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Clinical performance of occlusal onlays made of lithium disilicate ceramic in patients with severe tooth wear up to 11 years

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ABSTRACT

Objectives. Evaluation of survival and complication rate of monolithic occlusal onlays made of lithium disilicate ceramic used in patients with severe tooth wear up to 11 years of clinical service.

Methods. In a prospective non-randomized clinical study 7 patients (4 male, 3 female; median age: 44.3 ± 6.56 years old) were restored full mouth with a total of 103 adhesively bonded occlusal onlays made of lithium disilicate ceramic (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein). All restorations were examined during annual recall visits using periodontal parameters according to the modified United States Public Health Service (USPHS) criteria: (a) marginal discoloration, (b) secondary caries, (c) marginal integrity, (d) surface texture, (e) restoration fracture, and (f) occlusal wear, rating with Alpha, Bravo and Charlie over an observation period up to 11 years (68–139 months; median: 94.9 ± 26.1 months). Data was statistically analyzed using the Kaplan–Meier estimation.

Results. Monolithic lithium disilicate occlusal onlays presented a 100% survival rate. Four restorations within one patient (3.9%) presented marginal discoloration, one after 60 and three after 108 months (all rated Bravo). One restoration (1%) showed a marginal crack formation (technical complication) after 120 months, rated Bravo. No biological complication, debonding or secondary caries could be found and tested periodontal parameters showed excellent results.

Significance. Based on the analyzed data up to 11 years, monolithic occlusal onlays made of lithium disilicate ceramic can be considered as a reliable treatment option for full-mouth rehabilitations in patients with severe tooth wear.

1. Introduction

Continuing socioeconomic changes, advances in dental healthcare, and increased awareness of oral hygiene support patients in keeping their natural teeth for longer. According to the Fifth German Oral Health Study, extraction rates due to carious or periodontal lesions have decreased significantly in the last few decades [1]. The number of remaining teeth at an advanced age has increased significantly: younger seniors aged 65–74 years old had on average at least five more of their own teeth in 2014 than in 1997 [1]. Beyond this background, there is a clear trend moving from traditional removable prostheses towards fixed restorations [1,2].

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However, the substantial loss of dental hard tissue, associated with classical crown or bridge preparations, is increasingly considered a critical aspect. Attempts are made to avoid these invasive measures as far as possible or at least to postpone them until later in life [3,4].

Abrasion, attrition, and erosion and their combinations are increasingly considered to be the major risk factors for the early loss of hard tooth structure and, consequently, the vertical dimension of the occlusion (VDO); younger patients are also affected by these problems [5–7]. These effects are further potentiated by the fact that teeth now remain in function for much longer [8].

Due to continuous improvements in adhesive technology as well as material science, minimally invasive treatment protocols have become established in modern restorative dentistry. Adhesively luted occlusal onlays, which are characterized by a defect-specific, less retentive preparation allow a considerably reduced loss of hard tooth tissues [9–11].

Although minimally invasive occlusal onlays do not yet have reliable long-term clinical data available in the scientific literature, all-ceramic restorations — mostly circumferential crowns — generally display positive results [12–18]. In single-tooth restorations, lithium disilicate crowns (IPS e.max Press, Ivoclar Vivadent, Schaan. Liechtenstein) show reliable long-term clinical performance with survival rates of 92% after 5 years and 85.5% after 10 years [14]. Ten-year survival rates of 96.7% or an estimated survival rate of 91.4% at 10 years for lithium disilicate single crowns were presented in two other studies, illustrating the reliability of this restoration material [16,19]. To the best of the authors' knowledge, there is no specific long-term data available for occlusal onlays made of lithium disilicate ceramic.

The present prospective clinical study should therefore analyze and compare the clinical performance with long-term survival and failure rates of lithium disilicate glass-ceramic occlusal onlays up to 11 years in vivo.

2. Material and methods

Seven patients (4 male, 3 female; median age: 44.3 ± 6.56 years old), who met the inclusion criteria, had restorations in a prospective clinical study with a total of 103 adhesively bonded monolithic occlusal onlays made of lithium disilicate ceramic (IPS e.max Press, Ivoclar Vivadent). The requirements of the Declaration of Helsinki were observed, and all the patients gave informed consent. The study design was approved by the ethical committee (no. 012-12).

The inclusion and exclusion criteria were defined for all patients as follows:

(a) Age over 18 and under 70 years old.
(b) Optimal oral hygiene.
(c) Preparation guidelines for occlusal onlay restorations can be fulfilled.
(d) Planned increase of the VDO due to complete attritive, abrasive, and erosive or pathological damaged hard tooth structure.
(e) **No** periodontal disease.
(f) **No** pregnant or lactating women.

Fig. 1 – Preoperative situation of the full upper jaw with visible tooth wear.

Fig. 2 – Preoperative situation of the full lower jaw with visible tooth wear.

2.1. *Prosthetic procedure*

All participants were regular patients of the Department of Prosthetic Dentistry and decided upon minimally invasive tooth-colored full-mouth rehabilitation with monolithic occlusal onlays made out of lithium disilicate ceramic in the posterior regions due to moderate to severe loss of tooth structure combined with an individual but significant loss of the VDO (Figs. 1–3), hypersensitivities, functional impairments, or esthetic deficits. Within the full-mouth rehabilitation, the anterior regions were restored with either partial veneers or full veneers made out of lithium disilicate ceramic with an additional manual veneering. As it is difficult to compare those veneered restorations with different designs, data of these restorations were excluded from the present clinical study.

The main reason for tooth wear was a combination of erosion and mechanical stress with a minimal dominance of erosive effects. Despite the fact that the correct adjustment of a new VDO is different in its amount for patients suffering from moderate to severe tooth wear, the treatment process in such cases is quite similar. The treatment started with an esthetic and functional diagnostic wax-up in centric relation, which was evaluated with the patient using a

Fig. 3 – Preoperative situation of lower right quadrant with visible tooth wear.

Fig. 4 – Adhesively bonded PMMA chips of the upper jaw used as fixed repositioning splint and prep guide.

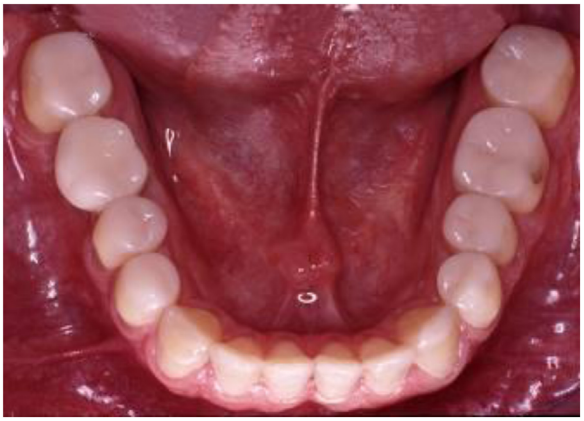

Fig. 5 – Adhesively bonded PMMA chips of the lower jaw used as fixed repositioning splint and prep guide.

direct mock-up (esthetic evaluation). The amount of vertical dimension increase (VDI) was determined according to multiple parameters, such as the incisal edge position of central incisors, the width-to-length ratio of the incisors, the phonetic distance, the freeway space, and the facial profile (upper and lower proportion of the face) which was also reported in literature [20–22]. After the successful esthetic evaluation, a functional evaluation was conducted for at least three months by transferring the VDI of the diagnostic wax-up into a reposition-splint or adhesively luted PMMA chips (Figs. 4 and 5). Finally, the transfer into definitive glass-ceramic occlusal onlays was performed in a segment-by-segment method. The removal of tooth substance was guided by a template (prep-guide), either made by a thermoplastic template/foil (Duran transparent 0.5 mm, Scheu-Dental, Germany) or a silicon index fabricated from the outer contour of the diagnostic wax-up, accompanied by a special parodontometer (CP-15UNC probe, Hu-Friedy) (Figs. 6 and 7).

Preparation guidelines for the occlusal onlays were set as follows (Fig. 8):

1 Central fissure: orientation groove (OG) with a ball-formed bur 8801.314.023 (up to stop shaft approx. 0.7 mm, Komet Dental, Gebr. Brasseler GmbH & Co. KG, Lemgo, Germany).
2 Cusps: OG (3 OG occlusal surface buccal side, 3 OG occlusal surface oral side, and 3 OG palatal functional cusps) with

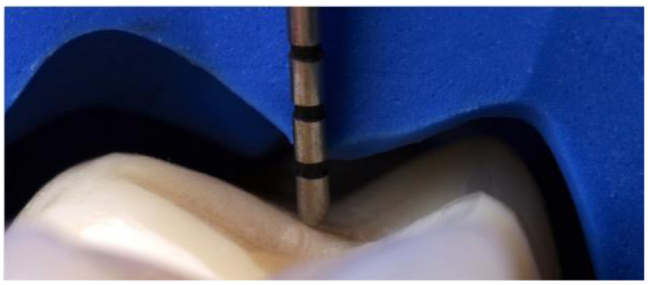

Fig. 6 – Tooth substance removal was guided by a template (prep-guide) made of a silicon index fabricated from the outer contour of the diagnostic wax-up, accompanied by a special pardontometer (CP-15UNC probe, Hu-Friedy).

Fig. 7 – Tooth substance removal was guided by a template (prep-guide) made by a thermoplastic template/foil (Duran transparent 0.5 mm, Scheu-Dental, Germany).

Fig. 8 – Postpreparation situation of lower right quadrant according to preparation guidelines for minimally invasive lithium disilicate occlusal onlays before impression taking (1 mm occlusal space).

8856.314.014 (Komet Dental, Gebr. Brasseler GmbH & Co. KG).

3 Occlusal surface: shortening and rounding off (create approx. 1 mm of space) with 8379.314.023 (Komet Dental, Gebr. Brasseler GmbH & Co. KG).

4 Creation of the circular preparation margin 8856.314.016 (about 1 mm of reduction, Komet Dental, Gebr. Brasseler GmbH & Co. KG).

5 For the approximal extension 856.314.014 (Komet Dental, Gebr. Brasseler GmbH & Co. KG) and with KaVo Sonicflex attachment "small hemisphere", finishing with 8856.314.014 and H375R.314.014 (Komet Dental, Gebr. Brasseler GmbH & Co. KG).

6 For the vestibular extension, proceed as for the facial preparation of a labial veneer.

7 Finishing buccally and orally with individualized Al_2O_3 stone 649.314.420 (individualized on a diamond disc, Komet Dental, Gebr. Brasseler GmbH & Co. KG) at a reduced speed and with sufficient water cooling.

8 Smoothing the occlusal preparation surface with Al_2O_3 stone 638R.314.420 (Komet Dental, Gebr. Brasseler GmbH & Co. KG) at a reduced speed and with sufficient water cooling (minimum 1–1.5 mm space requirement).

9 Optional: rounding off the edges with Soflex disc light brown 2382 M (3 M, Saint Paul, MN, USA) or rubber cup 9606.204.060 (Komet Dental, Gebr. Brasseler GmbH & Co. KG).

Impressions were taken with a polyether impression material (Impregum Penta, 3M, Seefeld, Germany). First, the plaster casts as well as final restorations (IPS e.max Press, Ivoclar Vivadent) were fabricated either in the dental laboratory of the Department of Prosthetic Dentistry of the LMU Munich or in the dental laboratory innovative dental design (Oliver Brix, Bad Homburg, Germany) according to the manufacturer's instructions, which have already been published in previous articles [23–25] (Fig. 9). Lithium disilicate glass-ceramics with the associated staining agents were used in a press technique, according to ISO 6872.

During the fabrication time, the prepared abutment teeth were covered with temporary restorations (C & B, Ivoclar Vivadent), being temporarily fixed with bond (Heliobond, Ivoclar Vivadent). The minimum thickness of 1 mm of the final restoration was checked using a caliper (Fig. 10). All occlusal onlays were tried in the patient, and the fit was checked with high-precision A-silicone (Fit & Test, Voco, Cuxhaven,

Fig. 9 – Final pressed minimally invasive lithium disilicate occlusal onlays with 1 mm minimum occlusal thickness (IPS e.max Press, ingot HT, Ivoclar Vivadent).

Fig. 10 – Minimum thickness of restoration (1 mm) was controlled by a caliber by dental technicans.

Fig. 11 – Postprosthetic situation of lower right quadrant directly after defintive bonding of pressed lithium disilicate occlusal onlays with Syntac Total etch and rinse in combination with Varionlink II (Ivoclar Vivadent) in June 2008.

Germany). In the case of small-area corrections (<1 mm diameter), the surface was repolished chair-side to a high gloss with ceramic polishers prior to definite adhesive bonding. For larger corrections, the restoration was again provided with a glaze firing in the dental laboratory. All the restorations were adhesively luted (Syntac Total etch & rinse technique, Variolink II Professional Set, low viscosity, light-curing, Ivoclar Vivadent) (Fig. 11). For cases where no rubber dam could be used, impregnated retraction cords (size 000, Ultrapak, Ultradent) were used during the luting procedures to protect the gingival areas and ensure good bonding conditions.

Annual recall visits on technical, esthetical, and biological failures (including marginal discoloration, secondary caries, marginal integrity, surface texture, restoration fracture, and occlusal wear) were performed using the modified United States Public Health Service (USPHS) criteria specified in Table 1 according to previous investigations [26,27]. The parameters measured were rated Alpha in the case of no problems, Bravo in the case of minor complications, and Charlie in the case of major complications, making the renewal of the restoration necessary (see Table 1).

Moreover, clinical variables like the periodontal parameters including the plaque index (PI), gingival index (GI), and oral and vestibular probing depth (PD), as well as bleeding on probing (BOP), around the abutment teeth were assessed [28–30]. In addition, the FDI guidelines and the guidelines for reporting non-randomized studies (CONSORT statements) were partly included in the present clinical study [31]. In addition, occlusal as well as functional relationships of the restorations were recorded. The recall evaluations were performed by one examiner with 9 years of expertise in all-ceramic and adhesive practice, who did not perform the prosthetic rehabilitation.

2.2. *Statistical analysis*

The survival and complication rates were calculated using the Kaplan–Meier survival analysis method. A restoration was considered as a total failure when the restoration had to be

Table 1 – Modified United States Public Health Service (USPHS) ryge criteria for direct clinical evaluation of restorations used [22,23].

USPHS	Alpha (A)	Bravo (B)	Charlie (C)
Marginal discoloration	No visual evidence of marginal discoloration	Visual evidence of marginal discoloration at the junction of the tooth structure and the restoration, but the discoloration has not penetrated along the restoration in a pulpal direction	Visual evidence of marginal discoloration at the junction of the tooth structure and the restoration that has penetrated along the restoration in a pulpal direction, renewal necessary
Secondary caries	The restoration is a continuation of existing anatomic form adjacent to the restoration	Visual evidence of dark deep discoloration adjacent to the restoration	Renewal necessary
Marginal integrity	Probe did not catch	Slight catch on probing, no gap	Highly over or undercontoured, renewal necessary
Surface texture	Surface texture similar to polished enamel	Surface texture gritty or similar to a surface subjected to a white stone or similar to a composite containing supramicron-sized particles	Surface pitting is sufficiently coarse to inhibit the continuous movement of an explorer across the surface, renewal necessary
Restoration fracture	Restoration is intact and fully retained, no fracture	Restoration is partially retained, polishing or repair is possible	Restoration is completely missing or huge fracture, renewal necessary
Occlusal wear	No occlusal wear on reconstruction or opposite teeth	Occlusal wear on reconstruction or opposite teeth	Massive occlusal wear, renewal necessary

replaced. Data were analyzed with SPSS 25 (SPSS Inc., Chicago, IL, USA).

3. Results

A total of seven patients could be assessed in the recall appointments without any drop-out. The mean observation time was 7.9 years (range from 68 months (5.7 years) to 139 months (11.6 years)). All detailed patient information is listed in Table 2 separately.

Monolithic lithium disilicate occlusal onlays presented a survival rate of 100%. All survival and specific complication rates are presented as primary outcomes in Tables 3 and 4 as well as Fig. 12, listing both the technical/biological complication rate, repair rate, discoloration, as well as the chipping rate and USPHS criteria used. In total, four restorations within one patient (3.9%) presented marginal discoloration — one after 60 months (5 years) and three after 108 months (9 years) of clinical use (all rated Bravo) (Fig. 13). One restoration (1%) showed a marginal crack formation (technical failure) after 120 months (10 years), which was rated Bravo (Figs. 14 and 15). Occlusal wear rated Bravo occurred within the ceramic restorations in 65% of the restorations (Figs. 16–18). All the patients were non-smokers. No further biological complication, debonding, or secondary caries could be found as secondary outcomes. The detailed surface and periodontal parameters, including the PI, GI, oral and vestibular PD, BOP, as well as the marginal/surface quality of the abutment teeth, are summarized in Table 5.

4. Discussion

In modern dental practice, there is an ongoing change in prosthetic restorations as patients increasingly retain their natural teeth until old age. During their period of use, natural teeth are subject to both the physiological and pathological loss of hard tooth structure by attrition, abrasion, erosion, and combinations thereof. Non-invasive direct and minimally invasive indirect defect-oriented therapies are available for esthetic and functional rehabilitation of lost hard tooth substance.

For smaller defects and younger patients, *direct* composite restorations might be the first choice, as these therapies represent a minimum of invasiveness combined with lower costs compared to indirect procedures. Direct restorations are initially satisfying [32], but clinical follow-ups showed that in more complex cases, *direct* posterior composite restorations discernibly deteriorate after an observation time of 5.5 years, especially in terms of surface texture, anatomical shape, and marginal fit [33].

In contrast, *indirect* restorations — such as ones made of glass-ceramics in the present study — facilitate a safer and more stable implementation of physiological occlusion. In more extensive restorative approaches, they provide better control over the optimal form and esthetics as time progresses, but they are associated with higher costs [34].

The specific designation of occlusal onlays instead of just onlays was chosen as it highlights the lifting of the VDO with a redefining of the occlusal relations. To the best of the authors' knowledge, there are unfortunately no long-term clinical data for occlusal onlays in patients with an increased VDO.

Table 2 – Survival and (esthetic) failure rate (FR) of monolithic lithium disilicate occlusal onlays investigated in situ with USPHS criteria included (A/B/C).

Patient (number)	Age (years)	Gender (m/f)	Time in situ (months)	Number of restorations (No. molars/No. premolars)	Survival rate (%)	FDI position	FR (USPHS rate)	FR (months)
1	49	m	139	16 (8 molars, 8 premolars)	100	26	Marginal discoloration (B)	60
						36	Marginal discoloration (B)	108
						45	Marginal discoloration (B)	108
						46	Marginal discoloration (B)	108
						15	Marginal crack formation (B)	120
2	39	m	128	16 (8 molars, 8 premolars)	100			
3	38	m	87	16 (8 molars, 8 premolars)	100			
4	41	f	80	16 (8 molars, 8 premolars)	100			
5	39	m	83	15 (7 molars, 8 premolars)	100			
6	48	f	68	14 (8 molars, 6 premolars)	100			
7	56	f	79	10 (4 molars, 6 premolars)	100			

Table 3 – Total survival and failure rates of monolithic lithium disilicate occlusal onlays.

Total Survival and failure rates	Total number	%
Survival rate	103/103	100
Technical failure rate	1/103	1.0
Biological failure rate	0/103	0
Repair rate	0/103	0
Chipping rate	0/103	0
Discoloration rate	4/103	3.9

Table 4 – Results of modified USPHS criteria [22,23].

	Alpha	Bravo	Charlie
Marginal discoloration	96 (96.1%)	4 (3.9%)	0 (0%)
Secondary caries	103 (100%)	0 (0%)	0 (0%)
Marginal integrity	65 (63.1%)	38 (36.9%)	0 (0%)
Surface texture	103 (100%)	0 (0%)	0 (0%)
Restoration fracture	102 (99%)	1 (1%)	0 (0%)
Occlusal wear	36 (35%)	67 (65%)	0 (0%)

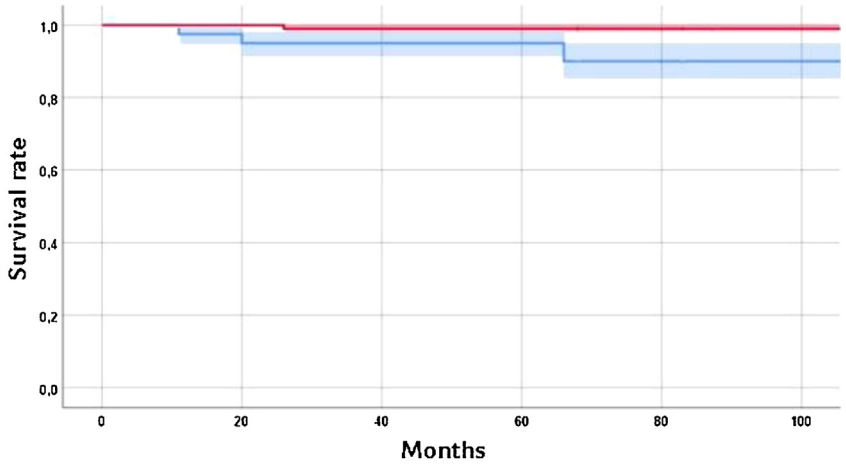

Fig. 12 – Kaplan–Meier survival rate combined with the complications occurred, rated Bravo (B: Discoloration and marginal crack formation).

Fig. 13 – Marginal discoloration of bonding gap of first molar in lower left quadrant after 108 months of clinical use, rated Bravo. The discoloration penetrated slightly underneath the restoration and could therefore not completely repolished.

Fig. 14 – Marginal crack formation at the palatal aspect of second premolar of upper right quadrant after 120 months of clinical service, rated Bravo.

Occlusal onlays, surveyed in the present study, showed a total survival rate of 100%. In addition, there were no further complications except for marginal discoloration in four restorations and one marginal crack formation. Three of the occurring discolorations after five years could be repolished, one was penetrated partially underneath the restoration and was monitored (Fig. 13). The minor marginal crack after 10 years of clinical use was also monitored in the following recall appointments. These incidents consequently had no impact on the survival rate of the occlusal onlay restorations. However, it is striking that — with one exception (marginal discoloration) — most of the complications or necessary repol-

Fig. 15 – Magnification of the marginal crack formation at second premolar of upper right quadrant after 120 months of clinical use, rated Bravo.

Fig. 16 – Postoperative situation of lower right quadrant after 78 months of clinical use with visible occlusal wear on glass-ceramic material.

Fig. 17 – Postprosthetic situation of lower right quadrant after 108 months of clinical use with visible occlusal wear on glass-ceramic material.

ishing occurred not before 5 years after insertion and that all complications in the present study occurred in one patient with the longest observation time of 11 years. This is kind of surprising, as prosthetic treatment was performed identically, but the post-treatment compliance of the patient was reduced, especially in wearing his protection splint at night. This might be an indication for the higher number of complications; however, any additional causes and influencing factors remain unclear. Also, the patient was a non-smoker, and the discolorations cannot be clarified.

Not just clinical studies on the type of restoration used, but also clinical studies on the monolithic material IPS e.max Press (Ivoclar Vivadent) are scarce in the scientific literature [25].

Investigations of 106 and 87 full crowns made of pressed IPS Empress 2 ceramic (Ivoclar Vivadent) showed a cumulative 10-year survival rate of 86.1% [23] and 85.5%, respectively [14]. In addition, a clinical study analyzing adhesively luted silicate and lithium disilicate single crowns led to estimated survival rates of 99.4% at 5 years and 91.4% at 10 years. Those studies exhibited a comparable study design in points like the adhesive luting procedure, restorations partly fabricated from monolithic lithium disilicate ceramic and performing full-mouth rehabilitation with VDI [19]. The limitation to compare these clinical studies can be seen in the fact that a different preparation geometry (full crowns - occlusal onlays) and therefore, different restoration designs were used. A further investigation of the periodontal parameters of Teichmann

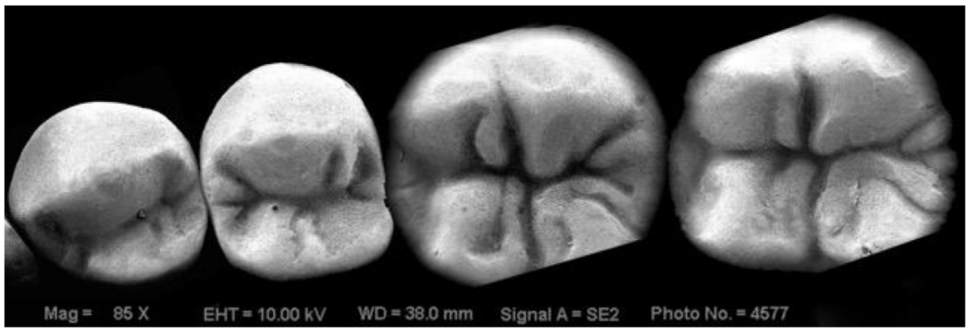

Fig. 18 – SEM image of restorations of lower right quadrant after 78 months with visible occlusal wear on the monolithic lithium disilicate material. Speparate pictures added in one Figure with a restricted field of view.

Table 5 – Detailed surface and periodontal parameters including plaque index (PI), gingival index (GI), oral and vestibular probing depth (PD), and bleeding on probing (BOP) of abutment teeth.

Parameter tested	Rating	Number	Percentage (%)
PI (0–3 according to Silness and Loe, 1964)	0	67	65.0
	1	32	31.1
	2	4	3.9
	3	0	0
GI (0–3 according to Loe and Silness, 1963)	0	35	34.0
	1	66	64.1
	2	2	1.9
	3	0	0
Vestibular PD	1	14	13.6
	2	84	81.6
	3	5	4.9
Oral PD	1	9	8.7
	2	79	76.7
	3	15	14.6
BOP (0–4 according to Muehlemann, 1978)	0	91	88.3
	1	12	11.7
	2	0	0
	3	0	0
	4	0	0
Marginal quality (1: perfect; 2: irregular; 3: surplus)	1	65	63.1
	2	30	29.1
	3	8	7.8
Surface quality (1: smooth; 2: slightly rough; 3: rough)	1	103	100
	2	0	0
	3	0	0

et al. reported that the surface, color, and marginal integrity of the crowns were in the range of excellence [24]. These good results of the periodontal parameters could be confirmed by the present clinical study, as clinical parameters like probing depths, surface quality, esthetics, and marginal integrity could be rated as optimal. This might be positively influenced by the location of the preparation margin in onlay restorations (predominantly supragingival) compared to full-crown preparations (predominantly intrasulcular). Clinically there were no visible bone losses or periodontal changes detected in the present study. Since all the preparation margins were predominantly supragingival, no specific control radiographs were performed, also to avoid unnecessary radiation exposure. However, the present survival rate of the analyzed occlusal onlays from IPS e.max Press (Ivoclar Vivadent) was higher, with a total survival rate of 100% during the mean observation time of 7.9 years. Although the occlusal onlays were minimally invasive and produced in a minimum layer thickness of 1 mm, they showed even better results than the full crowns in the before mentioned studies. Nevertheless, the exact layer thickness of each occlusal onlay was not recorded, representing a limitation of the present study. Among other things, one reason might be the further developed material and the different preparation geometries avoiding inner stress and enabling a reliable bond to enamel. It is known that the adequate adhesive bonding of partial crowns, somewhat comparable to occlusal onlays, can stabilize them despite their minimal thicknesses and could replace conventional crown restorations [34]. There was just one minor marginal crack formation after 10 years of clinical service in the need of monitoring in the present study. Due to the different restoration designs and layer thicknesses; however, the three mentioned investigations are not ideally comparable with the present clinical study. In all the clinical studies, the occlusion relation-

ships of the patients also play an important role. Depending on whether the patient cohort includes more male or female patients, whether the study refers to the previous jaw relations (the degree of change in the tooth position) or whether maximum mechanical loads such as bruxism have been included. These influences alone can lead to significant differences in the results. The patient cohort was very balanced in the present study, but aspects such as bruxism and previous occlusal relationships were not directly included. This represents an additional limitation of the present study. As all patients had full-mouth restorations predominantly with identical restorative materials opposing each other, the principles of a mutual occlusal concept could be realized [35]. Anterior-canine guidance associated with the "freedom in centric" concept could be realized in each patient [36].

In a further prospective split-mouth examination with IPS e.max Press and CAD (both Ivoclar Vivadent), a comparable 7-year survival rate for the partial crowns of 100% for the pressed and 97% for the milled restorations were reported, where the USPHC criteria showed slightly worse results, especially with respect to the surface quality and discoloration of the restoration for the pressed partial crowns [25].

Apart from the restoration material itself, the appropriate preparation geometry also has an impact on the longevity of all-ceramic restorations. In particular, the enamel support of the occlusal onlays in minimally invasive preparations, as performed in the present study, appears to have a positive influence on the restoration stability, in contrast to dentin-supported onlays. Within a finite element investigation, it was found that monolithic lithium disilicate onlays (0.6–1.4 mm thick), which are enamel supported (elastic modulus of enamel: about 70 GPa), achieved 70% of the failure load of a monolithic zirconia onlay. In contrast, the same dentin-supported onlays (elastic modulus of dentin: about 18 GPa) reached only 57% [37–40]. This illustrates the theoretical advantages of the minimally invasive preparations performed as much as possible in the enamel structure, which are supported by the present clinical study. Another in-vitro study tested the influence of various preparation designs and restoration thicknesses of adhesively bonded lithium disilicate ceramic (IPS e.max Press, Ivoclar Vivadent) on fracture toughness. Occlusal veneers at a normal layer of thickness presented increased fracture resistance than the thin and ultra-thin restorations tested [25]. However, this study design cannot be implemented in clinical application and is therefore, not directly comparable.

There are several limitations of the present prospective non-randomized clinical study that need to be addressed. Due to the fact, that all patients were treated with the same restorative material and preparation geometry, no comparisons to a control group could be made. In addition, there was a small number of treated patients but with a high number of restorations each. It is obvious that the patients' characteristics might have influenced the present results due to specific occlusion, function characteristics, and compliance. Further clinical studies need to be performed with a larger patient cohort. The patients were also treated by one experienced single operator and a separate post-examiner for the annual recall visits. Therefore, limited bias cannot be excluded.

All teeth and restorative materials underlay physiological wear, which may vary slightly from teeth to teeth and material to material. In scientific literature, different information on the wear rates for diverse materials can be found. However, some investigations have shown so far that lithium disilicate ceramics — also IPS e.max Press (Ivoclar Vivadent) — show higher wear rates than natural human enamel but not statistically different in direct comparison [41–44]. Since all the posterior teeth of all patients included in the present clinical study were restored bimaxillary with the same glass-ceramic material, the wear rates cannot be compared with the wear rates of the natural teeth, since all antagonists were also supplied with glass-ceramic occlusal onlays.

According to the monitored USPHS criteria concerning occlusal wear, the used IPS e.max Press ceramic (Ivoclar Vivadent) presented occlusal wear. This is visible in Figs. 16–18 but was not specifically investigated further. Therefore, regular functional controls should be carried out during recall visits.

Despite the limitations of the present clinical study, it could be shown that monolithic lithium disilicate ceramic restorations (IPS e.max Press, Ivoclar Vivadent) with a minimum layer thickness of 1 mm represent a reliable treatment option, even and especially if the VDO needs to be increased. Since only one restorative material was examined in the present clinical study, further studies with different materials may be useful, also in a randomized study setup.

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