Clin Oral Invest (2017) 21:2123–2131
DOI 10.1007/s00784-016-2002-1

ORIGINAL ARTICLE

Risk factors for failure in the management of cervical caries lesions

R. J. Wierichs [1] · E. J. Kramer [2] · H. Meyer-Lueckel [1]

Received: 3 May 2016 / Accepted: 1 November 2016 / Published online: 10 November 2016

Abstract

Objectives The aim of this retrospective, non-interventional clinical study was to analyze factors influencing the survival of restorative treatments of active cervical (root) caries lesions (aCCLs) and the success of non-invasive treatment options of inactive cervical (root) caries lesions (iCCLs).

Material and methods Records from patients who visited a single private practice regularly were searched for the presence of solely buccal CCLs. Data from 345 aCCLs and 232 iCCLs being detected at least 6 months before the last recall visit in 295 patients were recorded. Kaplan-Meier analyses were used to analyze time to failure in both groups. Cox proportional hazards models were used to evaluate the association between clinical factors and time until failure.

Results Within 120 months, 20 aCCLs had received a second restorative follow-up treatment. For iCCLs, 35 lesions had to be restored within 120 months. Median survival/success time was 111 months for aCCLs (annual failure rate 1.7%) and 120 months for iCCLs (annual "restoration" rate 4.3%). In multivariate Cox regression, active and inactive CCLs being checked up more than twice a year showed significantly higher failure/restoration rates than CCLs being checked up less than twice a year ($p < 0.001$).

Conclusion Low failure/restoration rates could be found for both treatment strategies for CCLs, and only the "number of check-ups per year" was significantly positively associated with failures.

Clinical relevance Caries monitoring is a viable way to manage CCLs. However, individual check-up interval should be defined carefully, since higher rate of check-ups seems to lead to increased intervention rates in the management of CCLs.

The study was registered in the German Clinical Trials Register (DRKS-ID: DRKS00010003).

Keywords Risk factor · Root caries/resorption · Clinical studies/trials · Preventive dentistry · Restorative dentistry · Geriatric dentistry

Introduction

Several improvements in dental health over the last decades have resulted in more retained teeth than the past generation had [1–4]. Besides, prevalence of gingival recessions increases in an aging population. Thus, cervical dentinal surfaces are more frequently exposed to the oral environment and consequently the risk for developing root caries lesions will be increased [3].

Recently, it could be revealed that there are several approaches for primary, secondary [5], and tertiary prevention [6] of cervical root caries lesions. Nonetheless, there is a need for more research in this area due to the low numbers of clinical trials for the respective approaches, the high risk of bias within the studies, and the limiting grade of evidence [5, 6].

Regarding the invasive treatment of active cervical root caries lesions (aCCLs) (tertiary prevention), several clinical studies have been published [7–11]. However, due to inhomogeneous methodologies and techniques as well as relatively short follow-up periods of up to 24 months, risk factors for clinical failures were not presented [6]. Furthermore, the five

✉ R. J. Wierichs
rwierichs@ukaachen.de

1 Department of Operative Dentistry, Periodontology and Preventive Dentistry, RWTH Aachen University, Pauwelsstrasse 30, 52074 Aachen, Germany

2 Private Practice, Norden, Germany

studies included “only” 629 active carious cervical lesions in a total of 269 patients. Cumulative failure rates after 24 months between the different restorative materials as well as for the same material among various studies differed widely [6]. Interestingly, regarding inactive cervical root caries lesions (iCCLs), there is no scientific data concerning risk factors for failure (re-activation) either when monitoring these lesions only or with additional use of secondary preventive measures (e.g., local fluoridation).

In order to compare the success of different types of (non-)invasive treatments, prospective randomized controlled trials should be designed [12, 13]. Although prospective (non-)randomized controlled trials reveal clinical efficacy, data do not reflect effectiveness of daily dental care in general practices. Furthermore, though realizing a more accurate data collection with regard to exposures, confounders, and endpoint with a prospective design, the retrospective design is a very time-efficient and elegant way of answering new questions and to generate new hypotheses [12, 14]. This is because differences between different risk factors often appear only after long-term observation times of 5 to 10 years [15].

Thus, the aim of the present retrospective, non-interventional clinical study was to investigate factors influencing the long-term survival of restorative treatments of active buccally located cervical root caries lesions and the long-term success of non-invasive treatment options (monitoring plus individualized oral health instruction) for inactive buccally located cervical root caries lesions in a single private practice.

Materials and methods

Study design

This study was a retrospective, non-interventional clinical study without the need for local review board approval according to European guidelines for good clinical practice (CPMP/ICH/135/95). This study conforms to the STROBE guideline for cohort studies [16].

Patient selection

Patient files from a single private practice in Germany (EK) were used for collecting data for this study anonymously (without reference to patient names). Records from patients who visited the practice regularly between 1997 and 2014 were searched for the presence of active or inactive cervical root caries lesions (CCLs). Inclusion criteria for the CCLs were as follows:

1. The CCL was detected at least 6 months before the last recall visit. Restorative treatment for aCCLs had also to be done at least 6 months before the last recall visit.
2. The CCL was located on the cervical surface (class V in case of restoration).
3. The record contained information on the grade of activity (active/inactive).

Exclusion criteria for the CCLs were as follows:

1. The tooth was scheduled to be restored by placing a crown, telescopic crown, or bridge anchor or was scheduled to be extracted at first detection of CCL.
2. The cervical root caries lesions was detected on a wisdom tooth.

Data extraction

The following data were collected from the patients’ records meeting the inclusion criteria:

- Characteristics of the involved tooth and the dentition including the tooth localization and restored tooth surfaces
- Number of teeth (per patient) being included in the study
- Grade of activity (active/inactive) according to the definitions of Nyvad and Fejerskov [17]
- Number of the remaining teeth
- Date of the first visit
- Date of the last visit
- Date of the detection of the CCL
- DMFT/S at the date of first CCL detection
- Date of the first and second restorative intervention (on the cervical surface)—if present—including information such as the type of intervention/restoration (e.g., filling, crown, extraction) and material used
- Age and sex
- Number of the regular check-ups during the observation period
- Risk level of caries (only the DMFT at a respective age was taken into account) [18, 19]

The following data could not be collected (from the patients’ records meeting the inclusion criteria):

- Plaque indices
- Gingival indices
- Exact content of the individualized oral health instructions
- Intra-examiner calibration prior to the study
- Active cervical root caries lesions, without invasive treatment
- ICDAS score of the lesion
- General diseases

Failure of treatment decision

- Inactive cervical root caries lesions (iCCLs):

Table 1 Frequency and number of failures of teeth included in study by categories of each baseline characteristic

	Inactive carious cervical lesions (without restoration)					Active carious cervical lesions (with restoration)				
	Mean	SD				Mean	SD			
Observation time	42	27				40	29			
DMFT at first visit	19	6				20	5			
Age at first visit	40	19				48	17			
CCLs/per patient at first visit	1.9	1.8				1.7	1.4			
	Patients		Teeth			Patients		Teeth		
Category	Frequency [*n* (%)]	Failures [*n* (%)]	Frequency [*n* (%)]	Failures [*n* (%)]	Median survival time [months]	Frequency [*n* (%)]	Failures [*n* (%)]	Frequency [*n* (%)]	Failures [*n* (%)]	Median survival time [months]
Total	123 (100%)	21 (17%)	232 (100%)	35 (15%)	120	201 (100%)	16 (8%)	345 (100%)	20 (6%)	111
Age										
<30	21 (17%)	6 (29%)	76 (33%)	7 (9%)	108	26 (13%)	2 (8%)	45 (13%)	2 (4%)	87
30–60	76 (62%)	4 (5%)	118 (51%)	22 (19%)	120	106 (53%)	7 (7%)	194 (56%)	11 (6%)	111
>60	26 (21%)	11 (42%)	38 (16%)	6 (16%)	106	69 (34%)	7 (10%)	106 (31%)	7 (7%)	108
Total	123	21 (17%)	232	35 (15%)		201	16 (8%)	345	20 (6%)	
Sex										
Female	62 (50%)	14 (23%)	110 (47%)	25 (23%)	120	104 (52%)	11 (11%)	156 (45%)	11 (7%)	111
Male	61 (50%)	7 (11%)	122 (53%)	10 (8%)	108	97 (48%)	5 (5%)	189 (55%)	9 (5%)	111
Total	123	21 (17%)	232	35 (15%)		201	16 (8%)	345	20 (6%)	
Tooth type										
Incisive/canine	48 (34%)	8 (17%)	92 (40%)	16 (17%)	108	81 (35%)	8 (10%)	140 (41%)	9 (6%)	97
Premolar/molar	93 (66%)	16 (17%)	140 (60%)	19 (14%)	120	148 (65%)	10 (7%)	205 (59%)	11 (5%)	111
Total	141[a]	24 (17%)	232	35 (15%)		229[a]	18 (8%)	345	20 (6%)	
Number of check-ups per year										
<2	56 (41%)	3 (5%)	99 (43%)	5 (5%)	120	172 (81%)	13 (8%)	288 (83%)	15 (5%)	111
2	48 (35%)	8 (17%)	83 (36%)	11 (13%)	120	18 (8%)	1 (6%)	21 (6%)	1 (5%)	36
>2	32 (24%)	11 (34%)	50 (22%)	19 (38%)	30	22 (10%)	3 (14%)	36 (10%)	4 (11%)	48
Total	136[a]	22 (16%)	232	35 (15%)		212[a]	17 (8%)	345	20 (6%)	
Number of carious cervical lesions										
1	49 (40%)	5 (10%)	49 (21%)	5 (10%)	120	83 (41%)	2 (2%)	83 (24%)	2 (2%)	108
2	28 (23%)	2 (7%)	41 (18%)	2 (5%)	99	45 (22%)	3 (7%)	61 (18%)	3 (5%)	105
3	15 (12%)	5 (33%)	24 (10%)	7 (29%)	120	29 (14%)	3 (10%)	50 (14%)	3 (6%)	108
4	6 (5%)	2 (33%)	15 (6%)	3 (20%)	78	12 (6%)	1 (8%)	32 (9%)	1 (3%)	111
5	8 (7%)	2 (25%)	23 (10%)	2 (9%)	108	12 (6%)	1 (8%)	31 (9%)	1 (3%)	111
>5	17 (14%)	5 (29%)	80 (34%)	16 (20%)	106	20 (10%)	6 (30%)	88 (26%)	10 (11%)	102
Total	123	21 (17%)	232	35 (15%)		201	16 (8%)	345	20 (6%)	
Risk level of caries										
Low	41 (33%)	7 (17%)	89 (38%)	8 (9%)	107	78 (38%)	5 (6%)	108 (31%)	5 (5%)	108
Moderate	20 (16%)	2 (10%)	23 (10%)	2 (9%)	120	45 (22%)	5 (11%)	64 (19%)	5 (8%)	98
High	62 (50%)	12 (19%)	120 (52%)	25 (21%)	108	85 (41%)	6 (7%)	173 (50%)	10 (6%)	111
Total	123	21 (17%)	232	35 (15%)		208[a]	16 (8%)	345	20 (6%)	
DMFT										
>20	62 (50%)	12 (19%)	114 (49%)	25 (22%)	108	106 (51%)	10 (9%)	211 (61%)	14 (7%)	111
10–20	47 (38%)	7 (15%)	84 (36%)	7 (8%)	120	94 (45%)	5 (5%)	122 (35%)	5 (4%)	105
<10	14 (11%)	2 (14%)	34 (15%)	3 (9%)	99	9 (4%)	1 (11%)	12 (3%)	1 (8%)	108
Total	123	21 (17%)	232	35 (15%)		209[a]	16 (8%)	345	20 (6%)	

[a] Starting and ending points were recorded on tooth level; thus, on patient level, one patient may be listed in two subcategories

The observation period started with first detection. Whenever an iCCL was restored (“failure” for iCCLs) at the last check-up, the intervention was considered as failed.

- Active cervical root caries lesion (with invasive treatment need) (aCCLs):

The observation period started with the restoration inserted by the single dentist (EK). Whenever the cervical restoration was replaced, repaired, or scheduled for replacement (failure for aCCLs) at the last check-up for which an appointment was then made with the patient, the intervention was considered as failed.

- Active cervical root caries lesion (without invasive treatment need):

Although it could be shown that active, non-cavitated (cervical) root caries lesions can be inactivated [5, 17], factors influencing the longevity of preventing (non-cavitated) aCCLs from being restored could not be analyzed. Data of aCCLs without invasive treatment need could not be separated from data of aCCLs with invasive treatment need.

When an iCCL was not invasively treated or the restoration of an aCCL was still in function at the last check-up visit and found to be clinically acceptable, the intervention was considered successful.

In cases where a tooth was extracted ($n = 6$) or restored by placing a crown ($n = 7$), telescopic crown ($n = 0$), or bridge anchor ($n = 5$) in the investigated period and the intervention was not related to the direct cervical root caries lesion, it was not considered as failed, but the observation period was then censored.

Statistical analyses

For descriptive purposes, frequencies and percentages of measured baseline characteristics as well as frequencies and percentages of different failure types were tabulated (Tables 1 and 2).

Statistical analyses were performed using SPSS (SPSS 22.0; SPSS, Munich, Germany). Time until any failure was the dependent variable. Kaplan-Meier statistics and log-rank tests were used to calculate significant differences between the groups ($p < 0.05$). For Kaplan-Meier statistic, the independent method was used to generate survival curves up to 10 years [20]. The annual failure rate (AFR) and annual "restoration" rate (ARR) were calculated from life tables. Crude associations between baseline characteristics and time until failure were calculated by fitting separate models for each baseline characteristic as the independent variable. Factors associated with time until failure ($p < 0.25$) [21] in the separate models were entered in a multivariate Cox regression model.

Results

In this study, 295 patients with a mean (SD) age of 45 years (18) and with 577 inactive or active (solely buccal) cervical root caries lesions were included. Characteristics of patients and teeth are shown in Table 1. During the observation period, 90% of the CCLs in both groups were (re-)placed by using composite (mostly Enamel Plus HFO). No significant differences could be seen between different restorative materials.

Kaplan-Meier survival graphs and log-rank test

During a mean (SD) follow-up period of 41 months (28), interventions in 522 teeth (90%) were considered as successful because no (further) intervention was needed. Twenty out of 345 aCCLs (6%) had received a second restorative follow-up treatment, and 35 out of 232 iCCLs (15%) were restored. The annual failure rate for aCCLs after up to 10 years was 1.7% (median survival time 111 months) while the annual "restoration" rate for aCCLs was 4.3% (median success time 120 months). The survival/success curves of active and inactive cervical root caries lesions are shown in Fig. 1. Kaplan-Meier survival/success graphs according to "check-ups per year" are presented in Fig. 2.

Cox regression analysis

Crude bivariate associations between the different baseline characteristics and an increased failure rate are given in Table 2. For aCCLs, "tooth type," "number of check-ups per year," "number of CCLs," and "risk level of caries" were strongly associated with an increased failure rate ($p < 0.25$). For iCCLs, age, sex, "number of check-ups per year," "number of carious cervical lesions," "risk level of caries," and "DMFT at the date of first iCCL detection" were strongly associated with an increased restoration rate ($p < 0.25$) [21].

The results of the multivariate model including factors strongly associated with an increased failure rate are shown in Table 3. After multivariate regression, aCCLs being checked up more than twice a year showed a significantly higher failure rate than aCCLs being checked up less than twice a year ($p < 0.001$). Furthermore, iCCLs being checked up twice ($p = 0.008$) or more than twice a year ($p < 0.001$) showed significantly higher restoration rates than iCCLs being checked up less than twice a year.

Discussion

This study is a retrospective analysis of the survival of restorative treatment of active cervical root caries lesions and the success of non-invasive treatment options (monitoring plus individualized oral health instruction) for inactive cervical root caries lesions in a private practice. A total of 345 active and 232 inactive CCLs were followed for 0.6 to 10 years (mean observation time of 3.5 years), and several baseline parameters on the survival/success were analyzed. At overall low annual failure and restoration rates, the "number of check-ups per year" was the only significant predictor for both the failure rate of restorative treatment of active CLLs and the restoration rate of inactive CCLs.

This study in a general practice environment showed a good longevity for solely buccal cervical restorations. After

Table 2 Bivariate Cox proportional hazard regression analyses of time until failure by categories of each baseline characteristic

Category	Inactive carious cervical lesions (without restoration)			Active carious cervical lesions (with restoration)		
	HR	95% CI	*p* value	HR	95% CI	*p* value
Total	1	Reference		0.4	0.2–0.7	0.001
Age						
<30	1.0	Reference		1.0	Reference	
30–60	2.5	1.1–5.9	**0.033**	0.6	0.1–3	0.575
>60	2.2	0.7–6.7	**0.151**	0.8	0.2–3.8	0.764
Sex						
Female	1.0	Reference		1.0	Reference	
Male	0.3	0.1–0.6	**0.002**	0.7	0.3–1.8	0.499
Tooth type						
Incisive/canine	1.0	Reference		1.0	Reference	
Premolar/molar	0.7	0.4–1.4	0.309	0.6	0.2–1.4	**0.211**
Number of check-ups per year						
<2	1.0	Reference		1.0	Reference	
2	3.1	1.1–9	**0.038**	3.4	0.4–27.3	0.250
>2	24.1	8.6–67.3	**<0.001**	18.8	5.4–65.4	**<0.001**
Number of carious cervical lesions						
1	1.0	Reference		1.0	Reference	
2	0.4	0.1–2.2	0.318	1.7	0.3–9.9	0.583
3	2.4	0.8–7.5	**0.141**	2.4	0.4–14.3	0.342
4	2.1	0.5–8.8	0.312	1.1	0.1–12.2	0.940
5	0.8	0.1–4	0.760	1.3	0.1–14.4	0.831
>5	1.6	0.6–4.4	0.348	4.4	1–20	**0.057**
Risk level of caries						
Low	1.0	Reference		1.0	Reference	
Moderate	1.2	0.3–5.6	0.829	2.2	0.6–7.7	**0.212**
High	2.5	1.1–5.6	**0.022**	1.4	0.5–4.1	0.532
DMFT						
>20	1.0	Reference		1.0	Reference	
10–20	0.3	0.1–0.8	**0.009**	0.7	0.2–1.9	0.455
<10	0.3	0.1–1.1	**0.060**	0.7	0.1–5.8	0.774

Factors associated with time until failure ($p < 0.25$; bold) in the separate models were entered in the multivariate Cox regression model (Table 3)

up to 10 years of observation, AFR for cervical (mostly) composite restorations was 1.7% and hence at the lower end of the range of the AFR for restorative treatment of non-carious cervical lesions (NCCLs) (1.9 to 5.8%) [22] and of posterior composite restorations (1.6 to 4.6%) [23]. Further information on distinction between NCCL and CCL can be found in the supplementary document. Furthermore, the annual "restoration" rate for iCCLs was 4.3%. Although to date no comparable long-term data for iCCLs is available, previous studies on occlusal caries lesions [24, 25] seem to be in agreement with the present result. In the first study, 478 of 491 inactive lesions (97%) did not progress within 1 year [25]. In the second study, about 90% of the inactive lesions remained inactive over a study period of 3 years [24]. Thus, the results of the present study indicate that restorative treatment of iCCLs can be avoided over a long time by using individualized non-invasive treatment options (monitoring plus individualized oral health instruction).

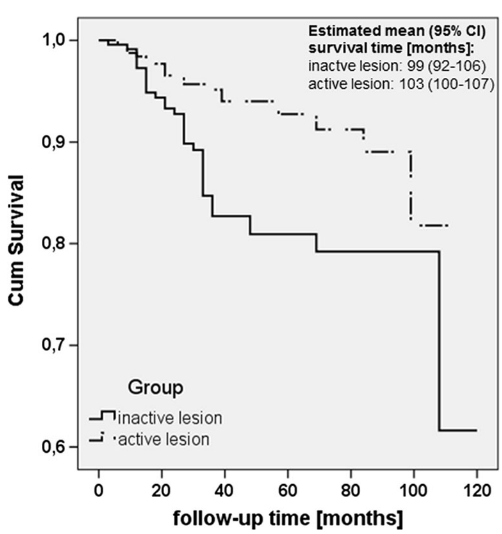

Fig. 1 Kaplan-Meier survival graphs for inactive and active cervical root caries lesions

Twenty class V restorations out of 345 restorations failed (6%) in the present study during an observation period of up to 10 years. Compared to recent studies analyzing cervical restorations, this cumulative failure rate seems to be very low [7–11]. The included study populations might explain the different failure rates. In the previous studies, patients were suffering from post-radiation

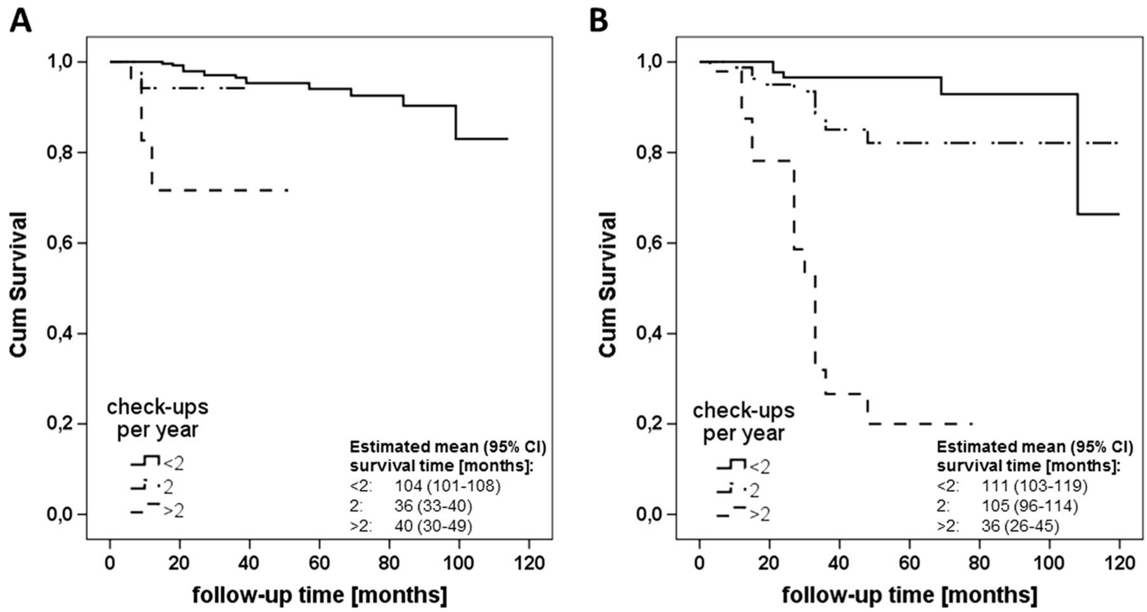

Fig. 2 Kaplan-Meier survival/success graphs for restorative treatment of active cervical root caries lesions (**a**; log-rank test: $p < 0.001$) and non-invasive treatment of inactive cervical root caries lesions (**b**; log-rank test: $p < 0.001$) according to check-ups per year

Table 3. Multivariate Cox proportional hazard regression analyses of time until failure as function of baseline characteristics identified

Inactive carious cervical lesions (without restoration)				Active carious cervical lesions (with restoration)			
Category	HR	95% CI	p value	Category	HR	95% CI	p value
Total: n = 232				*Total: n* = 345			
Age			0.285	*Tooth type*			
<30	1.0	Reference		Incisive/canine	1.0	Reference	
30–60	1.0	0.3–2.9	0.967	Premolar/M	0.5	0.2–1.4	0.199
>60	2.6	0.6–11.6	0.217				
Sex							
Female	1.0	Reference					
Male	0.9	0.3–2.5	0.839				
Number of check-ups per year			**<0.001**	*Number of check-ups per year*			**<0.001**
<2	1.0	Reference		<2	1.0	Reference	
2	6.2	1.6–24.2	**0.008**	2	2.7	0.3–23.1	0.354
>2	45.0	9.4–216	**<0.001**	>2	25.5	5.9–110.7	**<0.001**
Number of carious cervical lesions			0.052	*Number of carious cervical lesions*			0.527
1	1.0	Reference		1	1.0	Reference	
2	0.6	0.1–3.5	0.569	2	2.6	0.4–16.3	0.309
3	6.7	1.6–28.6	**0.011**	3	3.2	0.5–19.8	0.206
4	1.4	0.3–6.5	0.703	4	1.3	0.1–15.2	0.837
5	2.9	0.4–20.8	0.279	5	2.0	0.2–24.4	0.574
>5	2.9	0.8–10.2	0.094	>5	4.3	0.8–22.4	0.080
Risk level of caries			0.443	*Risk level of caries*			0.228
Low	1.0	Reference		Low	1.0	Reference	
Moderate	0.7	0.1–4.9	0.741	Moderate	2.1	0.5–8.2	0.306
High	2.2	0.4–11.4	0.334	High	0.7	0.2–2.7	0.644
DMFT			0.468				
>20	1.0	Reference					
10–20	2.0	0.4–10.3	0.386				
<10	0.8	0.1–6.6	0.850				

($p < 0.05$) indicate factors strongly associated with an increased failure rate xerostomia [8, 9, 11], which is not the common status of the older adult dental patients [26, 27]. Contrastingly, in the present study, all patients without any restriction to their medical history having at least one active or inactive root caries lesion were included. Furthermore, the previous studies analyzing cervical restoration were published two to three decades ago [8–10]. Since then, the chemical and physical properties of restorative materials have been improved. Thus, data of the previous studies may not reflect the performance of newer materials.

Records of the general dental services of England and Wales [28, 29] revealed that patients visiting dental practices more frequently had significantly reduced survival times for direct restorations (class I to V). This is in agreement with the results of the present study. A positive significant relation between frequency of check-ups per year and failure rate for restorative treatments of aCCLs and restoration rate for iCCLs was found. This might be explained by the examination method [30–33]. For smooth surfaces, it could be observed that less than 72.5% of the non-cavitated inactive caries lesions could be reconfirmed as non-cavitated inactive ones [32]. The same diagnostic problem could recently be shown when detecting secondary caries [33]. In this meta-analysis, around 20% of the sufficient proximal and non-proximal restorations were falsely classified as insufficient. Although both studies [32, 33] did not primarily investigate cervical surfaces, the results indicate the non-perfect specificity for visual-tactile examination even under optimal conditions (clearly visible and smooth cervical surfaces) and that the chance to falsely classify an inactive CCL as active (or a sufficient restoration as insufficient) increases with an increasing number of check-ups per year. However, the longevity might also be related to operator- and/or patient-related factors [29, 34]. By using patient-related factors (e.g., oral hygiene, the dental history, or the age of the patient), the operator has to define the individual check-up intervals. The "worse" these factors are, the shorter the check-up intervals get. Nonetheless, data for plaque and gingival indices could not be collected from the patients' records. Thus, it remains unclear if some patient-related factors might influence failure rates.

Recently, it could be shown that the "risk level of caries" is a dominant factor for posterior composite restoration survival [23]. This is in contrast to the results of the present study, in which no significant influence of the "risk level of caries" could be observed. The contrary results could be attributed to the different methods to calculate the risk levels. In the present study, the age and the DMFT at the beginning of the study were used to calculate the risk level. Plaque and gingival indices were not included. Other studies used the history of occurrence of new lesions over the study period [15] or did not even define the calculation [23, 35, 36]. Another reason could also be the relatively low failure rate for cervical restorations in the present study. It might be speculated that due to the relatively low number of failures, no correlation between "risk level of caries" and failure rate could be observed. Consequently, it might also be speculated that the influence of the "risk level of caries" as (significant) predictor would increase when a larger sample size, and hence more failures, was included.

In a previous study, patients' age was a significant predictor of failure for direct restorations [35]. One explanation for this finding was that restorations in younger patients may be the first restorations in sound teeth, while teeth in older patients are more likely to have existing restorations. Thus, re-intervention could have been indicated by caries or fractures adjacent to a restoration [35, 36]. In the present, study this explanation could presumably be neglected. During data extraction, it was impossible to distinguish between two separate proximal (e.g., mesio-occluso-distal) and single cervical restorations and one combined "proximal-cervical" restoration. In consequence, teeth having rather large combined buccal and proximal restorations were excluded. This might have resulted in smaller differences with respect to age categories. Consequently, it might be speculated that the influence of the patients' age as (significant) predictor would increase, when a distinction between one combined proximal-cervical restoration and two separate proximal and cervical restorations could be performed.

Factors influencing the longevity of the first restorative treatment were analyzed for aCCLs, whereas for iCCLs factors influencing the longevity of preventing the lesion from being restored were investigated. For these, two different starting points for the observation periods were used. Due to the structure of the dental practice, check-ups and invasive treatments were not performed at the same appointment. After detecting an aCCL, which has to be restored, an additional appointment for the restoration had to be scheduled and, thus, the day of the restorative treatment was defined as the start of the observation. In contrast, for iCCLs, the date of first detection was used, since the individualized non-invasive intervention (monitoring plus individualized oral health instruction) started on this day. Furthermore, no distinction between iCCLs being detected at a regular check-up and iCCLs being detected at the first visit of a "new" patient in the dental practice was made. Although it may be assumed that the iCCLs of the two subgroups may be treated differently [37], no significant differences were found. In both subgroups, 15% of the lesions had to be restored and no difference in risk factors could be observed (data not presented). Thus, both subgroups were merged into one category.

In the present study, neither special protocols for the prophylactic treatment of iCCLs nor protocols for the preparation depending on the size and shape of the defect of aCCLs were performed. This may cause difficulties to control bias and confounders. Furthermore, although the patient files were accurately and precisely documented, it was impossible to access all necessary information. For instance, factors influencing the longevity of preventing (non-cavitated) aCCLs from being restored could not be analyzed since data of aCCLs without invasive treatment need could not be separated from data of aCCLs with invasive treatment need. Furthermore, prophylactic treatments and oral health instructions were applied on an individual decision and not standardized (further information on shared decision-making can be found in the supplementary document). No intra-examiner calibration with, e.g., respect to caries detection resulting in adequate reproducibility prior to the study, was performed. However, the present study setting reflects the situation in a private practice, since treatment decisions were made by the dentist together with the patient based on the specific clinical case. Thus, the present study might be closer to daily (clinical) routine in dental practices than prospective studies.

In conclusion, the chosen treatment decisions for buccal root caries lesions (invasive treatment of aCCLs and non-invasive treatment of iCCLs) were both successful in a private practice environment after a mean observation time of 3.5 years. Nonetheless, the results of the present study suggest that the risk of invasive treatment of iCCLs and failure of class V treatment increases the more check-ups per year are scheduled. However, this conclusion is based on a limited number of events.

Authors' contributions R.J.W. and H.M.-L. designed and planned the study, E.K. treated the patient and provided the patient files, R.J.W. performed the statistical analysis, R.J.W. and H.M.-L. wrote the manuscript, and E.K. commented on and revised the manuscript.

Compliance with ethical standards

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

Funding This study was funded by the authors and their institution.

Ethical approval This study was a retrospective, non-interventional clinical study without the need for local review board approval according to European guidelines for good clinical practice (CPMP/ICH/135/95). This study conforms to the STROBE guideline for cohort studies [16].

Informed consent For this type of study, formal consent is not required.

References

1. Griffin SO, Griffin PM, Swann JL, Zlobin N (2004) Estimating rates of new root caries in older adults. J Dent Res 83:634–638. doi:10.1177/154405910408300810
2. US Department of Health and Human Services (2000) Oral health in America: a report of the surgeon general. US Department of Health and Human Services, National Institute of Dental and Craniofacial Research, National Institutes of Health, Rockville Book title
3. Michaelis W, Schiffner U (2006) The Fourth German Oral Health Study (DMS IV). Book title. Institute of German Dentists (IDZ), Deutscher Zahnärzte Verlag, Köln
4. Marthaler TM, O'Mullane DM, Vrbic V (1996) The prevalence of dental caries in Europe 1990-1995. ORCA Saturday afternoon symposium 1995. Caries Res 30:237–255
5. Wierichs RJ, Meyer-Lueckel H (2015) Systematic Review on Noninvasive Treatment of Root Caries Lesions. J Dent Res 94(2): 261–271
6. Hayes M, Brady P, Burke FM, Allen PF (2014) Failure rates of class V restorations in the management of root caries in adults—a systematic review. Gerodontology. doi:10.1111/ger.12167
7. Lo EC, Luo Y, Tan HP, Dyson JE, Corbet EF (2006) ART and conventional root restorations in elders after 12 months. J Dent Res 85:929–932
8. McComb D, Erickson RL, Maxymiw WG, Wood RE (2002) A clinical comparison of glass ionomer, resin-modified glass ionomer and resin composite restorations in the treatment of cervical caries in xerostomic head and neck radiation patients. Oper Dent 27:430–437
9. Wood RE, Maxymiw WG, McComb D (1993) A clinical comparison of glass ionomer (polyalkenoate) and silver amalgam restorations in the treatment of class 5 caries in xerostomic head and neck cancer patients. Oper Dent 18:94–102
10. Levy SM, Jensen ME (1990) A clinical evaluation of the restoration of root surface caries. Spec Care Dentist 10:156–160
11. De Moor RJ, Stassen IG, van 't Veldt Y, Torbeyns D, Hommez GM (2011) Two-year clinical performance of glass ionomer and resin composite restorations in xerostomic head- and neck-irradiated cancer patients. Clin Oral Investig 15:31–38. doi:10.1007/s00784-009-0355-4
12. Hess DR (2004) Retrospective studies and chart reviews. Respir Care 49:1171–1174
13. Vandenbroucke JP (2008) Observational research, randomised trials, and two views of medical science. PLoS Med 5:e67. doi:10.1371/journal.pmed.0050067
14. Euser AM, Zoccali C, Jager KJ, Dekker FW (2009) Cohort studies: prospective versus retrospective. Nephron Clin Pract 113:c214–c217. doi:10.1159/000235241
15. Opdam NJ, Bronkhorst EM, Loomans BA, Huysmans MC (2010) 12-year survival of composite vs. amalgam restorations. J Dent Res 89:1063–1067. doi:10.1177/0022034510376071
16. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP, Initiative S (2008) The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. J Clin Epidemiol 61:344–349. doi:10.1016/j.jclinepi.2007.11.008
17. Nyvad B, Fejerskov O (1986) Active root surface caries converted into inactive caries as a response to oral hygiene. Scand J Dent Res 94:281–284
18. Bratthall D, Hansel Petersson G (2005) Cariogram—a multifactorial risk assessment model for a multifactorial disease. Community Dent Oral Epidemiol 33:256–264. doi:10.1111/j.1600-0528.2005.00233.x
19. Paris S, Haak R, Meyer-Lueckel H (2013) Diagnostics, treatment decision, and documentation. In: Meyer-Lueckel H, Paris S, Ekstrand KR (eds) Book title. Georg Thieme Verlag KG, Stuttgart
20. Chuang SK, Tian L, Wei LJ, Dodson TB (2001) Kaplan-Meier analysis of dental implant survival: a strategy for estimating survival with clustered observations. J Dent Res 80:2016–2020
21. Naumann M, Koelpin M, Beuer F, Meyer-Lueckel H (2012) 10-year survival evaluation for glass-fiber-supported postendodontic restoration: a prospective observational clinical study. J Endod 38: 432–435. doi:10.1016/j.joen.2012.01.003

22. Peumans M, De Munck J, Mine A, Van Meerbeek B (2014) Clinical effectiveness of contemporary adhesives for the restoration of non-carious cervical lesions. A systematic review. Dent Mater 30:1089–1103. doi:10.1016/j.dental.2014.07.007
23. Opdam NJ, van de Sande FH, Bronkhorst E, Cenci MS, Bottenberg P, Pallesen U, Gaengler P, Lindberg A, Huysmans MC, van Dijken JW (2014) Longevity of posterior composite restorations: a systematic review and meta-analysis. J Dent Res 93:943–949. doi:10.1177/0022034514544217
24. Carvalho JC, Thylstrup A, Ekstrand KR (1992) Results after 3 years of non-operative occlusal caries treatment of erupting permanent first molars. Community Dent Oral Epidemiol 20:187–192
25. Zenkner JE, Carvalho JC, Wagner MB, Alves LS, de Oliveira RS, Rocha RO, Maltz M (2016) One-year evaluation of inactive occlusal enamel lesions in children and adolescents. Clin Oral Investig 20:133–139. doi:10.1007/s00784-015-1490-8
26. Wallace MC, Retief DH, Bradley EL Jr (1988) Prevalence of root caries in a population of older adults. Gerodontics 4:84–89
27. Sumney DL, Jordan HV, Englander HR (1973) The prevalence of root surface caries in selected populations. J Periodontol 44:500–504. doi:10.1902/jop.1973.44.8.500
28. Lucarotti PS, Holder RL, Burke FJ (2005) Analysis of an administrative database of half a million restorations over 11 years. J Dent 33:791–803. doi:10.1016/j.jdent.2005.06.011
29. Burke FJ, Lucarotti PS (2009) How long do direct restorations placed within the general dental services in England and Wales survive? Br Dent J 206:E2 . doi:10.1038/sj.bdj.2008.1042 discussion 26-7
30. Bader JD, Shugars DA, Rozier G, Lohr KN, Bonito AJ, Nelson JP, Jackman AM (2001) Diagnosis and management of dental caries. Evid Rep Technol Assess (Summ):1–4
31. AI I (2004) Visual and visuo-tactile detection of dental caries. J Dent Res 83 Spec No C:C56–C66
32. Nyvad B, Machiulskiene V, Baelum V (1999) Reliability of a new caries diagnostic system differentiating between active and inactive caries lesions. Caries Res 33:252–260
33. Brouwer F, Askar H, Paris S, Schwendicke F (2015) Detecting secondary caries lesions: a systematic review and meta-analysis. J Dent Res. doi:10.1177/0022034515611041
34. Demarco FF, Correa MB, Cenci MS, Moraes RR, Opdam NJ (2012) Longevity of posterior composite restorations: not only a matter of materials. Dent Mater 28:87–101. doi:10.1016/j.dental.2011.09.003
35. Opdam NJ, Bronkhorst EM, Roeters JM, Loomans BA (2007) Longevity and reasons for failure of sandwich and total-etch posterior composite resin restorations. J Adhes Dent 9:469–475
36. van Dijken JW, Pallesen U (2013) A six-year prospective randomized study of a nano-hybrid and a conventional hybrid resin composite in class II restorations. Dent Mater 29:191–198. doi:10.1016/j.dental.2012.08.013
37. Burke FJ, Lucarotti PS, Holder RL (2005) Outcome of direct restorations placed within the general dental services in England and Wales (part 2): variation by patients' characteristics. J Dent 33:817–826. doi:10.1016/j.jdent.2005.03.007