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Up to 12 years clinical evaluation of 197 partial indirect restorations with deep margin elevation in the posterior region☆

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ABSTRACT

Objectives: Deep margin elevation (DME) relocates the cervical outline of large-sized cavity dimensions in the posterior area supragingivally, using a resin composite in a direct technique. The aim of this study is to evaluate the clinical performance of partial indirect restorations with DME and compare the effects of selected baseline variables on the (quality of) survival of the restorations.

Methods: All teeth that were restored in combination with indirect restorations and DME between 2007 and 2016 were eligible for inclusion. Overall cumulative survival rates were calculated (Kaplan–Meier estimates) and compared among subsets of variables.

Qualitative evaluation of all surviving restorations was performed using the modified United States Public Health Service (USPHS) criteria using Chi-square tests.

Results: A total of 197 indirect restorations in 120 patients could be included. Restorations or teeth presenting with secondary caries, fracture of the restoration/tooth, debonding of the indirect restoration, root caries, severe periodontal breakdown or pulpal necrosis were considered as absolute failures (n = 8) leading to an overall cumulative survival rate of 95.9% (SE 2.9%) up to 12 years, with an average evaluation time of 57.7 months.

Some indication of degradation of the restorations was seen over time. Indirect composite restorations showed more degradation compared to ceramic restorations (p = 0.000). More wear of the antagonist was observed when teeth were opposed to ceramic restorations (p = 0.04). Endodontic treatment negatively impacted the occurrence of fracture of restorations and teeth (p = 0.000).

Conclusions: Indirect restorations with DME have a good survival rate in this study, however longer follow-up is needed as degradation of the restorations is seen over time.

Clinical significance: This long-term study shows the possible clinical applicability of deep margin elevation.

1. Introduction

When molar teeth have medium to large-sized cavity dimensions in the posterior area, partial indirect restorations are a good option to restore histomorphological and functional integrity [1]. Indirect restorations are made to reduce polymerization shrinkage, reduce the stresses inside the tooth, prevent fracture and improve margin adaptation to prevent microleakage [2,3]. Both indirect composites and glass ceramics are used [4]. In a review on the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition it is concluded that the mean annual failure rate of indirect composite restorations and ceramic restorations is 2.9% and 1.9% respectively [5,6]. The long-term survival rate of ceramic onlays and -inlays after 5 years (98.9%; 98.9%), 10 years (92.4%; 96.8%) and 12 years (92.4%; 89.6%) years can be considered good [7]. Long term studies on indirect composite restorations show a survival rate of 80–88% after 10–12

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years of function [8,9].

Indirect adhesive restorations supposedly have a significantly lower mean annual failure rate than direct restorations [5], with better adhesion to enamel than to dentin when investigating marginal adaptation and marginal seal [10,11]. Immediate Dentin Sealing (IDS) significantly increases the shear bond strength of indirect ceramic restorations to dentin and can be used to overcome this problem, also when large areas of dentin are exposed [12–17]. Using direct adhesive materials on freshly exposed area's such as subgingival margins could be beneficial for the adaptation and may reduce marginal leakage.

A dry working field is of great importance for the clinical outcome when applying both direct and indirect adhesive restorations [18,19,34]. However, large cavities often extend beyond the cemento-enamel junction (CEJ). This complicates isolation by means of rubberdam and the luting of extensive indirect restorations with subgingival margins [20]. A clinical approach to this problem is to perform surgical crown lengthening. However, this treatment is not always needed or desired by the patient. Forced orthodontic eruption may be an alternative, be it a time consuming one [21]. A less invasive, practical alternative approach could be to perform a deep margin elevation (DME), a concept proposed already over 25 years ago [20–22]. DME relocates the cervical margin of a subgingival preparation supragingivally, using a resin composite material. Subsequently, indirect ceramic or composite restorations can be luted in an isolated workfield using rubberdam [22]. This technique makes impression taking and luting of indirect restorations easier and more predictable [23].

The technique is based on practical wisdom and although several in vitro studies are available, in vivo studies to support or discourage the clinical use of the DME-technique is lacking [24]. In some in vitro studies the benefits of DME were not evident [10,25,26], but others found that DME does not compromise marginal adaptation or fracture behavior [27–29]. One may wonder whether or not the use of a composite resin underneath or adjacent to an indirect restoration can be considered prudent clinical practice. However, in a study on laminate veneers, no significant differences were found with or without the presence of prior existing composite restorations (class III and class IV), also on the long run [16,17]. Clearly, not all scientific research and practical beliefs are in synchronization.

Therefore, the aim is to evaluate the long-term clinical performance of partial indirect restorations with DME and compare the effect of selected baseline variables on the (quality of) survival of these restorations. The null hypothesis was that there would be no differences in survival of partial indirect restorations in posterior teeth treated with DME on endodontic treatment or without, ceramic or indirect composite, bad or good emergence profile and with or without contact point. There will also be no differences in the quality of survival of the partial indirect restorations in time.

2. Materials and methods

2.1. Patient population

This clinical study was approved by the medical ethical committee of the university institutional review board and registered in the national trial register (research register number: NL7851). Patients who were treated in a private dental practice by one restorative dentist between 2007 and 2016 and received indirect restorations in combination with DME, were eligible for inclusion. DME was indicated in situations with deep subgingival margins that would complicate impression taking and adhesive luting of the indirect restoration because a dry working field would be difficult to obtain. Inclusion criteria: candidates had to be at least 18 years old, physically and psychologically able to tolerate conventional restorative procedures below the cemento-enamel junction. Exclusion criteria: patients without active periodontal or pulpal diseases, not allergic to resin-based materials, not pregnant or nursing, and willing to return for follow-up examinations as outlined by the investigators. Reasons for exclusion were: not willing to enroll in the study, changing dentist or having moved to another city or dental practice after restoration.

2.2. Case set-up

Intraoral radiographs with a holder were made prior to treatment of the indirect ceramic restorations combining DME. A three step adhesive system (Optibond FL, Kerr) and a hybrid nanofiller composite (Tetric EvoCeram, Ivoclar Vivadent AG, Schaan, Lichtenstein, Germany or Estelite Σquick, Tokuyama, Tokyo, Japan) was used for DME. Lithium disilicate (IPS e.max (Ivoclar Vivadent AG, Schaan, Lichtenstein, Germany) and multiphase resin composite materials (Adoro, Ivoclar Vivadent AG, Schaan, Lichtenstein, Germany) were used for the partial indirect restorations. All cases were treated with the same preparation protocol. Color shade was visually determined using a shade guide (Vita classical A1-D4 Ivoclar Vivadent, Bäd Sackingen, Germany).

2.3. Tooth preparation and DME

All restorations were made by one operator using a magnifying microscope (×10–15, OPMI Pico ZEISS, Jena, Germany). Anesthesia (Ultracaïne DS Forte, Sanofi, Frankfurt, Germany) was given and the preparation was made under rubberdam isolation (Dental Dam Nic Tone Heavy, Mexico). All existing restorations and caries lesions were completely removed using various shapes of red coarse diamond burs ((Intensiv SA PS0, PS1, PS2, PS3, 801 ISO 018 N°201 FG, 801 ISO 027 N°400 FG, Montagnola, Switzerland) (Dentsply Sirona D0023 28 mm ISO 012 CA, York, England) (Komet Dental 836KR.314.014FG, 830RM.314.009FG, Shanghai, China; Shofu Dental GmbH H413, 0413, 0403, H414, 0414, Ratingen, Germany) and carbide burs (Komet Dental H1SE.204.014 CA, Shanghai, China). Cusps were capped when less than 1.5 mm of thickness of natural tooth material was present or large fissures and cracks were visible in the cusp. Cavity design optimization was performed and large approximal cavities with deep margins (below CEJ) were remaining. A circular matrix (automatrix KerrHawe, Bioggio, Switzerland) or a sectional matrix (DeTrey Dentsply Palodent, Konstanz, Germany) and wedges ensured closure of deep cervical margins and anatomy was restored. Teflon tape was packed when no wedge could be used due to damaging the profile of the matrix and therefore the anatomical shape of the DME. IDS was made directly after cavity design optimization and before DME. A 3-step adhesive was used; etching the dentin for 10 s. with 35% phosphoric acid (Ultradent Ultra-etch, South Jordan, USA), primer for 20 s (Optibond FL primer Kerr, Bioggio, Switzerland) and adhesive (Optibond FL adhesive Kerr, Bioggio, Switzerland) (thick layer not air blown) were used for IDS. At cervical margin in dentin, IDS was applied up to the outline. In very few occasions flow (Tetric EvoFlow Bulk Fill Ivoclar Vivadent AG, Schaan, Lichtenstein, Germany) was used to fill the undercuts. A hybrid nanofilled restorative composite (Tetric EvoCeram dentin shade or pre-heated Estelite Σquick) was adapted using hand instruments and used to perform DME and 1 min photo-polymerization was performed at > 1000 mW/cm^2 (Bluephase II, Ivoclar Vivadent AG, Lichtenstein) the photo-polymerization unit was monthly checked using a radiometer (Bluephase Meter II, Ivoclar Vivadent AG, Schaan, Lichtenstein). Finishing of the preparation margins was performed by using red coarse diamond burs (Intensiv SA 863 ISO 011 N°4405L FG, 863 ISO 017 N°4312N FG, 861 ISO 011 N°4205L FG, 859 ISO 012 N°D3 FG, 859 ISO 011 N°40D3 FG, 955 ISO 010 N°80D9 FG, Montagnola, Switzerland) in various shapes depending on the access. Final polymerization was performed using glycerin gel (KY gel Johnson and Johnson, Jacksonville, US). Polyvinylsiloxane (PVS) Impression material (Hydrorise, Zhermack, Marl, Germany) with double viscosity (light body, heavy body) was used for impression taking. Before applying a provisional restoration (Telio CS Ivoclar Vivadent AG, Schaan, Lichtenstein, Germany) the cavity was filled with glycerin gel to ensure

no interaction with the IDS layer. The provisional was then cemented in the cavity using cement (3 M Durelon Maxicap Carboxylate cement, Delft, Netherlands) as a simple space maintainer.

2.4. Adhesive luting

All indirect restorations were made by one dental technician (Gregoire Martin, dental lab, Montreux, Switzerland) following the manufacturers' instructions. The resulting indirect restorations 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). Rubberdam was placed after removal of the provisional restoration. No anesthesia was given prior to the luting procedure. The lithium disilicate (IPS e.max, Ivoclar Vivadent, Schaan, Liechtenstein) partial indirect restorations were tried in the cavity of the tooth and then etched with 4,9% hydrofluoric acid (IPS Ceramic etching gel, Ivoclar Vivadent) and washed thoroughly for 1 min in a cup with neutralizing powder (IPS Neutralizing powder, Ivoclar Vivadent, Schaan, Liechtenstein). Indirect composite restorations were silica-coated (2–3 s, 2 bar, 10 mm distance, angle 45°) (CoJet 3M Espe, St. Paul, min, USA). Since etching with hydrofluoric acid leaves a significant amount of crystalline debris precipitate at the ceramic surface, the partial ceramic restorations were also 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 to remove solvants and obtain a monolayer of silane (DI 500, Coltene Whaledent) for 5 min. After silanization, adhesive resin (Optibond FL adhesive) was applied, but not polymerized. The IDS layer and DME were silicacoated until a dull surface was obtained. Enamel was etched with phosphoric acid for 30 s, rinsed with copious water and airdried. Thereafter, the IDS layer and DME were silanized (Monobond S Ivoclar Vivadent, Schaan, Lichtenstein, Germany) [16,17]. Finally, adhesive (Optibond FL adhesive) was applied and left unpolymerized and the restoration was luted using a pre-heated photo-polymerizing luting composite (Estelite Σquick Tokuyama, Tokyo, Japan) [30,31]. Excess of luting material was easily removed before polymerization using hand instruments and a microbrush. 1 Min of photo-polymerization (minimum of 1000 mW/cm^2) was performed at three sides of the restoration. Application of glycerin gel was applied and 1 more minute of further polymerization was performed to eliminate oxygen inhibition layer. After rinsing the glycerin gel, excess cement was removed with a scaler and a 12d surgical blade. Accessible restoration margins were further polished with silicone polishers (Ceragloss, Edenta) at 7500–10,000 rpm under water and interproximal polishing strips (Diatech, Coltene Whaledent). Rubberdam was removed and an intraoral radiograph was taken to check for excess of luting cement, evaluation and adaptation. The average treatment time for each restoration was estimated to be approximately 90–120 min. Finally, the occlusion was checked in protrusive and lateral movements and corrected if necessary. The patient was instructed to contact the office in case of severe post-operative sensitivity or any kind of failure between control visits. Patients with suspected bruxism (signs of wear) were not excluded but provided with an acrylic occlusal splint.

2.5. Evaluation

The restorations were observed by three observers and clinically evaluated. They evaluated 10 cases together for calibration purposes. In case of discrepancies in scoring among observers, restorations were evaluated again, until consensus was reached, and this was accepted as the final USPHS score. Restorations which were in place at all follow up were counted as survived restorations and were scored for success. Succes was scored according the USPHS parameters. Secondary caries, fracture of the restoration / tooth, debonding of the indirect restoration, root caries, severe periodontal breakdown or pulpal necrosis were considered as absolute failures. Clinical qualitative evaluation of surviving restorations was performed using the modified United States Public Health Service (USPHS) criteria (Table 1). The emergence profile of the DME ideally mimics the normal morphology of the tooth and was evaluated on intraoral radiographs (good / poor). The restorations were visually inspected with a dental mirror, probe (150EX probe, Deppeler SA, Rolle, Switzerland) and perioprobe. The presence of the contact points between adjacent teeth was evaluated using metal measuring strips (Deppeler SA, Rolle, Switzerland) [32].

Table 1
List of modified United States Public Health Service (USPHS) criteria used for the clinical evaluation of the partial indirect restorations.

Category	Score	criteria
Adaptation restoration	0	Smooth margin
	1	All margins closed or possess minor voids or defects (enamel)
	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
Margin discoloration	0	No discoloration evident
	1	Slight staining, can be polished away
	2	Obvious staining, cannot be polished away
	3	Gross staining
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
	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
Caries	0	No evidence of caries continuous along the margin
	1	Caries evident continuous with the margin of the restoration
Postoperative sensitivity	0	No symptoms
	1	Slight sensitivity
	2	Moderate sensitivity
	3	Severe pain
Periodontal health	0	Healthy gums
	1	Bleeding on probing
	2	Periodontal problems with bone loss

2.6. Data analysis and statistical methods

The overall cumulative survival rate over time was calculated using the Kaplan–Meier estimate. Subsets of restorations / situations that were deemed influential to (quality) of survival were defined: prior endodontic treatment (yes/no), material used for the indirect restoration (ceramic/composite resin), the DME emergence profile (good/poor), cusp coverage (yes/no), quality of the contact point (present/absent). Their influence was compared over time using Log Rank (Mantel-Cox) tests.

Qualitative evaluation of the surviving restorations was performed

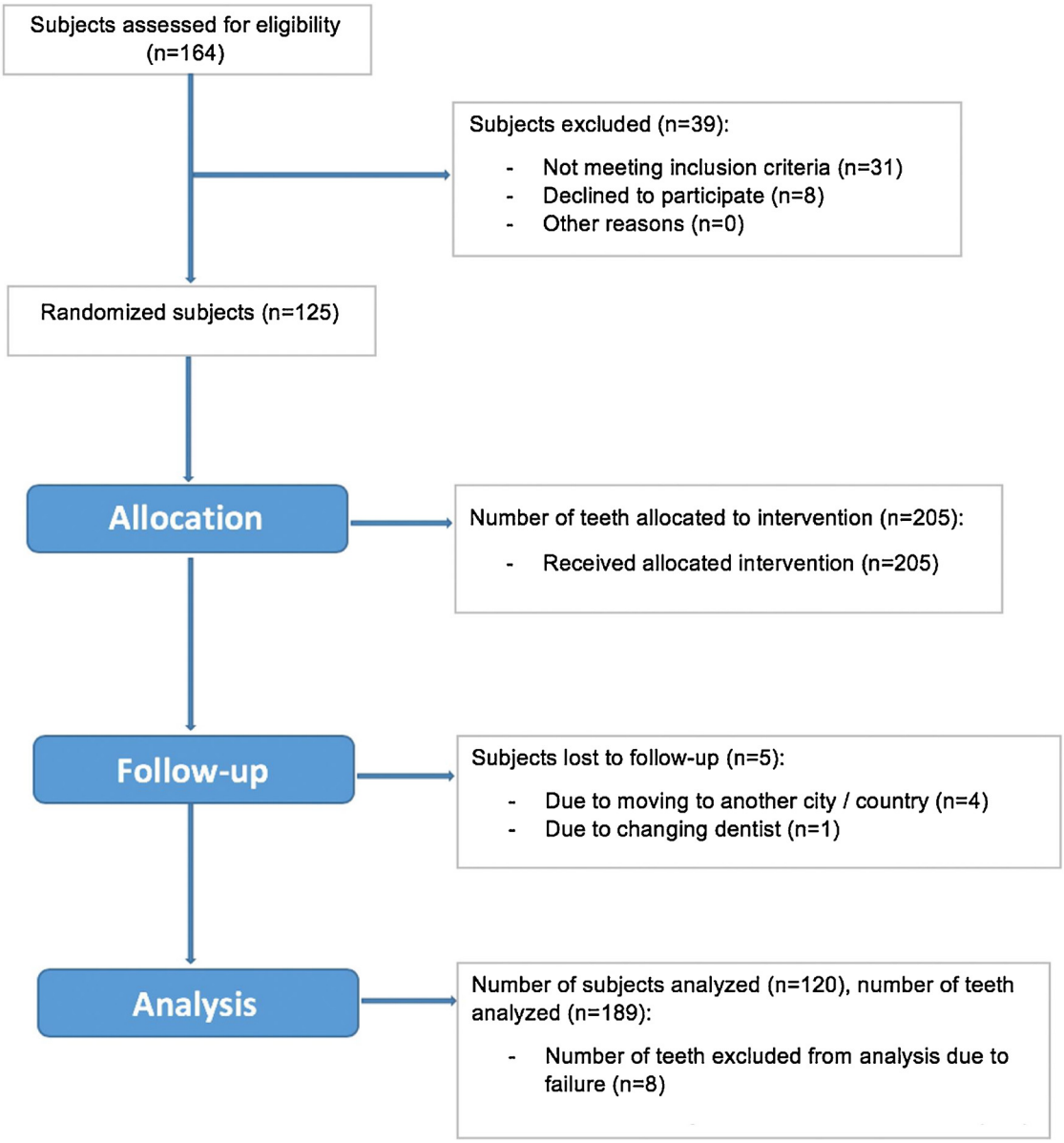

Fig. 1. CONSORT statement presenting the inclusion and exclusion criteria and the final characteristics of the patients recruited to participate in this study.

using the modified United States Public Health Service (USPHS) criteria. The outcomes on the USPHS clusters were compared amongst the earlier mentioned subsets, as well as over time (< 3 years old, ≥ 3 years old) to evaluate whether they influenced the quality and degradation behavior of the restorations (Chi-square tests). The data were analyzed using the Statistical Package for the Social Sciences (IBM SPSS Statistics, version 25.0, IBM Corp., Armonk, NY, USA). The alpha level was set at 0.05 for all tests.

3. Results

A total of 120 patients (78 females, 42 males; mean age 61.6 years, range: 30–106 years old) with 197 restorations were included (Fig. 1). 189 Indirect restorations were clinically evaluated because 8 failures had occurred. 143 Restorations were made on molars and 54 restorations were made on premolars. One patient received a splint because of suspected bruxism. Mean observation time was 57.7 months (range 4–144 months).

The eight failures occurred between 46–57 months in the form of secondary caries (n = 5), pulpal necrosis (n = 1), severe periodontal breakdown (n = 1) and fracture (n = 1), to an overall survival rate of 95.9% (SE 2.9%) after 10 years and longer (Fig. 2). Two patients experienced postoperative sensitivity after treatment.

Forty-five teeth had endodontic treatment prior to restorative treatment. No statistical difference in time-dependent survival curves was found between non-vital and vital teeth (96.7% (SE 5.7%) versus 93.3% (SE 3.4%, $p > 0.05$, Kaplan–Meier, Log Rank (Mantel-Cox)) (CI = 95%) (Fig. 3). Fifty-three restorations were made of indirect composite material and 144 restorations were made of lithium disilicate. No significant difference in the estimated survival curves was observed between the composite and ceramic indirect restorations (94.3% (SE 3.8%) versus (96.5% (SE 2.8%), $p > 0.05$, Kaplan-Meier, Log Rank (Mantel-Cox)) (CI = 95%) (Fig. 4). One-hundred-fifteen partial indirect restorations had a good DME profile while 82 partial indirect restorations had a poor DME profile (respectively 56% and 44%), with no evident effect on survival between good and poor DME profiles (95.7% (SE 3.8%) versus (96.3% (SE 3.9%), $p > 0.05$, Kaplan Meier, Log Rank (Mantel-cox)) (CI = 95%) (Fig. 5). One-hundred-seventy-five indirect restorations presented with a proper contact point and 21 had no contact point, without a statistically significant effect on

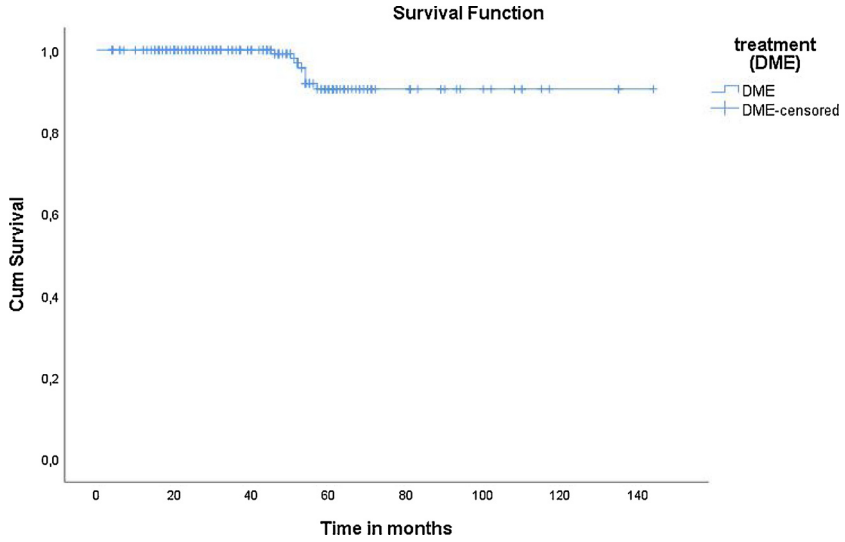

Fig. 2. Survival curve in time (Kaplan–Meier estimate) of 197 indirect restorations using Deep Margin Elevation (DME) (events n = 8, survival 96%).

their survival curves (97.1% (SE 2.8%) versus (85.7% (SE 6.8%, $p > 0.05$, Kaplan-Meier, Log Rank (Mantel-Cox)) (CI = 95%) (Fig. 6).

The results of the qualitative evaluation on the modified USPHS clusters are presented in Tables 1 and 2. Some indication of degradation of the restorations was seen over time (> 3 year versus < 3 years old). Older restorations had more margin discoloration ($\chi^2(2) = 9.02$, $p = 0.01$), more fractures of the indirect restoration and fracture of the tooth itself ($\chi^2(2) = 42.03$, $p = 0.000$ and $\chi^2(2) = 23.18$, $p = 0.000$ respectively). Caries was seen more often adjacent to older restorations (> 3 years old) as well ($\chi^2(2) = 9.02$, $p = 0.000$). Indirect composite restorations showed more degradation compared to ceramic restorations with more fractures of the restoration ($\chi^2(2) = 38.52$, $p = 0.000$), more fractures of the teeth ($\chi^2(2) = 31.39$, $p = 0.000$) and more wear of the indirect restorations ($\chi^2(2) = 31.39$, $p = 0.000$). More wear of the antagonist was observed when they were opposed to ceramic restorations compared to indirect composite restorations ($\chi^2(2) = 6.62$, $p = 0.04$. Fracture of restorations and teeth was more prevalent in case of prior endodontic treatment ($\chi^2(2) = 38.52$, $p = 0.000$) and $\chi^2(2) = 20.67$, $p = 0.000$ respectively). All other predefined variables were not of statistically significant influence on either survival or quality of survival ($p > 0.05$). A typical clinical case is presented here with deep margin elevation (Fig. 7).

4. Discussion

This clinical study reports on premolar and molar teeth that were restored with Deep Margin Elevation (DME) and indirect restorations. No long term data on this treatment concept have been reported in the literature to date. Within the described setting and following the outlined restorative principles, promising results in terms of survival of the restorations were obtained. Eight absolute failures in 197 partial indirect restorations were observed to an overall survival rate of approximately 96% up to 12 years: 97% for the partial, ceramic lithium disilicate restorations and 94% for the composite resin restorations. Both perform better when compared to data from the literature concerning indirect restorations without DME, with maximum survival rates of 90% and 88% respectively [5–9]. Both in the literature and in the present, partial indirect restorations made from composite tend to perform worse than ceramic ones [5–8]. Several explanations can be offered, one being the DME used in the present study, but also different material properties or operator factors [33]. For in depth analysis of other influencing factors a randomized controlled trial rather than a

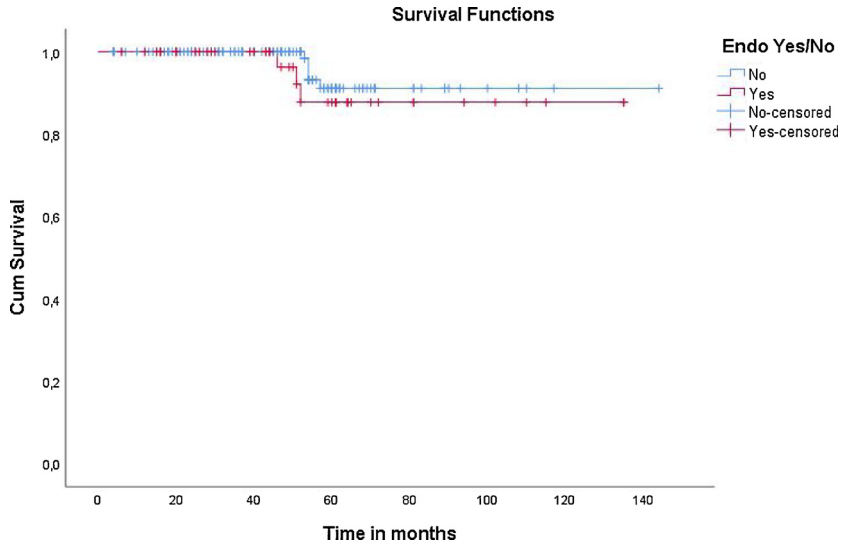

Fig. 3. Survival curve in time (Kaplan–Meier estimate) of 197 indirect restorations using Deep Margin Elevation (DME) split by endodontic status (vital teeth: n = 152, events n = 5), survival 97%; non-vital teeth: n = 45, events n = 3, survival 93%, $p > 0.05$).

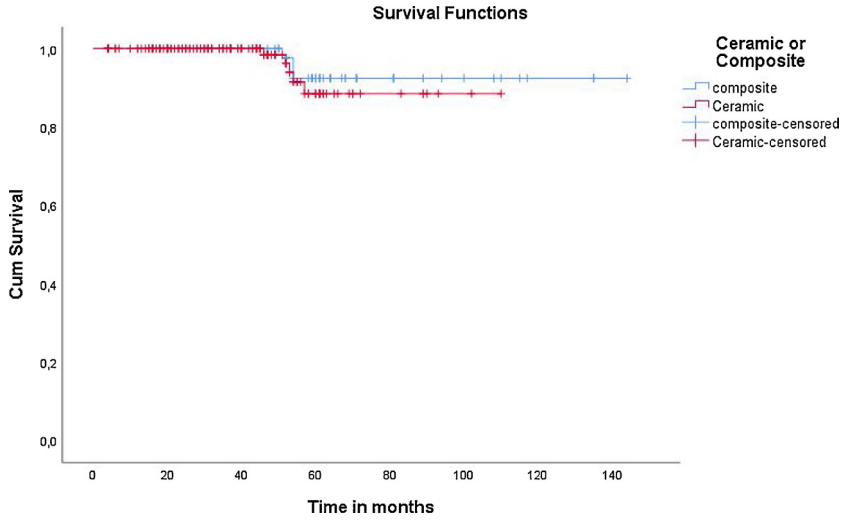

Fig. 4. Survival curve in time (Kaplan–Meier estimate) of 197 indirect restorations using Deep Margin Elevation (DME) split by type of material used (ceramic: n = 144, events n = 5, survival 97%; composite: n = 53, events n = 3, survival 94%, p > 0.05).

retrospective study would be advisable.

All 8 failures occurred in a relatively small time frame after luting of the partial indirect restorations (46–57 months). The null hypothesis was that there would be no differences in survival of partial indirect restorations in posterior teeth treated with DME on endodontic treatment or without, ceramic or indirect composite, bad or good emergence profile and with or without contact point. This hypothesis is accepted as none of the above parameters had any influence on the survival of the partial indirect restorations. Their failures could not be attributed to the preoperative endodontic status (endodontic treatment / no endodontic treatment), the type of material used (composite or ceramic), DME profile (good or too steep) or presence of a contact point (yes / no). The emergence profile of DME was evaluated using intraoral radiographs. Size of the restoration is seen as an important factor for the survival rate of partial indirect restorations. As in literature, onlays seem to be somewhat more at risk [34]. The remaining thickness of a cusp during preparation of a partial indirect restoration determines whether or not to overlay the cusp. Usually 1.5–2 mm thickness of the cusps is required to exclude it from the indirect restoration. The presence of fissures in remaining cusps, for instance to be determined by means of high magnification microscopy with transillumination, could be another predisposing factor for future fracture of the cusp. The vast majority of the teeth that were treated in the present study had pre-existing amalgam restorations. Pre-existing fractures or fissures may have been overlooked and underdiagnosed leaving cusps uncapped, where capping would have been indicated.

The surviving restorations were evaluated on their quality according to the USPHS list. The hypothesis; there will be no differences in the quality of survival of the partial indirect restorations in time was rejected as more degradation of the partial indirect restorations was seen in time. Indirect restorations with DME showed more degradation when restorations were more than 3 years old than indirect restorations that were more recently made. Older restorations showed more margin discoloration, more fracture of the restoration, more fracture of the tooth and more caries. This degradation in time for specific subsets of the modified USPHS criteria are also found in literature and might be considered as a ‘normal’ phenomenon [9]. One may have expected a decline of periodontal health in time when biological width is involved in restorative procedures, which could be the case, when performing DME [22,35]. However, no such effect could be demonstrated. When

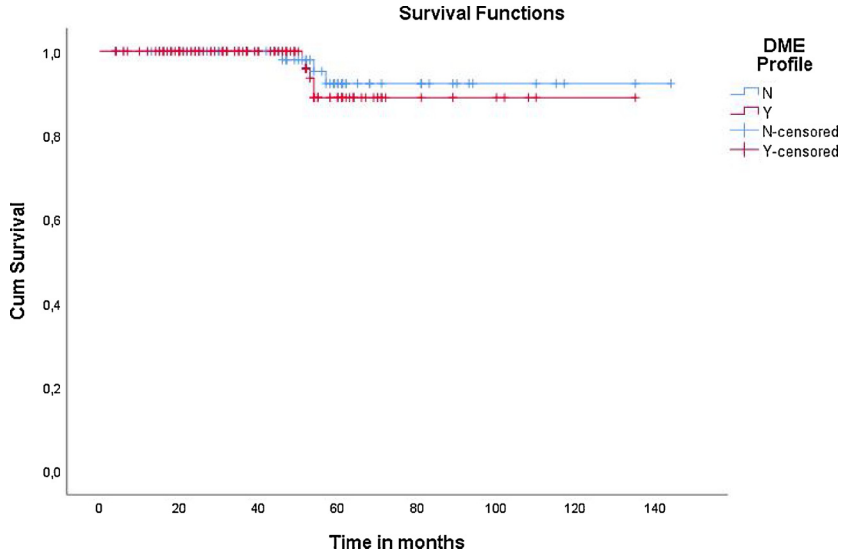

Fig. 5. Survival curve in time (Kaplan–Meier estimate) of 197 indirect restorations using Deep Margin Elevation (DME) split by the emergence profile of the DME (good: n = 115, events n = 5, survival 96%; poor: n = 82, events n = 3, survival 96%, p > 0.05).

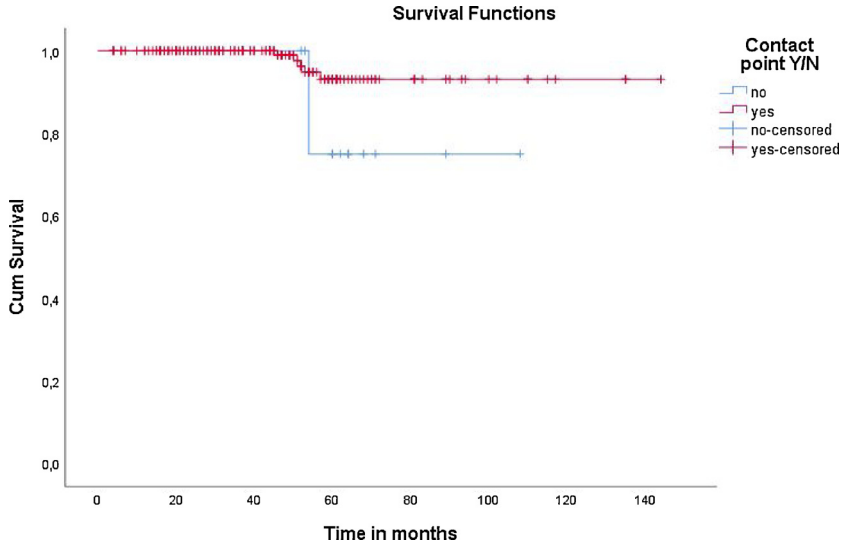

Fig. 6. Survival curve in time (Kaplan–Meier estimate) of 197 indirect restorations using Deep Margin Elevation (DME) split by the presence of the contact point (yes, present: n = 175, events n = 5, survival 97.1%; n = 21, events n = 3, survival 86%, p > 0.05).

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

Criteria		Baseline (n = 196)	Final recall (n = 189)	Percentage (%)
Adaptation of restoration	0	196	34	18%
	1	0	98	52%
	2	0	56	30%
	3	0	0	0%
	4	0	1	0%
Color match	0	189	21	11%
	1	0	68	36%
	2	0	91	48%
	3	0	8	4%
	4	0	1	1%
Margin discoloration	0	189	79	42%
	1	0	53	28%
	2	0	56	30%
	3	0	1	0%
Fracture of the restoration	0	189	173	92%
	1	0	11	6%
	2	0	5	2%
	3	0	0	0%
	4	0	0	0%
	5	0	0	0%
Fracture of the tooth	0	189	157	83%
	1	0	31	16%
	2	0	0	0%
	3	0	0	0%
	4	0	1	1%
	5	0	0	0%
Wear of the restoration	0	189	119	63%
	1	0	70	37%
Wear of the antagonist	0	189	125	66%
	1	0	64	34%
Caries	0	189	180	95%
	1	0	9	5%
Postoperative sensitivity	0	189	187	99%
	1	0	1	0,5%
	2	0	1	0,5%
	3	0	0	0%
Periodontal health	0	187	72	39%
	1	0	93	50%
	2	0	22	11%

involving the biological width one should consider doing a crown lengthening procedure.

Composite restorations present with more degradation in qualitative evaluation compared to ceramic restorations. More wear of indirect composite restorations can be explained by the fact that composite is less wear resistant compared to ceramic [36,37]. This also explains why ceramic restorations induce more wear to the antagonistic teeth [38,39]. Wear was controlled by noticing loss of occlusal morphology or a decrease in gloss of the partial indirect restoration when compared to the baseline evaluation. In this study only 1 occlusal appliance was made to protect the teeth during the night. Greater mismatch in color between vital and non-vital teeth, which would be expected [40], could not be demonstrated. But endodontic treatment does present significant more fracture of the restoration itself and the tooth. All other predefined variables were not of statistically significant influence in time on either survival or quality of survival. Hardly any postoperative sensitivity is experienced by patients. This may be attributed to the IDS layer applied although the potential benefit of the IDS technique in a randomized clinical study on partial ceramic restorations in molars could not be demonstrated [41]. Twenty-one restorations were missing a contact point during follow-up evaluation. Those contact points were present directly after placement of the partial indirect restorations, this is probably due to migration.

A proper isolation of the working field is relevant to the successful application of adhesive procedures [18,19,42,43]. The purpose of performing DME during the cavity preparation step is then to facilitate impression, the rubberdam placement at the cementation time, and to facilitate also the cementation of the bonded indirect restoration. In particular, the elimination of excess of luting composite is much easier to perform. It is clinically relevant to note that when an operating field can be properly isolated by using a rubberdam, no DME may be needed at all. It is then obvious that an ideal proximal emergence profile will be easier to achieve in the laboratory than in the clinic. Furthermore, with practice it becomes possible to successfully isolate deep subgingival margins and lute indirect restorations without DME.

5. Conclusion

Indirect restorations with DME have a good survival rate, however longer follow-up is needed as degradation is seen in time. Ceramic indirect restorations exhibit less wear than composite resin restorations but are more abrasive to the antagonist. Composite resin indirect restorations and restorations on non-vital teeth are associated with a

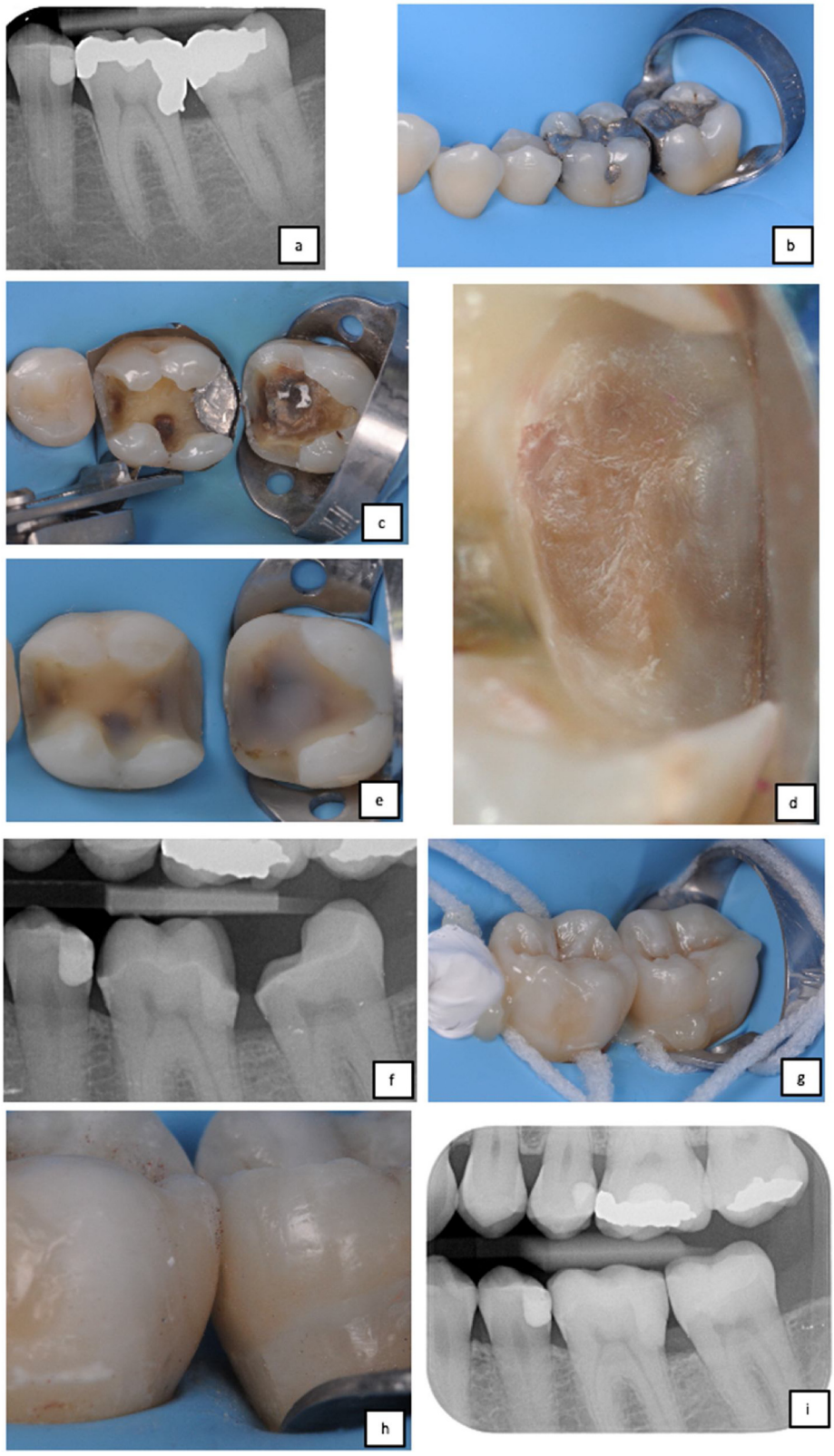

Fig. 7. a–i. Example of a successful case involving tooth number 36 (a. Pre-operative intraoral radiograph of amalgam restoration. b. Clinical pre-operative view under rubberdam. c. Removal of amalgam restoration subgingival preparation under rubberdam. d. Close-up of the marginal seal after carefully adjusting the matrix system. e. Composite was used to perform DME. f. Intraoral radiograph to illustrate the successful DME. g. Luting of the indirect restoration. h. Post-operative clinical view of the marginal seal after excess cement removal and polishing. i. Post-operative intraoral radiograph of the indirect restoration.

higher incidence of fractures of both restorations and teeth.

Disclosure statement

The authors did not have any commercial interest in any of the materials used in this study and each of the authors listed below declare no conflict of interest.

References

[1] D. Dietschi, P. Magne, J. Holz, Recent trends in esthetic restorations for posterior teeth, Quintessence Int. 25 (1994) 659–677.
[2] L. Giachetti, D. Scaminaci Russo, C. Bambi, R. Grandini, A review of polymerization shrinkage stress: current techniques for posterior direct resin restorations, J. Contemp. Dent. Pract. 7 (2006) 79–88.
[3] P. Magne, Composite resins and bonded porcelain: the postamalgam era? J. Calif. Dent. Assoc. 34 (2006) 135–147.
[4] M. Veneziani, Adhesive restorations in the posterior area with subgingival cervical margins: new classification and differentiated treatment approach, Eur. J. Esthet. Dent. 5 (2010) 50–76.
[5] J. Manhart, H.Y. Chen, G. Hamm, R. Hickel, Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition, Oper. Dent. 29 (2004) 481–508.
[6] G.R. Goldstein, The longevity of direct and indirect posterior restorations is uncertain and may be affected by a number of dentist-, patient-, and material-related factors, J. Evid. Based Dent. Pract. 10 (2010) 30–31, https://doi.org/10.1016/j.jebdp.2009.11.015.
[7] U.S. Beier, I. Kapferer, D. Burtscher, J.M. Giesinger, H. Dumfahrt, Clinical performance of all-ceramic inlay and onlay restorations in posterior teeth, Int. J. Prosthodont. 25 (2012) 395–402.
[8] M. Thordrup, F. Isidor, P. Hörsted-Bindslev, A prospective clinical study of indirect and direct composite and ceramic inlays: ten-year results, Quintessence Int. 37 (2006) 139–144.
[9] G. Derchi, V. Marchio, V. Borgia, M. Özcan, M.R. Giuca, A. Barone, 12-year longitudinal clinical evaluation of bonded indirect composite resin inlays, Quintessence Int. 9 (2019) 2–8, https://doi.org/10.3290/j.qi.a42477.
[10] S. Köken, J. Juloski, R. Sorrentino, S. Grandini, M. Ferrari, Marginal sealing of relocated cervical margins of mesio-occluso-distal overlays, J. Oral Sci. 60 (2018) 460–468, https://doi.org/10.2334/josnusd.17-0331.
[11] D. Dietschi, M. Monasevic, I. Krejci, C. Davidson, Marginal and internal adaptation of class II restorations after immediate or delayed composite placement, J. Dent. 30 (2002) 259–269.
[12] Y.S. Choi, I.H. Cho, An effect of immediate dentin sealing on the shear bond strength of resin cement to porcelain restoration, J. Adv. Prosthodont. 2 (2010) 39–45, https://doi.org/10.4047/jap.2010.2.2.39.
[13] C.R. Van den Breemer, M. Özcan, M.R.E. Pols, A.R. Postema, M.S. Cune, M.M. Gresnigt, Adhesion of resin cement to dentin: effects of adhesive promoters, Immediate Dentin Sealing and surface conditioning, Int. J. Esthet. Dent. 14 (2019) 52–63.
[14] M.M.M. Gresnigt, M.S. Cune, J.G. de Roos, M. Özcan, Effect of immediate and delayed dentin sealing on the fracture strength, failure type and Weibull characteristics of lithiumdisilicate laminate veneers, Dent. Mater. 32 (2016) 73–81, https://doi.org/10.1016/j.dental.2016.01.001.
[15] J. Goldberg, J.F. Güth, P. Magne, Accelerated fatigue resistance of thick CAD/CAM composite resin overlays bonded with light-and dual-polymerizing luting resins, J. Adhes. Dent. 18 (2016) 341–348, https://doi.org/10.3290/j.jad.a36515.
[16] M.M.M. Gresnigt, W. Kalk, M. Özcan, Clinical longevity of ceramic laminate veneers bonded to teeth with and without existing composite restorations up to 40 months, Clin. Oral Investig. 17 (2013) 823–832, https://doi.org/10.1007/s00784-012-0790-5.
[17] M.M.M. Gresnigt, M.S. Cune, J. Schuitemaker, S.A.M. van der Made, E.W. Meisberger, P. Magne, M. Özcan, Performance of ceramic laminate veneers with immediate dentine sealing: an 11 year prospective clinical trial, Dent. Mater. 35 (2019) 1042–1052, https://doi.org/10.1016/j.dental.2019.04.008.
[18] A.G.A. Dias, M.B. Magno, A.C.B. Delbem, R.F. Cunha, L.C. Maia, J.P. Pessan, Clinical performance of glass ionomer cement and composite resin in Class II restorations in primary teeth: a systematic review and meta-analysis, J. Dent. 73 (2018) 1–13, https://doi.org/10.1016/j.jdent.2018.04.004.
[19] S.D. Heintze, V. Rousson, Clinical effectiveness of direct class II restorations—a meta-analysis, J. Adhes. Dent. 14 (2012) 407–431, https://doi.org/10.3290/j.jad.a28390.
[20] D. Dietschi, S. Olsburgh, I. Krejci, C. Davidson, In vitro evaluation of marginal and internal adaptation after occlusal stressing of indirect class II composite restorations with different resinous bases, Eur. J. Oral Sci. 111 (2003) 73–80, https://doi.org/10.1034/j.1600-0722.2003.00004.x.
[21] L.A. Felippe, S. Monteiro Júnior, L.C. Vieira, E. Araujo, Reestablishing biologic width with forced eruption, Quintessence Int. 34 (2003) 733–738.
[22] M. Ferrari, S. Koken, S. Grandini, E.F. Cagidiaco, T. Joda, N. Discepoli, Influence of cervical margin relocation (CMR) on periodontal health: 12-month results of a controlled trial, J. Dent. 69 (2018) 70–76, https://doi.org/10.1016/j.jdent.2017.10.008.
[23] D. Dietschi, P. Magne, J. Holz, An in vitro study of parameters related to marginal and internal seal of bonded restorations, Quintessence Int. 24 (1993) 281–291.
[24] J. Juloski, S. Köken, M. Ferrari, Cervical margin relocation in indirect adhesive restorations: a literature review, J. Prosthodont. Res. 62 (2018) 273–280, https://doi.org/10.1016/j.jpor.2017.09.005.
[25] R. Frankenberger, J. Hehn, J. Hajtó, N. Krämer, M. Naumann, A. Koch, M.J. Roggendorf, Effect of proximal box elevation with resin composite on marginal quality of ceramic inlays in vitro, Clin. Oral Investig. 17 (2013) 177–183, https://doi.org/10.1007/s00784-012-0677-5.
[26] M.J. Roggendorf, N. Krämer, C. Dippold, V.E. Vosen, M. Naumann, A. Jablonski-Momeni, R. Frankenberger, Effect of proximal box elevation with resin composite on marginal quality of resin composite inlays in vitro, J. Dent. 40 (2012) 1068–1073, https://doi.org/10.1016/j.jdent.2012.08.019.
[27] M. Zaruba, T.N. Göhring, F.J. Wegehaupt, T. Attin, Influence of a proximal margin elevation technique on marginal adaptation of ceramic inlays, Acta Odontol. Scand. 71 (2013) 317–324, https://doi.org/10.3109/00016357.2012.680905.
[28] V. Müller, K.H. Friedl, K. Friedl, S. Hahnel, G. Handel, R. Lang, Influence of proximal box elevation technique on marginal integrity of adhesively luted Cerec inlays, Clin. Oral Investig. 21 (2017) 607–612, https://doi.org/10.1007/s00784-016-1927-8.
[29] I. Ilgenstein, N.U. Zitzmann, J. Bühler, F.J. Wegehaupt, T. Attin, R. Weiger, G. Krastl, Influence of proximal box elevation on the marginal quality and fracture behavior of root-filled molars with CAD/CAM ceramic or composite onlays, Clin. Oral Investig. 19 (2015) 1021–1028, https://doi.org/10.1007/s00784-014-1325-z.
[30] A. Kameyama, K. Bonroy, C. Elsen, A.K. Lührs, Y. Suyama, M. Peumans, et al., Luting of CAD/CAM ceramic inlays: direct composite versus dual-cure luting cement, Biomed. Mater. Eng. 25 (2015) 279–288, https://doi.org/10.3233/BME-151274.
[31] M.M.M. Gresnigt, M. Özcan, M. Carvalho, P. Lazari, M.S. Cune, P. Razavi, et al., Effect of luting agent on the load to failure and accelerated-fatigue resistance of lithium disilicate laminate veneers, Dent. Mater. 33 (2017) 1392–1401, https://doi.org/10.1016/j.dental.2017.09.010.
[32] R. Hickel, A. Peschke, M. Tyas, I. Mjör, S. Bayne, M. Peters, et al., FDI World Federation – clinical criteria for the evaluation of direct and indirect restorations. Update and clinical examples. https://doi.org/10.3290/j.jad.a19262.
[33] M.M.M. Gresnigt, M.S. Cune, K. Jansen, S.A.M. Van der Made, M. Özcan, Randomized clinical trial on indirect resin composite and ceramic laminate veneers: up to 10-year findings, J. Dent. 86 (2019) 102–109, https://doi.org/10.1016/j.jdent.2019.06.001.
[34] L. de V. Habekost, G.B. Carmacho, M.B. Pinto, F.F. Demarco, Fracture resistance of premolars with partial ceramic restorations and submitted to two different loading stresses, Oper. Dent. 31 (2006) 204–211, https://doi.org/10.2341/05-11.
[35] M. Schatzle, N.P. Land, A. Anerud, H. Boysen, W. Burgin, H. Loe, The influence of margins of restorations of the periodontal tissues over 26 years, J. Clin. Periodontol. 28 (2001) 57–64, https://doi.org/10.1111/j.1600-051X.2001.280109.x.
[36] B.L. Dahl, G. Oilo, In vivo wear ranking of some restorative materials, Quintessence Int. 25 (1994) 561–565.
[37] A. Ekfeldt, B. Fransson, B. Söderlund, G. Oilo, Wear resistance of some prosthodontic materials in vivo, Acta Odontol. Scand. 51 (1993) 99–107.
[38] F.S. Ludovichetti, F.Z. Trindade, A. Werner, C.J. Kleverlaan, R.G. Fonseca, Wear resistance and abrasiveness of CAD-CAM monolithic materials, J. Prosthet. Dent. 120 (2018) 318e1–e8, https://doi.org/10.1016/j.prosdent.2018.05.011.
[39] M. Gou, H. Chen, J. Kang, H. Wang, Antagonist enamel wear of tooth-supported monolithic zirconia posterior crowns in vivo: a systematic review, J. Prosthet. Dent. 121 (2019) 598–603, https://doi.org/10.1016/j.prosdent.2018.06.005.
[40] D.C. Greta, H.A. Colosi, C. Gasparik, D. Dudea, Color comparison between non-vital and vital teeth, J. Adv. Prosthodont. 10 (2018) 218–226, https://doi.org/10.4047/jap.2018.10.3.218.
[41] C.R.G. Van den Breemer, M.M.M. Gresnigt, M. Ozcan, W. Kerdijk, M.S. Cune, Prospective randomized clinical trial of lithium disilicate posterior partial crowns bonded using immediate or delayed dentin sealing: short-term results on tooth sensitivity and patient satisfaction, Oper Dent 44 (2019) E212–E222, https://doi.org/10.2341/18-047-C.
[42] A.B. Dablanca-Blanco, J. Blanco-Carrión, B. Martín-Biedma, P. Varela-Patiño, A. Bello-Castro, P. Castelo-Baz, Management of large class II lesions in molars: how to restore and when to perform surgical crown-lengthening? Restor. Dent. Endod. 42 (2017) 240–252, https://doi.org/10.5395/rde.2017.42.3.240.
[43] S. Browet, D. Gerdolle, Precision and security in restorative dentistry: the synergy of isolation and magnification, Int. J. Esthet. Dent. 12 (2017) 172–185.