

Clinical evaluation of ceramic inlays and onlays fabricated with two systems: 12-year follow-up

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Received: 16 December 2014 / Accepted: 18 November 2015 / Published online: 12 December 2015
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Abstract

Objectives The aim of this study was to evaluate the 12-year clinical performance of sintered (Duceram, Dentsply-Degussa, Dentsply International Inc., PA, USA)—D and pressable (IPS Empress, Ivoclar-Vivadent, Schaan, Leichtenstein)—IPS ceramic inlay and onlay restorations.

Methods Eighty-six restorations were placed in 35 patients with a median age of 33 years by a single operator. The restorations were luted with dual-cured resin luting material (Variolink II, Ivoclar-Vivadent, Schaan, Leichtenstein) and Syntac Classic adhesive under rubber dam. The evaluations were conducted by two independent investigators at the baseline, 1, 2, 3, 5, and 12 years using the modified USPHS criteria.

Results At the 12-year recall, 22 patients were evaluated (62.86 %), totalling 48 (55.81 %) restorations. Seven restorations were fractured (one from Duceram and six from IPS), eight restorations presented secondary caries (three from Duceram and five from IPS), nine restorations showed unacceptable defects at the restoration margin and needed repair or replacement (two from Duceram and seven from IPS), and four IPS restorations presented pulp sensitivity.

Conclusion Chi-square and Mann-Whitney tests revealed that IPS Empress system showed the best results for color match and surface texture ($p < 0.05$) but a significant worse result for fracture ($p = 0.05$). Wilcoxon test showed significant differences in relation to color match, surface texture, marginal

discoloration, and marginal integrity between the baseline and 12-year recall for both ceramic systems.

Clinical significance This long-term clinical study observed that the main reasons for failure of ceramic restorations were related to fracture, recurrent caries, and decreased marginal integrity over time. Carefully monitoring of the ceramic-tooth interface may extend their clinical longevity.

Keywords Clinical trial · Glass ceramics · All-ceramic restorations · Dentin bonding agents

Introduction

All-ceramic materials have been considered an excellent choice to restore teeth with highly esthetic demands since it can combine esthetic with wear resistance, especially when dealing with extensive posterior restorations. Due to the worldwide acceptance of all-ceramic restorations, ceramics with high flexural strength have been developed in order to extend their indication for more complex dental prostheses [1, 2]. The development of higher strength ceramics is resultant of the increased use of crystalline material and filler particles that were added to the glass matrix in order to improve the ceramic's mechanical properties with decreasingly less glass phase until, finally, no glass content. Although high *crystalline-content* ceramics present higher strength, predominantly, glassy dental ceramics are more esthetic and have shown high bond strength to resin-based luting materials [3]. Currently, all-ceramic materials can be divided into three main categories according to their glass-to-crystalline ratio: predominantly glass-based ceramics, particle-filled glass ceramics, and completely polycrystalline ceramics (without glass content) [3, 4].

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Glass-based ceramics have been extensively used to fabricate inlays and onlays since they give the dentist and technician great flexibility in reproducing the natural shades of the tooth structure due to their high translucency [5, 6]. Additionally, the “selective etching” of the internal surface of glass-ceramic restorations results in an adequate micromechanical bond with resin-based luting materials [7, 8]. Different ceramic systems are available in the market, and all-ceramic restorations may be fabricated by different methods: powder condensation (conventional powder slurry ceramics), heat pressed (pressable ceramics), slip-casting (infiltrated ceramics), and milled (machinable or CAD/CAM ceramics) [5, 7]. One of the main problems associated with the conventional powder slurry ceramic (sintered ceramic) restorations is the presence of microporosities that develop during the fabrication process [4, 9]. These microporosities can lead to crack initiation and propagation, which may result in the development of fractures in the ceramic restoration [4]. In the early 1990s, a pressable ceramic system, IPS-Empress (Ivoclar-Vivadent, Schaan, Leichtenstein), was introduced as an innovative processing method for all-ceramic restorations [10]. IPS-Empress system consists of a heat pressed ceramic fabricated by the traditional lost-wax technique [10, 11]. The main advantage of the Empress ceramic is that the glass-ceramic ingot is fabricated under controlled conditions and heated to a temperature at which it becomes a highly viscous liquid to allow the material to flow under pressure into the lost wax mold [2, 4, 10, 11]. Leucite crystals are incorporated into the glassy matrix to strengthen the ceramic material by acting as a barrier to cracks and improving its mechanical performance [12, 13].

Although encouraging data have been published for pressable systems, a few prospective clinical studies have provided long-term evidence of clinical performance of inlay and onlay ceramic systems [14–17]. The most common failures observed on the clinical trials are related to fracture of the ceramic restoration and degradation of adhesive interface [14, 15, 18–22]. Deterioration of the marginal integrity has been related to luting agent wear, which tends to increase over time due to high differences in modulus of elasticity between ceramic and resin luting materials [23, 24]. Fracture has been associated with crack propagation through the ceramic restoration due to the brittle characteristic of the ceramic material [9]. Other factors have also been addressed as coadjutants on the ceramic crack propagation, such as the microstructure of the ceramic material, the fabrication technique, the surface finishing, and the luting protocol [25, 26].

The present prospective study aimed to evaluate the clinical performance of adhesively bonded all-ceramic inlay and onlay restorations made with two different systems (IPS Empress and Duceram), according to USPHS criteria over 12 years. The null hypotheses of this study are (a) there would be no significant differences in the clinical performance among the

ceramic restorations made with two different systems and (b) there would be no significant differences in the clinical performance of ceramic restorations between baseline and 12 years.

Methods and Materials

This study involved 86 Class II inlay and onlay restorations fabricated with two different ceramic systems: 42 sintered ceramics (Duceram-Plus/LFC—D, Dentsply Degussa Dental, Hanau, Germany) and 44 pressable ceramics (IPS Empress-IPS, Ivoclar-Vivadent, Schaan, Leichtenstein). A total of 33 onlays and 53 inlays were made in 27 premolars and 59 M by one operator to create a standardized cavity preparation. A minimum of two restorations was placed in each patient (one from each system). In the few cases in which the patients needed more than two restorations, one of the two systems was chosen in an attempt to achieve a similar number of both ceramic systems in total.

Thirty-five patients including 17 females and 18 males with a median age of 33 years, (ranging from 25 to 44 years) who required inlay and onlay restorations, were selected for this study. The involved teeth were in occlusal contact. The volunteers underwent to a careful case history review, and bitewing and periapical radiographs were taken. The following items were considered as exclusion criteria: high caries risk, periodontal disease, the presence of a removable or fixed orthodontic appliance, signs of bruxism or clenching, the absence of more than one unit in the posterior region and poor oral hygiene or pregnancy. All patients were treated at the Bauru Dental School, University of São Paulo, SP, Brazil. They were informed about the research methodology, risks and benefits, and their right to withdraw participation in this research at any time. A written informed consent was signed. The study was carried out according to research norms and guidelines for human beings deriving from Resolution #196 approved on October, 1996 by the National Health Council and Ethics Research Committee from the Bauru Dental School, University of São Paulo, SP, Brazil.

Tooth preparation

The isthmus width was established between 1.5 to 2.0 mm, the pulpal floor depth was between 1.5 to 2.0 mm, the axial wall depth was 1.5 mm, the internal line angles were rounded, and the divergence angle of the cavity was approximately 10 to 15°, with no bevel. Minimum occlusal reduction of 1.5 to 2.0 mm was established. The undercuts were covered with resin-modified glass ionomer (Vitremmer, 3 M Dental Products Div, St. Paul, MN, USA) to achieve the cavity form by removing the build-up material in order to preserve sound tooth structure. The tooth was prepared by means of a tapered,

rounded diamond tip in high speed #4137 (ISO #025), #4138 (ISO #018) (KG Sorensen Ind Com Ltda, São Paulo, SP, Brazil) with water spray. The enamel margins were subsequently finished using hand instruments (Zerfing chisel, Duflex, SS White, Rio de Janeiro, RJ, Brazil).

Impression and provisional restoration procedures

Full-arch impressions were made with a polyvinylsiloxane material (Express, 3 M Dental Products Div, St. Paul, MN, USA) from the prepared arches and with irreversible hydrocolloid (Jeltrate–Dentsply International Inc., PA, USA) from the antagonist arches. Both casts were poured with dental stone type IV (Durone, Dentsply International Inc., PA, USA). The bite-registration records were made by a polyvinylsiloxane material (Bite Registration, 3 M Dental Products Div, St. Paul, MN, USA). Two dental ceramists were selected to produce the inlays and onlays, whose shades were selected from the Vita shade guide (Vita Zahnfabrick, Bad Sackingen, Germany).

Provisional restorations were directly fabricated with the use of self-curing acrylic resin (Duralay–Reliance Dental Mfg Co, Worth, IL, USA) and fixed with eugenol-free cement (Temp Bond NE, Keer, Karlsruhe, Germany).

Luting procedures

The intraoral fit was evaluated under rubber dam and the internal adjustments performed using diamond burs (KG Sorensen Ind Com Ltda, São Paulo, SP, Brazil) with low speed. Following adjustments, the internal surfaces were sandblasted with 50 μm aluminum oxide particles at a pressure of 5.99 bar (Opiblast, Buffalo Dental Mfg, Inc., NY, NY, USA). These surfaces were then etched with 10 % hydrofluoric acid (Dentsply International Inc., PA, USA) for 60 s, washed, and the silane agent (Monobond S, Ivoclar-Vivadent, Schaan, Leichtenstein) applied for 60 s and dried. The cavity was cleaned with pumice slurry and etched with 35 % phosphoric acid gel for 15 s, rinsed with water and gently air dried, taking care to avoid desiccation of the tooth substrate. The dentinal surface was treated with a dentin-bonding agent (Syntac Primer and Adhesive, Ivoclar-Vivadent, Schaan, Leichtenstein). Subsequently, the cavity preparation and intaglio surface of the ceramic inlays were covered with a layer of bonding agent (Heliobond, Ivoclar-Vivadent, Schaan, Leichtenstein) that was air thinned but not light cured. The dual-cured resin luting material Variolink II (Ivoclar-Vivadent, Schaan, Leichtenstein) was used for the luting procedures of all inlays and onlays according to the manufacturer's instructions. Polymerization of the luting agent was performed by light curing the restoration from different positions—occlusal, buccal, lingual,

and proximal surfaces for 60 s in each direction (XL2500, 3 M Dental Products, St. Paul, MN, USA; 570 mW/cm^2).

Finishing procedures

Excess luting composite was removed and the occlusal contacts adjusted with diamond finishing burs #1190 FF (ISO #010) and #3203 FF (ISO #012) (KG Sorensen Ind Com Ltda, São Paulo, SP, Brazil), under water cooling. The surfaces were carefully polished with rubber tips (Cerapol Plus—Edenta AG Dental Rotary Instruments, Hauptstrasse, Switzerland), and the final polishing was conducted using felt disks with diamond polishing gel (KG Sorensen Ind Com Ltda, São Paulo, SP, Brazil).

Evaluation procedures

One week following placement, the restorations were assessed according to the modified United States Public Health Service (USPHS) criteria (Table 1) by two independent investigators calibrated in the use of the system using only mirrors and probes. The investigators did not participate in the clinical procedures and did not know which system was used on the teeth they were evaluating. In addition, bitewing radiographs and intraoral photographs were made and impressions taken (Express, 3 M Dental Products Div, St. Paul, MN, USA). The same procedures performed at the baseline were performed at 1, 2, 3, 5, and 12 years. Statistical analyses were carried out with Chisquare, Mann-Whitney, and Wilcoxon tests at a 0.05 level of significance.

Results

Table 2 summarizes the results of “Alpha” ratings obtained for both ceramic materials at baseline and at 1, 2, 3, 5, and 12-year recalls, according to the USPHS criteria.

Recall rate The recall rate was 100 % at 2 years, 74.28 % at 5 years, and dropped to 62.86 % at 12 years. At 12-year recall, 22 patients (including 48 restorations—56 %) were evaluated. Twenty-five IPS Empress restorations and twenty-three Duceram restorations were assessed by two independent evaluators. Thirteen patients were not present at the 12-year recall due to different reasons: four moved to a different city, and nine could not be reached by the given telephone number or address.

Marginal discoloration/marginal integrity At 12-year evaluation, an increased number of “Bravo” scores were recorded for both ceramic systems with regard to marginal discoloration. No “Charlie” scores were observed for the IPS

Table 1 Modified USPHS criteria for the clinical evaluation of ceramic inlays and onlays used in this study

Characteristic	Rating	Criteria
Postoperative sensitivity	Alpha	No postoperative sensitivity
	Bravo	Postoperative sensitivity
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 discoloration	Alpha	No discoloration on the margin between the restoration and the tooth structure
	Bravo	Discoloration on the margin between the restoration and the tooth structure
	Charlie	Discoloration has penetrated along the margin of the restorative material in a pulpal direction
Surface texture	Alpha	Smooth surface
	Bravo	Slightly rough or pitted, can be refinished
	Charlie	Rough, cannot be refinished
Marginal integrity	Alpha	No visible evidence of ditching along the margin
	Bravo	Visible evidence of ditching along the margin not extending to the DE junction
	Charlie	Dentin or base is exposed along the margin
	Delta	Restoration is mobile, fractured or missing
Color match	Alpha	No mismatch in color, shade and translucency between restoration and adjacent tooth structure
	Bravo	Mismatch between restoration and tooth structure within the normal range of color, shade and translucency
	Charlie	Mismatch between restoration and tooth structure outside the normal range of color, shade and translucency
Fracture	Alpha	No evidence of fracture
	Bravo	Evidence of fracture

Empress restorations, and just one “Charlie” score was detected on the Duceram system. Marginal integrity was recorded as “Charlie” in seven restorations for the IPS system, and in one restoration for Duceram, totaling eight restorations that needed repair or replacement. Wilcoxon test showed significant differences in relation to marginal discoloration and marginal integrity between the baseline and 12-year recall for both systems ($p < 0.05$).

Surface texture/color match Although decreased “Alpha” scores were observed for both ceramic systems over the years, Whitney tests revealed that IPS Empress system showed the best results for color match and surface texture after 12-year evaluation ($p < 0.05$).

Post-operative sensitivity/secondary caries After the 12-year follow-up, none of the teeth restored with Duceram

Table 2 “Alpha” results of IPS Empress and Duceram ceramics according to modified USPHS criteria on baseline, 2, 3, 5, and 12 years

Recall (SD)	Baseline ($n = 86$) 100 %		2 years ($n = 86$) 100 %		3 years ($n = 79$) 92 %		5 years ($n = 62$) 72 %		12 years ($n = 48$) 56 %	
	IPS	D	IPS	D	IPS	D	IPS	D	IPS	D
Criterion										
Postoperative sensitivity	97.6	92.1	100	100	100	100	93.8	100	84.0	100
Secondary caries	100	100	100	100	97.5	97.4	96.9	96.7	80.0	86.9
Fracture	100	100	100	100	100	100	87.5	100	76.0	95.6
Color match	97.7	90.5	95.4	90.5	95.0	89.7	37.5	56.7	36.0	13.0
Marginal discoloration	100	100	68.2	76.2	62.5	64.1	21.9	23.3	12.0	13.0
Marginal integrity	100	100	81.8	88.1	77.5	84.6	31.3	33.3	4.0	13.0
Surface texture	97.7	88.1	97.7	85.7	82.5	56.4	25.0	10.0	24.0	8.7

presented post-operative sensitivity (Alpha = 100 %) and just four patients reported sensitivity for the IPS system (Alpha = 84 %). In relation to secondary caries, three ceramic restorations from the Duceram system (Alpha = 86.9 %) and five ceramic restorations from the IPS Empress presented recurrent caries and were classified as failures (Alpha = 80 %).

Fracture Six restorations from the IPS Empress ceramic system exhibited fractures, lowering the Alpha rate to 76 %. The fractured restorations consisted of two inlays and four onlays located on the molar region. Just one fracture was recorded for the restorations fabricated with the Duceram ceramic system (Alpha = 95.6 %). Mann-Whitney test showed a significantly higher fracture rate for IPS system with a p value of 0.05 at the 12-year evaluation.

Clinical success rate At the 12-year recall, seven restorations were fractured (one from Duceram and six from IPS), eight restorations presented secondary caries (three from Duceram and five from IPS), four IPS restorations presented pulp sensitivity, and nine restorations showed unacceptable defects at the restoration margin and needed repair or replacement (two from Duceram and seven from IPS). Chi-square and Mann-Whitney tests revealed that IPS Empress system showed best results for color match and surface texture. Wilcoxon test showed significant differences in relation to color match, surface texture, marginal discoloration, and marginal integrity between the baseline and 12-year recall for both systems.

Discussion

Many studies have reported the clinical performance of ceramic inlays and onlays fabricated by different methods. Among them, several clinical studies have been published in order to evaluate the clinical behavior of IPS Empress [14–22, 24–30]. Survival rates change dramatically when comparing ceramic systems among different periods of evaluation. Most of the studies have covered few years of clinical evaluation (1–5 years), while only a few have extended the observation period to 10 years. Clinical evaluations of IPS Empress inlays and onlays reported survival rates ranging from 93 to 98 % at 5 years [18, 21, 27, 28] to 64 to 95 % after 8 years [14–17]. The high success rate is associated with the capacity of these glass ceramic systems to be etched and bonded to the tooth structure with resin-based luting materials [8, 29–32].

In the present study, significant differences were observed between the two ceramic systems used to fabricate ceramic inlay and onlay restorations for three of the aspects evaluated at the 12-year evaluation. The null hypothesis that there would be no difference in the clinical performance between the two ceramic systems was rejected after the 12-year follow-up. IPS

Empress system showed best results for color match and surface texture but worse results for fracture ($p = 0.05$). Type of tooth (molar vs. premolar) was not significantly related to survival of the restoration ($p = 0.53$). Similarly, type of restoration (inlay vs onlay) was not significant ($p = 0.54$).

At the 12-year recall, 22 patients were evaluated (62.86 %), totalling 48 (55.81 %) restorations. Dropout of subjects in long-term clinical trials is expected, which is considered a drawback of prospective longitudinal studies [17]. However, the value of a clinical study is stronger over a long period of evaluation. Another prospective study of ceramic onlays showed similar dropout rate over the same evaluation period [15]. A two-sided test for equality of proportions to identify the load distribution (molar/premolar ratio and ceramic type) between baseline and 12-year follow-up showed no significant differences in load distribution after the dropouts. At the 12-year evaluation of the present study, seven of the 48 restorations evaluated presented catastrophic failure due to fracture (one from Duceram and six from IPS). Clinical photographs of the fractured IPS ceramic restorations are displayed in Fig. 1a–e. Failure of ceramic inlay and onlay restorations associated with bulk fracture has been reported in many other studies [14–18, 20, 26, 28]. Because of the high modulus of elasticity, ceramic materials are unable to suffer elastic deformation, which is a limiting property of brittle materials [3, 4]. Although ceramic materials possess high compressive strengths, they present low tensile and flexural strengths and fracture toughness [17]. Frankenberger and others [15] reported 16 % failure rate of IPS Empress inlays and onlays due to bulk fracture after 12-year of evaluation. Van Dijken and Hasselrot [17] reported 24.1 % of failed IPS Empress restorations at a mean observation period of 12.6 years (11–15 years). Stoll and others [26] emphasized that the main disadvantages of the ceramic restorations are related to their susceptibility to fracture and poor stability of the luting material at the margin. A previous study [33] has reported that an increase in thickness of ceramic restorations from 1 to 2 mm considerably reduced the risk of fracture. Other studies have agreed that a ceramic thickness of preferably 2 mm is recommended to decrease unfavorable cusp failures [17, 28]. In the present study, care was taken during the cavity preparation to provide a minimum thickness of 1.5 mm on the central groove area and 2 mm on the cusps. However, it is important to notice that the occlusal adjustment is performed after the luting procedure, which increases the chance of achieving an undesired thickness in some areas. The finishing and polishing procedures performed after occlusal adjustment should also be taken into consideration, since others studies have also correlated the bulk fractures to the presence of cracks on the ceramic restoration surface produced during the finishing procedure [29]. According to Thompson and others [32], cracks as small as 25 μm can lead to fracture of the ceramic restoration under function.

Fig. 1 Clinical photographs of fractured restorations from the IPS Empress system taken at 12-year evaluation (a to e)



Ona and others [33] using a finite element analysis verified that adhesive failure increases the probability of fracture on the occlusal ceramic surface. According to the authors, the ceramic-enamel complex is able to transfer the occlusal stress from the ceramic to the dental structure, but if failure at the interface occurs, the ceramic restoration will no longer be supported by the bonded tooth structure, leading to fracture or ceramic chipping. Failure of the adhesive bonds has been exhaustively reported in the last few years and has been attributed to both mechanical and chemical degradation [17]. Although the use of phosphoric acid has been advocated to simultaneously etch dentin and enamel since Fusayama [34] has first introduced the concept of total-etching technique, it has been revealed that the presence of denuded and unprotected collagen fibrils can potentially accelerate the hydrolytic breakdown and jeopardize the long-term durability of these adhesively bonded restorations [35–39]. Enzymatic degradation of denuded collagen fibrils by endogenous dentin proteolytic enzymes (matrix metalloproteinases-MMPs) poses higher risk when etch and rinse adhesives are used, since incompletely resin-infiltrated hybrid layers are formed due to the presence of an extensive demineralized zone (up to 5–8 μm), leaving denuded collagen fibrils exposed. [36, 38] Mechanical stress generated by occlusal forces and chemical degradation as a consequence of hydrolytic degradation of collagen fibrils will reduce the clinical performance of

adhesively bonded restorations. As a result, marginal discoloration, reduced marginal integrity, secondary caries, and loss of restoration or fracture will occur due to failure of the adhesive bonds [16, 17, 35, 36].

Secondary caries were observed in one restoration from each system at 3-year recall and one more for each system at 5-year recall. At the 12-year evaluation, eight restorations presented secondary caries (three from Duceram and five from IPS). Post-operative sensitivity was detected in just four patients on the IPS restorations. With regard to marginal integrity, an increased number of Charlie scores were observed, resulting in eight restorations that needed repair or replacement (two from Duceram and seven from IPS). The second hypothesis that stated no significant differences in the clinical performance of ceramic restorations between baseline and 12 years was also rejected. The decreased marginal integrity observed over time has been reported by several clinical studies [14–22, 25]. Kramer and Frankenberger [14] reported 83 % of marginal ditching of ceramic inlays and onlays after 8 years of clinical service. Hayashi and others [16] have also reported marginal disintegration in 77 % of ceramic inlays and onlays from both clinical and scanning electron microscope (SEM) evaluation after 8 years. According to the authors, when the effect of reinforcement provided by the resin luting material is lost, the margins of the ceramic restoration are likely to fracture. Over time, this micro-disintegration will expand and lead to a critical fracture.

With regard to the surface texture, Duceram system presented higher roughness compared to the IPS Empress system at all periods of evaluation. Duceram is a feldspathic ceramic with high glass content that uses powder condensation as a traditional method to fabricate restorations. Powders and de-ionized water are used to produce a slurry. Several steps, including powder compaction, process of forming, firing, and shaping the restoration over a refractory die are part of the laboratory processes. As a result, microporosities may be developed in the microstructure of the ceramic due to the limitations of this handmade fabrication [2, 4, 5]. In contrast, the IPS Empress system consists of a leucite-reinforced castable glass ceramic, which is available in preceramed ingots that are fabricated under controlled conditions and heated to a temperature at which they become a highly viscous liquid to allow the material to flow under pressure into the lost wax mold, which minimizes the formation of surface flaws [2, 4, 10, 11]. The difference between composition and fabrication processes in the two systems is probably the best explanation for the difference in the surface texture presented by the two ceramic systems.

Color match, on the other hand, showed better results for the IPS Empress system at the 12-year evaluation, contrasting with the previous recalls in which the Duceram system had shown superior esthetic results. Although porcelain has been established as a material with good color stability, previous studies have reported color changing after immersion in storage media [40–42]. The reason for the color change of Duceram restorations may be explained on the basis of water sorption over an extended period of time that probably resulted in the breakdown at matrix filler interface [40]. Also, it has been hypothesized that the glaze layer can undergo disruption due to acidic solutions, causing retention of stains that may be absorbed within the body of the porcelain. Jain et al. [40] showed significant color change for Duceram after immersion in tea solution. The higher surface roughness may also have played a role on the accumulation of pigments on the ceramic surface, which may have been incorporated into these porosities impeding surface cleaning over time. The improved color match observed after 12 years is in agreement with Frankenberger et al. [15] who have also reported improved color match for IPS Empress inlays and onlays over time.

Despite the better results achieved for the IPS Empress with regard to the color match and surface texture, it presented significant worse results for fracture and no significant differences were verified for the other aspects evaluated at the 12-year evaluation. The main reasons for failure of the ceramic restorations observed in the present study were related to fracture, recurrent caries, and decreased marginal integrity, corroborating the findings of previous perspective studies [15, 17, 19, 43, 44].

Careful monitoring of the ceramic-tooth interface over time has been suggested in order to perform small restorative interventions and avoid later catastrophic failure [15].

Conclusions

The evaluated restorative systems revealed significant increase in marginal discoloration and deterioration of marginal integrity at the 12-year recall. IPS Empress system presented significantly better results for color match and surface texture but worse results for fracture ($p = 0.05$). A statistically significant difference in clinical performance between the two ceramic systems was observed at 12-year follow-up.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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