form a constant strain system because of the mismatch of elastic moduli across the framework-veneer interface, which could be an important source of flaws.[19] The majority of the fractures in the present material (84%) were judged to be cohesive. This is in accordance with the results from another clinical study, as well as an in vitro study that did not find any adhesive fractures.[6,20] There are difficulties in ascertaining whether a veneer fracture is adhesive. A fracture judged to be adhesive could in fact be cohesive unless microscopic or chemical surface analysis proves otherwise, since remnants of the porcelain could be present on the surface but not detectable visually without the aid of a high-powered microscope. On the other hand, when defining a fracture as cohesive, veneering porcelain remnants are present to such an extent on the surface that it is easily detected visually. In the present study, all fractures with any visually detectable veneering porcelain remnants were judged as cohesive. Since no FDPs were to be removed, no further analyses were feasible. Therefore it is possible that the amount of fractures judged to be adhesive in the present material is actually less than reported because of the difficulties in defining them, as previously discussed. Consequently, poor compatibility or problems with the bond mechanisms between the veneer and framework are probably not major factors in explaining chip-off fractures.

Another possible reason for veneer fractures could be the mechanical properties within the veneering porcelain. To avoid exposing the zirconia framework to unfavorably high temperatures during porcelain firing, creating undesirable phase transformation, porcelain of a low firing temperature was used. Glass modifiers are added to lower the firing temperature of veneering porcelain. This modification, however, affects the mechanical properties of the veneering porcelain, making it more susceptible to tensile forces.[21] The veneering porcelain used for DZ (Esprident Triceram) is fired at temperatures ranging from 760°C to 800°C, while the veneering porcelain used for InZ (Vitadur Alpha) is fired at temperatures ranging from 920°C to 960°C. The difference in firing temperatures could be one explanation for the differences in veneer fractures between the two material systems in the present study. These porcelains were recommended by the manufacturers at the time; the recommendations concerning veneering porcelains for DZ have now been changed.

It is well known from the fracture mechanics of dental ceramics that strength is highly dependent on inherent flaws and cracks in the veneering material. Such defects can create mechanically defective microstructural regions, decreasing the strength of the material. Defects may originate from agglomerates in the porcelain powder, created during dental laboratory production or by the clinical procedures used. At the laboratory, such defects may stem from air bubbles or impurities incorporated when building up the porcelain. Surface cracks may be induced when grinding to create the final shape. Poorly calibrated furnaces may result in over- or underfired porcelain. In the clinical setting, surface flaws may be introduced when adjusting the occlusion by grinding. When introducing new techniques, a learning curve is expected, and the experience and material-handling of the dental technician, as well as the clinician, are important factors influencing the results.[6,8] However, in the present study, one dental technician fabricated all the InZ FDPs, and another, all the DZ FDPs, following the manufacturer's instructions. Both technicians were experienced in working with the materials used and were informed of the research protocol for the study. They were calibrated to minimize the risk of incorrect handling. The clinicians responsible for the treatment were experienced and were working at a specialist clinic. Thus, the most likely reason for the differences between the two materials can probably not be explained by the aforementioned factors, but is instead attributable to the differences in the mechanical properties and design limitations of the two material systems.

Conclusion

Results from this 5-year study suggest that all-ceramic implant-supported FDPs of two to five units may be considered a treatment alternative. When comparing the DZ and InZ ceramic systems, however, this study indicates that the DZ system, as used in the present study (Denzir in combination with Esprident Triceram veneering porcelain), cannot be recommended for the type of treatment evaluated until further studies have solved the problem of the unacceptably high frequency of veneering porcelain fractures.

Poor compatibility or problems with the bond mechanisms between the veneer and framework could not explain the chip-off fractures in the present study. The stress distribution in the interface between framework and veneer, however, as well as other factors concerning veneering porcelain, need to be further evaluated in future studies.

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