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Performance of ceramic laminate veneers with immediate dentine sealing: An 11 year prospective clinical trial☆

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ABSTRACT

Objective. In this prospective clinical trial the survival, success rate and patient satisfaction of ceramic laminate veneers with special interest on existing restorations, immediate dentin sealing and endodontically treated teeth was evaluated.
Methods. A total of 104 patients (mean age: 42.1 years old) received 384 feldspathic ceramic laminate veneers on maxillary anterior teeth. Veneer preparations with incisal overlap were performed using a mock up technique. Existing resin composite restorations of acceptable quality were not removed but conditioned using silica coating and silanization. Immediate dentin sealing (IDS) was applied when more than 50% of dentin was exposed during preparation. Endodontically treated teeth were not excluded. After adhesive cementation, restorations were evaluated by calibrated evaluators at baseline and final follow-up using modified USPHS criteria.
Results. 225 Laminate veneers were bonded onto teeth without existing restorations, 159 on teeth with pre-existing resin composite restorations, 87 to teeth with more than 50% of exposed dentin surface and 43 to endodontically-treated teeth. In total, 19 failures were observed in form of debonding (n = 3), fracture (n = 15) and extraction due to endodontic complications (n = 1). In teeth with more than 50% of dentin exposure, a significant increase in survival rate was observed when IDS was used (96.4% versus 81.8%). No significant difference

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was found between teeth with and without pre-existing composite resin restorations (84.6% versus 95.5%) or between vital and non-vital teeth (95.6% versus 88.1%). Laminate veneers luted to endontically-treated teeth had a significant mis-match in color compared to vital teeth. Patients who smoked presented with significantly more marginal discoloration, but no intervention was needed. Patients scored favorably values on the Oral Health Impact Profile questionnaire and were generally satisfied with the treatment. In this clinical trial, the ceramic laminate veneers had a relatively high survival rate.

Significance. Teeth with more than 50% of dentin exposure significantly benefit from IDS. Pre-existing restorations or endodontic treatments do not have an effect on the survival rate of ceramic laminate veneers. However, smoking habits and previous endodontic treatments negatively affect the success rate due to color changes.

Clinical Trial Registration Number: NCT03645551

1. Introduction

Ceramic laminate veneers are known for their minimal invasive character thereby, removing merely one third of tooth structure compared to full coverage crowns [1]. As these restorations do not rely on their macro-mechanical retention, the bond of ceramic to tooth structure has to be optimal in order to resist shear forces during oral function. Using adhesive materials and techniques, a reliable bond strength can be obtained between the laminate veneer and enamel. As a result, survival rates of ceramic laminate veneers range between 82–96% after 10–21 years [2–7]. In a meta-analysis by Morimoto et al. [8] a cumulative survival rate of 89% with 2848 laminate veneers was observed after a follow-up of 9 years. However, laminate veneers are often made in sub-optimal conditions with significant amount of dentin as a substrate to adhere to. Laminate veneer restorations are also commonly placed when teeth have existing direct composite resin restorations. Little is known on the clinical performance of ceramic laminate veneers bonded to existing restorations in the long term. Some clinical studies concluded that success rates in teeth with existing restorations are compromised due to poor marginal quality and presence of discoloration in 18–25% of the cases up to 10 years of function [9–11]. On the other hand, results from an in vitro study indicate that veneers bonded to teeth with existing restorations performed similarly to those bonded solely to enamel [12]. In a short term prospective clinical trial by Gresnigt et al. [13] it was concluded that by conditioning the tooth surface using silica-coating and silanization these adverse effects on marginal integrity could be prevented.

Vast amounts of exposed dentin are commonly found when laminate veneers need to be replaced, or when patients are diagnosed with hypocalcified amelogenesis imperfecta, but also in cases of severe bio-corrosion lesions. Significantly more debonding is experienced when 50% of dentin is exposed [11,14]. In a recent retrospective clinical study, it was concluded that large areas of exposed dentin (>50%) were associated with lower success rates [14]. A systematic review and meta-analysis of survival concluded that 2% of debonding is experienced with laminate veneers, which is related to bonding to dentin [8]. To overcome this problem of dentin bonding an Immediate dentin sealing (IDS) procedure was proposed when indirect restorations are made [15–19]. The beneficial effect of IDS on the bond and fracture strength of glass ceramic restorations has been substantiated by several in vitro studies [15,16,18–21]. In an in vitro study on the fracture strength of laminate veneers the effect was particularly obvious when more than 50% of dentin was exposed [19]. However, to the knowledge of the present authors, there are no clinical studies published about the application of IDS when applying indirect laminate veneers.

Endodontically-treated teeth constitute another common situation where clinicians are tempted to provide full coverage crowns instead of choosing the less invasive laminate veneer restorations. But bearing in mind that less sound tissue would have to be removed, laminate veneers have been suggested as a good alternative, with internal bleaching prior to veneer application in heavily discolored teeth [22]. A systematic review and meta-analysis of survival debated the fact that not all included studies disclosed whether included teeth were endodontically treated or not [8]. For the studies in which endodontically-treated teeth were identified, the conclusion was that they were associated to higher failure rates.

The objective of this clinical trial was to evaluate the clinical performance of laminate veneers up to 11 years of clinical service. The null hypothesis tested was that the presence of existing composite restorations, the use of IDS and the presence of endodontic treatment would not influence the clinical performance and that the quality of life would not be impaired due to the laminate veneer treatment.

2. Materials and methods

2.1. Patient inclusion and exclusion criteria

Between July-2007 and July-2018, a total of 118 patients with an age range between 18 and 78 years (80 female, 38 male, mean age: 42.1 years) received 444 indirect ceramic laminate veneers. Patients recruited for this study had been referred to a specialized clinic in restorative dentistry. Before inclusion, all patients provided informed consent, as the study was approved by the ethical committee of the regional review board of the Martini Hospital (Clinical Trial Registration Num-

ber: NCT03645551). The inclusion criteria were as follows: subject is at least 18 years old, able to read and sign the informed consent document, physically and psychologically able to tolerate conventional restorative procedures, having no active periodontal or pulpal diseases, having teeth with good restorations, require esthetic improvement of anterior teeth, not allergic to resin-based materials, not pregnant or nursing, and willing to return for follow-up examinations as outlined by the investigators.

Existing composite resin restorations of acceptable quality, presenting no caries, ditching or marginal staining were not removed prior to tooth preparation. Restorations which were not acceptable were removed and replaced with new direct composite resin restorations. All existing restorations were rated for their size; restorations covering more than half of the labial surfaces were considered as large and the others as 'small' restorations. Non-vital teeth were not excluded from the study. Endodontically-treated teeth were evaluated by a specialist and retreated when indicated, no endodontic posts were placed.

2.2. *Tooth preparation*

Prior to treatment with laminate veneers, gingival corrections and/or bleaching were performed when indicated. Alignment corrections were made through orthodontics where necessary. Treatment planning and incisal edge position was performed using digital photographs. A waxup was made on the plaster model and used for the mock–up technique [23,24]. The mock-up (Structur SC, Voco, Cuxhaven, Germany) was used to communicate about potential corrections of form and position of the teeth and also to evaluate the expectations of the patient. Only after patient's approval of the mock-up, teeth were prepared. Shade was determined using different shade tabs under standard conditions (6500 K, 8 light intensity, Longlife, Aura, The Netherlands) in the dental laboratory.

A dental microscope (x3.4–21.3) (Opmipico, Zeiss, Sliedrecht, The Netherlands) was used for minimal preparations. Ball-shaped diamond burs (ISO 801-010 and 801-018, Diatech, Altstätten, Switzerland) were used to mark preparation depths through the mock-up. The labial surfaces were axially reduced by 0.1 (cervical) to 0.7 mm (mid-height). Tapered round-ended diamond burs (ISO 856 018, Diatech) were used for uniform preparations. A flat incisal overlap of 1–1.5 mm was obtained. A shallow chamfer finish line (ca. 0.1 mm) was created equi-gingivally or up to 0.5 mm intrasulcular to maintain good periodontal health. A similar marginal finish line extended inter-proximally to hide the restoration margins inside the contact area. Starting in March 2011, teeth with more than 50% of dentin exposure were sealed with the IDS technique. After etching (35% phosphoric acid, Ultra-etch, Ultradent Products Inc., South Jordan, UT, USA) and priming (Optibond FL Prime, KaVo Kerr, Orange, CA, USA) an adhesive layer (Optibond FL Adhesive) was applied at the dentin immediately after preparation including air-blocking of the adhesive layer glycerin gel (K–Y Jelly, Johnson and Johnson, New Brunswick, NJ, USA). If the cervical margin was dentin, IDS was applied up to the outline. Exposures of more than 50% of the bonded surface were especially noticed when replacing existing veneers, or on teeth with amelogenesis imperfecta.

All internal sharp angles were smoothed to reduce stress concentration. The enamel margins were finished using Arkansas stones (Dura-White stones FL2 FG, Shofu, Kyoto, Japan) and the rest of enamel polished using silicon rubbers (Brownie minipoints FG 0413, Shofu) at 7500–10,000 rpm under water cooling. Impressions were then made using a silicon impression material (Aquasil XLV and Heavy, Dentsply, York, USA). Temporary veneers were made chair-side using an auto-polymerizing BIS-Acrylic resin (Structur SC, Voco). For the fixation of the temporary veneers, enamel was spot etched with 35% phosphoric acid (Ultra-etch, Ultradent) for 30 s, while IDS surfaces were isolated with glycerin gel (K–Y Jelly).

Feldspathic ceramic containing leucite crystals (Creation Zi CT, Willi Geller International, Meiningen, Austria) was used according to the manufacturer's instructions along with the refractory die technique. The resulting ceramic laminate veneers were hand polished using diamond burs, silicone rubber points (3044HP-30044HP Ceragloss, Edenta, St. Gallen, Switzerland) and diamond pastes with brushes (Estenia C&B polishing compound and Yeti Diaglaze).

2.3. *Adhesive luting*

Form, adaptation and shade match of the restorations were checked at try-in clinically using glycerin gel (K–Y Jelly). After cleaning with compressed air and water, the fitting surfaces of the laminates were etched with 9% hydrofluoric acid (Porcelain etch, Ultradent) for 2 min, washed thoroughly for 1 min in a cup with neutralizing powder (IPS Neutralizing powder, Ivoclar Vivadent, Schaan, Liechtenstein). Since etching with hydrofluoric acid leaves a significant amount of crystalline debris precipitate at the ceramic surface, laminate veneers were cleaned using phosphoric acid (Ultra-etch, Ultradent) for 1 min and ultrasonically cleaned in distilled water for 5 min. Thereafter, the etched surfaces were silanized (Bis-Silane, Bisco, Schaumburg, IL, USA) for 1 min and dried in an oven (DI 500, Coltene Whaledent) for 5 min. After silanization, adhesive resin (Optibond FL adhesive) was applied, but not polymerized.

Tooth preparations were isolated using a non-latex rubberdam (Isodam, Sigma Dental Systems, Handewitt, Germany) and Teflon tape (PTFE sealing tape, Griffon, New York, USA).

Silica coating (CoJet, 3 M Espe, St. Paul, Min, USA) was applied (45° angle, 2 bar pressure 10 mm distance) to existing composite resin restorations (3–5 s) and/or to the IDS layer (1–2 s). Then, dentin and enamel were etched with 35% phosphoric acid (Ultra-etch, Ultradent) for 10 (dentin) to 30 s (enamel). After rinsing for 30 s and air-drying, the silane provided with the Cojet system (ESPE-Sil, 3M ESPE AG) was applied to the existing composite resin restorations, air-dried and left to evaporate for 5 min. The adhesive resin (Optibond FL adhesive, Kerr) was then applied on both the tooth and the restoration surfaces with a microbrush for 15 s, air-thinned but not polymerized.

Laminate veneers were cemented using a photo-polymerizing composite based on urethane dimethacrylate, inorganic fillers, ytteriumtrifluoride, initiators, stabilizers, pigments (UD1 or UD2, Enamel Plus HFO, Micerium, Avegno, Italy). The material was preheated at 55 °C in the Ena Heat

composite heater (Micerium, Avegno, Italy) and applied to the fitting surface of the laminates. After complete seating, gross excess cement at the margins was removed immediately with the aid of the probe and brushes (GC, Leuven, Belgium) followed by application of the light (Bluephase 20i, Ivoclar Vivadent) at 1000 mW/cm^2. Buccal, oral, and proximal surfaces were polymerized for 3 × 40 s. Application of glycerin gel (Liquid-Strip, Ivoclar Vivadent) at the margins ensured oxygen inhibition during polymerization. After rinsing the glycerin gel, excess cement was removed with a scaler and a 12d surgical blade. Restoration margins were further polished with silicone polishers (Ceragloss, Edenta) at 7500–10,000 rpm under water and interproximal polishing strips (Diatech, Coltene Whaledent). One clinician (M.G.) placed all restorations using the dental microscope (OpmiPico, Zeiss, Jena, Germany). Finally, the occlusion was checked and articulation in protrusive and lateral movements of the mandible. Patients with bruxism were not excluded but provided with an acrylic occlusal splint.

2.4. *Evaluation*

Restorations were evaluated at baseline, 3 months, one year and final follow-up by two calibrated observers who were unaware of the variables of this study. Digital photographs (1:1) were made on all appointments: initial, during the procedure, after placement of the veneers and during all follow-up sessions. All veneers which had to be replaced (survival) were considered as absolute failures (caries, fractures, chipping, severe marginal discoloration). Patients were also questioned about possible post-operative complications. Both observers evaluated the restorations independently, according to the modified United States Public Health Service (USPHS) criteria (success, Table 1). The restorations were visually inspected with dental mirror and probe (150EX probe, Deppeler SA, Rolle, Switzerland). After data collection, in case of discrepancies in scoring, restorations were evaluated again, a consensus was reached and this was accepted as the final score. The restorations were also analyzed for internal microcracks using light transillumination (Microlux, Addent, Danburry, CT, USA). Patients were instructed to call upon any kind of failure. In case of failure, an impression (Ultra-Light and Heavy body Aquasil, Dentsply) was taken from the failure site after cleansing the surface with absorbent paper and sodium hypochlorite 0.5%. Impressions were poured with cold mounting epoxy resin (Epoxy-Cure, Buehler, IL, USA) then sputter-coated with a 3 nm thick layer of gold (80%) / palladium (20%) (90 s, 45 mA; Balzers SCD 030, Balzers, Liechtenstein) and analyzed using cold field emission Scanning Electron Microscope (SEM) (LyraTC, Tescan, Brno, Czech Republic). Images were made at 15 kV at a magnification of ×35 to ×5.000. At the final follow-up exam, patients were asked to complete a 37-item Oral Health Impact Profile questionnaire. Patients were asked about the impact of veneer treatment on their oral health and about the problems they experienced. The answers were scored on a 5-point ordinal scale, higher scores implying a more impaired oral health and related quality of life [25].

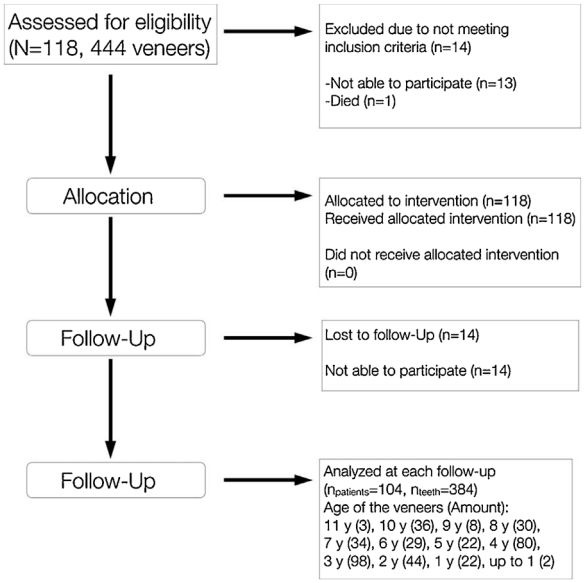

Fig. 1 – CONSORT flowchart presenting the inclusion and exclusion criteria and the final characteristics of the patients recruited to participate in this study.

2.5. *Statistical analysis*

Cumulative survival analyses were performed with statistical software program (SPSS 25.0; SPSS Inc, Chicago, IL, USA) using Kaplan–Meier and Log Rank (Mantel–Cox) tests to obtain the overall survival rate in relation to observation time and compare several subpopulations. A Fisher's exact test was performed to examine the relation between endodontic treatment and discoloration of the restored tooth. A Chi-square test was used to examine the relation between smoking and marginal discoloration. Alpha was set at 0.05 in all tests.

3. Results

After baseline measurements 14 patients were not able to attend further follow-up evaluations (Fig. 1, none of these participants reported failures) yielding to the evaluation of 104 patients with 384 indirect laminate veneers. Their mean observation time was 55.8 months (ranging 8 months to 133 months). Of the 384 laminate veneers initially under observation, 225 were bonded onto intact teeth and 159 onto teeth with existing composite resin restorations (135 small; 24 large restorations). Eighty-seven laminate veneers were luted to teeth with more than 50% of dentin exposure. Forty-three of 384 teeth had been endodontically treated prior to the start of treatment. 16 Teeth were treated with IDS and existing restorations, 9 teeth treated with IDS and had an endodontic treatment, 6 teeth treated with IDS, existing restorations and endodontic treatment and 29 with existing restorations and endodontic treatment. Hundred-and-fifty-six veneers were placed on central incisors, 125 on lateral incisors, and 103 on canines. Average treatment time for each restoration was estimated to be approximately 90 min. Eighteen patients received

Table 1 – List of modified United States Public Health Service (USPHS) criteria used for the clinical evaluations of the laminate veneers.

Category	Score	Criteria
Adaptation	0	Smooth margin
	1	All margins closed or possess minor voids or defects (enamel exposed)
	2	Obvious crevice at margin, dentin or base exposed
	3	Debonded from one end
	4	Debonded from both ends
Color match	0	Very good color match
	1	Good color match
	2	Slight mismatch in color or shade
	3	Obvious mismatch, outside the normal range
	4	Gross mismatch
Marginal discoloration	0	No discoloration evident
	1	Slight staining, can be polished away
	2	Obvious staining, cannot be polished away
	3	Gross staining
Surface roughness	0	Smooth surface
	1	Slightly rough or pitted
	2	Rough, cannot be refinished
	3	Surface deeply pitted, irregular grooves
Fracture of restoration	0	No fracture
	1	Minor crack lines over restoration
	2	Minor chippings of restoration (1/4 of restoration)
	3	Moderate chippings of restoration (1/2 of restoration)
	4	Severe chippings (3/4 restoration)
	5	Debonding of restoration
Fracture of tooth	0	No fracture of tooth
	1	Minor crack lines in tooth
	2	Minor chippings of tooth (1/4 of crown)
	3	Moderate chippings of tooth (1/2 of crown)
	4	Crown fracture near cementum enamel line
	5	Crown-root fracture (extraction)
Wear of restoration	0	No wear
	1	Wear
Wear of antagonist	0	No wear
	1	Wear of antagonist
Caries	0	No evidence of caries continuous along the margin of the restoration
	1	Caries evident continuous with the margin of he restoration
Postoperative sensitivity	0	No symptoms
	1	Slight sensitivity
	2	Moderate sensitivity
	3	Severe pain

an occlusal splint after delivery as they were suspected to have parafunctional habits.

The overall survival rate was 95% (Fig. 2) over 11 years, 19 failures were observed in the form of debonding (n = 3), cracking and fracture (n = 15) and extraction due to endodontic complications (n = 1). Most failures were seen in patients treated during the first four years of the study when IDS was not yet applied (84.6% survival, n = 16 failures) compared to the following 7 years including IDS application (99% survival, n = 3 failures) (Fig. 4). Nine failures occurred in patients who omitted to wear their prescribed occlusal appliance, 2 due to dental trauma, 5 due to adhesive failure and the rest is unknown. No significant difference in survival rate was observed between teeth with and without existing resin composite restorations (84.6% (SE%) versus (95.5% (SE%, $p > 0.05$, Kaplan–Meier, Log Rank (Mantel–Cox) (Cl = 95%) (Fig. 3). The debondings resulted from a complete adhesive failure between the tooth (dentin) and the luting cement, which occurred 3 to 32 months after cementation. A significant difference ($P = 0.017$) was observed when teeth with more than 50% of dentin exposure were sealed with an immediate dentin sealing (96.4%) or without (81.8%) on the survival rate of laminate veneers [Kaplan–Meier, Log Rank (Mantel–Cox) (Cl = 95%)] (Fig. 4). Fourteen failures were experienced in laminate veneers bonded to vital teeth and 5 in laminate veneers bonded to endodontically treated teeth. The cumulative proportion of absolute failures at time of the laminates bonded to teeth without (95.6%) and with endodontic treatment (88.1%) did not show significant differences ($p > 0.05$) [Kaplan–Meier, Log Rank (Mantel–Cox) (Cl = 95%)] (Fig. 5).

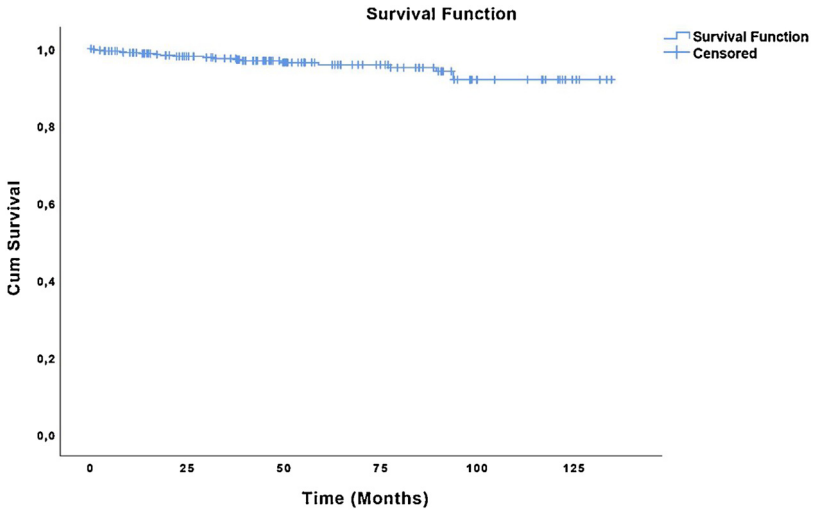

Fig. 2 – Event-free survival rates of indirect ceramic laminate veneers (95%; n = 384, events n = 19).

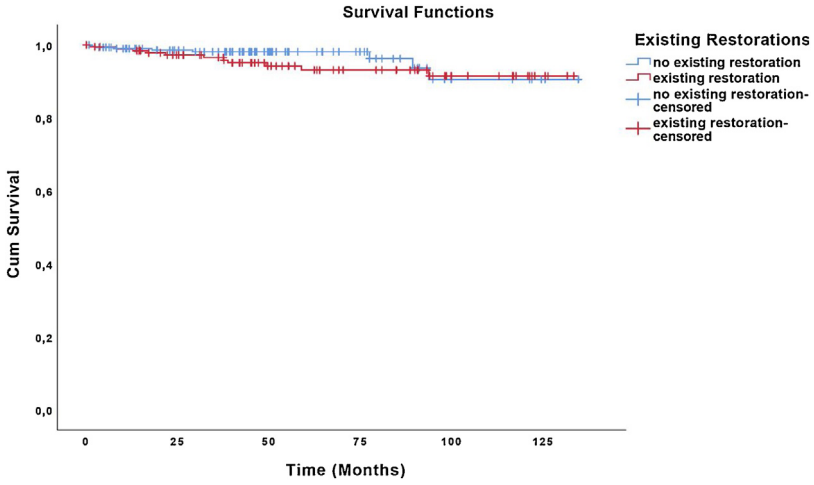

Fig. 3 – Event-free survival rates of laminate veneers with and without existing resin composite restorations (Without existing restorations: 96%; n = 225, events n = 9; With existing restorations: 94%; n = 159, events n = 10).

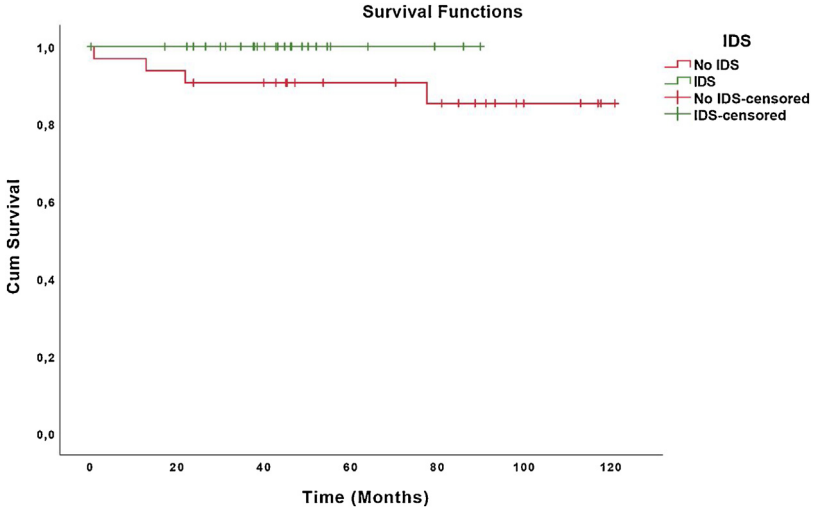

Fig. 4 – Event-free survival rates of laminate veneers with more than 50% of dentin exposure with and without immediate dentin sealing (Without IDS: 82%; n = 29, events n = 5; With IDS: 98%; n = 58, events n = 1).

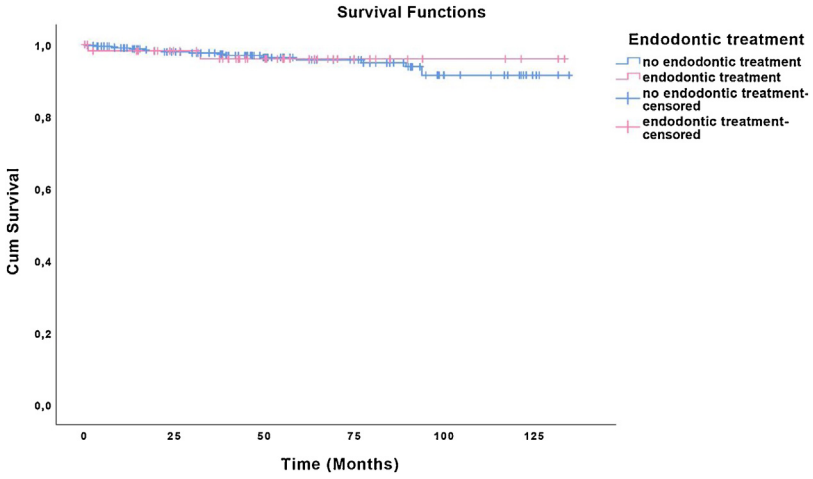

Fig. 5 – Event-free survival rates of laminate veneers bonded to teeth with and without endodontic treatment (Without endodontic treatment: 96%; n = 341, events n = 11; With endodontic treatment: 91%; n = 43, events n = 4).

Besides absolute failures, success was scored using the USPHS criteria (Tables 1 and 2). Qualitative evaluation (success) showed some differences between baseline and last follow-up. Eleven percent of the restorations had marginal defects, this was especially noticeable in the veneers made in the first 4 years. Laminate veneers luted to teeth with endodontic treatment had a significantly worse color match than the teeth without endodontic treatment at final observation ($p < 0.000$) [Fisher's exact test]. When using Chi-square a significant correlation between marginal discoloration and patients with smoking habits was observed ($\chi^2(2) = 45{,}716$; $p < 0.000$). Some laminate veneers (4%) had internal cracks however these restorations were not removed but repaired by resin infiltration, 3 chippings on the palatal side were repaired using a direct composite resin restoration. Five percent of the restorations showed wear on the palatal side due to masticatory forces. Significant wear of antagonist teeth was seen in only 2% of the veneers. In general, there was almost no surface roughness, no tooth fractures, or caries. All postoperative sensitivities disappeared after 2 weeks; at the final recall 1 tooth was still sensitive to cold.

SEM and digital pictures were used for failure analysis and as can be seen in Fig. 6, clearly demonstrates how and why the fractures happened. This particular fracture occurred due to the bond strength difference between enamel and dentin in a case where IDS was not used.

The results for the modified OHIP questionnaire are displayed in Table 3. Patients were happy with their treatment in general and did not experience problems in Oral Health Quality of life, as all scores were relatively low. There were no signs of functional limitations, physical pain/disabilities, psychological discomfort/disabilities or social disabilities.

4. Discussion

In this prospective clinical trial, the performance of ceramic laminate veneers was evaluated in view of existing restorations, the use of immediate dentin sealing, and the presence of endodontic treatment. This is the first clinical trial where such variables (presence of existing restorations and use of immediate dentin sealing) are evaluated over 5 years on average of follow up. The results presented observations up to 133 months of clinical function. In total 95% of the laminates required no intervention, which can be considered as clinically acceptable. Based on the significant differences related to immediate dentin sealing (survival), smoking (success), endodontic treatment (success), it is suggested that these factors impact the survival and success of ceramic laminate veneers in the long term.

The overall survival rate was 95% (Fig. 2, n = 19 failures), however, when omitting the first 4 years of the study, an even higher survival rate would have been reached (Fig. 2, 99% survival, n = 3 failures). Most of the failures were fractures and debondings related to patient (n = 11) and adhesion problems (n = 5). In this study, instructions to the patients were given at insertion of the laminate veneers regarding habits like nail biting and tearing materials with teeth. Eighteen patients were given a hard acrylic resin occlusal appliance as they were diagnosed with nocturnal bruxing. Patients were informed that there was a risk of fracture if compliance was inadequate. Nine failures, however, occurred in patients not wearing their night guard. These patient factor related failures were not removed from the study. When stress on the veneer is increased a higher adhesive and cohesive strength of the tooth-restorative complex is then required for functional success. All debonded laminate veneers could be rebonded after sandblasting (Aquacare, Velopex, London, UK) of enamel and dentin, performing a three step dentin bonding adhesive (Optibond FL, Kerr) and using a direct resin composite (HFO, Micerium) as a cement [26,27]. All laminate veneers subsequently functioned until the end of the study but were scored as failure and were not screened for follow up evaluations.

Existing restorations on teeth receiving laminate veneers in this study were not removed prior application of the veneers but conditioned using tribochemical surface conditioning [12,13,28,29]. Related to the absolute failures, nine teeth had existing restorations. However, none of the failures could be related to the existing restorations as was concluded

Table 2 – Summaries of USPHS evaluations at baseline and final follow-up.

Criteria		Baseline (n = 444)	Final evaluation (n = 384) percentage (%)	
Adaptation of restoration	0	444	341	89%
	1	–	42	11%
	2	–	1	–
	3	–	–	–
	4	–	–	
Color match	0	444	358	93%
	1	–	25	7%
	2	–	1	
	3	–	–	
	4	–	–	
Marginal discoloration	0	444	313	82%
	1	–	65	17%
	2	–	6	1%
	3	–	–	
Surface roughness	0	444	379	99%
	1	–	5	1%
	2	–	–	
	3	–	–	
Fracture of	0	444	367	96%
Restoration	1	–	14	4%
	2	–	2	–
	3	–	1	–
	4	–	–	–
	5	–	–	–
Fracture of tooth	0	444	381	99%
	1	–	1	–
	2	–	2	1%
	3	–	–	–
	4	–	–	–
	5	–	–	–
Wear of restoration	0	444	364	95%
	1	–	15	5%
Wear of antagonist	0	444	375	98%
	1	–	9	2%
Caries	0	444	383	100%
	1	–	1	–
Post-operative sensitivity	0	426	383	100%
	1	15	1	–
	2	2	–	–
	3	1	–	–

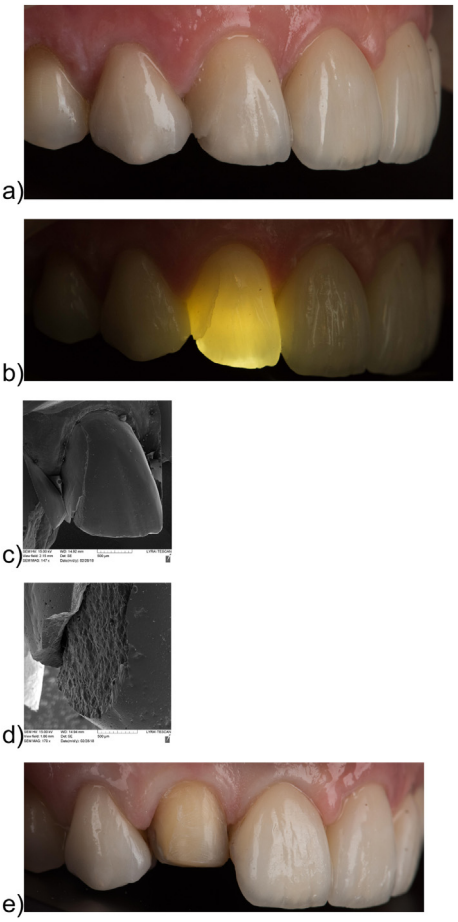

Fig. 6 – (a–d) Example of a patient where a fracture occurred due to adhesive failure. (A) The fracture can be seen on tooth 12. (B) by transillumination the fracture extension can be clearly seen (C–D) using a replica and SEM, the fracture site can be analysed, (E) seeing the direction of the fracture by transillumination and SEM and comparing this by the preparation it can be clearly noticed that the fracture pattern followed the transition of enamel and dentin preparation (without the use of an immediate dentin sealing).

in other in vivo studies [4,30,31]. In this study 41% of the laminate veneers overlapped existing restorations. In other studies, 60% of the veneers were placed on existing restorations and showed decreased longevity and increased marginal discoloration [4,32]. However, no information was provided on the method of conditioning the existing restorations. In this study no chipping, fracture or crack were seen when overlapping existing direct composite resin restorations.

Bonding to dentin is significantly diminished when applying indirect restorations [21]. Application of the so called immediate dentin sealing with indirect restorations has proved to be valuable for the bond strength [15,16,20,21]. An in vitro study demonstrated that IDS had a positive effect on the fracture strength of laminate veneers when more than 50% of dentin exposure was present [19]. Exposure of only 1/3 of the surface at the cervical part of the preparation did not affect the fracture strength [19]. In this study IDS was applied only after the 4th year as the operator was not familiar with the procedure before that point. The data clearly shows that IDS was beneficial for the survival of laminate veneers with teeth over 50% of dentin exposure and not for the less than 50% of dentin exposure. Teeth that did not receive IDS (n = 32) had significantly (p = 0,017) more failures (n = 4) than teeth with IDS (teeth with IDS n = 60, failures n = 0). Fig. 3 clearly demonstrates that fact.

Some in vivo studies concluded that there is an increased risk of failure when luting laminate veneers to endodontically-treated teeth [4,5]. In the present study all nonvital teeth were evaluated by a specialist in endodontics to decide if retreatment/extraction was necessary, which may have positively influenced the findings about the absence of difference in

Table 3 – Modified OHIP questionnaire with ordinal scale representing 0 as never; 4 very often.

Questions	Min.	Max.	Mean	St. Dv.
1. Have you had difficulty chewing any food with your laminate veneers?	0	1	0.23	0.48
2. Have you had trouble pronouncing any words with your laminate veneers?	0	1	0.05	0.21
3. Have you noticed a tooth with veneer which doesn't look right?	0	2	0.19	0.55
4. Have you felt that your appearance has been negatively affected by the veneers?	0	2	0.09	0.35
5. Have you had sensitive teeth for example by eating or drinking?	0	3	0.57	0.8
6. Have you had painful gums?	0	2	0.29	0.52
7. Have you felt that your digestion was worsened by the laminate veneers?	0	1	0.18	0.46
8. Have you had painful aching in your mouth?	0	1	0.13	0.34
9. Have you felt insecure due to your laminate veneers?	0	1	0.13	0.38
10. Have you felt miserable due to the treatment with laminate veneers?	0	1	0.08	0.27
11. Have you felt uncomfortable about the appearance of your laminate veneers	0	2	0.11	0.36
12. Have you felt tense because of your laminate veneers?	0	1	0.16	0.37
13. Has your speech been unclear because of your laminate veneers?	0	1	0.03	0.17
14. Have people misunderstood some of your words because of your veneers?	0	0	0.00	0
15. Have you been unable to brush your teeth properly with the laminate veneers?	0	2	0.06	0.30
16. Have you had to avoid eating some foods because of your laminate veneers?	0	1	0.14	0.35
17. Has your diet been unsatisfactory because of problems with your veneers?	0	1	0.03	0.17
18. Did you avoid smiling after treatment with the laminate veneers?	0	2	0.11	0.36
19. Have you had to interrupt meals because of problems with your veneers?	0	1	0.04	0.21
20. Has your sleep been interrupted because of problems with your veneers?	0	1	0.06	0.30
21. Have you been upset because of problems with your veneers?	0	1	0.08	0.27
22. Have you found it difficult to relax because of problems with your veneers?	0	1	0.06	0.24
23. Have you felt depressed after treatment with the laminate veneers?	0	1	0.01	0.12
24. Has your concentration been affected because of problems with your veneers?	0	1	0.01	0.12
25. Have you been a bit embarrassed because of your laminate veneers?	0	1	0.11	0.32
26. Did you avoid going out due to the laminate veneers?	0	1	0.03	0.17
27. Have you been less tolerant of you partner or family because of the veneers?	0	1	0.04	0.21
28. Did you have difficulties contacting other people due to the laminate veneers?	0	1	0.04	0.21
29. Have you been a bit irritable with other people because of your veneers?	0	1	0.01	0.12
30. Have you had difficulty doing your usual jobs due to the veneer treatment?	0	1	0.03	0.17
31. Do you have the idea that your health decreased due to the laminate veneers?	0	1	0.03	0.17
32. Have you suffered any financial loss due to the laminate veneers?	0	2	0.16	0.45
33. Have you been unable to enjoy other people's company due to the veneers?	0	1	0.01	0.12
34. Have you felt that life in general was less satisfying due to the veneers?	0	1	0.06	0.24
35. Have you been totally unable to function because of problems with your veneers?	0	1	0.03	0.17
36. Have you been unable to work to your full capacity because of the veneers?	0	1	0.01	0.12
37. Are you unhappy with your laminate veneers?	0	1	0.11	0.66

failures between vital (n = 341, events n = 17) and non-vital teeth (n = 43, events n = 2). Although there are some studies where fiber posts were used, no posts were placed in this study and only composite resin was applied in the endodontic access [33,34]. After internal bleaching a delay of 2–3 weeks was respected before application of the final composite resin restoration. As oxygen radicals could prevent optimum adhesion of the resin composite to tooth structure.

Success was scored according to the modified USPHS criteria list. All restorations suffered from some kind of degradation especially at the palatal aspect due to function. Eleven percent of the restorations had marginal defects which was especially noticeable with the veneers placed during the first 4 years of the study. Significant effect on the final color of the restoration was seen in endodontically-treated teeth. It is often a dilemma to choose between internal bleaching or a more extensive preparation in order to mask the discoloration. In this study, it was decided not to remove additional tooth structure and perform bleaching instead. At the time of delivery no discoloration of the restorations was found. During follow-ups, none of the patients noticed the discolored tooth as it was only minimal. Discolorations at the margin were highly significant with smokers, although acceptable by the patient and could have more discoloration due to marginal defects. Besides discolorations at the margins of the restorations, the overall dentition of those patients was also more stained due to ingredients in tobacco. Some veneers (4%) had internal cracks probably due to contraction stresses at polymerization (seen at the 3 month follow up). Patients were informed about the possibilities, removing and making a new veneer or using resin infiltration [35]. All veneers were repaired by infiltration and patients were satisfied with the result. In total, 3 small marginal chippings were seen on the palatal side of the veneers due to occlusion and articulation and were repaired using direct composite resin after appropriate conditioning of both substrates. Five percent of the restorations exhibited a small amount of wear on the ceramic and margins due to masticatory forces which was compared to the baseline pictures. Only 2% of wear was found on the antagonist teeth which can be probably attributed to the smooth surface of the ceramic and the polishing system used. There was no deterioration of the facial ceramic surface and no caries or tooth fractures were found. Postoperative sensitivity was experienced only during the first two weeks after delivering the veneers but the pain disappeared for almost all but 1 tooth after some weeks. One patient still

experienced some sensitivity when eating hot food on that tooth.

With respect to the patient satisfaction, all patients were still satisfied with their restorations and these restorations didn't have a negative effect on the Oral Health Quality of life. There were no functional limitations or psychological negative effects when the laminate veneers were applied, also not after the aging period of the laminate veneers.

5. Conclusion

From this study it can be concluded that, teeth with more than 50% of dentin exposure significantly benefit from the immediate dentin sealing technique. Pre-existing restorations or endodontic treatment do not have an effect on the survival rate of ceramic laminate veneers. However, smoking habit and previous endodontic treatment negatively affect he success rate due to color changes. The quality of life was not impaired due to the laminate veneer treatment and patients were highly satisfied with their restorations.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.dental.2019.04.008.

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