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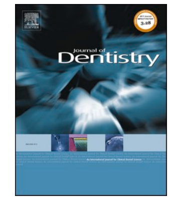

Clinical performance of bonded partial lithium disilicate restorations: The influence of preparation characteristics on survival and success

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ABSTRACT

Objectives: The aim of this study was to investigate the influence of preparation characteristics on the survival, success, and clinical performance of partial indirect lithium disilicate restorations with immediate dentin sealing.

Methods: This retrospective clinical study evaluated partial indirect lithium disilicate restorations placed in conjunction with Immediate Dentin Sealing (IDS) in (pre)molar teeth between March 2018 and May 2021. The restorations were luted using pre-heated composite. The study focused on survival, success, and clinical performance, which was evaluated using the modified United States Public Health Service (USPHS) criteria. Results were analyzed using the Kaplan-Meier estimates, log-rank tests, and Fisher exact tests.

Results: Partial indirect lithium disilicate restorations (N = 454) were evaluated in 214 patients. The mean evaluation time was 37 months, with a cumulative survival rate of 99.2 % and a cumulative success rate of 97.6 %. Fourteen failures occurred, with endodontic pathology as the predominant failure mode, followed by secondary caries, debonding, and tooth fracture. No statistically significant influence of the preparation variables on survival and success was observed ($p > .05$). The short-term clinical performance was clinically acceptable in > 90 % of the evaluations.

Conclusions: This retrospective study on partial indirect lithium disilicate restorations in conjunction with IDS demonstrates survival and success rates of 99.2 and 96.7 % over a mean evaluation period of 37 months. A marked influence of the studied preparation characteristics on the survival, success and clinical performance of lithium disilicate partial restorations could not be demonstrated. Partial lithium disilicate restorations exhibit good clinical performance in >90 % of the cases.

Clinical significance: The results of this study suggest that preparation characteristics had no significant impact on the survival, success, and clinical performance of partial lithium disilicate restorations in conjunction with IDS. Results show good clinical performance and high survival and success rates, regardless of preparation characteristics.

1. Introduction

Partial indirect restorations may be recommended as a minimally invasive restorative treatment when restoring the form and function of a tooth with an extensive defect using direct composite restorations is challenging. Monolithic lithium disilicate restorations have gained popularity in posterior teeth as this particular glass ceramic has a higher flexural strength than feldspathic and leucite-reinforced glass ceramics, which makes restorations less prone to fracture [1].

Long term results of complete and partial coverage lithium disilicate indirect restorations show good survival and success [2,3]. The cumulative survival rate of 1410 monolithic lithium disilicate complete

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crowns after 10.4 years was 96.5 %, with seven failures recorded, which were bulk fractures or large chipping [2]. Posterior complete and partial coverage crowns show excellent results after a follow-up of 16.9 years, with survival of 96.75 and 95.27 %, respectively [3]. However, there is need for more knowledge on the survival of partial restorations of lithium disilicate [4]. Most of the studies included in a systematic review by Morimoto et al. were on feldspathic and leucite-reinforced ceramics [4]. Therefore, most of the failures in studies with leucite restorations were related to the flexural strength of the material, resulting in fractures or chipping [5–7]. There is a substantial number of studies on leucite-reinforced partial restorations, but there is a need for more studies on partial lithium disilicate restorations.

Partial lithium disilicate restorations are adhesively bonded to the tooth. To improve adhesion of the restorations to dentin, the Immediate Dentin Sealing (IDS) technique has been developed [8]. This technique involves immediately sealing freshly prepared dentin with a layer of adhesive and flowable composite to increase bond strength of restorations to dentin [9,10]. Two systematic reviews of *in vitro* studies on IDS included tensile and shear bond strength test articles [11,12]. They presented an improved immediate bond strength of restorations to dentin, regardless of the adhesive strategy used ($p < .001$) [11]. Hardan et al. state that the use of a three-step etch-and-rinse adhesive system or the combination of an adhesive system plus a layer of flowable resin seems to considerably enhance the bond strength in the long term [11]. Elbishari et al. revealed a substantial amount of *in-vitro* evidence supporting the IDS benefits [12]. Both systematic reviews present a higher bond strength when IDS was used [11,12]. In addition, Elbishari et al. described improved restoration adaptation and increased fracture strength of restorations [12]. Hofsteenge et al. (2020) investigated the influence of preparation characteristics, in conjunction with the use of IDS on the fracture strength of partial restorations [13]. No statistically significant difference was observed in fracture strength between molars restored with lithium disilicate inlay and onlay restorations after IDS application and therefore they indicated that the fracture strength achieved is adequate for clinical use regardless of the preparation design [13]. However, there is only limited evidence from clinical trials to demonstrate the clinical benefits of IDS in conjunction with partial restorations [12]. Recently, Gresnigt et al. demonstrated the positive effect of IDS on survival of ceramic laminate veneers [14]. It is noteworthy that in teeth exhibiting over 50 % dentin exposure, the application of IDS yielded a statistically significant increase ($p = .017$) in survival rate, with a recorded rate of 96.4 % at a maximum follow-up of 11 years. By contrast, the survival rate of teeth treated with a Delayed Dentin Sealing (DDS) technique was approximately 81.1 % [14]. Considering posterior restorations, a study on 765 partial lithium disilicate restorations in conjunction with IDS reported a cumulative survival rate of 99.6 % after 5 years of function [15]. The effect of preparation characteristics on the survival of teeth restored with lithium disilicate partial restorations in conjunction with IDS has not been thoroughly investigated in a clinical setting.

The objective of this retrospective follow-up study is therefore to evaluate whether there is an influence of preparation characteristics on the survival and success of partial indirect lithium disilicate restorations. The null hypothesis states that there would be no statistically significant effect of preparation characteristics on the survival and success of partial lithium disilicate restorations in combination with IDS.

2. Materials and methods

2.1. Patient population and study design

This retrospective clinical study was discussed by the Medical Ethics Review Board of the University Medical Centre Groningen, Groningen, The Netherlands, and was considered not a clinical research with human subjects as meant in the Medical Research Involving Human Subjects Act (2021/082). It has been registered in the national trial register (NL9026). In accordance with the Dutch Medical Treatment Contracts Act (WGBO), active permission from patients was not required; however, patients did have the option to object to the use of their data. The study included patients who received partial indirect lithium disilicate restorations with IDS between March 2018 and May 2021, and excluded patients with active periodontal or pulpal disease. Partial indirect restorations were used to treat (pre)molar teeth with extensive decay, failing restorations, or cusp fracture, with minimally invasive preparations replacing old restorative and decayed tooth material. All teeth were prepared and restored by four dental practitioners using the adhesive protocol described below, at a single private practice located in Groningen. The adhesive protocol is a generalized workflow defined by the dental practice and adhered to by all dentists.

2.2. Preparation procedure

Silicone putty impressions (ZETALABOR putty hard, Zhermack, Badia Polesine, Italy; Indurent gel (catalyst), Zhermack) with liner (speedex light body and speedex universal activator, Coltene, Whaledent Inc., Ohio, USA) were made prior to the preparation procedure, to fabricate the provisional restorations at a later time. All preparation and restoration procedures were performed under rubber dam (Hygenic Dental Dam, Coltène Whaledent Inc.,Ohio, USA and Nic tone, MDC Dental, Mexico) using a dental microscope (x10–15, OPMI Pico ZEISS, Jena, Germany). All old restorative and decayed tooth material were removed with a high-speed electric handpiece (KaVo, Biberach/Riß, Germany) and diamond burs. The preparations adhered to a minimally invasive approach, thereby ensuring the preservation of sound enamel, by limiting its removal to a minimal degree. Coverage of cusps was conducted solely when the measurement of sound tooth structure at the base of the cusp was less than 1.5 mm, or when substantial cracks were evident, irrespective of previous endodontic treatment. Preparation walls were marginally divergent to facilitate appropriate seating of the restoration. Avoidance of occlusion and articulation at the restorative interface was not pursued. Diamond burs were utilized for the finalizing of the preparation outlines, using either a red and blue high speed electric handpiece (KaVo, Biberach/Riß, Germany), or a SONICflex prep ceram handpiece (KaVo, Biberach/Riß, Germany).

2.3. IDS and impression

Under rubber dam isolation, IDS was directly applied after preparation of the teeth to seal the freshly prepared dentin to increase the adhesive bond layer. Additive measurements, including the incorporation of teflon packing, the addition of retracting rubber dam clamps, or wedges, were implemented to ensure proper isolation of the teeth. The IDS technique was performed using a self-etching dentin primer (Clearfil SE Bond, Kuraray, Osaka, Japan) which was actively scrubbed into the dentin for 20 s and air-dried. A thin layer of adhesive bond (Clearfil SE Bond, Kuraray) was applied only to the dentin, air blown and photopolymerized for 40 s at > 1000 mW/cm^2 (Bluephase powercure lamp, Ivoclar Vivadent). A thin layer of flowable composite (GrandIO flow, VOCO, Cuxhaven, Germany) was applied on top of the adhesive layer, to obtain a smooth surface and to compensate for incidental undercuts after preparation, and photopolymerized for 40 s (>1000 mW/cm^2). Glycerin gel (K-Y* lubricating jelly, Johnson & Johnson, Sezanne, France) was applied to the tooth and photopolymerized for another 40 s to remove the oxygen inhibition layer. The IDS layer was checked with the microscope and any adhesive was removed from the enamel with fine diamond burs and rubber points (Brownie mini points fg, Shofu, Kyoto, Japan). Finally, the rubberdam was removed to take impressions.

Gingivectomy, using electrosurgery was performed in case of subgingival margins to allow proper impression taking. Retraction cords (Knitterax #0, Sigma Dental Systems, Handewitt, Germany and Ultrapak #000, Ultradent, South Jordan, Utah) were adjusted circumferential in the sulcus of the prepared teeth. Impressions were made with hydrocolloid material (Aqualoid purple extra strong and orange extra strong, Gingi-Pak, Camarilla, USA) in twofold. Provisional restorations were made using the putty impression with a chemically curing material (Protemp, 3 M ESPE, Seefeld, Germany) and cemented using a polycarboxylate cement (Durelon, 3 M ESPE Seefeld, Germany). Excess polycarboxylate cement was carefully removed.

2.4. Laboratory procedure

One dental technician made all indirect restorations of pressable lithium disilicate ceramics (IPS e.max press, Ivoclar Vivadent, Schaan, Liechtenstein) using lost wax technique following manufacturer's instructions. Fissure staining (IPS e.max Stains, Ivoclar Vivadent) was applied to mimic original tooth color and natural molars as closely as possible. Thereafter, the glass-ceramic restorations were glazed (IPS e.max Fluoglaze, Ivoclar Vivadent) and handpolished (Signum HP diamond polishing, Hereaus Kulzer GmbH, Hanau, Germany). All restorations were made and carefully checked for quality and marginal adaptation with magnification loupes x 4.2 (Examvision, Rotterdam, The Netherlands) and microscope × 8–25 (OpmiPico, Zeiss). All preparations, with and without the finished restoration in place, were photographed using a DSLR camera (Nikon D850) from occlusal and buccal views for examining the preparation characteristics.

2.5. Restoration placement and luting procedure

The seating and adaptation of the restorations to the gypsum model were checked prior to the arrival of the patient. The intaglio surface of the lithium disilicate restoration was checked with a microscope to be clear form glaze and, if present, carefully removed from the adhesive surface of the restoration with aluminum oxide sandblasting (50 µm). Temporary restoration(s) and remaining polycarboxylate cement were removed using a scaler and ultrasonic tip. The partial indirect restorations were fitted and checked for marginal adaptation and contact points. Teeth were isolated using rubber dam (Hygenic Dental Dam, Coltène Whaledent; Nic tone, MDC Dental). Subsequently, the neighboring teeth were protected with teflon tape and the IDS layer was activated with 50 µm aluminum oxide using an intra-oral air-abrasion device (Dento-prepTM, RØNVIG A/S, Daugaard, Denmark) at a pressure of 2.5 bar from a distance of approximately 10 mm for 2-3 s to clean the IDS surface until it exhibited a dull appearance. The aluminum oxide particles were rinsed of for 30 s with water and the tooth was air-dried. The enamel was etched with 37 % phosphoric acid (Ultra-etch; Ultradent; St Louis; USA) for 20 s and then rinsed with water for 20 s and air-dried. Then, silane (EPSE-Sil, 3 M ESPE, Neuss, Germany) was applied to the IDS layer for 60 s and air-dried. If dentin was exposed, a dentin primer (Clearfil SE Bond, Kuraray) was rubbed in for 20 s and air-dried, Thereafter, the adhesive (Clearfil SE Bond, Kuraray) was applied to the cavity, air thinned but not photopolymerized.

Meanwhile, the indirect restorations were etched with 9 % hydrofluoric acid (Porcelain etch; Ultradent; St Louis; USA) for 60 s, rinsed with water and etched again for 60 s with 37 % phosphoric acid (Ultra-etch; Ultradent; St Louis; USA) to remove part of the glass-matrix. The indirect restorations were ultrasonically cleaned in alcohol for 5 min to remove remaining contamination and etched glass-particles. The indirect restorations were air-dried and silane (Monobond Plus, Ivoclar Vivadent) was applied for 60 s. After silanization, a thin layer of adhesive was applied to the indirect restoration, air thinned but not photopolymerized. Pre-heated, 55 °C, resin composite (HFO composite, Micerium S.p.A., Avegno, Italy) was applied and evenly distributed in the cavity. All margins were covered with pre-heated resin composite, and the indirect restorations were gently placed into the cavity. Pressure was applied to seat the restorations appropriately. Excess composite was repeatedly removed with a dental probe. The restorations were photopolymerized for 40 s from all 3 sides and photopolymerization was repeated for 40 s with glycerin gel on the margins to eliminate the oxygen inhibition layer. Excess luting cement was removed with a hand scaler, surgical blade (12D), and an EVA handpiece (7LP; 61 LG) (Kavo, Biberach/Riß, Germany). Several polishers were used (brownie, Shofu and Optidisc 12.6 mm, Kerr, Orange, USA) to finish the outline between tooth and restoration.

2.6. Evaluation

Intra-oral digital photographs and radiographs were made by the general practitioners of all partial indirect restorations as part of regular dental care and clinical evaluation of their dental restorative work. Restorations were evaluated on survival, success, and clinical performance. Survival failures were defined as secondary decay, debonding, replacement, catastrophic fracture, and restorations in need of restorative treatment or extraction. Success failures were defined as chipping or minor adjustments to the restoration, or endodontic treatment. Extraction following severe periodontal breakdown was censored. Caries risk was also determined. A patient was classified as having a high risk of caries based on the presence or development of at least one carious lesion within the year following their last check-up. Most of the restorations were evaluated according to modified United States Public Health Service (USPHS) criteria (Table 1), based on the provided digital photographs and radiographs by a calibrated investigator (JWH). Twenty cases were checked with two colleagues for calibration purposes (RAB & CRB). Statistical analyses were performed after all evaluations were completed to eliminate the possibility of selective reporting bias. Study data were collected and managed using REDCap electronic data capture tools hosted at University Medical Centre Groningen, Groningen, The Netherlands [16,17].

2.7. Preparation characteristics measurement

Preparation characteristics were analyzed based on digital photographs of the gypsum model of the preparation and gypsum model with the lithium disilicate restoration *in situ*, provided by the dental technician. The restorations were randomly selected from the total number of restorations made between March 2018 and May 2021. The photographs were made in a standardized set-up in the dental lab, capturing both occlusal and buccal views. Occlusal photographs were utilized for measurement purposes. Before commencing the measurements, the investigator verified the inclination of each photograph. If the inclination was deemed inappropriate, those specific preparations were excluded from the measurement process. Measurements were done using Adobe Photoshop 2023. The 'Ruler tool' was used to measure the maximum width of the teeth and the width of the preparation (at the occlusal outline) in pixels. The surface area (in pixels) of the restoration and the complete tooth were measured using the 'Magnetic lasso tool' to select the surface area.

The following variables were noted and calculated:

- Number of surfaces involved;
- Number of cusps involved;
- Relative width (%) of the preparation (dividing the width of the preparation in pixels by the width of the tooth in pixels);
- Relative surface area (%) of the restoration (dividing the surface area of the restoration in pixels by the surface area of the complete tooth in pixels).

2.8. Statistical analysis

The results were analyzed using the statistical program IBM SPSS statistics 28.0 (IBM Corp. NY, USA) and R version 3.3.3 (R Foundation for Statistical Computing, Vienna, Austria). The alpha level was set at 0.05 for all tests and corrected accordingly for post-hoc testing. The Kaplan-Meier estimate was used to calculate the overall cumulative survival and success rate. A Cox regression multilevel analysis with a

Table 1
Criteria used for the clinical evaluations of the restorations (adapted version of modified USPHS criteria).

Category	S*	Criteria
Photograph		
1. Adaptation restoration	0	Restoration contour is continuous with existing anatomical form and margins of the restorations
	1	Restoration is slightly under of over contoured
	2	Marginal overhang or tooth structure (dentin or enamel) is exposed
	3	Restoration is missing, traumatic occlusion or restoration cause pain in tooth or adjacent tissue
2. Caries	0	No visible caries
	1	Caries contiguous with the margin of the restoration
3. Marginal adaptation	0	Excellent continuity at resin—enamel interface; no ledge formation, no discoloration
	1	Slight discoloration at resin—enamel interface; ledge at interface
	2	Moderate discoloration at resin—enamel interface measuring 1 mm or greater
	3	Recurrent decay at margin
4. Polishability	0	Smooth and highly shiny, similar to enamel
	1	Smooth and satin, highly reflective
	2	Rough and shiny, satin, somewhat reflective
	3	Rough and dull or satin, not reflective
5. Surface staining	0	Absent
	1	Present
6. Contact points	0	Absent
	1	Present
7. Fracture of restoration	0	No fracture of the restoration
	1	Small lines of the restoration
	2	Small chippings (1/4 of restoration)
	3	Moderate chippings (1/2 of restoration)
	4	Severe chippings (3/4 of restoration)
	5	Loose of the restoration
8. Wear restoration	0	No wear
	1	Wear
Radiograph		
9. Adaptation restoration	0	Restorations contour is continuous with existing anatomical form and margins
	1	Restoration is slightly under of over contoured
	2	Marginal overhang or tooth structure (dentin or enamel) is exposed
	3	Restoration is missing, traumatic occlusion or restoration cause pain in tooth or adjacent tissue
10. Caries	0	No visible caries
	1	Caries contiguous with the margin of the restoration
11. Marginal adaptation	0	Excellent continuity at resin—enamel interface; no ledge formation, no discoloration
	1	Slight discoloration at resin—enamel interface; ledge at interface
	2	Moderate discoloration at resin—enamel interface measuring 1 mm or greater
	3	Recurrent decay at margin

S = score. * Scores 0, 1, 2, 3, 4 and 5 can also be read as Alpha, Beta, Charlie, Delta, Echo and Foxtrot.

frailty index could not be conducted to evaluate the influence of multiple predictor variables on survival due to the restricted incidence of events [18]. To compare the influence of different preparation characteristics, sub-analyses of the survival and success of restorations were performed using log-rank tests. In the statistical analysis, consideration was given to account for the correlation of multiple restorations within a single patient. Five log-rank tests were run to determine the difference between:

(1) Narrow (<50 % prep width) versus medium (50–60 % prep width) versus wide (>60 % prep width) inlays.
(2) Inlays (without covering the cusps) versus overlays (with coverage of all cusps) on vital teeth.
(3) Inlays (without covering the cusps) versus overlays (with coverage of all cusps) on endodontic treated teeth
(4) The number of cusps
(5) The number of surfaces
(6) The relative surface area of the restoration

Analysis of the quality of the restoration (USPHS criteria) was performed by using the Fisher exact test as the assumptions for the chi-square test were violated.

3. Results

In total, 509 restorations were documented by the dental technician, which represents approximately 33 % of the total number of restorations produced in between March 2018 and May 2021. A total of 454 partial indirect lithium disilicate restorations were retrospectively evaluated in 214 patients, with an loss in follow-up of 11 %. Among the evaluated patients, 93 were men, and 121 were women, with the mean age at placement of the restorations being 53.1 years for men and 53.9 years for women. 176 patients were classified as having a low caries risk while 38 were categorized as having a high caries risk.

Considering the jaw of placement, 255 partial indirect restorations were placed in the maxilla and 199 in the mandibula. Additionally, 334 restorations were placed in molars, where 120 were placed in premolars The cusp and surface involvement in the restoration is presented in Table 2 and Table 3 respectively. Regarding the pre-operative endodontic status of restorations, 67 of the 454 restorations had been endodontically treated prior to receiving a partial indirect restoration. Of these 67 restorations, 55 were classified as endocrowns (with extension of the indirect restoration into the pulp chamber). Considering the margin of the restorations, in 157 restorations, at least one approximal margin was located below the CEJ. In 246 restorations at least one margin was above CEJ and in 10 restorations, the margins did not extend approximally. Of the 454 restorations, operator 1 placed 207 restorations, operator 2 placed 107 restorations, and operator 3 and 4 both placed 70 restorations.

During a maximum evaluation period of 58 months, 14 restorations had failed. The mean evaluation time for the restorations was 37 months (range: 0.3–58 months). Endodontic pathology was the most predominant cause of failure ($n = 8$), followed by secondary caries ($n = 3$), debonding ($n = 2$) and tooth fracture ($n = 1$). Table 4 presents a schematic overview of the failures. Kaplan-Meier analysis demonstrated a cumulative survival rate after 37 months of 99.2 % (95 % CI: 98.2–100 %) with an annual failure rate (AFR) of 0.26 % (95 % CI:0–0.59 %). The cumulative success rate was 97.6 % (CI 95 %: 96.0–99.2 %) with an AFR of 0.77 % (95 % CI: 0.26–1.30 %) after a mean follow-up of 37 months. Fig. 1 visualizes the survival and success Kaplan-Meier curves. The descriptives of preparation characteristics and statistical analyses using log-rank tests were reported in Table 5. No association between the investigated preparation characteristics and the survival and success of the restorations was observed.

Clinical performance was determined using clinical and radiographic modified USPHS criteria. The 14 failures were excluded from qualitative analysis, besides that some of the restorations were not evaluated due to incompleteness or inadequate quality of the photographs and radiographs, eventually 257 and 299 restorations were scored with a mean evaluation time of 30 months for both radiographic and clinical criteria, respectively. The short-term clinical performance of the evaluated partial lithium disilicate restorations is presented in Table 6. Fig. 2A–I presents the preparation, the clinical and radiographic appearance of representative restorations after a follow-up of 43 months. The evaluation period had a statistically significant influence on a minor marginal discoloration (p=.013). Restorations with follow-up of 24–48 months presented more marginal discoloration; 65.5–75.5 % showed no discoloration and 19.6–27.6 % showed minor discolorations. Fig. 2G visualizes the marginal discoloration seen in this study. Restoration with a shorter follow-up (0–24 months), presented in 79.3–93.1 % of the evaluations no marginal discoloration. There is no apparent influence of the preparation characteristics, number of surfaces, number of cusps, relative width of the preparation, and relative surface area of the

Table 2
The incidence of cusp involvement in the restoration in molars and premolars.

		Premolars			*Molars*					*Total (n)*
Cusps involved		0	1	2	0	1	2	3	4	
Restorations	n	74	31	15	68	68	82	49	67	454
		61.7 %	23.8 %	12.5 %	20.4 %	20.4 %	24.6 %	14.7 %	20.1 %	
Total (n)		120 (100 %)			334 (100 %)					

Table 3
The number of surfaces involved in the restoration in molars and premolars.

	Premolars					Molars					Total (n)
Surfaces involved	1	2	3	4	5	1	2	3	4	5	
Restorations	0	34	42	27	17	7	38	59	109	121	454
	0 %	28.3 %	35.0 %	22.5 %	14.2 %	2.1 %	11.4 %	17.7 %	32.6 %	36.2 %	
Total (n)	120 (100 %)					334 (100 %)					

Table 4
Specified details on failures.

Tooth	Follow-up (months)	Operator	Endo	Caries risk	Surfaces	Cusps	Prep width %	Prep surface %	Intervention	Indication
Molars										
26	0.3	1	Non-vital	Low	4	2	82.60 %	90.76 %	Apex resection	Endodontic pathology
16	0.5	4	Vital	Low	4	3	100.00 %	92.31 %	Endodontic treatment	Endodontic pathology
47	5.1	1	Vital	Low	4	2	100.00 %	65.46 %	Endodontic treatment	Endodontic pathology
37	6.7	1	Vital	Low	1	0	69.17 %	*	Endodontic treatment	Endodontic pathology
27	9.9	2	Vital	Low	5	4	85.11 %	92.42 %	Endodontic treatment	Endodontic pathology
46	16.7	4	Vital	High	3	3	100.00 %	77.41 %	Endodontic treatment	Endodontic pathology
16	26.1	3	Vital	High	5	4	100.00 %	90.74 %	New indirect restoration	Secondary caries
37	26.5	2	Vital	Low	4	1	89.65 %	82.58 %	Endodontic treatment	Endodontic pathology
26	29.1	1	Vital	High	2	0	55.49 %	36.99 %	Composite restoration	Secondary caries
37	38.3	1	Vital	Low	4	1	62.68 %	65.16 %	Endodontic treatment	Endodontic pathology
26	40.5	2	Non-vital	High	4	2	90.53 %	86.56 %	Reattachment	Debonding
27	54.7	3	Non-vital	Low	5	4	100.00 %	100.00 %	Extraction	Secondary caries
Premolars										
45	28.7	2	Vital	Low	2	0	58.76 %	19.96 %	Reattachment	Debonding
25	44.8	1	Vital	Low	4	1	87.85 %	72.91 %	Extraction	Tooth fracture

[*] measurements were not possible.

restoration on the clinical performance ($p > .05$).

4. Discussion

The present retrospective study evaluated the clinical performance of 454 partial indirect lithium disilicate restorations with IDS in 214 patients over a maximum period of 58 months.

The null hypothesis, stating that there would be no statistically significant effect of preparation characteristics on the survival and success of partial lithium disilicate restorations in combination with IDS, could not be rejected. Log-rank analyses found no apparent statistically significant influence of preparation characteristics on survival and success. The cumulative survival rate was 99.2 % (95 % CI: 98.2–100 %), and the cumulative success rate at an average of 37 months was 97.6 % (CI 95 %: 96.0–99.2 %). These results are in accordance with the findings from previous studies that have reported high survival and success rates for partial lithium disilicate restorations as well [3,15,19–21].

In the present study, no significant difference in survival and success was observed between inlays and onlays. This result aligns with previous studies that have demonstrated similar success rates for inlays and onlays made from lithium disilicate materials [15]. The absence of an apparent statistically significant influence of the width of the inlay on restoration survival and success supports the notion that lithium disilicate can be reliably used for both conservative and more extensive inlay restorations and cusp capping could be avoided. This is in consensus with previous *in vitro* research, which reports no statistically significant difference in fracture strength between premolars restored with 75 % and 100 % intercuspal width inlays made of lithium disilicate [22]. The not apparent influence of the number of surfaces involved on survival and success, is in consensus with a practice-based study on ceramic inlays and onlays [23].

The most predominant cause of failure was endodontic pathology ($n = 8$), followed by secondary caries ($n = 3$), debonding ($n = 2$), and tooth fracture ($n = 1$). The occurrence of endodontic pathology as a predominant cause of failure is consistent with other studies on indirect restorations [4,15,24]. This finding suggests that adequate pretreatment

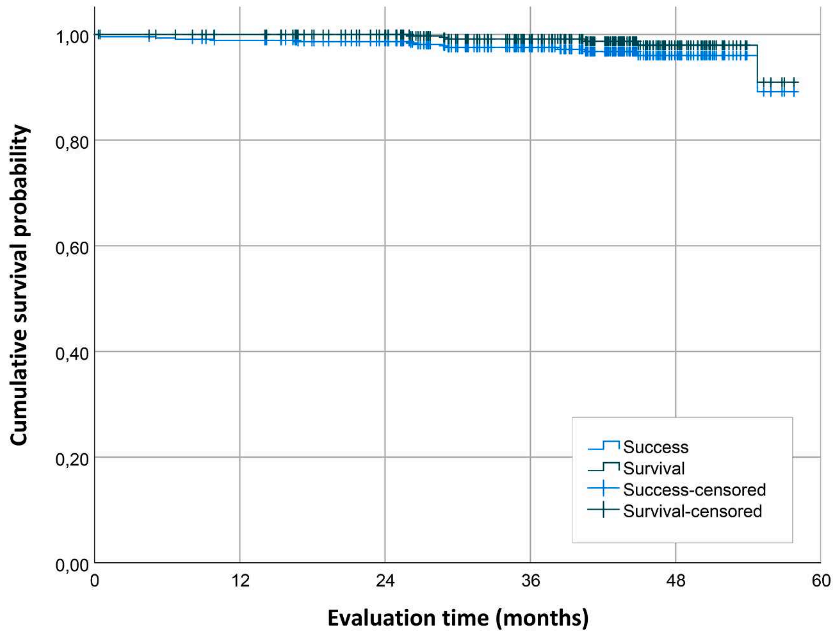

Fig. 1. Cumulative survival probability for the survival and success rates of partial indirect lithium disilicate restorations ($n = 454$).

Table 5
Descriptives of preparation characteristics and sub analyses: Number of restorations, events, and results of Log-rank tests on survival and success.

	Survival Events	Restorations	Statistic	Success Events	Restorations	Statistic
Prep design (vital teeth)						
Inlay (0 cusps)	2	121	p>.05	2	121	p>.05
Overlay (all cusps)	1	56		2	56	
Prep design (endodontic treated teeth)						
Inlay (0 cusps)	0	7	p>.05	0	7	p>.05
Overlay (all cusps)	1	26		1	26	
Width of inlay						
Narrow (<50 %)	0	30	p>.05	0	30	p>.05
Medium (50–60 %)	2	43		2	43	
Wide (>60 %)	0	43		0	43	
Cusps (Premolars)						
0	1	74	p>.05	1	74	p>.05
1	1	30		1	31	
2	0	15		0	15	
Cusps (Molars)						
0	1	68	p>.05	2	68	p>.05
1	0	68		2	68	
2	1	82		3	82	
3	0	49		2	49	
4	2	67		3	67	
Surfaces						
1	0	7	p>.05	1	7	p>.05
2	2	72		2	12	
3	0	101		1	101	
4	2	136		7	136	
5	2	138		3	138	
Restoration surface (%)						
10–30	1	9	p>.05	1	9	p>.05
30–50	1	38		1	38	
50–70	0	118		2	118	
70–90	2	162		4	162	
90–100	2	88		5	88	

and diagnosis of potential endodontic issues could be crucial factors in the success of indirect restorations. There were no fractures observed of the lithium disilicate restorations. Another study, with the inclusion of predominantly feldspathic and leucite reinforced inlays and onlays found in most cases failures due to restoration or tooth fracture (44,5 %) [23]. Hence, lithium disilicate restorations seem less prone to fracture.

The high survival and success rates of the evaluated restorations may be attributed to the favorable material properties of lithium disilicate, such as its high flexural strength, esthetics, and wear resistance [1]. Moreover, the use of adhesive bonding techniques, like IDS, with lithium disilicate restorations has been shown to improve the mechanical retention of restorations, leading to better clinical outcomes for laminate veneers [9,14,19].

The short-term clinical performance of the partial lithium disilicate

Table 6
Criteria used for the clinical evaluations of the restorations adapted version of modified USPHS criteria.

Category Photograph	S*	Criteria 0–12 months		12–24 months		24–36 months		36–48 months		48–60 months	
		$n = 34$		$n = 29$		$n = 102$		$n = 87$		$n = 5$	
12. Adaptation restoration	0	34	100 %	28	96.6 %	99	97.1 %	85	97.7 %	5	100 %
	1			1	3.4 %	3	2.9 %	2	2.3 %		
	2										
	3										
		$n = 34$		$n = 29$		$n = 102$		$n = 87$		$n = 5$	
13. Caries	0	34	100 %	29	100 %	102	100 %	87	100 %	5	100 %
	1										
		$n = 34$		$n = 29$		$n = 102$		$n = 87$		$n = 5$	
14. Marginal staining	0	33	97.1 %	23	79.3 %	78	76.5 %	57	65.5 %	33	97.1 %
	1	1	2.9 %	6	20.7 %	20	19.6 %	24	27.6 %	1	2.9 %
	2					4	3.9 %	6	6.9 %		
	3										
		$n = 33$		$n = 29$		$n = 102$		$n = 84$		$n = 5$	
15. Surface luster	0	32	94.1 %	26	89.7 %	87	85.3 %	76	90.5 %	5	100.0 %
	1	1	2.9 %	3	10.3 %	15	14.7 %	7	8.3 %		
	2	1	2.9 %					1	1.2 %		
	3										
		$n = 34$		$n = 29$		$n = 102$		$n = 87$		$n = 5$	
16. Surface staining	0	34	100.0 %	29	100.0 %	101	99.0 %	85	97.7 %	5	100.0 %
	1					1	1.0 %	2	2.3 %		
		$n = 33$		$n = 28$		$n = 100$		$n = 83$		$n = 5$	
17. Contact points	0					1	1.0 %				
	1	33	100.0 %	28	100.0 %	99	99.0 %	83	100.0 %	5	100.0 %
		$n = 34$		$n = 29$		$n = 102$		$n = 87$		$n = 5$	
18. Fracture of restoration	0	34	100 %	29	100 %	102	100 %	87	100 %	5	100 %
	1										
	2										
	3										
	4										
	5										
		$n = 34$		$n = 29$		$n = 102$		$n = 87$		$n = 5$	
19. Wear restoration	0	33	97.1 %	29	100 %	102	100 %	87	100 %	5	100 %
	1	1	2.9 %								
Radiograph											
		$n = 34$		$n = 61$		$n = 96$		$n = 76$		$n = 31$	
20. Adaptation restoration	0	33	97.1 %	59	96.7 %	87	90.6 %	71	93.4 %	29	93.5 %
	1	1	2.9 %	2	3.3 %	7	7.3 %	4	5.3 %	2	6.5 %
	2					2	2.1 %	1	1.3 %		
	3										
		$n = 34$		$n = 61$		$n = 96$		$n = 76$		$n = 31$	
21. Caries	0	34	100.0 %	61	100.0 %	96	100.0 %	75	98.7 %	31	100.0 %
	1							1	1.3 %		
		$n = 34$		$n = 61$		$n = 96$		$n = 76$		$n = 31$	
22. Marginal adaptation	0	34	100.0 %	61	100.0 %	91	94.8 %	70	92.1 %	30	96.8 %
	1					5	5.2 %	6	7.9 %	1	3.2 %
	2										
	3										

S = score. * Scores 0, 1, 2, 3, 4 and 5 can also be read as Alpha, Beta, Charlie, Delta, Echo and Foxtrot.

restorations was found to be good, restorations with a longer evaluation period, 24–48 months, show a statistically significant increase in minor marginal discoloration. However, the clinical performance is clinically acceptable in >90 % of the cases. This is consistent with previous studies that have reported satisfactory clinical performance of lithium disilicate restorations in terms of color match, marginal adaptation, secondary caries, and tooth sensitivity [15,19].

Despite the favorable outcomes, this study has some limitations. At first, teeth are not randomly assigned to a particular preparation design or characteristic; therefore variables could only be associated, but causality cannot be identified. In addition, the fact that it is a retrospective study may have introduced potential bias, as some patients might have been lost to follow-up. The patients were not treated for research purposes, and some of them received treatment prior to the commencement of this observational study. Therefore, a retrospective study design was the most suitable approach. The detailed materials and methods section was made possible by the stringent treatment protocol followed in the dental practice. Furthermore, the maximum evaluation period of 58 months restricts the assessment of long-term clinical performance. One might argue that the conversion of a photo-polymerized composite used in this study is insufficient beneath lithium disilicate restorations. However, recent *in vitro* studies have indicated successful conversion beneath a substantial layer of lithium disilicate [25,26].

Future studies should consider prospective designs, randomly assigned designs, and longer follow-up periods to validate the findings of the present study. Additionally, further research should explore the influence of other factors such as patient-related factors like caries risk, oral hygiene and parafunctional habits on the clinical performance of lithium disilicate restorations.

5. Conclusion

This retrospective study on partial indirect lithium disilicate restorations in conjunction with IDS demonstrates survival and success rates of 99.2 and 96.7 % over a mean evaluation period of 37 months. A marked influence of the studied preparation characteristics on the survival, success and clinical performance of lithium disilicate partial restorations could not be demonstrated. The partial lithium disilicate

Fig. 2. Two representative restorations (#36 and #37) after a follow-up of 43 months. (A) Occlusal view of the die stone cast of the preparations; (B) Lingual view of the die stone cast of the preparations. (C) Occlusal view of the lithium disilicate restorations on the die stone cast; (D) Lingual view of the lithium disilicate restorations on the die stone cast; (E) Occlusal view of clinical appearance of the lithium disilicate restorations on #36 and #37 after 43 months of function. Note the lack of marginal and surface staining; (F) Lingual view after 43 months of function; (G) Detail photograph of the buccal side of the restorations on #36 and #37, note the slight marginal staining; (H) Pre-treatment radiograph; (I) Post-treatment radiograph after 43 months of follow-up.

restorations exhibit good clinical performance in >90 % of the cases.

CRediT authorship contribution statement

Jelte W Hofsteenge: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Rijkje A Bresser:** Conceptualization, Investigation, Methodology, Writing – review & editing. **Gerrit J Buijs:** Investigation, Resources, Writing – review & editing. **Stephan AM van der Made:** Investigation, Resources, Writing – review & editing. **Mutlu Özcan:** Conceptualization, Methodology, Writing – review & editing. **Marco S Cune:** Conceptualization, Methodology, Writing – review & editing. **Marco MM Gresnigt:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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