International Journal of Dental Research and Allied Sciences
2023, Volume 3, Issue 1, Page No: 105-118

Available online at: www.tsdp.net

ISSN: 3062-3502

Original Article

Clinical Assessment of Direct Posterior Composite Restorations Over a 23-Year Follow-Up Period

Lars Bakker[1], Sophie van Leeuwen[1]*, Sem Jansen[1]

[1]Department of Dentistry, Radboud Institute for Health Sciences, Radboud University Medical Center, Nijmegen, Netherlands.

***E-mail** ✉ sophie.vleeuwen.official@gmail.com

Received: 05 February 2023; **Revised:** 28 May 2023; **Accepted:** 29 May 2023

ABSTRACT

This long-term observational study assessed the durability and clinical performance of posterior composite restorations over a period exceeding 23 years. Twenty-two patients (13 men, 9 women; mean age 66.1 years, range 50–84) contributing a total of 42 restorations were examined during two follow-up sessions. A single clinician evaluated all restorations according to modified FDI criteria. Statistical comparisons were performed using the Wilcoxon Mann–Whitney U test and the Wilcoxon exact matched-pairs test (significance level p = 0.05), with Bonferroni–Holm correction applied. Over time, six of seven evaluated criteria demonstrated significant deterioration, except for approximal anatomical form, which remained largely stable, except in molars where it declined. No notable differences were observed based on the restorations' jaw location or whether they were single- or multi-surface. These results indicate that posterior composite restorations show measurable clinical changes after more than two decades, underscoring the importance of further long-term evaluations at regular intervals to monitor their performance.

Keywords: Clinical performance, Posterior composite restoration, Modified FDI criteria, Long-term study

How to Cite This Article: Bakker L, van Leeuwen S, Jansen S. Clinical Assessment of Direct Posterior Composite Restorations Over a 23-Year Follow-Up Period. Int J Dent Res Allied Sci. 2023;3(1):105-18. https://doi.org/10.51847/4mQEsQRw9O

Introduction

Since their introduction, resin-based composites have gained widespread acceptance, primarily due to the growing demand for tooth-colored restorations in posterior teeth [1–5]. The declining use of amalgam, coupled with concerns about its biocompatibility and mercury content, has further emphasized the need for suitable alternatives [6–8]. Resin-based composites offer advantages such as minimally invasive cavity preparation and superior aesthetics, contributing to their predominance in dental restorations across many countries [9, 10]. Manufacturers provide a wide array of composite materials for direct restorations in both anterior and posterior teeth, differing in inorganic filler characteristics that influence handling properties, viscosity, and overall physical performance [11–15]. The composition, filler type, size, and concentration significantly affect the clinical outcomes of restorations [16]. Reviews by Ferracane (2011) highlighted nanohybrid and nano-filled composites as advanced filler formulations [16], while Alzraikat *et al*. (2018) reported that nanocomposites and hybrid composites exhibit comparable mechanical properties and clinical performance [17]. Similarly, clinical studies indicate that nanohybrid composites perform on par with conventional hybrid composites, and nano-filled composites show similar outcomes to micro-hybrid formulations [18, 19].

Despite these advancements, posterior composite restorations have a finite lifespan. Long-term studies report survival rates ranging from 64% after 20 years [14] to 87.7% after 3 years [20], with intermediate results such as 80.7% after 10 years [18], 84.7% after 12 years [21], and 69.9% after up to 15 years [22]. Replacement of failed restorations often results in larger cavities and additional loss of tooth structure [23], highlighting the importance of prolonging restoration longevity. Clinical follow-ups provide valuable insights into material behavior and the impact of applied techniques [14, 18, 20–22]. Numerous factors influence restoration survival, including operator skill, material choice, clinical technique [24], and patient-specific factors such as oral hygiene, restoration location and size, bruxism, and caries risk [5, 15, 25].

For long-term evaluation, the USPHS (United States Public Health Service) criteria have historically been used [5, 26–28], but their limited sensitivity prompted the development of more discriminative assessment methods. Hickel *et al*. (2007) introduced a system categorizing restorations into aesthetic, functional, and biological domains, each assessed across multiple criteria with a five-point rating scale [29, 30]. These 16 criteria were subsequently adopted by the FDI World Dental Federation and formalized as "Standard Criteria" in 2008 [29–31]. The FDI system remains flexible, allowing examiners to select the most relevant criteria for a given study [30, 31].

Several clinical and systematic reviews have examined the longevity and performance of posterior composite restorations over periods ranging from 3 to 22 years [5, 14, 18, 20-22, 32–37]. However, there is a paucity of long-term longitudinal studies extending beyond 10 years. Therefore, the present study provides valuable insight by evaluating the clinical performance of posterior composite restorations more than 23 years after placement.

Between 1995 and 1996, adult patients requiring posterior composite restorations who attended student courses at the Department of Operative Dentistry, Dental School (Carolinum), University Hospital, Goethe University Frankfurt (Germany), were informed about the study and invited to participate in follow-up evaluations. During the first follow-up, these restorations were assessed over a three-year observation period (1995–1997) at intervals of 6, 12, 18, 24, and 36 months across different study groups, with the results published in 2016 [38]. The present study revisited the same cohort, conducting a follow-up examination more than 23 years after the initial placement.

Clinical assessments of the restorations at both follow-ups were performed using FDI criteria [29, 31], enabling direct comparison between the first and second evaluations and allowing alignment with other international studies, such as Marquillier *et al*., 2018 [30]. FDI criteria offer enhanced sensitivity in detecting variations in composite restorations compared to USPHS criteria [30, 31] and improve standardization of clinical judgment. Given the complexity of FDI scoring, this study—like most comparable research [39–43]—focused on selected criteria relevant to the research objectives, in line with recommendations by Hickel *et al*. [31] and a 2018 systematic review on the use of FDI criteria in direct dental restorations [30].

The purpose of this second follow-up was to evaluate changes in restoration quality over time, recognizing that assessments are inherently influenced by examiner subjectivity. To minimize this bias and standardize clinical evaluation, the experienced clinician performing the study underwent training and calibration using a web-based interactive tool [44], supplemented with hands-on calibration on restored extracted teeth and live patients. The examiner was blinded to the original follow-up grades and had not placed the restorations initially.

This study aimed to assess the long-term clinical performance and identify potential issues of posterior composite restorations over a period exceeding 23 years, using modified FDI criteria. Insights gained may help refine clinical protocols, improve restoration longevity predictions, and validate or challenge existing knowledge.

The null hypothesis tested proposed that there would be no difference between the restoration scores recorded during the 2019 evaluation and those from the first follow-up between 1995 and 1997. No restorations were repaired or replaced during this period; teeth either received prosthetic treatment or were lost. Additionally, no significant differences were observed in scores based on restoration type (single-surface vs. multi-surface), tooth type (premolar vs. molar), or jaw location (maxilla vs. mandible).

Materials and Methods

The posterior composite restorations analyzed in this study were originally placed between 1995 and 1996 by dental students participating in courses at the Department of Operative Dentistry, Dental School (Carolinum), University Hospital, Goethe University Frankfurt (Germany). All procedures followed a strict, standardized clinical protocol, which included: avoiding beveling of cavity margins; consistent use of a rubber dam; uniform application of metal matrix bands; performing a total-etch bonding technique with Optibond FL (Kerr, Karlsruhe, Germany); applying Herculite XRV composite (Kerr, Karlsruhe, Germany) in incremental layers of 2 mm; and finishing surfaces with carbide or fine diamond burs [38]. Restoration evaluations during the first follow-up were performed by two trained and calibrated dentists.

Prior to the second follow-up, patients were fully informed about the study and provided written consent to participate. The study was conducted in line with the Declaration of Helsinki and received approval from the Ethics Committee of Goethe University Frankfurt (Ethical approval code: 130/18).

Participants included in this long-term follow-up **(Figure 1)** fulfilled the following eligibility criteria:

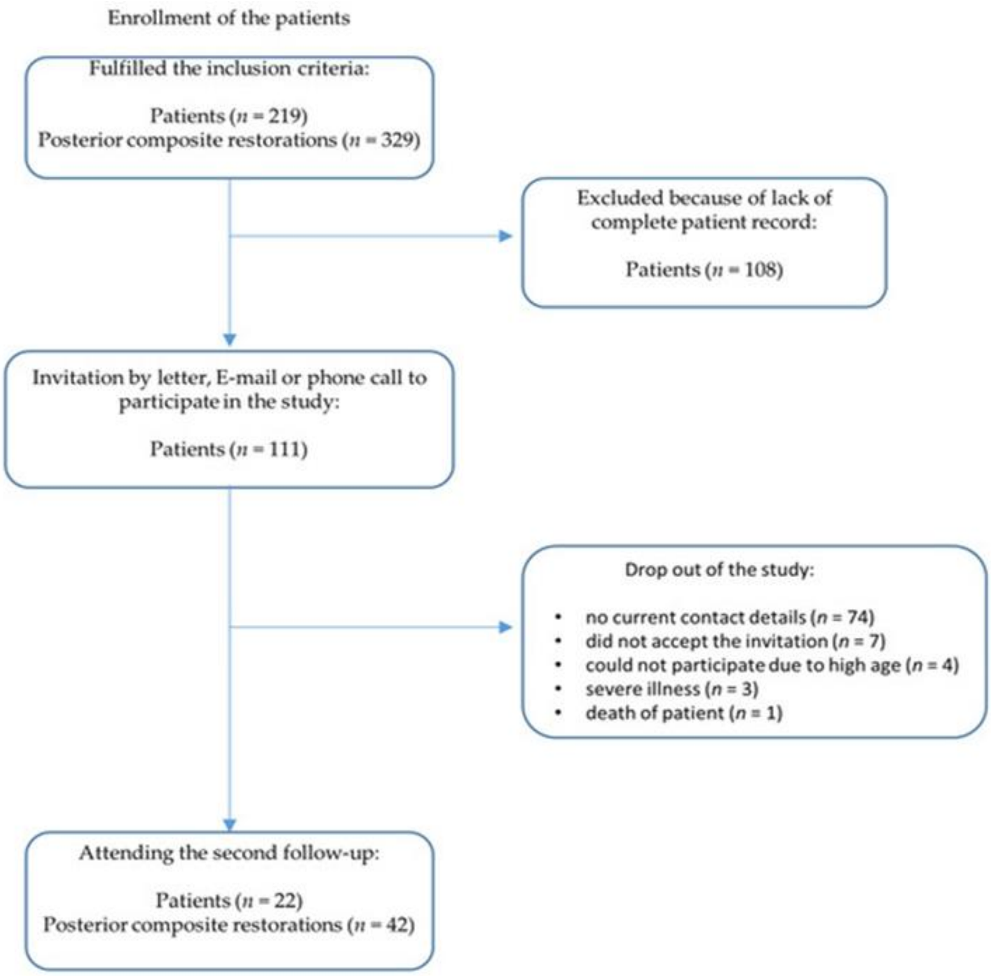


Figure 1. Flow diagram: enrollment of the patients.

- Posterior composite restorations were carried out during the 1995–1996 student courses at the Department of Operative Dentistry.
- Only permanent teeth that were vital and free of symptoms at the time of treatment were included.
- All restorations utilized a micro-hybrid composite material (Herculite XRV, Kerr, Karlsruhe, Germany).
- Procedures adhered to a strict, pre-established clinical protocol.
- Patients were aged between 18 and 70 years at the time of restoration placement.
- Each participant had been evaluated consecutively during the first follow-up, which took place between 1995 and 1997 within 36 months of restoration placement.
- Patients did not receive night guards or other protective dental devices.

Before initiating the second follow-up, a sample size calculation was conducted using "marginal adaptation" as the primary endpoint. Reference data from a previous study [38] reported a baseline mean (SD) of 1.55 at six months, rising to 2.25 at 36 months, based on 219 patients with 329 restorations. Considering a 5% significance level and 85% test power, it was determined that following up 41 restorations would yield sufficient statistical reliability.

The second follow-up was performed between April and June 2019 **(Figure 2)**, approximately 23 years and 5 months (±171 days) after the initial restorations. All teeth were examined using FDI criteria [31]. In alignment with ethical recommendations, periapical radiographs were not obtained to avoid unnecessary radiation exposure [29]. Prior to examination, participants completed an updated medical history form to ensure safety and provide relevant clinical context.

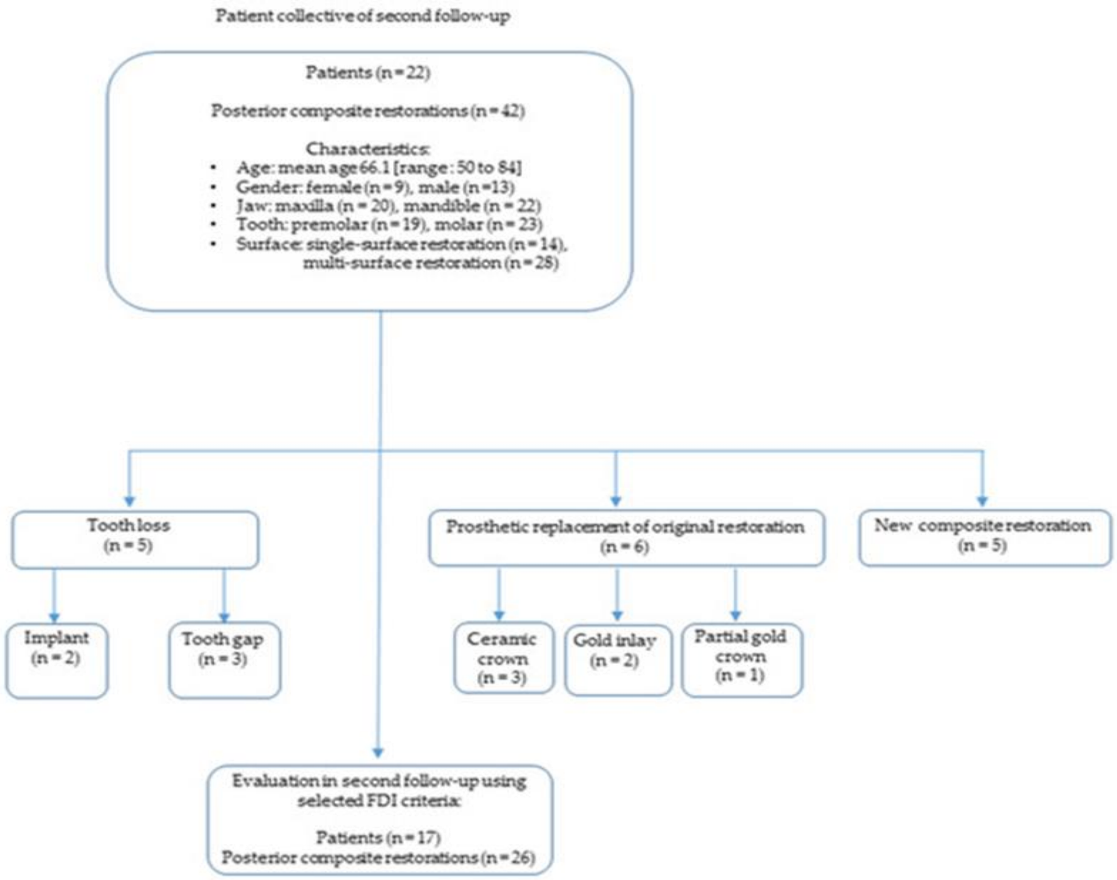


Figure 2. Flow diagram: patient collective of second follow-up.

The clinical assessment of the restorations was performed by an experienced, calibrated dentist who was blinded to prior results. For the evaluation, the examiner used 2.7× magnification glasses (starMed, Grafing, Germany), a dental mirror (DA026R surface and DA074R handle, AESCULAP, Tuttlingen, Germany), a silver line explorer probe (Hu-Friedy, Chicago, IL, USA), a periodontometer (PCPUNC15, Hu-Friedy, Chicago, IL, USA), dental floss (Oral-B Essentialfloss, Procter & Gamble, Schwalbach am Taunus, Germany), and thin metallic matrix bands (Hawe Tofflemire Matrices, 0.05 mm, Kerr Hawe SA, Bioggio, Switzerland). Tooth surfaces were air-dried before examination. Pulp vitality was checked with a cold spray (Plurasol Kältespray, Pluradent, Offenbach, Germany), and percussion testing was performed. Periodontal evaluation included measuring the Papillary Bleeding Index (PBI) [45] and six-site pocket depths (buccal, mesiobuccal, distobuccal, oral, mesiooral, and distooral) on both restored and contralateral reference teeth. Standardized intraoral photographs of all restorations were captured with a Canon EOS 450D and a MR-14EX macro ring light (Canon, Tokyo, Japan). All clinical findings were recorded on standardized data collection forms. The second follow-up was conducted by a different clinician than those involved in the original placement or the first follow-up.

Rather than applying the full set of 16 FDI criteria, seven criteria were selected to match the study's objectives [30]. These included:

Aesthetic:

1. Surface luster
2. Anatomical form

Functional:

3. Material fracture and retention
4. Marginal adaptation
5. Occlusal contour and wear
6. Approximal anatomical form

Biological:

7. Tooth integrity (enamel cracks or fractures)

Each restoration was scored on a six-point scale:

1—excellent/very good
2—good
3—satisfactory
4—unsatisfactory
5—poor
6—restoration or tooth missing

A restoration was considered failed if any of the seven criteria scored 5 or 6. New caries on unrelated surfaces were not counted as failures, as these did not require replacement of the evaluated restoration.

Restorations were also categorized following ISO 3950 guidelines regarding tooth type (premolar or molar), jaw location (maxilla or mandible), and restoration size (single-surface or multi-surface). To enable comparison with the first follow-up (1995–1997), previous results were converted to the same six-point scale, and only the seven selected FDI criteria were analyzed.

Statistical analyses were carried out using SPSS Statistics 28 (IBM, Chicago, IL, USA). Multiple restorations within the same patient were treated as independent observations. Differences between groups (premolar vs. molar, maxilla vs. mandible, single- vs. multi-surface) were evaluated using the Wilcoxon Mann–Whitney U test, while comparisons of paired scores from the first and second follow-ups were performed using the Wilcoxon exact matched-pairs test. Bonferroni–Holm correction was applied, with an adjusted significance threshold of $\alpha = 0.05$.

Results and Discussion

The analysis included 42 direct posterior restorations from 22 patients, with grades from both the initial and long-term follow-up used for statistical evaluation. Descriptive statistics were applied to illustrate the distribution of the seven selected FDI criteria for each restoration. Because the data did not follow a normal distribution, parametric tests such as the Student's t-test were not suitable. Nonparametric methods—the Wilcoxon Mann–Whitney U test and the Wilcoxon exact matched-pairs test—were therefore employed, using a significance level of $p = 0.05$.

Clinical outcomes based on selected FDI criteria aesthetic evaluation

Surface luster

At the first follow-up, nearly all restorations maintained a high degree of surface luster, with 31 restorations (73.8%) rated as clinically good (grade 2), 10 restorations (23.8%) as excellent (grade 1), and only one restoration (2.4%) deemed clinically unsatisfactory (grade 4). By the second follow-up, the results showed a broader range of performance: 10 restorations (23.8%) received grade 2, nine restorations (21.4%) grade 3, and six restorations (14.3%) grade 4, indicating some decline in luster but no need for replacement. Only one restoration maintained enamel-like luster (grade 1: 2.4%). Sixteen restorations (38.1%) were not assessable because the restoration or the tooth was no longer present (grade 6).

Comparisons of central tendency and dispersion demonstrated a marked decrease in surface luster over the 23-year period. The first follow-up revealed a median grade of 2.0 with a narrow interquartile range of 0.25, whereas the second follow-up showed a median of 4.0 and a considerably wider interquartile range of 2.0, reflecting increased variability and deterioration in the long-term aesthetic outcome **(Figure 3)**.

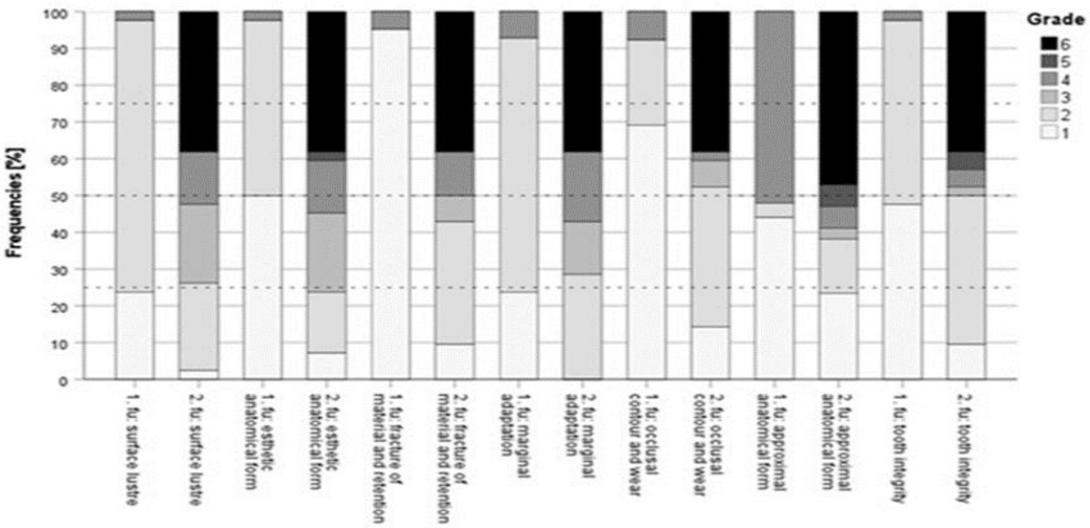


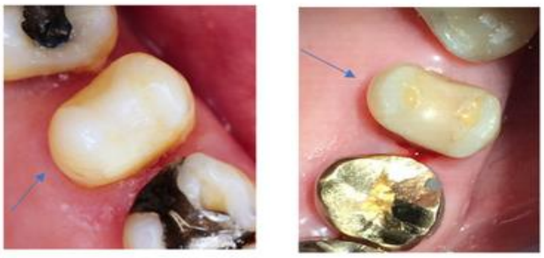
Figure 3. The stacked bar diagrams display the median values along with the first and third quartiles for 42 restorations in 22 patients, assessed at the first (1.fu) and second (2.fu) follow-ups.

No restorations improved in grade over time. Among the 42 restorations, 32 exhibited a higher grade at the second follow-up, whereas 10 remained unchanged. The criterion of surface luster showed a statistically significant decline over the observation period ($p < 0.001$; Wilcoxon exact matched-pairs test).

Aesthetic anatomical form

At the initial follow-up, most restorations were rated as clinically excellent (grade 1: 50%, n = 21) or clinically good (grade 2: 47.6%, n = 20), indicating minimal deviations from the ideal anatomical form. After 23 years, at the second follow-up, only 7.1% (n = 3) of restorations retained an excellent rating, and 16.7% (n = 7) were considered good. Sixteen restorations could not be assessed due to the absence of either the restoration or the tooth (grade 6: 38.1%).

Both the median and interquartile ranges increased considerably over time. The first follow-up had a median grade of 1.5 and an interquartile range of 1.0, while the second follow-up showed a median of 4.0 with an interquartile range of 3.25. Only one restoration demonstrated a lower score at the second follow-up; the majority (36 restorations) worsened, and in five cases, the grade remained the same. Changes in aesthetic anatomical form were statistically significant ($p < 0.001$; Wilcoxon exact matched-pairs test).



a) b)

Figure 4. (a) The clinical view of a Herculite XRV restoration on tooth 25 mod during the first follow-up shows that, 12 months after placement, it only achieved good scores (grade 2) for anatomical form, marginal adaptation, tooth integrity, and surface luster, falling short of excellent. (b) After 24 years, the same restoration displayed in Figure 4a revealed marginal fractures with exposed dentin, resulting in a clinically unsatisfactory rating (grade 4) for marginal adaptation and requiring repair. The anatomical form deviated from the ideal but remained aesthetically acceptable [31], and the surface exhibited dullness and multiple pores, giving only clinically satisfactory ratings (grade 3) for form and surface luster.

Functional properties – fracture resistance and retention

At the first follow-up, the majority of restorations (95.2 percent, n = 40) were free from fractures or cracks, earning the highest possible score (grade 1, clinically excellent) for fracture resistance and retention, which was the best-performing criterion. Two restorations (4.8%) experienced partial bulk fractures affecting less than half of the material, receiving grade 4 (clinically unsatisfactory but repairable), while no restorations were rated grade 2 [31]. By the second follow-up, only four restorations (9.5%) retained an excellent grade, whereas 16 restorations (38.1 percent) could not be assessed because the tooth or restoration was missing (grade 6).

The median and interquartile range of grades increased over time **(Figure 3)**. Initially, the median grade was 1.0 with an interquartile range of 0.0, indicating consistent excellence. At the second follow-up, both the median (3.5) and interquartile range (4.0) rose substantially, reflecting deterioration. No restorations improved in grade over time; in 38 cases, scores worsened, and four remained unchanged **(Figure 5)**. Overall, among 42 restorations, fracture and retention ratings declined significantly with time ($p < 0.001$, Wilcoxon exact matched-pairs test).

a) b)

Figure 5. (a) At the initial evaluation of the Herculite XRV restoration on tooth 34 modvl, nearly all assessed criteria (six out of seven) achieved top marks, indicating excellent clinical performance, while only the approximal anatomical form lagged behind, earning a clinically unsatisfactory rating. (b) Twenty-four years later, this same restoration demonstrated notable deterioration across most parameters. Retention and the aesthetic anatomical form were particularly affected, both receiving clinically unsatisfactory scores. Interestingly, the approximal anatomical form improved compared with the first evaluation, reflecting the influence of a newly placed prosthetic on the neighboring tooth, which optimized the contact point.

Marginal adaptation

Early follow-up assessments showed that the vast majority of restorations were well-adapted, with only a small fraction (7.1%, n = 3) considered repairable due to minor clinical deficiencies. Most restorations exhibited smooth margins with no detectable gaps or discoloration, or only minor marginal irregularities that could be polished or corrected with minimal intervention. By contrast, after 24 years, no restoration retained an excellent score; most demonstrated moderate to significant changes (grades 2–4), although none required full replacement. A substantial number (16 restorations, 38.1%) could not be assessed because the restoration or tooth was missing.

Statistical evaluation confirmed a clear decline in marginal adaptation over time. Initially, the median score was 2.0 with very little variability (IQR = 0.25), but after 24 years, the median increased to 4.0 and the interquartile range expanded to 4.0, reflecting both deterioration and greater inconsistency among restorations. In no instance did a restoration improve over time; in most cases (32 out of 42), scores worsened, while ten cases remained stable. Overall, changes in marginal adaptation were highly significant ($p < 0.001$, Wilcoxon exact matched-pairs test).

a) b)

Figure 6. (a) Initial clinical assessment of a Herculite XRV restoration on tooth 34 (occlusal-distal) showed grade 1 (clinically excellent/very good) for aesthetic anatomical form, approximal anatomical form, tooth integrity, and retention, whereas marginal adaptation, occlusal contour/wear, and surface luster were rated grade 2 (clinically good). (b) After twenty four years in situ, the same restoration exhibited unchanged grades for approximal anatomical form and occlusal contour/wear, while all remaining criteria received lower scores, with marginal adaptation declining to grade 4 (clinically unsatisfactory). The most pronounced changes between the two assessments were observed in marginal adaptation and retention.

Occlusal contour and wear

At the first follow-up, 69.2 percent (n = 27) of restorations showed enamel-like physiological wear and were scored grade 1 (clinically excellent). By the second follow-up, only 15.4 percent (n = 6) retained this rating, while 41.0 percent(n = 16) showed slightly greater wear than enamel, receiving grade 2. Fourteen restorations (35.9%) were not assessable due to loss of the restoration or tooth (grade 6).

Analysis of median and interquartile range revealed a trend toward higher grades over time **(Figure 3)**, with the median rising from 1.0 (IQR 2.0) at the first follow-up to 2.0 (IQR 4.0) at the second. Only one restoration improved at the second follow-up, 28 worsened, and ten remained unchanged **(Figure 7)**. Overall, occlusal contour and wear showed significant deterioration over the observation period ($p < 0.001$; Wilcoxon exact matched-pairs test).

a) b)

Figure 7. (a) The initial assessment of a Herculite XRV restoration on tooth 35 (occlusal-distal) revealed excellent results (grade 1) for aesthetic anatomical form, marginal adaptation, tooth integrity, retention, and surface luster, whereas occlusal contour/wear was slightly lower at grade 2. The only criterion rated poorly was approximal anatomical form, which scored grade 4, indicating an unsatisfactory contact point and/or contour. (b) After 24 years, the restoration maintained the same occlusal contour/wear (grade 2), while all other criteria previously rated excellent or good worsened by one grade, now receiving grade 2 (clinically good). Approximal anatomical form improved to grade 3, reflecting the replacement of the neighboring restoration and establishment of a functional contact.

Approximal anatomical form

At the first follow-up, approximal anatomical form varied widely: 44% of restorations (n = 11) had ideal contacts (grade 1), while over half (52%, n = 13) were rated grade 4 due to weak or poorly contoured contacts. Twenty-four years later, the full grading range (1–6) was observed: 32% (n = 8) retained grade 1, 20% (n = 5) showed minor deviations in contact or contour (grade 2), and 28% (n = 7) could not be assessed because the restoration or tooth was missing (grade 6).

The median score increased from 4.0 at the first follow-up to 5.0 at the second, and the interquartile range widened from 3.0 to 4.25, representing the greatest variability among all criteria. Across the 25 restorations evaluated, 11 worsened, 7 improved, and 7 remained unchanged, yet statistical analysis indicated no significant difference over time ($p > 0.999$; Wilcoxon exact matched-pairs test).

Biological properties

Tooth integrity (Enamel cracks, tooth fractures)

During the first follow-up, only 2.4 percent (n = 1) of restorations were rated clinically unsatisfactory (grade 4). The majority of restorations exhibited full integrity (grade 1: 47.6 percent, n = 20) or minor marginal enamel fractures (<150 µm) or hairline enamel cracks (150 µm) [31] (grade 2: 50.0 percent, n = 21). At the second follow-up, restoration ratings spanned the full spectrum from grades 1 to 6, with grade 2 being the most common (40.5 percent, n = 17). Sixteen restorations (38.1 percent) could not be evaluated due to the loss of the restoration or tooth (grade 6).

Analysis of the median and interquartile range revealed higher grades at the second follow-up **(Figure 3)**. Initially, the median was 2.0 with a narrow interquartile range of 1.0, whereas at the second follow-up, the median increased to 2.5 and the interquartile range widened to 4.0. In one case, the second follow-up grade was lower than the first; in 27 cases, it was higher, and 14 cases remained unchanged. Overall, 42 direct restorations were assessed, and the tooth integrity criterion showed statistically significant changes over time ($p < 0.001$; Wilcoxon exact matched-pairs test).

Comparison of groups

No statistically significant differences were observed in restoration grades between maxillary and mandibular placements at either follow-up ($p > 0.05$; Wilcoxon Mann–Whitney U test). Similarly, restorations in premolars and molars showed no significant differences at the first follow-up ($p > 0.05$). However, at the second follow-up, restorations in molars scored significantly higher in the criterion of approximal anatomical form ($p = 0.002$), with median grades of 2.0 for premolars and 6.0 for molars. No significant differences were found between single-surface and multi-surface restorations at either evaluation ($p > 0.05$).

This study aimed to assess the long-term clinical performance and challenges of posterior composite restorations in premolars and molars, serving as an observational follow-up to the research of Gerhardt-Szep *et al*. [38]. The same restorations were re-evaluated using identical FDI criteria after more than 23 years to provide a more precise understanding of their clinical behavior and enable comparative analysis, thus addressing a limitation of the original study.

However, the findings have limited generalizability due to the small sample size and reliance solely on visual assessment criteria, compounded by the absence of standardized evaluation methods. The study population's age at the time of restoration placement ranged widely from 18 to 70 years, and dietary habits, which could affect outcomes, varied independently of age.

Given the 23-year gap between evaluations, not all original patients or restorations could be re-examined, leaving a small cohort of 22 patients with 42 restorations. While sufficient according to statistical calculations, this represents a limitation common to long-term studies, as highlighted in a 2015 meta-analysis [37]. Extended follow-up periods inherently increase dropout rates [46], reducing statistical power and clinical relevance. Another limitation was the inability to assess events between the two follow-ups, such as restoration repairs, replacements, or tooth loss. Future studies should consider shorter intervals between evaluations to monitor restoration changes over time, record reasons for failure as in other studies [14, 46–48], and pinpoint the timing of failures for Kaplan–Meier survival analysis.

Additionally, restoration histories could not be traced via university dental records because patients transitioned to other dental practices after the first follow-up. This factor should be considered when interpreting restoration survival, as previous studies indicate an increased likelihood of restoration replacement following changes in dentists [15, 49–53].

Surface luster

At the second follow-up, the surface luster of the restorations had noticeably declined. Sixteen restorations were unassessable and therefore recorded as grade 6 due to the absence of either the tooth or the restoration. Interestingly, none were graded as 5, which would have signified that the restoration remained in place but was clinically unsatisfactory and in need of replacement. For those restorations still present, surface irregularities, dullness, or voids could be managed through repolishing or restorative repair. This supports the recommendation by Cieplik *et al*. [43], who emphasized that periodic repolishing at each recall helps preserve the restoration's surface quality and prolong its functional life.

Aesthetic anatomical form

The criterion of aesthetic anatomical form also showed a decline over time. Similar to surface luster, 16 restorations were rated grade 6 due to missing teeth or restorations, and only one restoration fell into grade 5, indicating a poor condition requiring replacement. Among the remaining restorations, 59.5% (n = 25) displayed a wide distribution of scores from 1 to 4. These findings align with Hickel *et al*. [29] and Heintze *et al*. [54], highlighting that assessments of aesthetic anatomical form are partly subjective, especially when changes to the restoration are minor. To reduce variability in future research, baseline and follow-up photographs of restorations should always be available for reference.

Fracture of material and retention

Unlike aesthetic criteria, fractures and retention failures are more objectively identifiable. Literature consistently shows that material fracture and secondary caries are the primary reasons for failure in posterior composite restorations [15, 37, 55], with long-term studies (over 10 years) reporting higher incidences of these failures [14, 33, 56]. In the current study, almost all restorations (95.2%, n = 40) were rated grade 1 for fracture and retention at the first follow-up, but after 23 years, only 9.5% (n = 4) remained at grade 1, while the remaining 90.5% (n = 38) showed deterioration. Pallesen *et al*. [55] reported that 70% of fractures over a 30-year period occurred in patients with parafunctional habits, emphasizing that patient selection significantly affects restoration longevity. Other studies [5, 55, 57–59] have confirmed that excluding high-risk patients—those prone to caries, poor oral hygiene, or parafunctional behaviors—can markedly improve outcomes. In contrast, this study included a general, non-selected patient population, reflecting real-world clinical conditions.

Marginal adaptation

At the 23-year follow-up, evaluations of marginal adaptation revealed considerable variability. Most restorations (26; 61.9%) fell between grades 2 and 4, whereas none were classified as grade 1 or 5. Sixteen restorations (38.1%) could not be assessed because either the tooth or the restoration was no longer present (grade 6). Despite the median grade increasing from 2.0 at the first follow-up to 4.0 at the second, many restorations that remained in place required only minor marginal repairs rather than complete replacement. Supporting this, van Dijken *et al*. [46] found no difference in cervical gap formation or secondary caries in class II restorations after 15 years, regardless of whether low-shrinkage or microhybrid composites were used. As highlighted by Hickel *et al*. [29] and other studies, marginal adaptation is influenced not solely by the material but also by operator technique, patient-specific caries risk, and parafunctional activity such as bruxism [5, 9, 15, 18, 22, 60]. Additionally, Loguercio *et al*. [61] reported that restorations bonded with etch-and-rinse adhesives exhibit better marginal adaptation and reduced discoloration compared to self-etch systems, corroborated by Heintze *et al*.'s meta-analysis [36]. In this study, the use of an etch-and-rinse protocol during placement likely contributed to the reparable and generally satisfactory margins observed in the majority of cases.

Occlusal contour and wear

The long-term assessment of occlusal contour and wear demonstrated predominantly positive outcomes, with 56.4 percent (n = 22) of restorations rated as grade 1 or 2. This aligns with Demarco *et al*. [15], who indicated that occlusal wear rarely constitutes a primary failure mode for posterior composite restorations. Nevertheless, patients with parafunctional behaviors such as clenching or bruxism may still experience significant wear [4, 15]. Evaluating wear can be challenging due to its uneven distribution across occlusal surfaces or when full occlusal reconstructions are involved. Comparisons with the enamel of adjacent unrestored teeth and reference to baseline and follow-up photographs enhance the reliability of these assessments [29, 31].

Approximal anatomical form

Among all evaluated criteria, approximal anatomical form exhibited the highest median (5.0) and the widest interquartile range (4.25) at the second follow-up, highlighting the challenges associated with achieving anatomically correct restorations and proper approximal contacts. It should be noted that, as this study included both class I and II restorations, only class II restorations were relevant for this criterion. Interestingly, approximal anatomical form was the sole criterion that did not show statistically significant changes over time ($p > 0.999$; Wilcoxon exact matched-pairs test). These findings are consistent with a 1999 clinical study [27] reporting the difficulty dentists faced in establishing adequate approximal contacts during that period, when the restorations in this study were placed (1995–1996). Advances in matrix systems and separation ring techniques have since improved the ability to create proper approximal contacts [15].

However, challenges extend beyond contact alone: even when an approximal contact is intact, the overall silhouette may be suboptimal, potentially promoting plaque accumulation and increasing the risk of periodontal damage or secondary caries [31]. Additionally, in class II cavities, the approximal cervical gap often lies within the dentin, which may contribute to poorer scores for this criterion [38]. Polymerization shrinkage stress in the composite layers may exacerbate this problem, potentially generating localized interfacial gaps and microleakage [62, 63]. According to a systematic review and meta-analysis by da Veiga *et al*. (2016) [64], it remains uncertain whether these gaps translate into clinically significant marginal discrepancies [62]. Factors influencing volumetric shrinkage include the composite's resin matrix composition, filler content, degree of conversion [46], whether the restoration is direct or indirect [65], and the use of incremental layering techniques [66].

Tooth integrity (Enamel cracks, tooth fractures)

Regarding tooth integrity, the restorations demonstrated only modest deterioration over time. The median grade increased slightly from 2.0 at the first follow-up to 2.5 at the second. At the first follow-up, half of the restorations (50.0%, n = 21) were rated grade 2, and at the second follow-up, 40.5% (n = 17) remained at this grade. These results are comparable to those reported by Cieplik *et al*. (2022) [43], who also observed hairline enamel cracks (grade 2) in approximately half of the restorations but concluded that significant loss of tooth integrity was generally not a major concern.

Multiple studies have indicated that the type of tooth can influence the durability of restorations, with premolar restorations generally demonstrating superior longevity compared to those placed in molars [5, 14, 33, 48, 56, 59, 67]. For instance, Palotie *et al*. [68] observed over 13 years that premolar restorations failed less frequently than molar restorations, reporting annual failure rates of 3.1% and 5.2%, respectively. This difference is likely attributable to the greater occlusal forces exerted on molars compared to premolars [15, 47], as well as the more challenging access to molars during restorative procedures, which may compromise technical precision [47].

In the present study, however, a significant difference between premolars and molars was observed only for the criterion of approximal anatomical form at the second follow-up ($p = 0.002$; Wilcoxon Mann–Whitney U test); all other evaluated criteria showed no statistically significant differences at either follow-up. Moreover, other investigations have similarly reported no consistent superiority of premolar restorations over molar restorations [46, 47, 55, 57, 64]. It is worth noting that prior to applying the Bonferroni–Holm correction for multiple comparisons ($\alpha = 0.05$), six out of seven FDI criteria at the second follow-up indicated significant differences favoring premolars. The conservative nature of the Bonferroni–Holm method, especially with a small sample size, strongly influenced the statistical outcome. With a larger cohort, some of these trends might have reached significance, although the sample size used in this study was determined based on prior clinical studies and in accordance with guidelines from the Institute of Biostatistics and Mathematical Modeling Frankfurt.

Regarding the number of restored surfaces, several studies report that single-surface restorations in posterior teeth tend to have lower failure rates than multi-surface restorations [5, 14, 56, 58, 61, 69]. Van de Sande *et al*. [48] emphasized that multi-surface restorations are more prone to collapse, primarily due to the reduced remaining tooth structure, which adversely affects longevity. In contrast, the present study did not find a significant difference in survival between single- and multi-surface restorations after applying the Bonferroni–Holm correction. Interestingly, before this adjustment, multi-surface restorations tended to perform better, with the first follow-up showing superior aesthetic anatomical form and the second follow-up showing better approximal anatomical form—findings that diverge from existing literature and remain unexplained.

It should also be noted that restoration longevity is influenced by cavity size and restoration area, parameters that were not assessed in this study. Furthermore, although both class I and II restorations were included, no separate analysis based on cavity type was conducted, which represents a limitation. Improved standardization in data collection and differentiation by cavity type could have strengthened the reliability and interpretability of the study results.

Evidence regarding whether the location of posterior composite restorations in the maxilla or mandible influences their longevity remains limited and inconsistent. For example, Palotie *et al*. [68] reported that multi-surface restorations in the maxilla tended to last longer than those in the mandible, whereas cariological data suggest that posterior teeth in both arches are largely comparable in terms of risk [70]. Lucarotti *et al*. [50] noted a slight but statistically significant advantage for mandibular restorations; however, this study combined data from anterior and posterior teeth and did not specifically include molar composites. In contrast, Pallesen *et al*. [55] found no difference in failure rates between restorations in the upper and lower arches. These observations are consistent with the findings of the present study, which, after Bonferroni–Holm correction, found no significant differences in the survival of posterior composite restorations between the maxilla and mandible at either follow-up.

The longevity of posterior direct composite restorations is influenced by multiple patient-, operator-, and material-related factors. Opdam *et al*. [5] concluded in a systematic review that the type of composite material does not constitute a significant risk factor for restoration survival, a notion supported by Demarco *et al*. [15, 71], who emphasized that contemporary resin composites generally meet the clinical demands for posterior restorations. Several studies have confirmed favorable outcomes for hybrid composites, reporting annual failure rates between 0.9% and 3.3% [5, 25, 36, 55, 57]. Conversely, patient-specific factors such as bruxism and caries risk are major determinants of restoration durability [22, 71], making patient selection a critical variable in clinical trials [55, 57]. Excluding high-risk individuals—those with elevated caries activity, poor oral hygiene, or parafunctional habits—typically results in better survival rates [5, 58, 59]. In the present study, participants were unselected, reflecting a typical clinical population.

Operator-related factors are arguably the most influential determinants of restoration longevity [47, 71], encompassing the clinician's training, experience, and precision. Decisions regarding when to replace a restoration are also operator-dependent, and diagnostic variability between dentists is substantial. Studies have shown that restorations are more likely to be replaced when patients change dentists, and both composite and amalgam restorations may have reduced longevity under such circumstances [49–53]. Practice-based research from 2016 [72, 73] further highlights that the risk of restoration failure is roughly doubled across different dental offices, with notable variation in outcomes between clinicians. To minimize this variability, evidence-based, standardized criteria should guide monitoring, repair, refurbishment, or replacement decisions [55, 58]. The FDI criteria, as recommended by Hickel *et al*. [31], provide an internationally accepted framework that can be applied by dental students, general practitioners, and researchers, promoting conservative management and avoiding unnecessary early replacement. Such approaches are advantageous because restoration repair preserves tooth structure, requires less clinical time, and reduces costs [14, 15, 74]. With increasing life expectancy and more retained teeth in Western populations, the burden of restorations requiring intervention is likely to grow [68]. Even modest improvements in restoration longevity could lead to substantial cost savings [75]. Therefore, future dental practice should prioritize conservative management strategies—monitoring, refurbishment, and repair—using standardized criteria like the FDI system to enhance the durability of restorations and prevent premature failure.

Conclusion

In summary, this long-term observational follow-up demonstrated that after over 23 years, six of the seven FDI criteria exhibited a notable decline in scores at the second evaluation. The only exception was the approximal anatomical form, which performed significantly better in premolar restorations compared to molars. Future research should focus on longer follow-up periods with more frequent assessments to monitor restorations over time more precisely.

Acknowledgments: None

Conflict of Interest: None

Financial Support: None

Ethics Statement: None

References

1. van Dijken JWV, Pallesen U. Posterior bulk-filled resin composite restorations: A 5-year randomized controlled clinical study. J Dent. 2016;51(1):29–35.
2. Javaheri DS. Placement technique for direct posterior composite restorations. Pract Proced Aesthet Dent. 2001;13(3):195–200.
3. Krämer N, Reinelt C, Frankenberger R. Ten-year clinical performance of posterior resin composite restorations. J Adhes Dent. 2015;17(5):433–41.
4. Ferracane JL. Is the wear of dental composites still a clinical concern? Is there still a need for in vitro wear simulating devices? Dent Mater. 2006;22(8):689–92.
5. Opdam NJM, 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(10):943–9.
6. Colson DG. A safe protocol for amalgam removal. J Environ Public Health. 2012;2012(1):517391.
7. Rasines Alcaraz MG, Veitz-Keenan A, Sahrmann P, Schmidlin PR, Davis D, Iheozor-Ejiofor Z. Direct composite resin fillings versus amalgam fillings for permanent or adult posterior teeth. Cochrane Database Syst Rev. 2014;(3):CD005620.

8. EUR-Lex Access to European Union law. Regulation (EU) 2017/852 of the European Parliament and of the Council of 17 May 2017 on mercury, and repealing Regulation (EC) No 1102/2008 (Text with EEA relevance). Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32017R0852. Accessed 2022 Dec 21.
9. Sunnegårdh-Grönberg K, van Dijken JWV, Funegård U, Lindberg A, Nilsson M. Selection of dental materials and longevity of replaced restorations in Public Dental Health clinics in northern Sweden. J Dent. 2009;37(9):673–8.
10. 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(6):539–48.
11. Kaleem M, Satterthwaite JD, Watts DC. Effect of filler particle size and morphology on force/work parameters for stickiness of unset resin-composites. Dent Mater. 2009;25(12):1585–92.
12. Karabela MM, Sideridou ID. Synthesis and study of properties of dental resin composites with different nanosilica particle sizes. Dent Mater. 2011;27(8):825–35.
13. Gonçalves F, Kawano Y, Braga RR. Contraction stress related to composite inorganic content. Dent Mater. 2010;26(7):704–9.
14. Da Rosa Rodolpho PA, Donassollo TA, Cenci MS, Loguércio 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(10):955–63.
15. Demarco FF, Corrêa MB, Cenci MS, Moraes RR, Opdam NJM. Longevity of posterior composite restorations: Not only a matter of materials. Dent Mater. 2012;28(1):87–101.
16. Ferracane JL. Resin composite—state of the art. Dent Mater. 2011;27(1):29–38.
17. Alzraikat H, Burrow MF, Maghaireh GA, Taha NA. Nanofilled resin composite properties and clinical performance: a review. Oper Dent. 2018;43(6):E173–90.
18. van Dijken JWV, Pallesen U. A randomized 10-year prospective follow-up of Class II nanohybrid and conventional hybrid resin composite restorations. J Adhes Dent. 2014;16(6):585–92.
19. Palaniappan S, Bharadwaj D, Mattar DL, Peumans M, van Meerbeek B, Lambrechts P. Three-year randomized clinical trial to evaluate the clinical performance and wear of a nanocomposite versus a hybrid composite. Dent Mater. 2009;25(10):1302–14.
20. Laegreid T, Gjerdet NR, Johansson A-K. Extensive composite molar restorations: 3 years clinical evaluation. Acta Odontol Scand. 2012;70(4):344–52.
21. Opdam NJM, Bronkhorst EM, Loomans BAC, Huysmans MCDNJM. 12-year survival of composite vs. amalgam restorations. J Dent Res. 2010;89(10):1063–7.
22. van de Sande FH, Opdam NJ, da Rosa Rodolpho PA, Corrêa MB, Demarco FF, Cenci MS. Patient risk factors' influence on survival of posterior composites. J Dent Res. 2013;92(7 Suppl):78S–83S.
23. Brantley CF, Bader JD, Shugars DA, Nesbit SP. Does the cycle of rerestoration lead to larger restorations? J Am Dent Assoc. 1995;126(10):1407–13.
24. Lopes GC, Vieira LCC, Araujo E. Direct composite resin restorations: a review of some clinical procedures to achieve predictable results in posterior teeth. J Esthet Restor Dent. 2004;16(1):19–31.
25. Manhart J, Chen H, Hamm G, Hickel R. Buonocore Memorial Lecture. Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition. Oper Dent. 2004;29(5):481–508.
26. Köhler B, Rasmusson C-G, Ödman P. A five-year clinical evaluation of Class II composite resin restorations. J Dent. 2000;28(2):111–6.
27. Raskin A, Michotte-Theall B, Vreven J, Wilson NHF. Clinical evaluation of a posterior composite: 10-year report. J Dent. 1999;27(1):13–9.
28. Nikaido T, Takada T, Kitasako Y, Ogata M, Shimada Y, Yoshikawa T, et al. Retrospective study of the 10-year clinical performance of direct resin composite restorations placed with the acid-etch technique. Quintessence Int. 2007;38(5):e240–6.
29. Hickel R, Roulet J-F, Bayne S, Heintze SD, Mjör IA, Peters M, et al. Recommendations for conducting controlled clinical studies of dental restorative materials. Clin Oral Investig. 2007;11(1):5–33.
30. Marquillier T, Doméjean S, Le Clerc J, Chemla F, Gritsch K, Maurin J-C, et al. The use of FDI criteria in clinical trials on direct dental restorations: a scoping review. J Dent. 2018;68:1–9.
31. 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 Investig. 2010;14(4):349–66.

32. van Dijken JWV. Durability of resin composite restorations in high C-factor cavities: a 12-year follow-up. J Dent. 2010;38(6):469–74.
33. Pallesen U, Qvist V. Composite resin fillings and inlays: An 11-year evaluation. Clin Oral Investig. 2003;7(2):71–9.
34. Opdam NJM, Loomans BAC, Roeters FJM, Bronkhorst EM. Five-year clinical performance of posterior resin composite restorations placed by dental students. J Dent. 2004;32(5):379–83.
35. Deliperi S, Bardwell DN. Clinical evaluation of direct cuspal coverage with posterior composite resin restorations. J Esthet Restor Dent. 2006;18(5):256–65.
36. Heintze SD, Rousson V. Clinical effectiveness of direct class II restorations: a meta-analysis. J Adhes Dent. 2012;14(5):407–31.
37. Beck F, Lettner S, Graf A, Bitriol B, Dumitrescu N, Bauer P, et al. Survival of direct resin restorations in posterior teeth within a 19-year period (1996–2015): a meta-analysis of prospective studies. Dent Mater. 2015;31(8):958–85.
38. Gerhardt-Szep S, Schröder-Schichtel E, Zücker Q, Zahn T, Feierabend S, Rüttermann S. Problems of direct composite posterior restorations: a clinical study. J Dent Probl Solut. 2016;93(1):35–9.
39. Vogl V, Hiller K-A, Buchalla W, Federlin M, Schmalz G. Controlled, prospective, randomized, clinical split-mouth evaluation of partial ceramic crowns luted with a new universal adhesive system/resin cement: results after 18 months. Clin Oral Investig. 2016;20(9):2481–92.
40. May S, Cieplik F, Hiller K-A, Buchalla W, Federlin M, Schmalz G. Flowable composites for restoration of non-carious cervical lesions: Three-year results. Dent Mater. 2017;33(12):e136–45.
41. de Paula EA, Tay LY, Kose C, Mena-Serrano A, Reis A, Perdigão J, Loguercio AD. Randomized clinical trial of four adhesion strategies in cervical lesions: 12-month results. Int J Esthet Dent. 2015;10(1):122–45.
42. Perdigão J, Kose C, Mena-Serrano AP, de Paula EA, Tay LY, Reis A, et al. A new universal simplified adhesive: 18-month clinical evaluation. Oper Dent. 2014;39(2):113–27.
43. Cieplik F, Scholz KJ, Anthony JC, Tabenski I, Ettenberger S, Hiller K-A, et al. One-year results of a novel self-adhesive bulk-fill restorative and a conventional bulk-fill composite in class II cavities: a randomized clinical split-mouth study. Clin Oral Investig. 2022;26(1):449–61.
44. Calibration Tool E-Calib. E-Calib. Available from: www.e-calib.info. Accessed 2018 Dec 30.
45. Saxer UP, Mühlemann HR. Motivation und Aufklärung. Schweiz Monatsschr Zahnheilkd. 1975;85(9):905–19.
46. van Dijken JWV, Lindberg A. A 15-year randomized controlled study of a reduced shrinkage stress resin composite. Dent Mater. 2015;31(10):1150–8.
47. Lempel E, Tóth Á, Fábián T, Krajczár K, Szalma J. Retrospective evaluation of posterior direct composite restorations: 10-year findings. Dent Mater. 2015;31(10):115–22.
48. van de Sande FH, da Rosa Rodolpho PA, Basso GR, Patias R, da Rosa QF, Demarco FF, et al. 18-year survival of posterior composite resin restorations with and without glass ionomer cement as base. Dent Mater. 2015;31(6):669–75.
49. Burke FJT, Lucarotti PSK, Holder RL. Outcome of direct restorations placed within the general dental services in England and Wales. Part 2: Variation by patients' characteristics. J Dent. 2005;33(10):817–26.
50. Lucarotti PSK, Holder RL, Burke FJT. Outcome of direct restorations placed within the general dental services in England and Wales. Part 1: Variation by type of restoration and re-intervention. J Dent. 2005;33(10):805–15.
51. Lucarotti PSK, Holder RL, Burke FJT. Outcome of direct restorations placed within the general dental services in England and Wales. Part 3: Variation by dentist factors. J Dent. 2005;33(10):827–35.
52. Burke FJT, Lucarotti PSK, Holder R. Outcome of direct restorations placed within the general dental services in England and Wales. Part 4: Influence of time and place. J Dent. 2005;33(10):837–47.
53. Bogacki RE, Hunt RJ, del Aguila M, Smith WR. Survival analysis of posterior restorations using an insurance claims database. Oper Dent. 2002;27(5):488–92.
54. Heintze SD, Ilie N, Hickel R, Reis A, Loguercio A, Rousson V. Laboratory mechanical parameters of composite resins and their relation to fractures and wear in clinical trials: a systematic review. Dent Mater. 2017;33(2):e101–14.
55. Pallesen U, van Dijken JWV. A randomized controlled 30-year follow-up of three conventional resin composites in Class II restorations. Dent Mater. 2015;31(10):1232–44.
56. da Rosa Rodolpho PA, Cenci MS, Donassollo TA, Loguércio AD, Demarco FF. A clinical evaluation of posterior composite restorations: 17-year findings. J Dent. 2006;34(7):427–35.
57. Pallesen U, van Dijken JWV. A randomized controlled 27-year follow-up of three resin

composites in Class II restorations. J Dent. 2015;43(12):1547–58.
58. Ástvaldsdóttir Á, Dagerhamn J, van Dijken JWV, Naimi-Akbar A, Sandborgh-Englund G, Tranæus S, Nilsson M. Longevity of posterior resin composite restorations in adults: a systematic review. J Dent. 2015;43(8):934–54.
59. Frankenberger R, Reinelt C, Krämer N. Nanohybrid vs. fine hybrid composite in extended Class II cavities: 8-year results. Clin Oral Investig. 2014;18(1):125–37.
60. van Dijken JWV, Pallesen U. Eight-year randomized clinical evaluation of Class II nanohybrid resin composite restorations bonded with a one-step self-etch or a two-step etch-and-rinse adhesive. Clin Oral Investig. 2015;19(5):1371–9.
61. Loguercio AD, Rezende M, Gutierrez MF, Costa TF, Armas-Vega A, Reis A. Randomized 36-month follow-up of posterior bulk-filled resin composite restorations. J Dent. 2019;85:93–102.
62. Nedeljkovic I, Teughels W, de Munck J, van Meerbeek B, van Landuyt KL. Is secondary caries with composites a material-based problem? Dent Mater. 2015;31(11):e247–77.
63. Schneider LFJ, Cavalcante LM, Silikas N. Shrinkage stresses generated during resin-composite applications: a review. J Dent Biomech. 2010;2010:131630.
64. 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.
65. Dejak B, Młotkowski A. A comparison of stresses in molar teeth restored with inlays and direct restorations, including polymerization shrinkage of composite resin and tooth loading during mastication. Dent Mater. 2015;31(3):e77–87.
66. van Ende A, Mine A, de Munck J, Poitevin A, van Meerbeek B. Bonding of low-shrinking composites in high C-factor cavities. J Dent. 2012;40(4):295–303.
67. Pallesen U, van Dijken JWV, Halken J, Hallonsten A-L, Höigaard R. Longevity of posterior resin composite restorations in permanent teeth in Public Dental Health Service: a prospective 8-year follow-up. J Dent. 2013;41(4):297–306.
68. Palotie U, Eronen AK, Vehkalahti K, Vehkalahti MM. Longevity of 2- and 3-surface restorations in posterior teeth of 25- to 30-year-olds attending public dental service: a 13-year observation. J Dent. 2017;62:13–17.
69. Borgia E, Baron R, Borgia JL. Quality and survival of direct light-activated composite resin restorations in posterior teeth: a 5- to 20-year retrospective longitudinal study. J Prosthodont. 2019;28(1):e195–203.
70. Batchelor PA, Sheiham A. Grouping of tooth surfaces by susceptibility to caries: a study in 5–16-year-old children. BMC Oral Health. 2004;4(1):2.
71. Demarco FF, Collares K, Corrêa MB, Cenci MS, Moraes RR, Opdam NJ. Should my composite restorations last forever? Why are they failing? Braz Oral Res. 2017;31:e56.
72. 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(3):292–9.
73. 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.
74. Gordan VV, Shen C, Riley J, Mjör IA. Two-year clinical evaluation of repair versus replacement of composite restorations. J Esthet Restor Dent. 2006;18(3):144–53.
75. Kanzow P, Wiegand A, Schwendicke F. Cost-effectiveness of repairing versus replacing composite or amalgam restorations. J Dent. 2016;54:41–7.