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A prospective, multi-center, practice-based cohort study on all-ceramic crowns

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ABSTRACT

Objectives. The aim of this prospective, multi-center, practice-based cohort study was to analyze factors associated with the success of all-ceramic crowns.

Methods. All-ceramic crowns placed in a practice-based research network ([Ceramic Success Analysis, AG Keramik) were analyzed. Data from 1254 patients with (mostly in-office CAD/CAM) all-ceramic crowns placed by 101 dentists being followed up for more than 5 years were evaluated. At the last follow-up visit crowns were considered as successful (not failed) if they were sufficient, whereas crowns were considered as survived (not lost) if they were still in function. Multi-level Cox proportional hazards models were used to evaluate the association between a range of predictors and time of success or survival.

Results. Within a mean follow-up period (SD) of 7.2(2)years [maximum:15years] 776 crowns were considered successful (annual failure rate[AFR]:8.4%) and 1041 crowns survived (AFR:4.9%). The presence of a post in endodontically treated teeth resulted in a risk for failure 2.7 times lower than that of restorations without a post (95%CI:1.4–5.0;$p = 0.002$). Regarding the restorative material and adhesive technique, hybrid composite ceramics and single-step adhesives showed a 3.4 and 2.2 times higher failure rate than feldspathic porcelain and multi-step adhesives, respectively ($p < 0.001$). Use of an oxygen-blocking gel as well as an EVA instrument resulted in a 1.5–1.8 times higher failure rate than their non-use ($p \leq 0.001$).

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Significance. After up to 15years AFR were rather high for all-ceramic crowns. Operative factors, but no patient- or tooth-level factors were significantly associated with failure.
The study was registered in the German Clinical Trials Register (DRKS-ID: DRKS00020271).

1. Introduction

In recent years several types of ceramics have been introduced to indirectly restore teeth. In general, silica-based ceramics and oxide ceramics can be differentiated. Silica-ceramics offer high translucency and excellent aesthetic results associated with reduced tensile strengths [1]. They can be subdivided to feldspathic ceramics and (evolved) glass infiltrated ceramics. Feldspathic ceramics were used for the first all-ceramic crowns [2]. They are relatively brittle and show flexural strengths about 60–70 MPa [3]. Several attempts have been made to improve the low mechanical stability of feldspathic ceramics and to expand the clinical use of all-ceramic crowns [3]. For this, crystals of alumina, fluormica, leucite or lithium disilicate are added to feldspathic ceramics [2,3]. In leucite glass-ceramics - the first developed pressable glass-ceramics - the crystalline content is increased up to 50% [3], resulting in flexural strengths about 160 MPa [3]. In lithium disilicate glass-ceramics the crystalline content is increased up to 70% correlating with flexural strengths of about 400 MPa [3,4]. However, leucite glass-ceramics still seem to be insufficient for posterior fixed dental prosthetics and lithium disilicate glass-ceramics can only be used for 3-unit bridges up to the second premolar [3]. Contrastingly, oxide ceramics consist of an opaque high-strength core onto which esthetic layering ceramic must be applied to accomplish a natural appearance [1]. Their mechanical characteristics seem to be superior to those of silica-ceramics. In vitro the zirconia- or alumina-based ceramics show flexural strengths twice as high as the ones for glass-ceramics [5,6]. Thus, oxide ceramics are recommended for posterior crowns and 3-unit posterior bridges and offer the possibility of masking discolored teeth [3].

Regarding all-ceramic single crowns acceptable failure rates after 5 years could be observed. In previous systematic reviews on prospective as well as retrospective cohort studies 5-year success rates were estimated at 93% [4] or 92–96% [7]. Depending on the ceramic material and tooth position success rates differed. For instance, glass-ceramic crowns showed a significant lower success rate than alumina crowns or reinforced glass-ceramic crowns [4] and anterior all-ceramic crowns showed significantly lower failure rates than posterior ones [4,7]. However, in one of the reviews comparison between different ceramic materials and tooth positions were calculated indirectly [4] and direct comparisons could only be found for tooth position [7]. Overall, both reviews concluded that there is still a lack of information on the long term success of all-ceramic crowns.

Most of the studies on all-ceramic crowns have been university-based studies [4]. Although this may allow a more standardized data collection with regard to exposures, confounders and endpoints, such data might not reflect the effectiveness of daily dental care in general practice [8,9]. Contrastingly, in general practice dentist-, patient-, tooth- and material- level factors together influences the results. To resolve this, studies require a large number of restorations in one dataset [10]. Practice-based studies offer the opportunity to (routinely) collect large datasets [11]. Furthermore, practice-based studies allow to better understand the impact of daily treatment decisions on restoration success in general dental practice [12].

Thus, the aim of the present prospective, non-interventional, multi-center, practice-based, clinical study was, firstly, to evaluate the longevity of different all-ceramic crowns and, secondly, to analyze factors influencing the success of these restoration after up to 15 years' follow-up.

2. Materials and methods

2.1. Study design

This study was a prospective, non-interventional, multi-center, practice-based, clinical study according to the European guidelines for good clinical practice (Clinical trials – Directive 2001/20/EC) [13]. This study is reported according to the STROBE guideline for cohort studies [14]. The study has been registered in the German Clinical Trials Register (DRKS-ID: DRKS00020271).

2.2. Restoration selection

Dentists participating in restoratively-focused postgradual education or training courses on CAD/CAM restorations were asked to insert consecutive cases of patients that had the need for at least one ceramic restorations in a standardized digital entry form For that, security and data protection conditions of the practice-based research network 'Ceramic Success Analysis' (CSA, AG Keramik e.V., Malsch, Germany) had to be accepted [13].

We included all- participating in restoratively storations (85% of all cases), CAD-CAM labside fabricated restorations (10%) and restorations manufactured by dental laboratories (5%). No exclusion criteria applied, i.e. we did not specify the number of restorations per patient, the number of patients and restorations per dentist, the materials, brands, and techniques being used.

To minimize reporting bias of the involved dentists not reporting on their own failures (more information on that can be found in the discussion) only crowns being followed up for more than 5 years and all those restorations which had failed during the first five years or afterwards were considered in the present manuscript.

2.3. Data extraction

The following data were collected anonymously (without reference to patient names): On dentist-level; country, sex, the dentist itself; patient-level; age, date of the first restorative treatment, date of the second restorative (re-)intervention, date of the last visit, number of teeth/restorations (per patient) being included in the study; on tooth-level; characteristics of the involved tooth (Fédération Dentaire Internationale [FDI] notation system), clinical manifestation and sequel of the caries if present (caries superficialis, caries profunda, direct capping), mode of failure, the presence of an endodontic treatment, type of restoration (single-tooth vs. bridge anchor); on technique-level; cavity outline of the preparation (enamel vs. dentin), finishing line of the preparation (chamfer, shoulder, partial shoulder), technique-related factors (use of rubber dam, matrix, silane, oxygen-blocking gel, EVA oscillating instrument, ultrasonic cementation); on material-level; materials being used (e.g. ceramic type, adhesive type, luting material).

The following data were not inserted in the electronic forms and therefore not collected:

- Characteristics of study participants (e.g. demographic, clinical, social) and information on exposures and potential confounders
- Characteristics of the study dentists (e.g. demographic, experience, skills, 'dentist profile' [15]) and information on exposures and potential confounders

2.4. Success, survival and failure of treatment

Assessment of the status of the all-ceramic crowns was done in the same practice usually by the dentist who placed the restoration when patients attended for routine care, recall or when a problem occurred. The observation period started with the restoration being inserted. When the restoration was still in function at the last check-up visit and found to be clinically acceptable, the intervention was defined as success. Whenever the restoration was replaced, or scheduled for this treatment at the last check-up, the intervention was considered as failed. Also, in cases where a tooth was extracted or where the replacement of the restoration was related to a change in the prosthetic treatment plan, the restoration was defined as failure.

Success: If the crown was without clinical or radiographic sings of failures (e.g.: loss of retention or chipping) at the last follow-up visit the crown was judged as successful. Consequently, the crown was considered as failed (primary endpoint: no success) if the crown was renewed, repaired, recemented or the tooth was extracted / received an endodontic treatment.

Survival: If the crown was still in function at the last follow-up visit without clinical or radiographic signs of technical failure (e.g.: loss of retention or endodontic treatment) the restoration was judged as survived even though a re-treatment was needed in the meantime. In a statistical meaning whenever the crown was repaired (n = 27), recemented (n = 98) or the tooth received an endodontic treatment during the observation period (n = 111) the intervention was not considered as failed, but the observation period was then censored. In contrast, the restoration was assessed as major failure (secondary endpoint: no survival) if the restoration was renewed or the tooth was extracted.

2.5. Statistical analysis and power analysis

For descriptive purposes frequencies and percentages of measured baseline characteristics as well as frequencies and percentages of different failure types were tabulated. Statistical analysis was performed using SPSS (SPSS 25.0; SPSS, Munich, Germany). Time until any failure was the dependent variable. Kaplan–Meier statistics were used to calculate significant differences between the groups ($p < 0.05$). For Kaplan–Meier statistic the independent method was used to generate success curves up to 10 years [16]. The annual failure rates (AFR) were calculated from life tables [17].

For further analysis, only crowns being followed up for more than 5 years (n = 886) and all those crowns which had failed during the first five years success: 490 crowns; survival: 272 crowns) or afterwards (109 crowns; 61 crowns) were considered.

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 ($p < 0.25$ [18,19]) in the separate models were entered in a non-clustered multivariate Cox regression model (independent model).

For baseline characteristics with more than 100 variables separate models and inclusion in multivariate models are not appropriate. Nonetheless, dentists can significantly influence success rates [11,20]. Therefore, for a second multivariate Cox regression analysis the factors dentist and patient were used as a cluster-specific random effect (dependent model) [21].

For the present study no prospective power or sample size calculation was performed since this was a comprehensive data set from an ongoing practice-based research project. Regarding a retrospective power analysis for categories being included in multivariate Cox regression analysis, the analysis provided a power of ≥80% for the categories tooth type, endodontic treatment, EVA instrument, liner or build-up material. Nonetheless, due to the pragmatic design of the present study the study is likely to be underpowered to detect moderate to clinically significant relative risks in some categories.

3. Results

Between November 1996 and March 2019 6543 all-ceramic crowns in 4529 patients with at least one follow-up visit were placed by a total of 140 dentists. However, only 1375 of these were followed up for more than 5 years or had failed during the first five years. The mean number of restorations (standard deviation [SD]) per patient was 1.1 (0.5) and the number of restorations per dentist was 14 (22). Characteristics of teeth/crownsare shown in Table 1 and appendix table A.1.

Table 1 – Frequency, number of failures of teeth included in study and bivariate Cox proportional hazard regression analyses of time until failure by categories of each baseline characteristic for outcome success.

Category	Teeth Frequency [n (%)]	Failures [n (%)]	p-value	HR	95% CI	Estimated Median success time	95% CI	AFR
Overall	1375 (100%)	599 (44%)				103.9	98.6–109.2	8.3%
Patient-level								
Age [years]								
0–20	12 (1%)	3 (25%)		1.0	Reference	85.1	69.5–100.6	4.1%
21–40	334 (24%)	130 (39%)	0.389	1.7	0.5–5.2	115.5	106.7–124.4	6.9%
41–60	711 (52%)	299 (42%)	0.264	1.9	0.6–6	105.8	97.7–113.8	8.1%
>60	317 (23%)	166 (52%)	**0.112**	2.5	0.8–7.9	87.7	79.1–96.2	11.0%
n/a*	1 (0%)	1 (100%)	**0.206**	4.3	0.4–41.4	63.1	63.1–63.1	19.0%
Jaw								
Upper	691 (50%)	308 (45%)		1.0	Reference	98.6	91.4–105.7	8.8%
Lower	684 (50%)	291 (43%)	0.589	1.0	0.8–1.1	108.7	101.9–115.5	8.5%
Number of restorations per patient								
1	971 (71%)	373 (38%)		1.0	Reference	112.9	106.8–119	6.9%
2	144 (10%)	64 (44%)	**0.024**	1.4	1–1.8	97.2	83.8–110.6	9.7%
3	98 (7%)	63 (64%)	**<0.001**	2.4	1.9–3.2	56.2	47–65.4	18.1%
4	38 (3%)	21 (55%)	**0.001**	2.2	1.4–3.3	66.5	48.3–84.6	16.2%
≥5	124 (9%)	78 (63%)	**<0.001**	2.6	2.1–3.4	48.2	41.5–54.8	20.8%
Tooth-level								
Tooth type								
Incisive	56 (4%)	36 (64%)		1.0	Reference	40.8	33.7–48	19.3%
Canine	18 (1%)	15 (83%)	**0.101**	1.7	0.9–3	27.3	17.6–37.1	39.5%
Premolar	428 (31%)	180 (42%)	**<0.001**	0.5	0.3–0.7	101.6	88–115.2	8.4%
Molar	858 (62%)	359 (42%)	**<0.001**	0.4	0.3–0.6	107.1	100.8–113.4	8.0%
Wisdom	15 (1%)	9 (60%)	0.681	0.9	0.4–1.8	55.5	31.6–79.3	16.5%
Endodontic treatment								
No	749 (54%)	340 (45%)		1.0	Reference	101.9	95–108.7	9.5%
Yes without post	397 (29%)	200 (50%)	0.265	1.1	0.9–1.3	89.1	81.5–96.7	10.6%
Yes with post	229 (17%)	59 (26%)	**<0.001**	0.5	0.3–0.6	113.2	106.9–119.4	4.1%
Clinical manifestation of the caries								
Caries superficialis	409 (30%)	164 (40%)		1.0	Reference	113.8	105.4–122.3	8.0%
Caries profunda	365 (27%)	169 (46%)	**0.150**	1.2	0.9–1.5	95.0	86.5–103.5	9.5%
Direct capping	11 (1%)	9 (82%)	**0.014**	2.3	1.2–4.5	55.4	30.9–79.9	20.1%
n/a* and no caries	590 (43%)	257 (44%)	0.629	1.0	0.9–1.3	98.8	92–105.6	8.4%
Technique-level								
Cavity outline								
Enamel	245 (18%)	94 (38%)		1.0	Reference	113.8	104.9–122.8	6.4%
Dentin	1130 (82%)	505 (45%)	**0.002**	1.4	1.1–1.8	99.8	93.4–106.3	9.2%
Rubber dam								
Use	283 (21%)	100 (35%)		1.0	Reference	124.5	115.3–133.8	5.9%
Non-use	1092 (79%)	499 (46%)	**<0.001**	1.6	1.3–2	95.1	90–100.2	9.6%
Matrix								
Use	218 (16%)	87 (40%)		1.0	Reference	110.9	99.5–122.2	7.3%
Non-use	1157 (84%)	512 (44%)	**0.075**	1.2	1–1.5	103.3	97.6–108.9	8.9%
Silane								
Use	1170 (85%)	484 (41%)		1.0	Reference	107.8	101.9–113.7	8.1%
Non-use	205 (15%)	115 (56%)	**0.003**	1.4	1.1–1.7	87.3	77.5–97.2	11.8%
Ultrasonic cementation								
Use	262 (19%)	118 (45%)		1.0	Reference	103.5	93.4–113.7	9.1%
Non-use	1113 (81%)	481 (43%)	0.935	1.0	0.8–1.2	103.8	96.8–110.8	8.6%
Dental flossing								
Use	1235 (90%)	545 (44%)		1.0	Reference	103.3	97.8–108.8	8.9%
Non-use	140 (10%)	54 (39%)	**0.034**	0.7	0.6–1	115.2	102.1–128.4	6.7%
Oxygen-blocking								
Use	297 (22%)	160 (54%)		1.0	Reference	86.7	76–97.4	11.9%
Non-use	1078 (78%)	439 (41%)	**<0.001**	0.7	0.6–0.8	108.0	102.1–113.8	7.9%
EVA instrument								
Use	155 (11%)	84 (54%)		1.0	Reference	67.5	58.5–76.4	13.5%
Non-use	1220 (89%)	515 (42%)	**<0.001**	0.6	0.5–0.8	106.8	101.3–112.4	8.2%

– Table 1 (Continued)

Category	Teeth Frequency [n (%)]	Failures [n (%)]	p-value	HR	95% CI	Estimated Median success time	95% CI	AFR
Finishing line of the preparation								
Chamfer	522 (38%)	270 (52%)		1.0	Reference	87.0	80.1–93.8	11.5%
Partial shoulder	208 (15%)	102 (49%)	0.937	1.0	0.8–1.2	92.8	79.4–106.1	11.5%
Shoulder	593 (43%)	213 (36%)	**<0.001**	0.6	0.5–0.7	111.8	105.5–118.1	6.5%
n/a*	52 (4%)	14 (27%)	**<0.001**	0.3	0.2–0.5	146.7	131.1–162.3	3.4%
Material-level								
Build-up								
No	692 (50%)	317 (46%)		1.0	Reference	99.4	92.6–106.2	9.4%
Yes	683 (50%)	282 (41%)	**0.100**	0.9	0.7–1	111.3	104.6–118	8.0%
Adhesive type								
Multi-step	765 (56%)	276 (36%)		1.0	Reference	115.5	108.7–122.2	6.7%
Single-step	192 (14%)	124 (65%)	**<0.001**	2.2	1.8–2.8	77.0	65.6–88.4	15.8%
No adhesive	91 (7%)	32 (35%)	0.885	1.0	0.7–1.4	94.1	83.9–104.3	6.2%
n/a*	327 (24%)	167 (51%)	**<0.001**	1.7	1.4–2	80.0	73.2–86.9	n/a
Ceramic type								
Feldspathic porcelain (FP)	456 (33%)	169 (37%)		1.0	Reference	118.5	110.8–126.2	6.4%
Leucite glass-ceramic (LEU)	285 (21%)	98 (34%)	0.993	1.0	0.8–1.3	101.8	95.1–108.5	6.2%
Lithium dissilicate glass-ceramic (LD)	473 (34%)	205 (43%)	**<0.001**	1.5	1.2–1.8	82.6	77.2–87.9	9.2%
Hybrid composite	79 (6%)	74 (94%)	**<0.001**	6.1	4.6–8	24.0	19.9–28.1	50.1%
Zr und Al-oxide	82 (6%)	53 (65%)	**<0.001**	2.6	1.9–3.6	64.3	51.1–77.4	17.6%
Luting material								
Photoactivated luting agent	297 (22%)	107 (36%)		1.0	Reference	119.6	109.9–129.3	6.0%
Dual-cured luting agent	961 (70%)	428 (45%)	**<0.001**	1.5	1.2–1.8	97.7	92.1–103.3	9.1%
Chemicalactivated luting agent	107 (8%)	61 (57%)	**<0.001**	2.4	1.8–3.3	55.8	48.2–63.5	16.3%
Provisorial	10 (1%)	3 (30%)	0.934	1.0	0.3–3	72.0	55.4–88.5	3.9%
Type of fabrication								
CAD-CAM chairside	1171 (85%)	487 (42%)		1.0	Reference	107.3	101.7–112.9	7.9%
CAD-CAM lab	136 (10%)	97 (71%)	**<0.001**	2.9	2.3–3.6	40.0	33.8–46.3	26.0%
Individual lab	68 (5%)	15 (22%)	**0.005**	0.5	0.3–0.8	118.3	105.9–130.7	3.8%

Factors associated with time until failure ($p < 0.25$; bold) in the separate models were entered in the multivariate Cox regression model (Table 2).
* n/a: not available, for some crowns one or two (sub-)categories was/were not provided.

3.1. *Success and survival*

At the end of the observation time (mean (SD) follow-up period: 7.2 (2) years (maximum: 15 years)) 56% of the crowns (776 out of 1375) were considered as successful (Table 1), no additional treatment was necessary. Moreover, 75% of the crowns (776 out of 1158) survived (appendix table A.1). Regarding the categories success and survival the AFRs were 8.4% and 4.9%, respectively. However, AFR between dentists varied widely (mean(95%CI): 12.6% (6.1%–19.1%)). The main failure type was extraction of the tooth (n = 90) followed by ceramic fracture (n = 45) and defective margin (n = 34). However, for 58 failures the reason for failure was not provided. The success curves of restorations according to ceramic materials are shown in Fig. 1. Success stratified according to adhesive types are presented in Fig. 2.

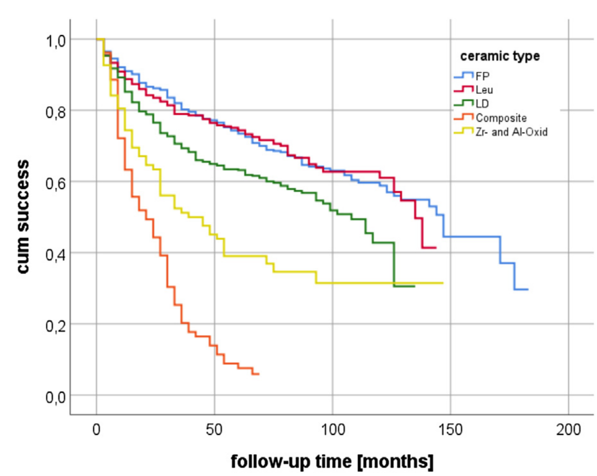

Fig. 1 – Kaplan–Meier curve for all-ceramic crowns according to the factor ceramic material.

3.2. *Cox Regression Analysis*

Crude bivariate associations between the different baseline characteristics and an increased failure rate are given in Table 1 and appendix table A.1. Endodontic treatment, cavity outline, oxygen-blocking gel, EVA instrument, ceramic type, liner or build-up material, adhesive type finishing line of the preparation clinical manifestation of the caries and type of fabrication were possibly associated with increased failure rates ($p < 0.25$).

Table 2 – Multivariate Cox proportional hazard regression analyses of time until failure as function of baseline characteristics identified (for outcome success).

Category	p-value	HR	95% CI
Patient-level			
Age [years]	0.292		
0–20		1.0	Reference
21–40	0.819	1.144	0.4–3.6
41–60	0.694	1.259	0.4–4
>60	0.539	1.435	0.5–4.6
n/a	0.212	4.605	0.4–50.7
Number of restorations per patient	**<0.001**		
1		1.0	Reference
2	0.263	1.177	0.9–1.6
3	**<0.001**	1.767	1.3–2.4
4	0.113	1.467	0.9–2.4
≥5	**<0.001**	1.780	1.3–2.4
Tooth-level			
Tooth type	**0.007**		
Incisive		1.0	Reference
Canine	0.416	1.295	0.7–2.4
Premolar	**0.046**	0.675	0.5–1
Molar	**0.014**	0.623	0.4–0.9
Wisdom	0.470	1.317	0.6–2.8
Endodontic treatment	**<0.001**		
No		1.0	Reference
Yes without post	0.376	0.748	0.4–1.4
Yes with post	**0.002**	0.373	0.2–0.7
Clinical manifestation of the caries	0.272		
Caries superficialis		1.0	Reference
Caries profunda	0.124	1.198	1–1.5
Direct capping	0.330	1.420	0.7–2.9
Na and no caries	0.198	1.514	0.8–2.8
Technique-level			
Cavity outline			
Enamel		1.0	Reference
Dentin	0.229	1.170	0.9–1.5
Rubber dam			
Use		1.0	Reference
Non-use	0.630	0.940	0.7–1.2
Matrix			
Use		1.0	Reference
Non-use	0.289	1.162	0.9–1.5
Silane			
Use		1.0	Reference
Non-use	0.444	0.891	0.7–1.2
Dental flossing			
Use		1.0	Reference
Non-use	0.319	0.843	0.6–1.2
Oxygen-blocking			
Use		1.0	Reference
Non-use	**<0.001**	0.559	0.5–0.7
EVA instrument			
Use		1.0	Reference
Non-use	**0.001**	0.647	0.5–0.8
Finishing line of the preparation			
Chamfer		1.0	Reference
Partial shoulder	0.579	1.1	0.8–1.4
Shoulder	**0.046**	0.8	0.7–1
Sonstiges	**<0.001**	0.2	0.1–0.5
Material-level			
Build-up			
No		1.0	Reference
Yes	0.413	1.1	0.9–1.3
Adhesive type	**<0.001**		
Multi-step		1.0	Reference

– Table 2 (*Continued*)

Category	p-value	HR	95% CI
Single-step	**<0.001**	2.2	1.7–2.8
No adhesive	**0.037**	0.7	0.4–1
Na	**0.045**	1.3	1–1.7
Ceramic type	<0.001		
Feldspathic porcelain (FP)		1.0	Reference
Leucite glass-ceramic (LEU)	0.997	0.999	0.8–1.3
Lithium dissilicate glass-ceramic (LD)	0.064	1.245	1–1.6
Hybrid composite	**<0.001**	3.420	2.5–4.7
Zr und Al-Oxid	0.510	1.159	0.7–1.8
Luting material			
Photoactivated luting agent		1.0	Reference
Dual-cured luting agent	0.059	1.3	1–1.6
Chemicalactivated luting agent	0.686	0.9	0.6–1.4
Provisorial	0.112	0.4	0.1–1.3
Type of fabrication			
CAD-CAM chairside		1.0	Reference
CAD-CAM lab	**<0.001**	2.214	1.6–3
Individual lab	**0.003**	0.426	0.2–0.7

Bold p-values (p < 0.05) indicate factors strongly associated with a de- or increased failure rate.

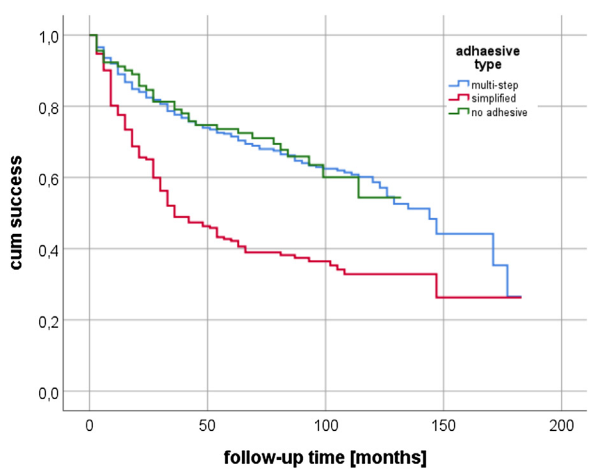

Fig. 2 – Kaplan–Meier curve for all-ceramic crowns according to the factor adhesive type.

The results of the non-clustered multivariate models including factors possibly associated with an increased failure rate in the bivariate models are shown in Table 2 (success) and appendix table A.2 (survival). After multivariate regression the additional oxygen-blocking (HR (95% CI): 1.8 (1.4–2.0); p < 0.001) as well as the use of an EVA oscillating instrument (HR: 1.5 (1.3–2.0); p = 0.001) shortened the time until any failure compared to treatment without them. In contrast, for all-ceramic crowns the presence of a post in endodontically treated teeth resulted in a significantly lower risk for failure than that of endodontically treated teeth without a post (HR: 2.7 (1.4–5.0); p < 0.001). The use of hybrid composite ceramics and single-step adhesives showed a 3.4 (95% CI:2.5–4.7) and 2.2 (95% CI:1.7–2.8) times higher failure rate than feldspathic porcelain and multi-step adhesives (p < 0.001), respectively. CAD-CAM labside fabricated restorations showed a 2.2 (95% CI: 1.6–3.0) higher risk for failure than chairside fabricated restorations. For survival, the included (non-)significant predictors for success remained (non-)significant, with two exceptions. The difference between endodontically treated teeth with and without posts become non-significant.

In the clustered multivariate model, in which the factors dentist and patient were used as a cluster-specific random effect, and the model, in which all 6543 all-ceramic crowns were included, the included (non-)significant predictors remained (non-)significant (appendix table A.3 and appendix table A.4).

4. Discussion

This multi-center, practice-based, clinical cohort study prospectively analyzed the success of all-ceramic crowns. A total of 6543 crowns with at least one follow-up visit were placed by a total of 140 dentists, of whom 1375 crowns have been followed-up for more than 5 years. The influence of several baseline parameters on the success were analyzed. At overall moderate annual failure rates the ceramic type, the adhesive type, the build-up material, EVA oscillating instrument and oxygen-blocking gel were significant predictors for decreased time until failure for both success and survival.

A large variety of ceramic materials have been introduced. Hybrid materials, including ceramic/polymer materials and polymer infiltrated ceramic-network materials, are supposed to combine the positive aspects of both ceramics and composites [22]. Compared to conventional ceramic materials hybrid materials are supposed to show good edge stability for minimal layer thickness, economical machinability, and less brittleness [23–25]. However, until now only a few (controlled) clinical studies [26] or case reports [27] have been published. In these studies, success rates of 97–100% were reported. Contrastingly, in the present study hybrid composite ceramics showed a 2.7–3.0 times higher failure rate than lithium disilicate glass-ceramic or Zr- or Al-oxide ceramics as well as a 3.4 times higher failure rate than feldspathic porcelain or leucite glass-ceramic. Thus, although hybrid composite ceramics seem to have superior material properties in vitro these factors seem to have limited relevance for the clinical practice.

From a clinical perspective in restorative dentistry annual failure rates at 5–10 years below 6% are considered as satisfying [10]. Thus, the present study in private practice environments showed higher failure rates for success (AFR: 8.4%) and satisfying failure rates for survival (AFR:4.9%). Furthermore, the present failure rates were higher than those of previous studies on all-ceramic restorations. In previews reviews cumulative failure rates after 5 years varied between 20% and 0% [4,7]. However, for the present study data had to be collected manually via an online platform. Thus, several dentists might not succeed to upload follow-up data, e.g. due to a loss of motivation, the voluntary characteristic of the CSA network [13] or the factor that dentists do not want to report one's own failure. To minimize these reporting bias only crowns being followed up for more than 5 years and all those restorations which had failed during the first five years or afterwards were considered. In contrast, this procedure may result in failure rates being higher than they actually would be. This might also be seen in the increase of the AFR for survival. AFR increases from 2.1% after a mean follow-up of 2.5 years to 4.9% after a mean follow-up of 7.2 years. The actual number of failed crowns after 5 years might, thus, in-between 2.1% and 4.9% and hence at the higher end of the range of previous university-based studies.

In the present study the assessment of the restorations was done by the dentist who placed the restoration and not by a second blinded dentist. No intra- or inter-examiner calibration regarding treatment decisions was performed prior to the study. However, before joining this study, dentists were in specific continuing education and training courses. Nonetheless, due to the high number of included dentists, criteria for failures might differentiate between dentists. This, of course, causes difficulties to control evaluation bias and confounders. However, predictors in the dependent model, in which the factor dentist and patient were used as a cluster-specific random effect and the independent model were (almost) the same. Furthermore, a high number of more than 1000 all-ceramic crowns could, thus, be included in one single study compared to recent systematic reviews in which 6006 crowns [4] or 2943 crowns [7] had been included. Interestingly, the studies being included in the reviews also were (prospective or retrospective) cohort studies. No randomized controlled trial was available. Although intra- or inter-examiner calibration has presumably been performed within a single study, it can be assumed that (1) for the 33 prospective cohort studies (being included in the reviews) criteria for failures differed between the studies and that (2) for the 15 retrospective studies no calibration could have been performed due to the study design. Thus, for both, the reviews and the present study, there are almost the same difficulties to control bias and confounders.

In a recent study of the CSA network ceramic ceramic inlays/onlays showed a 2.4 times higher failure rate after the use of a single-step adhesive than after the use of a 3-step etch and rinse or 2-step self-etch system [13]. This is in agreement with clinical studies on the longevity of posterior ceramic coverages [28], non-carious cervical class V restorations [29] and all-ceramic crowns (present study). Although single-step adhesives should shorten treatment time and facilitate treatment procedures within the daily clinical routine, 'gold-standard' adhesives (3-step etch and rinse or 2-step self-etch system) should be preferred, also for placing all-ceramic crowns. Furthermore, in previous in vitro studies it could be observed that due to the acidic nature of single-step adhesive the bonding of them to self/dual-cured composites might be compromised [30,31]. Thus, it might be assumed that this observation can also be seen in the present data. However, since several different (single-step) adhesives, luting materials, and ceramics have been used in combination, the present study cannot satisfactorily address this assumption.

In contact with activated monomer molecules, oxygen has a high affinity to form free radicals [32]. During the light curing, oxygen from the atmosphere inhibits the polymerization process [33]. In the delayed post-curing stage it could also be shown that the degree of monomer conversion and the surface micro-hardness were significantly higher in the absence than in the presence of oxygen [32]. Therefore, oxygen-blocking gels were developed by several manufactures to enhance the polymerization process of adhesive materials. However, in the present study the additional use of an oxygen-blocking gel resulted in a 1.8 times higher failure rate than the non-use. Interestingly, up to date in vitro the absence of oxygen was mostly simulated with oxygen free conditions and not by using oxygen-blocking gels. Furthermore, no in vivo study analyzed the influence of oxygen-blocking gels for all-ceramic single crowns. Although there is a lack of evidence, three aspects might explain the observed results: (1) The color and/or the application form of the oxygen-blocking gels might reduce the intensity or change the spectrum of the curing light; thereby reducing the strength of the tooth-restoration interface (2). For clinicians it might be easier to remove a slight excess of a luting material than to subsequently (re-)fill a gap at the margin of a restoration. Consequently, when polishing the margins of the restoration the luting material with a lower degree of monomer conversion might be removed (3). The use of an oxygen-blocking gel is an insufficiently trained working step; thereby, the clinicians' focus is shifted from the correct insertion of the restoration to the correct use of the blocking gel. Nonetheless, further clinical studies are needed to improve our knowledge about the use of oxygen-blocking gels.

For 155 crowns a sono-abrasion technique (EVA oscillating instrument) was used to finish the interproximal or cervical restoration areas. This technique is supposed to reduce risk of damage to adjacent surfaces when compared with rotary instruments [34]. Furthermore, it is supposed to not negatively affect the stability of the tooth-restoration interface [34,35]. However, when used with different bonding systems sono-abrasion seems to enhance or reduce the bonding strength to enamel and dentin [36]. With a two-step self-etch adhesive a significantly lower bonding strength to enamel and a significantly higher bonding strength to dentin was observed when compared with a three-step etch and rinse adhesive. Thus, it was indicated that in the clinical protocol the adhesive materials and the sono-abrasion technique should be aligned. However, in the present data set several different adhesives, luting materials, and ceramics have been used in combination with the sono-abrasion technique. This diversity can presumably also be seen in the present results: the use of an EVA oscillating instrument resulted in a 1.6 times higher risk of failure than the non-use. Thus, the present results might indicate that, the used materials and the sono-abrasion technique should be aligned when using the EVA oscillating instrument. However, it might also be speculated that EVA oscillating instruments were used often in those cases that deep subgingival outlines were present. Consequently, an indication bias would have led to the present finding. Since it was only recorded if the preparation outlines were in dentin or enamel but not if the outlines ware supra-,epi, or subgingival, the present study cannot satisfactorily address this speculation.

Within the limitation of this study, moderate failure rates for all-ceramic crowns could be found in a private practice environment after up to 15 years. Operative factors, but no patient- or tooth-level factors were significantly associated with failure. The use of hybrid composite ceramics, the presence of a liner or composite build-up, the use of a single-step adhesives, the use of an EVA oscillating instrument and the use of an oxygen-blocking gel were significant predictors for failure. However, for all-ceramic single crowns further studies are needed to improve our knowledge about several of these factors and to analyze patient-related factors which have not been included in the present study.

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Informed consent

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

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.dental.2021.04.005.

REFERENCES

[1] Gehrt M, Wolfart S, Rafai N, Reich S, Edelhoff D. Clinical results of lithium-disilicate crowns after up to 9 years of service. Clin Oral Investig 2013;17:275–84.
[2] McLean JW, Hughes TH. The reinforcement of dental porcelain with ceramic oxides. Br Dent J 1965;119:251–67.
[3] Saint-Jean SJ. Chapter 12 - Dental glasses and glass-ceramics. In: Shen JZ, Kosmac T, editors. Advanced ceramics for dentistry. Amsterdam: Elsevier; 2014. p. 255–78.
[4] Pjetursson BE, Sailer I, Zwahlen M, Hammerle CH. A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: single crowns. Clin Oral Implants Res 2007;18(Suppl 3):73–85.
[5] Seghi RR, Denry IL, Rosenstiel SF. Relative fracture toughness and hardness of new dental ceramics. J Prosthet Dent 1995;74:145–50.
[6] Lüthy H. Strength and toughness of dental ceramics. In: Mörmann WH, editor. CAD/CIM in aesthetic dentistry. Quintessence: CEREC 10-year Anniversary Symposium Chicago; 1996. p. 229–40.
[7] Kassardjian V, Varma S, Andiappan M, Creugers NH, Bartlett D. A systematic review and meta analysis of the longevity of anterior and posterior all-ceramic crowns. J Dent 2016;55:1–6.
[8] Kramer EJ, Meyer-Lueckel H, Wolf TG, Schwendicke F, Naumann M, Wierichs RJ. Success and survival of post-restorations: six-year results of a prospective observational practice-based clinical study. Int Endod J 2019;52:569–78.
[9] Perrin P, Meyer-Lueckel H, Wierichs RJ. Longevity of immediate rehabilitation with direct fiber reinforced composite fixed partial dentures after up to 9 years. J Dent 2020:103438.
[10] Opdam NJ, van de Sande FH, Bronkhorst E, Cenci MS, Bottenberg P, Pallesen U, et al. Longevity of posterior composite restorations: a systematic review and meta-analysis. J Dent Res 2014;93:943–9.
[11] Wierichs RJ, Kramer EJ, Meyer-Lueckel H. Risk factors for failure of direct restorations in general dental practices. J Dent Res 2020, 22034520924390.
[12] Mjor IA. Practice-based dental research. J Oral Rehabil 2007;34:913–20.
[13] Collares K, Correa MB, Laske M, Kramer E, Reiss B, Moraes RR, et al. A practice-based research network on the survival of ceramic inlay/onlay restorations. Dent Mater 2016;32:687–94.
[14] von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP, et al. The strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. J Clin Epidemiol 2008;61:344–9.
[15] Collares K, Opdam NJM, Laske M, Bronkhorst EM, Demarco FF, Correa MB, et al. Longevity of anterior composite restorations in a general dental practice-based network. J Dent Res 2017;96:1092–9.
[16] Chuang SK, Tian L, Wei LJ, Dodson TB. Kaplan–Meier analysis of dental implant survival: a strategy for estimating survival with clustered observations. J Dent Res 2001;80:2016–20.
[17] Linnemann T, Kramer EJ, Schwendicke F, Wolf TG, Meyer-Lueckel H, Wierichs RJ. Longevity and Risk Factors of Post Restorations after up to 15 Years: A Practice-based Study. J Endod 2020;47(4):577–84.
[18] Wierichs RJ, Kramer EJ, Meyer-Lueckel H. Risk factors for failure of class V restorations of carious cervical lesions in general dental practices. J Dent 2018;77:87–92.
[19] Wierichs RJ, Kramer EJ, Meyer-Lueckel H. Risk factors for failure in the management of cervical caries lesions. Clin Oral Investig 2017;21:2123–31.
[20] Collares K, Correa MB, Bronkhorst EM, Laske M, Huysmans M, Opdam NJ. A practice based longevity study on single-unit crowns. J Dent 2018;74:43–8.
[21] Chuang SK, Tian L, Wei LJ, Dodson TB. Kaplan-Meier analysis of dental implant survival: a strategy for estimating survival with clustered observations. J Dental Res 2001;80:2016–20.
[22] Spitznagel FA, Vuck A, Gierthmuhlen PC, Blatz MB, Horvath SD. Adhesive bonding to hybrid materials: an overview of materials and recommendations. Compend Contin Educ Dent 2016;37:630–7.

[23] Reich S. Tooth-colored CAD/CAM monolithic restorations. Int J Comput Dent 2015;18:131–46.

[24] Edelhoff D, Liebermann A, Beuer F, Stimmelmayr M, Guth JF. Minimally invasive treatment options in fixed prosthodontics. Quintessence Int (Berl) 2016;47:207–16.

[25] Coldea A, Swain MV, Thiel N. Mechanical properties of polymer-infiltrated-ceramic-network materials. Dent Mater 2013;29:419–26.

[26] Lu T, Peng L, Xiong F, Lin XY, Zhang P, Lin ZT, et al. A 3-year clinical evaluation of endodontically treated posterior teeth restored with two different materials using the CEREC AC chair-side system. J Prosthet Dent 2018;119:363–8.

[27] Selz CF, Vuck A, Guess PC. Full-mouth rehabilitation with monolithic CAD/CAM-fabricated hybrid and all-ceramic materials: a case report and 3-year follow up. Quintessence Int 2016;47:115–21.

[28] van Dijken JW, Hasselrot L. A prospective 15-year evaluation of extensive dentin-enamel-bonded pressed ceramic coverages. Dent Mater 2010;26:929–39.

[29] Peumans M, Kanumilli P, De Munck J, Van Landuyt K, Lambrechts P, Van Meerbeek B. Clinical effectiveness of contemporary adhesives: a systematic review of current clinical trials. Dent Mater 2005;21:864–81.

[30] Cheong C, King NM, Pashley DH, Ferrari M, Toledano M, Tay FR. Incompatibility of self-etch adhesives with chemical/dual-cured composites: two-step vs one-step systems. Oper Dent 2003;28:747–55.

[31] Tay FR, Suh BI, Pashley DH, Prati C, Chuang SF, Li F. Factors contributing to the incompatibility between simplified-step adhesives and self-cured or dual-cured composites. Part II. Single-bottle, total-etch adhesive. J Adhes Dent 2003;5:91–105.

[32] Aromaa MK, Vallittu PK. Delayed post-curing stage and oxygen inhibition of free-radical polymerization of dimethacrylate resin. Dent Mater 2018;34:1247–52.

[33] Rueggeberg FA, Margeson DH. The effect of oxygen inhibition on an unfilled/filled composite system. J Dent Res 1990;69:1652–8.

[34] Decup F, Lasfargues JJ. Minimal intervention dentistry II: part 4. Minimal intervention techniques of preparation and adhesive restorations. The contribution of the sono-abrasive techniques. Br Dent J 2014;216:393–400.

[35] de Oliveira MT, de Freitas PM, de Paula Eduardo C, Ambrosano GM, Giannini M. Influence of diamond sono-abrasion, air-abrasion and Er:YAG laser irradiation on bonding of different adhesive systems to dentin. Eur J Dent 2007;1:158–66.

[36] Van Meerbeek B, De Munck J, Mattar D, Van Landuyt K, Lambrechts P. Microtensile bond strengths of an etch&rinse and self-etch adhesive to enamel and dentin as a function of surface treatment. Oper Dent 2003;28:647–60.