



# Clinical survival and performance of premolars restored with direct or indirect cusp-replacing resin composite restorations with a mean follow-up of 14 years

JW Hofsteenge<sup>a,\*</sup>, W.M.M. Fennis<sup>b</sup>, R.H. Kuijs<sup>c</sup>, M. Özcan<sup>d</sup>, M.S. Cune<sup>a,e</sup>, M.M.M. Gresnigt<sup>a,f</sup>, C.M. Kreulen<sup>g</sup>

<sup>a</sup> University Medical Center Groningen, University of Groningen, Center for Dentistry and Oral Hygiene, Department of Restorative Dentistry and Biomaterials, Groningen, the Netherlands

<sup>b</sup> Department of Oral and Maxillofacial Surgery, Prosthodontics and Special Dental Care, University Medical Center Utrecht, Utrecht, the Netherlands

<sup>c</sup> Academic Centre for Dentistry Amsterdam, Department of Dental Materials Science, University of Amsterdam and Vrije Universiteit Amsterdam, Amsterdam, the Netherlands

<sup>d</sup> University of Zurich, Division of Dental Biomaterials, Center for Dental Medicine, Clinic for Reconstructive Dentistry, Zurich, Switzerland

<sup>e</sup> St. Antonius Hospital, Department of Oral Maxillofacial Surgery, Prosthodontics and Special Dental Care, Nieuwegein, the Netherlands

<sup>f</sup> Martini Hospital, Department of Special Dental Care, Groningen, the Netherlands

<sup>g</sup> Radboud University Medical Center, Radboud Institute for Health Sciences, Department of Dentistry, Nijmegen, the Netherlands

## ARTICLE INFO

### Keywords:

Clinical study  
Composite materials  
Restorative dentistry  
Cusp-replacing  
Adhesion  
Indirect  
Direct  
Survival  
Success  
Clinical performance

## ABSTRACT

**Objectives:** The objective is to evaluate the long-term clinical survival and performance of direct and indirect resin composite restorations replacing cusps in vital upper premolars.

**Methods:** Between 2001 and 2007, 176 upper premolars in 157 patients were restored with 92 direct and 84 indirect resin composite restorations as part of an RCT. Inclusion criteria were fracture of the buccal or palatal cusp of vital upper premolars along with a class II cavity or restoration in the same tooth.

**Results:** Forty patients having 23 direct and 22 indirect composite restorations respectively, were lost to follow-up (25.6%). The cumulative Kaplan-Meier survival rates were 63.6% (mean observation time: 15.3 years, SE 5.6%) with an AFR of 2.4% for direct restorations and 54.5% (mean observation time: 13.9 years, SE: 6.4%) with an AFR of 3.3% for indirect restorations. The Cox regression analysis revealed a statistically significant influence of the patient's age at placement on the survival of the restoration (HR 1.036,  $p = 0.024$ ), the variables gender, type of upper premolar, type of restoration, and which cusp involved in the restoration had no statistically significant influence. Direct composite restorations failed predominantly due to tooth fracture, indirect restorations primarily by adhesive failure ( $p < 0.05$ ).

**Significance:** There was no statistically significant difference in survival rates between direct and indirect composite cusp-replacing restorations. Both direct and indirect resin composite cusp-replacing restorations are suitable options to restore compromised premolars. The longer treatment time and higher costs for the indirect restoration argue in favor of the direct technique.

## 1. Introduction

Cusp fracture of restored posterior teeth is frequently observed, with incidence rates varying from 21 to 71 *per* 1000 person-years at risk [1,2]. It appeared that vital teeth showed a supragingival location in 91% of the fractures, enabling restorative intervention for the majority of teeth [1]. Conventional treatment options for a fractured premolar

are a full crown of zirconia or lithium disilicate, with a reported five-year survival rate of respectively 96.0% and 96.6% [3]. Despite this high survival rate, circumferential crowns come with a high biological cost. A considerable amount of mostly sound tooth tissue, for upper first premolars up to 64%, has to be sacrificed for adequate macro mechanical retention [4]. Adhesive restorations do not require this type of mechanical retention, reducing invasiveness of preparations, which

\* Correspondence to: Department of Restorative Dentistry and Biomaterials, Center for Dentistry and Oral Hygiene, University Medical Center Groningen, University of Groningen, Antonius Deusinglaan 1, 9713 AV Groningen, the Netherlands.

E-mail address: [j.w.hofsteenge@umcg.nl](mailto:j.w.hofsteenge@umcg.nl) (J. Hofsteenge).

<https://doi.org/10.1016/j.dental.2023.03.004>

Received 22 December 2022; Received in revised form 2 February 2023; Accepted 3 March 2023

0109-5641/© 2023 The Authors. Published by Elsevier Inc. on behalf of The Academy of Dental Materials. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

may prevent complications such as pulpal involvement, and extend the restorative cycle of the teeth involved [5,6]. Adhesive restorations can either be directly applied to the prepared dental cavity or be fabricated in an indirect way by the dental technician and subsequently luted to the tooth by the dentist.

Direct resin composite restorations do not require specific preparation designs. They are made in one treatment session with relatively low costs. Due to intraoral polymerization, direct resin composite restorations are associated with shrinkage stress, as demonstrated in *in vitro* studies, although, no direct clinical evidence exists to support any detrimental effect of these stresses [7]. Polymerization stress is positively associated with the number of walls involved in the cavity (the configuration factor): the more walls to adhere to, the higher the configuration factor [8,9]. A cusp-replacing restoration has a reduced configuration factor since the composite is adhered to a limited number of walls [9]. Due to fabrication in the lab indirect composite restorations are advocated to overcome problems related to polymerization shrinkage and presumed to facilitate better restoration of the original morphology. For adhesive restorations replacing cusps, both a direct and an indirect technique are adequate to restore morphology and function if treatment is provided by an experienced operator [10].

Practice-based studies on the clinical longevity of direct composite restorations reported mean annual failure rates (AFRs) between 1.5% and 4.9% after an evaluation time ranging from 4.6 to 22 years [11–13]. In some studies, a lower survival rate for larger restorations was observed [11,12,14], but there is contradictory evidence whether survival rates differ between restorations of different sizes [15]. A prospective study on extensive direct composite restorations, replacing cusps, showed good results after 3.5 years and the number of cusps involved did not influence the survival of the restorations [16]. However, long-term clinical data on adhesive restorations replacing cusps is scarce in the literature.

The number of studies comparing the survival of direct and indirect composite restorations is limited. The systematic review and meta-analysis by Da Veiga et al. (2016) concluded that there is no difference in terms of clinical longevity between direct and indirect resin composite restorations [17]. A meta-analysis on 5-year follow up studies ( $n = 3$ ) with a low-risk of bias did not reveal a statistically significant risk difference ( $p = .464$ ,  $RR = 1.278$  [0.663–2.465]) between direct and indirect composite restorations [17]. Most of the studies included in this systematic review had a limited follow-up time.

Fennis et al. (2014) reported the 5 years results of a randomized clinical trial (RCT) on direct and indirect composite cusp-replacing restorations [18]. Both types of cusp-replacing restorations obtained good survival after 5 years, where survival rates for complete failures were 91.2% and 83.2% respectively [18]. There was no statistically significant difference between the two treatment modalities ( $p = 0.15$ ). Direct restorations presented mostly fracture of the remaining cusp and cohesive failures. Indirect restorations mainly presented dislodgement, with or without cohesive failure.

There is a need for long term clinical evidence on the functioning of direct and indirect restorations replacing cusps. The present study is a prolongation of the RCT by Kuijs et al. (2006) and Fennis et al. (2014), and the objective is to evaluate the long-term clinical survival and performance of direct and indirect resin composite restorations replacing cusps in vital upper premolars [10,18].

## 2. Material and methods

### 2.1. Study design

The present retrospective follow-up study is a prolongation of the prospective randomized clinical study mentioned above [10,18]. The latter study was performed at the university clinic of the Radboud University Medical Centre, Nijmegen, The Netherlands, and approved by the local medical ethics committee (trial registration number

ISRCTN29200848; Radboud University Nijmegen Ethics Committee approval 2001/166). For evaluations of the prolongation of the prospective randomized clinical trial, the present follow-up study was not considered clinical research with test subjects as meant in the Medical Research Involving Human Subjects Act (WMO) (Radboud University Nijmegen Ethics Committee communication 2021–13008). The study was registered in the national trial register (research register number: NL9089).

### 2.2. Inclusion and exclusion criteria

Between 2001 and 2007, 176 upper premolars in 157 patients (77 males, 80 females) were restored with 92 direct and 84 indirect resin composite restorations. The majority of patients ( $n = 138$ ) received one restoration, and 19 patients received 2 restorations. Mean patient age at placement was 54.9 years (range 35.0–81.0 years). Inclusion criteria were fracture of the buccal or palatal cusp of vital upper premolars along with a class II cavity or restoration in the same tooth. The remaining cusp had to be sound. Exclusion criteria were absence of an antagonist, presence of rest seats for a removable partial denture, and tooth mobility score 3 (Miller 1950) [19]. Signs and symptoms of bruxism were no reasons for exclusion. Patients were randomly assigned to either type of restoration technique.

### 2.3. Clinical procedures and fabrication of the restorations

Details of the clinical procedures are specified in the original article [18]. In short: during preparation, where old restorative material and carious tissue were removed, pulp vitality was verified. For both restorative techniques moisture was controlled by cotton rolls and a suction device. For the direct technique, a contoured metal matrix, wooden wedges, and separations rings (Danville Materials, San Ramon, CA, USA) were placed. A three-step etch-and-rinse adhesive was applied (Clearfil SA primer and Clearfil PhotoBond, Kuraray, Osaka, Japan). The restoration was built up with a highly filled hybrid resin composite (70 vol%, 86 wt% filler load; AP-X, Kuraray) in incremental composite layers of 2 mm. Each layer was photo-polymerized for 40 s with a halogen curing light with an intensity of 650 mW/mm<sup>2</sup>.

For the indirect technique, a silicone impression of the prepared cavity was taken. All indirect resin composite restorations (82% vol, 92% wt filler load; Estenia, Kuraray) were made by one dental technician according to the manufacturer's instructions. At delivery, the cavity was cleaned with pumice. The internal surface of the restoration was air-abraded for 15 s with 50  $\mu$ m Al<sub>2</sub>O<sub>3</sub>, cleaned with 37% phosphoric acid etch gel, and treated with a silane coupling agent (SE Primer + Porcelain bond activator, Kuraray). The enamel was etched with phosphoric acid etch gel, rinsed, and gently air-dried. A self-etching primer (ED primer, Kuraray) was applied to enamel and dentin. The restoration was cemented with dual-cure resin composite cement (Panavia F, Kuraray). The cement was photo-polymerized for 20 s from the buccal, palatal, and occlusal surfaces. Both direct and indirect restorations were finished with fine grit diamonds, polishing discs, strips, and rubbers.

### 2.4. Evaluation

During the original study, patients were invited for a check-up once a year. They were instructed to contact the operators if an event occurred concerning their restoration. Failure was recorded on the basis of predefined criteria and considered as (1) reparable – interventions such as polishing after chipping of fragments of resin composite and re-cementation of dislodged indirect restorations or (2) complete – failures such as caries or tooth fracture and dislodged direct or re-cemented indirect restorations. Patients were recalled in the original study until November 2011. During the present prolongation study, the clinical evaluation was similar to the original evaluation protocol, extended by

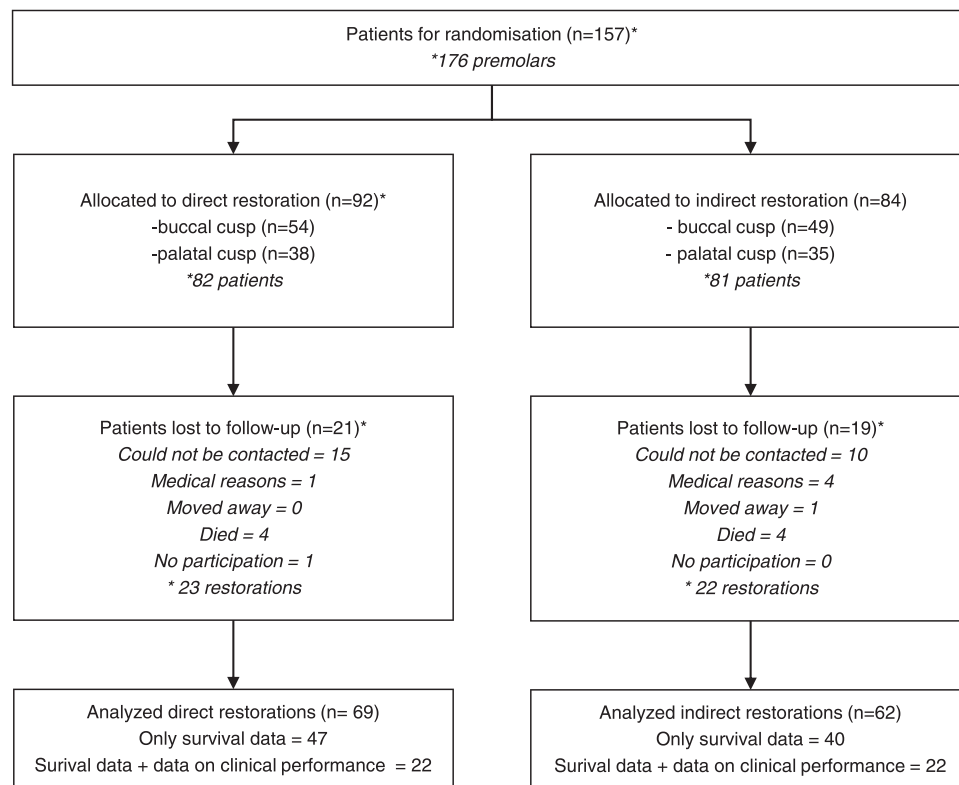


Fig. 1. Flow diagram detailing patient allocation, treatment and follow-up.

FDI criteria for available restorations [20]. The patients signed informed consent and were recalled between January 2022 and October 2022 by two calibrated operators (JH and CK) at the university clinic of the Radboud University Medical Centre, Nijmegen, The Netherlands. If failure had occurred, dental records of the patient's general practitioner were checked, if allowed, for specific date(s) and type of failure.

### 2.5. Statistical analysis

The results were analyzed using R version 3.3.3 (R Foundation for Statistical Computing, Vienna, Austria) and IBM SPSS statistics 28.0 (IBM Corp. NY, USA). The overall cumulative survival rates over time were calculated using the Kaplan–Meier estimates (standard error and 95% confidence intervals (CI)) differentiating between the direct and indirect restorations. Cox regression analysis with frailty index was used to analyze the influence of the variables age, gender, type of restoration technique (direct vs indirect), type of upper premolar (first vs second) and the cusp involved in the restoration on the survival. The hazard ratio (HR) and their significance were reported. The frailty index was used to correct for the dependence of the restorations as 19 patients received two restorations. A Fisher's exact test was applied to determine statistically significant differences in FDI criteria between direct and indirect resin composite restorations. The Fisher exact, combined with Bonferroni corrected pairwise comparisons was used to determine statistically significant differences in failure modes between the type of restorations. A  $p$ -value  $< .05$  was considered to indicate statistical significance for all analyses.

### 3. Results

The mean follow-up time for evaluated restorations was 18.4 years (SD 1.5 years; range 14.9–20.2 years) for the direct technique and 17.7 years (SD 0.3 years; range 15.2–19.6 years) for the indirect technique. Forty patients (respectively 23 direct and 22 indirect composite restorations) were lost to follow-up (25.6%) (Fig. 1). Most of the drop-out

patients could not be contacted or were unable to participate; 8 patients died during the follow-up.

The life cycle of the restorations is presented in Fig. 2. Failures ( $n = 71$ ) occurred at a mean follow-up of 8.7 years (SD 5.2 years) for the direct technique ( $n = 34$ ) and 7.7 years (SD 4.6 years) for the indirect technique ( $n = 37$ ). Seven of the failed restorations were considered repairable of which six indirect restorations were re-cemented and one direct restoration was polished. Three of the recemented restorations failed again. The number of failures per category is shown in Fig. 3. For direct restorations, fracture of remaining cusp ( $n = 8$ , 23.5%), crown indication ( $n = 7$ , 20.6%), and caries ( $n = 6$ , 17.6%) were the main causes for failure. For indirect restorations, adhesive failure ( $n = 10$ , 27.0%), caries ( $n = 7$ , 18.9%), and adhesive failure plus cohesive failure ( $n = 4$ , 10.8%) were the main problems. After loss of an adjacent tooth, four teeth with a restoration (3 indirect, 1 direct) served as an abutment for a bridge construction. Another tooth with an indirect restoration was extracted for periodontal reasons. These teeth were censored for the Kaplan–Meier survival analysis. Fisher's exact test revealed a significant difference in failure modes between direct and indirect composite restorations ( $p < 0.001$ ). Pairwise comparisons revealed a significantly higher amount of adhesive failures in indirect composite restorations ( $p = 0.030$ ) and significantly more cusp fracture in direct composite restorations ( $p = 0.039$ ).

Survival curves of direct and indirect restorations are shown in Fig. 4. The Kaplan–Meier 10-year survival rates were 73.8% (SE 5.0%) with an AFR of 2.6% for direct composite restorations and 65.7% (SE 5.8%) with an AFR of 3.4% for indirect composite restorations. For extended follow-up the cumulative Kaplan–Meier survival rates were 63.6% (mean observation time: 15.3 years, SE 5.6%) with an AFR of 2.4% for direct restorations and 54.5% (mean observation time: 13.9 years, SE: 6.4%) with an AFR of 3.3% for indirect restorations.

The results of the Cox regression analysis are presented in Table 1. The analysis revealed that only the age of the patient at placement had a significant influence on the survival of the restoration (HR 1.036,  $p = .024$ ). Patients between 45 and 55 years old at placement of the

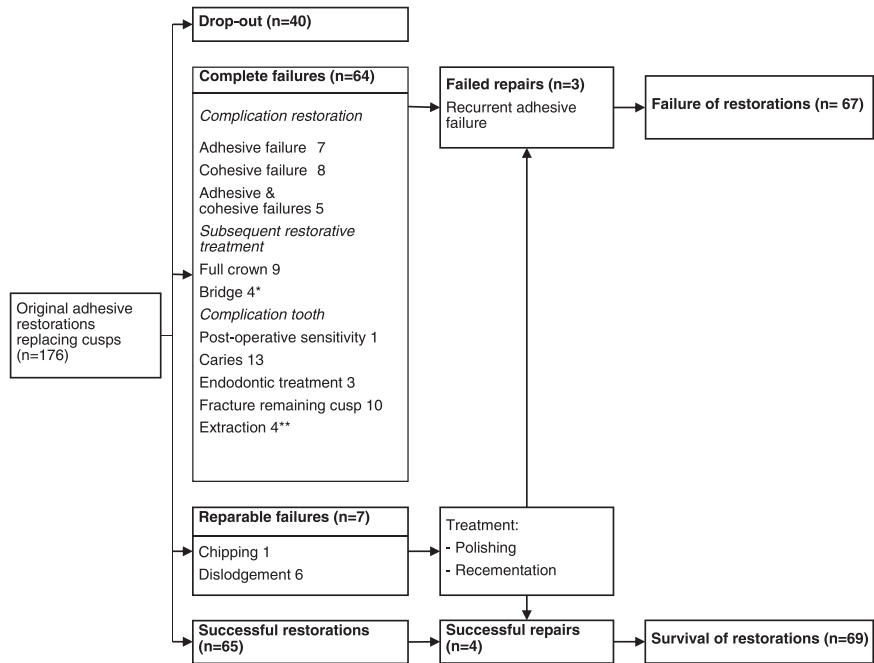


Fig. 2. Life cycle of the restorations. \*Due to loss of adjacent tooth. Censored for Kaplan Meier survival analyses \*\*One tooth was extracted for periodontal reasons. Censored for Kaplan Meier survival analyses.

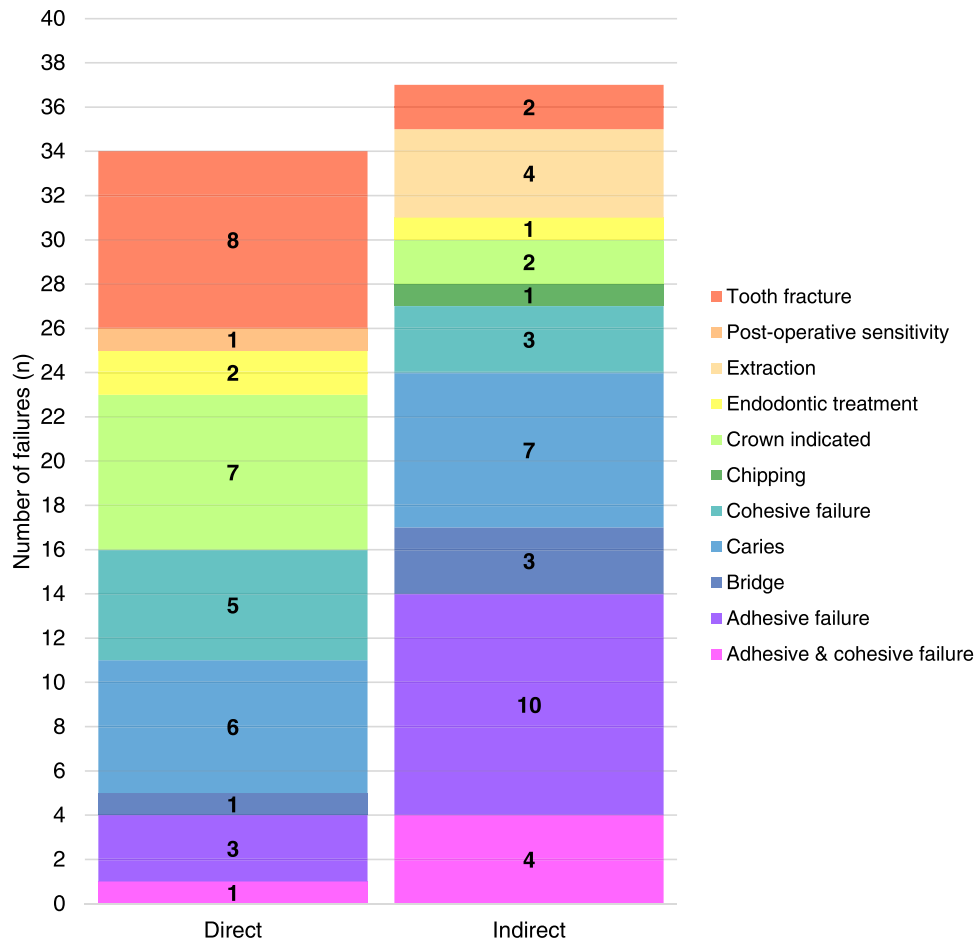
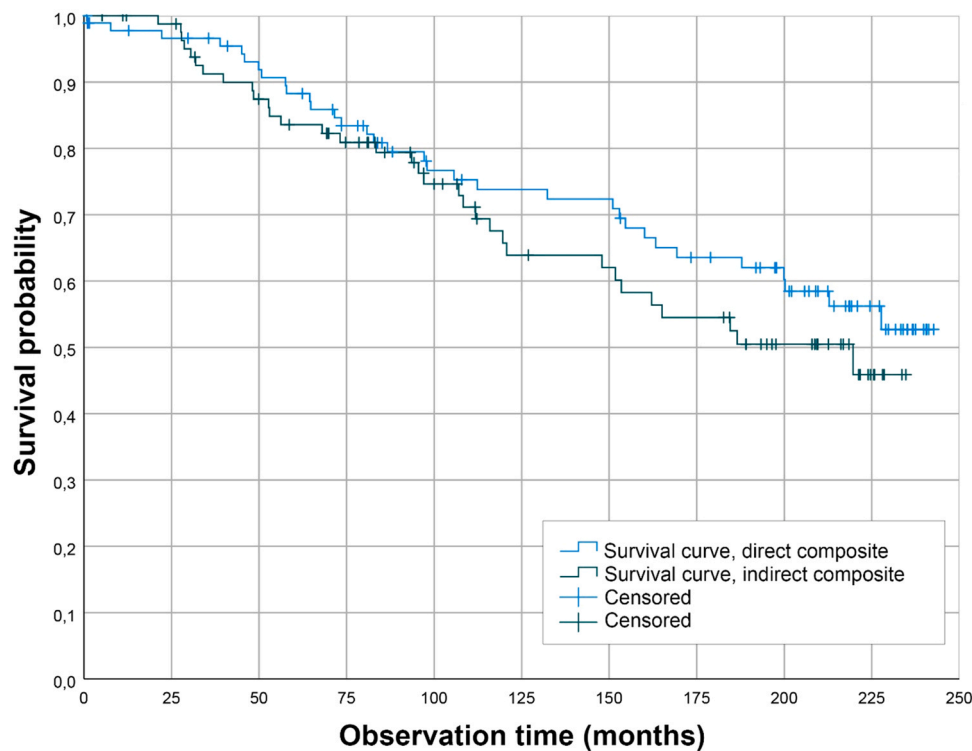


Fig. 3. Distribution of failure categories for the two restoration techniques.



**Fig. 4.** Kaplan-Meier curves of the survival of the cusp-replacing restorations, stratified by the type of restoration, direct (n = 92) and indirect (n = 84) cusp-replacing restorations.

**Table 1**  
Cox regression analysis on the influence of five variables on the restoration survival.

Variable	Comparison	Hazard Ratio	95% confidence interval		p
			Lower	Upper	
Age		1.034	1.004	1.065	0.027 <sup>a</sup>
Gender	Female vs Male	0.868	0.465	1.560	0.600
Type of upper premolar	First vs Second	0.964	0.362	1.157	0.140
Restoration technique	Direct vs Indirect	1.380	0.725	2.346	0.380
Cusp involved	Buccal vs Palatal	0.929	0.490	1.669	0.750

<sup>a</sup> Statistically significant.

restorations showed relatively more events. The influence of the type of restoration technique, type of upper premolar, the cusp involved in the restoration, and gender were not statistically significant ( $p > .05$ ).

For the evaluation of clinical performance, using FDI criteria, 48 of the 176 restorations were available. The mean observation time was 18.2 years (range: 14.9–20.2 years). There were only statistically significant difference between esthetic properties (Table 2). The significant FDI criteria and their absolute and relative numbers are reported in Table 3. There was significantly more margin staining in direct restorations ( $p = .037$ ). Indirect restorations show minor marginal staining most of the time, whereas direct restorations had more extensive marginal staining. Indirect restorations showed a significantly better esthetical anatomical form than direct restorations ( $p < .001$ ), but the direct composite restorations were all esthetically acceptable too. The morphology can be adequately restored with direct composite restorations, but the results were more esthetically pleasing with indirect restorations. At placement, the direct restorations were not polished to a high gloss, but the indirect restorations were. A Fisher's exact test on the difference in surface luster between placement and final evaluation on 22 indirect restorations revealed a significant reduction in surface luster ( $p < .001$ ): only 6 restorations had a luster comparable with enamel, the rest were slightly dull ( $n = 12$ ) or dull ( $n = 4$ ). Figs. 5 and 6 show representative cases of respectively a direct

and an indirect composite restoration at medium- and long-term follow-up.

4. Discussion

With the expanding indication for resin composite in the last decades, the key question of the original RCT, which was initiated approximately 20 years ago, was whether composite could provide a reliable restoration in case a fractured cusp of a premolar. To the best of our knowledge, long-term published evaluations of composite restorations replacing cusps on premolars longer than 10 years are lacking. This study reports the long-term results of restorations made within an RCT with a high follow-up percentage. The results of the present follow-up study showed a comparable non-significant difference in survival between direct and indirect cusp replacing restorations as in the 5-year evaluation [18]. The cumulative AFRs were 2.4% for direct composite restorations and 3.3% for indirect composite restorations. Compared to other studies, the 11-year results of direct fillings and indirect composite inlays by Pallesen and Qvist (2003) report better survival rates (83–84%), but no cusps were involved [21]. Recently, a retrospective study published the survival results of posterior teeth restored with extensive direct resin composite restorations in a general dental practice with a mean follow-up of 14 years [22]. The reported survival rates

**Table 2**  
FDI criteria and results of Fisher Exact test.

FDI criteria	Sig.
<i>Esthetic Properties</i>	
Surface luster	NA
Staining	
a. Surface	p = 0.106
b. Margin	<b>p = 0.037<sup>a</sup></b>
Color match and translucency	p = 0.999
Esthetic anatomical form	<b>p &lt; 0.001<sup>a</sup></b>
<i>Functional properties</i>	
Fracture of material and retention	p = 0.724
Marginal adaptation	p = 0.078
Occlusal contour and wear	p = 0.288
Approximal anatomical form	
a. Contact point	p = 0.660 *
	p = 0.654 * *
b. Contour	p = 0.061 *
	p = 0.152 * *
Patients view	p = 0.416
<i>Biological properties</i>	
Recurrence of caries	p = 0.091
Tooth integrity	p = 0.999
Periodontal response	p = 0.230
Adjacent mucosa	p = 0.150
Oral and general health	p = 0.288

Superscript and bold a indicate significant differences. NA = not applicable. Not tested due to baseline difference in surface luster. \* Mesial.

\* \* Distal

were comparable to the present results namely 62.5% survival after 14 years of function with an AFR of 2.79% [22].

The distribution of the reasons for failure differed between the present and the 5-year results of this RCT. It was noticed that the patient's dentist more frequently indicated to replace the included direct resin composite cusp-replacing restoration for a circumferential crown than the indirect resin composite cusp-replacing restoration. The reason that the direct composite cusp-replacing restoration was more often replaced than the indirect composite cusp-replacing restoration might be related to the character of the restoration: the direct restoration is often regarded as a temporary solution. Considering the indirect restorations, both in this observation period as in the first five years, mainly adhesive failures, dislodgements, of the restoration were seen. Adhesive failure could be influenced by the type of adhesive cementation of the indirect restorations. In this RCT, Panavia F was used in combination with selective etching of enamel using phosphoric acid and a self-etching ED primer to cement the indirect restorations. In vitro, u-TBS studies, show significantly less bond strength to dentin of Panavia F in combination with self-etching ED primer in comparison to other adhesive systems [23,24]. Panavia F in combination with a total etching adhesive system obtains significantly better bond strengths to dentin in comparison to the self-etching ED primer [25]. Bond strengths

in these studies were reported to range between 16.1 and 19.8 MPa [23–25]. Gold standard, modern, etch-and-rinse adhesives obtain micro tensile bond strengths of resin composite to dentin of 35.6 MPa (SD 7.3) after 6 months of water aging [26].

Fracture of the remaining cusp and adhesive dislodgement of indirect restorations are predominant modes of failure. The inclusion criteria, fracture of one of the cusps of a vital upper premolar, could be induced by parafunctions like clenching and grinding and could therefore influence the failure pattern of the restorations made in this study.

Within the limitations of the restricted number of evaluated teeth, the present results show that the clinical performance of both direct and indirect composite cusp-replacing restorations is acceptable. Indirect restorations obtain esthetically better results, but direct composite restorations are also esthetically acceptable. A previous report by Kuijs et al. (2006) of this RCT reported adequate restoration of morphology and function with direct and indirect cusp-replacing restorations in the short term [10]. These results could be confirmed on the long term in the present report.

The dominant reason of failure for the direct composite restorations was the fracture of the remaining cusp. This type of failure may be prevented by coverage of that cusp. However, there is no consensus on the advantage of cuspal coverage for direct and indirect composite restorations on vital teeth [27]. There are in vitro studies that revealed a higher fracture strength after cusp coverage [28,29]. However, there are also studies that did not report a significant improvement in fracture strength after cusp coverage [30,31]. Cuspal coverage led to more catastrophic failures in in-vitro conditions [28]. In a cross-sectional in vivo study, fracture outline ended in 91% supra gingivally [1].

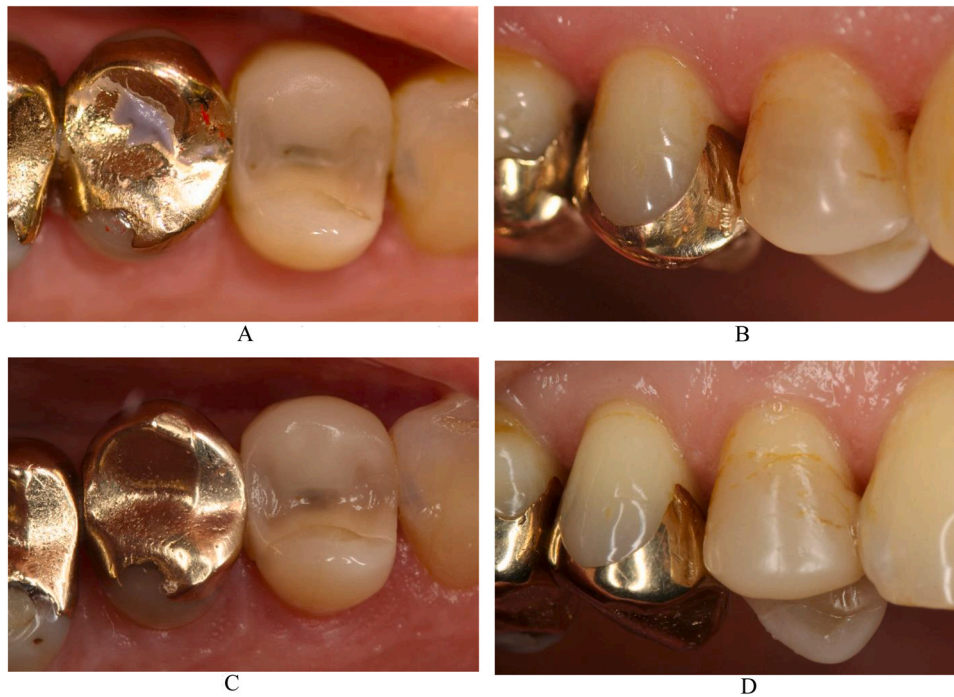
From a practice point of view, there is the question whether composite restorations are viable alternatives for full coverage crowns. Clinical studies report high 10-year survival rates for full coverage crowns, like 96.5% for monolithic e.max complete covering crowns (Malament et al., 2019) and 87.1% for porcelain-fused-to-metal crowns (Bacher et al., 2021) [32,33]. These survival rates are 15–20% higher than the reported survival for the present direct and indirect composite restorations. However, both financial and biological costs are higher for the traditional crown than for the cusp-replacing composite restoration. A cost-effectiveness-study (CEA) or a life cycle analysis might shed more light to this question, but both these types of research are challenging to perform and up to now no CEA data are available. The treatment advice of a dentist in practice and the resulting choice made together with the patient seems to depend more on personal preferences than on scientific facts. We found that even after a mean evaluation of 14 years, there was no statistically significant difference in survival between direct and indirect composite cusp-replacing restorations.

From the present data, we can conclude that both direct and indirect resin-composite cusp-replacing restorations are suitable treatment options to restore compromised premolars, with 10-year survival rates of 74% and 66%, respectively. Now, the longer treatment time and higher costs for the indirect restoration might argue in favor of the direct

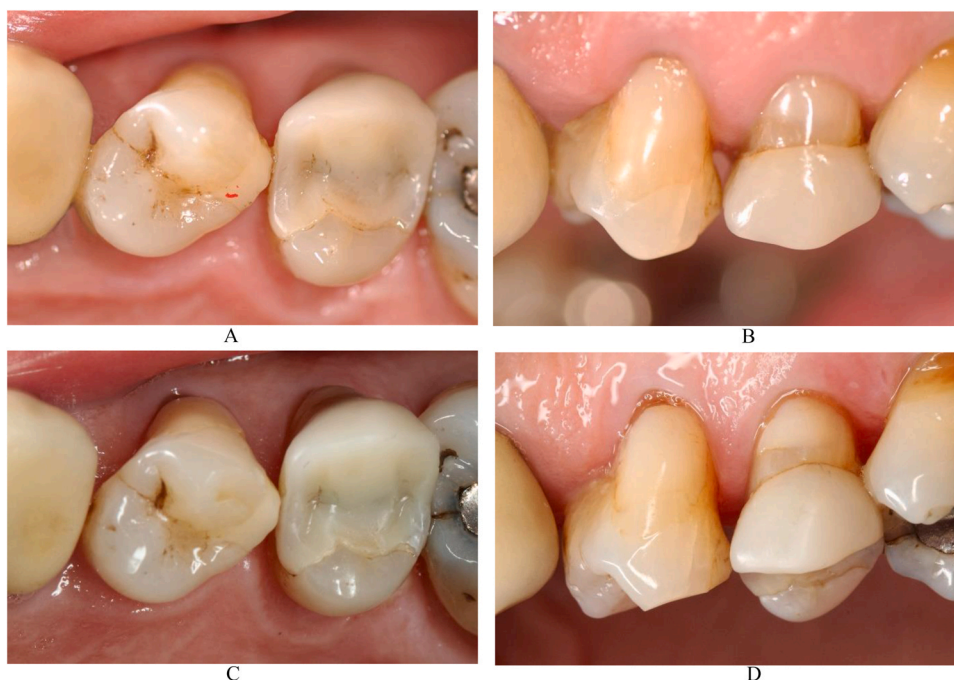
**Table 3**  
Statistically significant FDI criteria and the absolute and relative numbers (%).

Marginal staining (p = .037)			
	No marginal staining	Minor marginal staining	Moderate marginal staining
Direct	1 (3.8%)	10 (38.5%)	15 (57.7%)
Indirect	3 (13.6%)	14 (63.6%)	5 (22.7%)
Esthetic anatomical form (p < .001)			
	Form is ideal	Form deviates only slightly from the norm	Form deviates from the norm but is esthetically acceptable
Direct	4 (15.4%)	14 (53.8%)	8 (30.8%)
Indirect	15 (68.2%)	6 (27.3%)	1 (4.5%)
Surface luster of indirect restorations (p < .001)			
	Luster comparable to enamel	Slightly dull, not noticeable from speaking distance	Dull surface, but acceptable if covered with film of saliva
Baseline	22 (100%)	0	0
Evaluation	6 (27.3%)	12 (54.5%)	4 (18.2%)





**Fig. 5.** a-d. A representative case of a direct composite cusp-replacing restorations after 6.9 and 17.7 years of follow-up, Fig. 5A: Occlusal view of #14 after 6.9 years of function, Fig. 5C: Occlusal view of #14 after 17.7 years of function, with a comparable appearance as during the 6.9-year evaluation, Fig. 5B: Buccal view of #14 after 6.9 years of function. Note the surface staining as discolored lines due to built-up in layers. The surface is slightly dull, Fig. 5D: Buccal view of #14 after 17.7 years of function. Note the discolored lines due to built-up in layers. The surface is slightly dull. Comparable appearance as during the 6.9-year evaluation.



**Fig. 6.** a-d. A representative case of an indirect composite cusp-replacing restorations after 7.5 and 18 years of follow-up, Fig. 6A: Occlusal view of #25 after 7.5 years of function. Note the cement gap occlusal, Fig. 6B: Buccal view of #25 after 7.5 years of function. Note the moderate marginal staining. The surface luster is comparable to enamel. Adequate restoration of a normal approximal contour and contact point, Fig. 6C: Occlusal view of #25 after 18 years of function. Note the occlusal cement gap, no clear wear of the cement is visible. Appearance is comparable to 7.5-year evaluation, Fig. 6D: Buccal view of #25 after 18 years of function. Note the discolored lines due to built-up in layers. The surface has become slightly dull.

technique.

#### Declaration of Competing Interest

All authors declare that they have no conflicts of interest.

#### Acknowledgments

The authors received no financial support and declare no potential conflicts of interest with respect to the authorship and/or publication of this article. We acknowledge RA Hoefnagel for his help in contacting patients. IM Nolte is gratefully acknowledged for her help in building the R script.

#### References

- [1] Fennis WMM, Kuijs RH, Kreulen CM, Roeters FJM, Creugers NHJ, Burgersdijk RCW. A survey of cusp fractures in a population of general dental practices. *Int J Prosthodont* 2002;15:559–63.
- [2] Bader JD, Martin JA, Shugars DA. Incidence rates for complete cusp fracture. *Community Dent Oral Epidemiol* 2001;29:346–53. <https://doi.org/10.1034/j.1600-0528.2001.290504.x>
- [3] Sailer I, Makarov NA, Thoma DS, Zwahlen M, Pjetursson BE. All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (FDPs)? A systematic review of the survival and complication rates. Part I: Single crowns (SCs). *Dent Mater* 2015;31:603–23. <https://doi.org/10.1016/j.dental.2015.02.011>
- [4] Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for anterior teeth. *J Prosthet Dent* 2002;87:503–9. <https://doi.org/10.1067/mpd.2002.124094>
- [5] Murray PE, About I, Lumley PJ, Smith G, Franquin JC, Smith AJ. Postoperative

- pulpal and repair responses. *J Am Dent Assoc* 2000;131:321–9. <https://doi.org/10.14219/jada.archive.2000.0175>
- [6] Elderton RJ. Restorations without conventional cavity preparations. *Int Dent J* 1988;38:112–8.
  - [7] Ferracane JL, Hilton TJ. Polymerization stress - Is it clinically meaningful? *Dent Mater* 2016;32:1–10. <https://doi.org/10.1016/j.dental.2015.06.020>
  - [8] Davidson C, de Gee A, Feilzer A. The competition between the composite-dentin bond strength and the polymerization contraction stress. *J Dent Res* 1984;63:1396–9.
  - [9] Feilzer AJ, de Gee AJ, Davidson CL. Setting stress in composite resin in relation to configuration of the restoration. *J Dent Res* 1987;66:1636–9.
  - [10] Kuijs RH, Roeters FJM, Burgersdijk RCW, Fennis WMM, Kreulen CM, Creugers NHJ. A randomized clinical trial of cusp-replacing resin composite restorations: Efficiency and short-term effectiveness. *Int J Prosthodont* 2006;19:349–54.
  - [11] da Rosa Rodolpho PA, Donassollo TA, Cenci MS, Loguercio AD, Moraes RR, Bronkhorst EM, et al. 22-Year clinical evaluation of the performance of two posterior composites with different filler characteristics. *Dent Mater* 2011;27:955–63. <https://doi.org/10.1016/j.dental.2011.06.001>
  - [12] Laske M, Opdam NJM, Bronkhorst EM, Braspenning JCC, Huysmans MCDNJM. Ten-year survival of class ii restorations placed by general practitioners. *JDR Clin Trans Res* 2016;1:292–9. <https://doi.org/10.1177/2380084416663192>
  - [13] Kopperud SE, Tveit AB, Gaarden T, Sandvik L, Espelid I. Longevity of posterior dental restorations and reasons for failure. *Eur J Oral Sci* 2012;120:539–48. <https://doi.org/10.1111/eos.12004>
  - [14] Laske M, Opdam NJM, Bronkhorst EM, Braspenning JCC, Huysmans MCDNJM. Longevity of direct restorations in Dutch dental practices. Descriptive study out of a practice based research network. *J Dent* 2016;46:12–7. <https://doi.org/10.1016/j.jdent.2016.01.002>
  - [15] van de Sande FH, Opdam NJ, da Rosa Rodolpho PA, Correa MB, Demarco FF, Cenci MS. Patient risk factors— influence on survival of posterior composites. *J Dent Res* 2013;92:S78–83. <https://doi.org/10.1177/0022034513484337>
  - [16] Scholtanus JD, Özcan M. Clinical longevity of extensive direct composite restorations in amalgam replacement: Up to 3.5 years follow-up. *J Dent* 2014;42:1404–10. <https://doi.org/10.1016/j.jdent.2014.06.008>
  - [17] da Veiga AMA, Cunha AC, Ferreira DMTP, da Silva Fidalgo TK, Chianca TK, Reis KR, et al. Longevity of direct and indirect resin composite restorations in permanent posterior teeth: A systematic review and meta-analysis. *J Dent* 2016;54:1–12.
  - [18] Fennis WM, Kuijs RH, Roeters FJ, Creugers NH, Kreulen CM. Randomized control trial of composite cuspal restorations: Five-year results. *J Dent Res* 2014;93:36–41.
  - [19] Miller SC. *Textbook of Periodontia*. Philadelphia, PA: Blakiston,; 1950. p. 125.
  - [20] Hickel R, Peschke A, Tyas M, Mjör I, Bayne S, Peters M, et al. FDI World Dental Federation: clinical criteria for the evaluation of direct and indirect restorations—update and clinical examples. *Clin Oral Invest* 2010;14:349–66. <https://doi.org/10.1007/s00784-010-0432-8>
  - [21] Pallesen U, Qvist V. Composite resin fillings and inlays. An 11-year evaluation. *Clin Oral Invest* 2003;7:71–9. <https://doi.org/10.1007/s00784-003-0201-z>
  - [22] Hofsteenge JW, Scholtanus JD, Özcan M, Nolte IM, Cune MS, Gresnigt MMM. Clinical longevity of extensive direct resin composite restorations after amalgam replacement with a mean follow-up of 15 years. *J Dent* 2023;130:104409. <https://doi.org/10.1016/j.jdent.2023.104409>
  - [23] Mak Y-F, Lai SCN, Cheung GSP, Chan AWK, Tay FR, Pashley DH. Micro-tensile bond testing of resin cements to dentin and an indirect resin composite. *Dent Mater* 2002;18:609–21. [https://doi.org/10.1016/s0109-5641\(02\)00005-2](https://doi.org/10.1016/s0109-5641(02)00005-2)
  - [24] de Menezes MJL, Arrais CAG, Giannini M. Influence of light-activated and auto- and dual-polymerizing adhesive systems on bond strength of indirect composite resin to dentin. *J Prosthet Dent* 2006;96:115–21. <https://doi.org/10.1016/j.prosdent.2006.06.003>
  - [25] Marques Melo R, Özcan M, Barbosa SH, Galhano G, Amaral R, Bottino MA, et al. Bond strength of two resin cements on dentin using different cementation strategies. *J Esthet Restor Dent* 2010;22:262–8. <https://doi.org/10.1111/j.1708-8240.2010.00349.x>
  - [26] van den Breemer CR, Özcan M, Pols MR, Postema AR, Cune MS, Gresnigt MM. Adhesion of resin cement to dentin: effects of adhesive promoters, immediate dentin sealing strategies, and surface conditioning. *Int J Esthet Dent* 2019.
  - [27] Rocca GT, Rizcalla N, Krejci I, Dietschi D. Evidence-based concepts and procedures for bonded inlays and onlays. Part II. Guidelines for cavity preparation and restoration fabrication. *Int J Esthet Dent* 2015;10:392–413.
  - [28] Fennis WMM, Kuijs RH, Kreulen CM, Verdonshot N, Creugers NHJ. Fatigue resistance of teeth restored with cuspal-coverage composite restorations. *Int J Prosthodont* 2004;17:313–7.
  - [29] Magne P, Boff LL, Oderich E, Cardoso AC. Computer-aided-design/computer-assisted-manufactured adhesive restoration of molars with a compromised cusp: Effect of fiber-reinforced immediate dentin sealing and cusp overlap on fatigue strength. *J Esthet Restor Dent* 2012;24:135–46. <https://doi.org/10.1111/j.1708-8240.2011.00433.x>
  - [30] Hofsteenge JW, van den Heijkant IA, Cune MS, Bazos PK, van der Made S, Kerdijk W, et al. Influence of preparation design and restorative material on fatigue and fracture strength of restored maxillary premolars. *Oper Dent* 2021;46:E68–79. <https://doi.org/10.2341/20-032-L>
  - [31] Fonseca RB, Fernandes-Neto AJ, Correr-Sobrinho L, Soares CJ. The influence of cavity preparation design on fracture strength and mode of fracture of laboratory-processed composite resin restorations. *J Prosthet Dent* 2007;98:277–84.
  - [32] Malament KA, Natto ZS, Thompson V, Rekow D, Eckert S, Weber H-P. Ten-year survival of pressed, acid-etched e.max lithium disilicate monolithic and bilayered complete-coverage restorations: Performance and outcomes as a function of tooth position and age. *J Prosthet Dent* 2019;121:782–90. <https://doi.org/10.1016/j.prosdent.2018.11.024>
  - [33] Bacher H, Schweyen R, Olms C, Arnold C, Setz J, Hey J. 10-year clinical comparative study of ceramic and composite veneered metal crowns. *Eur J Prosthodont Restor Dent* 2021;29. [https://doi.org/10.1922/EJPRD\\_2148Bacher11](https://doi.org/10.1922/EJPRD_2148Bacher11)