An Analysis of Clinical Effectiveness of Different Types of Direct Restorative Materials in Permanent Posterior Teeth

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Abstract

AIM: To compare and evaluate the effectiveness of direct restorative materials in permanent posterior teeth based on different clinical outcomes and to review how various factors influence them.
METHODS: An intensive search using the PICOS elements was conducted through PubMed and Cochrane databases. Seventeen studies were selected and analyzed using primary and secondary outcomes.
RESULTS: Amalgam restorations showed slightly better longevity compared to composite resin and glass ionomer cement restorations. However, under certain conditions, composite resins and glass ionomer cement restorations perform equally well. Failures in composite resin restorations were consistently due to secondary caries, primary caries, postoperative sensitivity, marginal defects, and marginal discoloration. Glass ionomer cement restorations failed consistently due to loss of retention and surface texture. Amalgam restorations mainly failed due to poor color match and tooth fracture. Significantly higher restoration failure rates were observed in medium or large-sized cavities with two or more surfaces involved, molars, children, teenagers, elderly patients, and those with high caries risk or poor oral hygiene.
CONCLUSION: Patient-, oral-, and dentist-related factors significantly impact the performance and longevity of direct restorative materials. No material currently meets all criteria of an ideal material, as each has its advantages, disadvantages, and preferred indications.

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Accepted: Friday 30th August, 2024. **Data availability statement:** All relevant data are within the article or supplement files unless otherwise declared by the author(s).

1 Introduction

The clinical effectiveness of direct restorative materials is highly debated among dental practitioners who specialize in restoring damaged teeth or enhancing aesthetic appearance. One of the biggest functional challenges in this field is restoring posterior teeth with the most effective and durable direct restorative material. Dentists face the daunting task of establishing the most effective direct restorative material while identifying various risk factors that could result in restoration failure. When discussing the longevity of direct restorative materials, one must also carefully study the patient-, oral-, and dentist-related factors that can greatly influence their effectiveness.

According to the Glossary of Prosthodontic Terms, restoration is defined as “a broad term applied to any material or prosthesis that restores or replaces lost tooth structure, teeth, or oral tissues” (Ferro et al., 2017, p. 77). In simple terms, a restoration is done to restore the aesthetics or functionality of a damaged tooth. The British Society for Restorative Dentistry defines restorative dentistry as “the study, examination, and treatment of diseases of the oral cavity, the teeth, and their supporting structures.” Dental mono-specialties such as endodontics, periodontics, and prosthodontics are included in this umbrella. The foundation of this specialty is based upon managing cases that demand multifaceted care and therefore require consideration of the overall health of the oral cavity and the interaction of various factors (The British Society for Restorative Dentistry, n.d.).

Of all dental diseases and problems, untreated caries is the most common chronic disease of permanent teeth according to the Global Burden of Disease 2019 (World Health Organization, 2023). It was estimated in the Global Oral Health Status Report that around 2 billion people are affected worldwide due to carious permanent teeth (World Health Organization, 2022). When a tooth gets damaged by caries, wear or trauma, the most common method of treatment involves cleaning and preparing cavities in the involved tooth, and filling it with a suitable restorative material. Different cavities are prepared differently according to the extent of damage and considering the type of final restorative material to be used. According to G. V. Black, carious lesions can be classified based on the location of the caries on the tooth (occlusal, proximal, lingual, buccal, etc.) and the type of tooth affected (anterior or posterior tooth). This classification, with an addition, consists of six different classes and continues to be used at the present time. While Class III and IV are limited to anterior teeth and Class I, V, and VI can be found in both anterior and posterior teeth, Class II is limited to posterior teeth (Ireland, 2010).

When it comes to the functional aspect, the challenge in restoring posterior teeth is higher and more demanding compared to anterior teeth due to their location in high stress-bearing areas, difficulty of dentists in accessing and placing materials, and the difficulty of patients performing oral hygiene. Apart from the functional demand, aesthetic demands are growing in importance not only for the anterior aesthetic zone but also for the posterior teeth (Bohaty et al., 2013; Raghu & Srinivasan, 2011). Regarding restoring these cavities, there are two main types of techniques: direct and indirect restorative techniques. Direct restorations are performed intraorally in a single session chairside, whereas indirect restorations are performed extraorally in multiple sessions in the laboratory or with the help of technology (Azeem & Sureshbabu, 2018).

While dentistry has made significant advancements in research on restorative materials, selecting the most effective restorative material for treating posterior cavities, especially extensively carious or broken-down teeth, still seems to be a daunting challenge. Many restorative materials have been developed and tried, yet an ideal, long-term material has still eluded researchers (Kaur et al., 2011). Most importantly, a restorative material should be non-toxic and offer a good seal at the tooth-restoration interface, which not only guards against bacterial penetration but also minimizes micro-leakage that can cause post-operative sensitivity, marginal discoloration, secondary caries, fractures, etc (Diwanji et al., 2014; Kunert et al., 2022). This maintains pulpal health and vitality. A restorative material is also expected to reinforce the remaining tooth structure, withstand stress, and therefore have resistance to fracture and excellent longevity (Ilie et al., 2012; Vaidya & Pathak, 2019).

Longevity is considered one of the most important aspects when choosing a direct restorative material to restore the tooth (Kim et al., 2013). However, it seems difficult to assess the longevity of the restorations as many factors, apart from the type of material used, seem to affect or influence that (Mackert & Wahl, 2004; McCracken et al., 2013). Due to the improved material properties, minimally invasive nature of the treatment, reduced treatment time, and cost-effectiveness, direct restorations are usually the first choice of treatment over indirect restorations.

Together, a dental practitioner and patient choose from a variety of approved direct restorative materials to restore a tooth back to its function and aesthetics. While there are several options available in the market to restore permanent posterior teeth, the most common materials are dental amalgam, direct composite resin, and glass ionomer cement. Due to alleged adverse effects on health and the environment because of the release of mercury, inferior aesthetics, and extended cavities, alternatives to amalgam restorations were developed and explored (Manhart et al., 2002). These alternatives include glass ionomer cements and their modifications, as well as composite resins and their modifications. All of these alternatives are comparatively costlier, technique-sensitive, time-consuming, lacking few important mechanical properties, and suitable only in certain situations or conditions (Soares & Cavalheiro, 2010).

Dental amalgam, the most common and oldest restorative material was first used in 1816 by Dr. Auguste Taveau. Dental amalgam consists of a powdered alloy of silver, tin, and copper and liquid mercury (elemental). Advantages of amalgam include high compressive strength and wear resistance, low technique sensitivity, and the ability to seal the marginal spaces over time. However, disadvantages like extensive tooth preparation for mechanical retention, inferior aesthetics, and mercury contamination have caused a reduction in its use (Soares & Cavalheiro, 2010). When amalgam restorations fail, total replacement is the most common method, leading to further loss of tooth structure (Hickel et al., 2013). Due to the controversy that amalgam needs to be banned because of mercury toxicity and environmental harm, there has been a significant reduction in the use of amalgam. The Minamata Convention on Mercury, a legally binding treaty, proposed nations initiate a paced phase-down of dental amalgam according to local needs. Meanwhile, the World Health Organization stated that the shift from amalgam would depend on the quality of alternative restorative materials (British Dental Association, n.d.). While the European countries and the United Kingdom have agreed with the statement released by the World Health Organization on dental amalgam, they have not banned its use. Instead, they have put forward recommendations on the use of amalgam depending on patient characteristics. Restrictions on the use are placed for children or in primary teeth and in pregnancy or nursing unless absolutely necessary (British Dental Association, n.d.; Burke, 2004; Mitchell et al., 2007). Meanwhile, in the United States of America, the Food and Drug Administration states that dental amalgam is safe for adults and children aged 6 years and above (U.S. Food & Drug Administration, 2021). This official website also mentions that there could be a higher risk in certain groups of people, such as those mentioned above by the British Dental Association, along with those having systemic illnesses (pre-existing neurological disease, impaired kidney function) and allergies or hypersensitivity to the components of dental amalgam. With respect to toxicity, there is a possibility of different potentially toxic compounds being released from any of the restorative materials (Geurtsen, 2000). Modifications from basic silver-tin alloy to low copper or high copper alloys, gallium alloys, noble metal alloys, zinc-containing or zinc-free alloys, lathe-cut or admixed or spherical type, etc., were developed to improve the clinical performance of dental amalgam.

Composite resin is one of the many successes of biomaterial research as it replaces the tooth structure in both function and aesthetics (Cramer et al., 2011). It was expected to be the best alternative to amalgam. Bis-GMA, a methacrylate monomer used in modern composite resins, was first patented in 1962 by Dr. Bowen, and composites, the first acrylic resin replacement, were introduced in the 1970s. Popularity increased day by day after the introduction of the minimal intervention (MI) concept on October 1, 2002, which was adopted by the FDI (Fédération Dentaire Internationale) General Assembly in Vienna (Nomann et al., 2013). Almost half of the restorations now rely on composite resins (Naumann et al., 2006; Sadowsky, 2006; Zhou et al., 2019). It is composed of an organic matrix (resin matrix), inorganic matrix (glass filler particles), and a coupling agent. Additionally, initiators, accelerators, stabilizers, and inorganic oxide color pigments are also found. Bonding agents are used to bond composite resins with the tooth structure. While there are many advantages like aesthetics, minimal tooth preparation, micro-mechanical bonding to the tooth structure, strength to the tooth structure, reparability and low thermal conductivity, which is leading it to be one of the most preferred chair-side direct restorative materials, disadvantages due to certain mechanical properties, technique sensitivity, and time consumption leave significant room for advancements. Polymerization shrinkage and stress, insufficient wear and fracture resistance, color degradation over time, and sensitivity are a few of those mechanical properties causing disadvantages (Sadowsky, 2006; Tan et al., 2015). When composite resin restorations fail, the majority of the time, repair is possible without further extensive loss of tooth structure. There seem to be biocompatibility or sensitivity issues with composite resin due to bisphenol A, methacrylate monomers, unpolymerised monomers, etc (Dursun et al., 2016; Mousavinasab, 2011). Modifications were made to the formulation of resin, fillers' composition, size, distribution and loading, and curing mechanisms to improve the properties. Modification of filler particles has led to the development of hybrid, microfilm, condensable (packable), flowable, nanohybrid (nanocomposite). The use of nanotechnology has improved the mechanical and functional properties of the composite materials, while also providing superior antimicrobial activity (Cheng et al., 2015).

In 1972, Wilson and Kent introduced a "new translucent dental filling material" called glass ionomer cement. Initially, it was a powder/liquid cement, composed of aluminosilicate powder and polyacrylic acid liquid. This powder and liquid component has been modified over the years. While there are many advantages like biocompatibility, chemical adhesion with moist tooth structure, better adhesion to dentine and root surfaces, fluoride release and uptake, anti-cariogenic property, semi-permeable surface allowing calcium and phosphate ions in saliva to pass through the material, good thermal coefficient expansion, bulk placement and less technique sensitivity, disadvantages due to inadequate mechanical properties seem to make it difficult to use them in stress-bearing areas. Low fracture and wear resistance, high initial solubility and susceptibility to fracture if not protected from dehydration are a few of those mechanical properties causing disadvantages. Also, it may be an irritant to the pulp due to its initial high acidity (Mirsasaani et al., 2011; Sikka & Brizuela, 2023; Tyas, 2006). Other modifications such as metal-modified, highly viscous and reinforced, hybrid or resin-modified, zirconomer, and glass carbomer have been developed to overcome the drawbacks or challenges faced by conventional glass ionomer cement. Many dental practitioners choose glass ionomer cement since it is more economical along with its advantages like fluoride-releasing properties and less technique sensitivity, i.e., it can be placed in situations where moisture control is difficult or in high caries risk patients (Panpisut et al., 2020).

In adults, primary caries seem to be one of the main reasons for requiring a restoration followed by other reasons such as fracture, non-carious tooth surface loss (tooth wear), aesthetics, etc (Palotie, 2009). Regardless of the reason, these restorations may require repair or replacement over a period of time and use (Sharif et al., 2014). It has been reported that about 60 percent of the dental work constituted replacing of failed restorations (Chrysanthakopoulos, 2012; Mjor et al., 2002). This percentage highlights the need for a critical review that addresses multiple aspects involved in the longevity of the applied direct restorations.

Clinical significance: Over the past sixteen years, numerous clinical trials and studies have been published on the longevity and effectiveness of specific direct restorative materials or different modifications of the same type of direct restorative material. However, there is a dearth of quality clinical trials and studies with high level evidence that compares all the different direct restorative materials in posterior permanent teeth based on important primary and secondary outcome measures. This lack of comparison could potentially provide more insight into the reasons behind the success or failure of a restorative material. This is particularly evident when comparing amalgam, composite resin and glass ionomer cements as these three are the most often used direct restorative materials on the chairside in the majority of countries. Despite the preference for more amalgam alternatives and the ongoing shift towards minimally invasive and adhesive dentistry, clinical studies and reviewers continue to diverge in their conclusions regarding a direct restorative material that offers superior longevity and performance. This needs to be resolved as it has been reported that majority of the dental work constitutes replacement of failed restorations. At the same time, it has also been reported that dental practice seems to have become increasingly commodified and commercialized as a result of the power struggle between the dental practitioners' aspirations and commercial pressure. This calls for a periodic systematic review of the effectiveness of the direct restorative materials. To the author's best knowledge, no such systematic review has been published in the last sixteen years that compares the clinical effectiveness of the three different direct restorative materials (amalgam, composite resin and glass ionomer cement) in posterior permanent teeth, based on the extensive list of primary and secondary outcome measures mentioned in this review along with the assessment of risk factors.

This systematic review aims to evaluate the effectiveness and longevity of different direct restorative materials used in treating permanent posterior teeth, considering the impact of patient, oral condition, and dentist-related factors on clinical outcomes.

2 Methods

To ensure a comprehensive and focused review, the modified PICOS framework was utilized, incorporating the following criteria: **Patient** (permanent posterior teeth), **Intervention** (restoration with direct restorative materials), **Comparison** (restoration using amalgam, composite resin, or glass ionomer cement), **Outcomes** (primary: survival/failure rate of restorations; secondary: issues such as secondary caries, loss of retention, postoperative sensitivity, marginal defect, marginal discoloration, wear, poor color match, loss of surface texture, fracture of restoration and tooth, loss of contact point and primary caries), and **Study Type** (randomized clinical trials, retrospective, prospective, and cross-sectional studies). This structured approach aids in refining the research question and conducting an exhaustive search.

A comprehensive electronic database search conducted in the PubMed (MedLine) and Cochrane Library, dating from 2007 to 2023 with different combinations of keywords (derived from the PICOS elements) and Booleans (AND/OR) to identify all available information regarding the research questions mentioned in this review, revealed a gross search result of 8,178 records published in English. 6,820 records were excluded with the help of filters like article type and associated data. 1,358 records' titles/abstracts were screened and 1,310 title records were excluded based on certain exclusion criteria mentioned below. 48 records were then selected for full-text reading. Furthermore, the selected articles' references and Google Scholar were used for manual search in order to gather all possible relevant information meeting the criteria. Seventeen studies were selected after applying the inclusion and exclusion criteria again and were processed for data extraction (**Figure 1**).

The search strategy was performed using the below keywords in many combinations using Boolean operators: *dental restoration permanent, posterior restoration, direct restoration permanent, composite resin, resin composite, glass ionomer cement, glass ionomer, dental amalgam, bonded amalgam, amalgam, failure, survival, success, longevity, clinical performance, clinical effectiveness, risk factors.*

The inclusion criteria for this research encompassed various types of studies such as randomized clinical trials, retrospective studies, prospective studies, and cross-sectional studies that made comparisons between two or more different direct restorative materials. The studies needed to include subjects with cavities in permanent posterior teeth who were receiving direct restorative materials as part of their treatment.

Conversely, several types of studies were excluded from this analysis. Specifically, animal studies, in vitro studies, case studies, case reports, pure surveys, and reviews were not considered. Studies involving subjects treated with direct restorative materials in primary or anterior teeth were also excluded, as were studies with insufficient data to support the objectives. Research comparing different restorative techniques rather than focusing on the direct restorative materials used was not included, nor were studies that involved treatments performed solely by dental students. Additionally, studies that included subjects with cancer or disabilities, those that compared restorative materials within the same class, and different reports or commentaries of the same study were also excluded from consideration.

For each of the selected studies, the following data were recorded:

- Author and year of publication
- Study characteristics (study type, evaluation method, number of patients, age of patients, type of teeth, cavity class type, restorative materials being compared, number of restorations, restorative material brands used, isolation method, follow-up period)
- Primary outcomes (survival rate, annual failure rate)
- Secondary outcomes (secondary caries, loss of retention, postoperative sensitivity, marginal defect, marginal discoloration, wear, poor color match, loss of surface texture, fracture of restoration and tooth, loss of contact point and primary caries)
- Risk factors involved

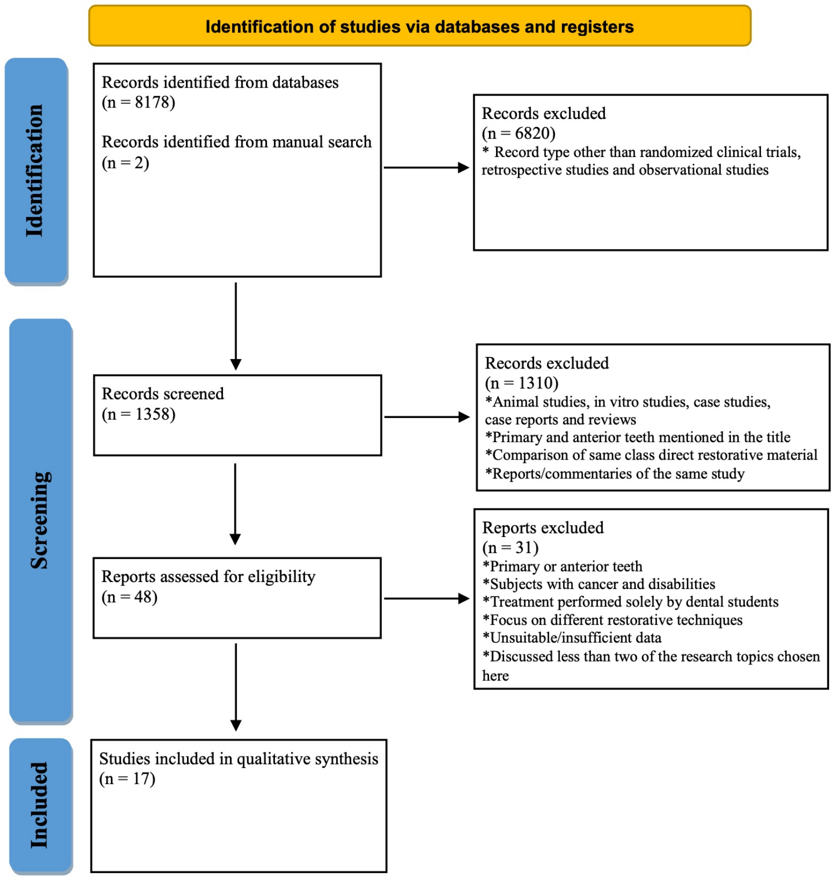

Figure 1. PRISMA 2020 flow diagram.

An attempt was made to contact the authors of six different studies for further clarification on their data, of which four authors responded with the required details or explanations.

A moderate to high risk of bias can be found as the differences in the direct restorative materials are obvious. Blinding those involved in the study (performance and detection bias) would have been difficult or even not possible, especially in the case of amalgam. Therefore, there could be a high risk of bias in all of the studies with respect to this aspect. Issues with randomization, allocation, incomplete outcome data and selective reporting (selection bias, attrition bias, reporting bias) were also observed. Overall, the available evidence is judged to be of moderate certainty.

A meaningful meta-analysis could not be done as the studies differed in terms of sample size, type of teeth involved, cavity class type, material brands used, follow-up period, etc. High heterogeneity was observed among the included studies. Therefore, a thorough qualitative synthesis was performed with the information collected for analysis in this review.

2.1 Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyze the textual content of the included studies. It is important to note that, given the narrative nature of this study, regression analysis and meta-analysis techniques were not deemed suitable for the analytical framework.

3 Results

Ten randomized clinical trials, five retrospective studies, one prospective study, and one cross-sectional study were selected for this review (supplemental **Table S1**). Studies varied in their evaluation method from modified United States Public Health Service (USPHS) / modified Ryge criteria to FDI criteria, while some other studies used their own criteria to judge the restorations. The number of participants ranged from 15 to 61,121. The age group ranged from 5 to 95 years. Four of the studies were limited to Class I restorations, seven studies were restricted to Class II restorations, and five studies included combined Class I and II restorations. Out of the seventeen studies, ten studies compared composite resin with amalgam, while seven other studies compared composite resin with glass ionomer cement. The number of direct restorations among the studies varied greatly. The number of amalgam restorations ranged from 25 to 27,893, composite resin restorations ranged from 25 to 188,683, and glass ionomer cement restorations ranged from 25 to 5,569. The studies used different brands of restorative materials. While ten studies used cotton roll and suction/rubber dam for isolation, no information is available regarding the same in six studies. The final follow-up period ranged from 9 months to 13 years.

3.1 Primary outcome

The primary outcome parameters assembled for the analysis of the selected studies are the survival rate and annual failure rate. Survival or failure as respective complementary term, is the parameter of primary interest. **Table S2** and **Table 3** list all studies that include at least one of the corresponding options to report this parameter. For better comparability, the corresponding data on survival or failure was calculated from the originally reported data in the studies.

3.1.1 Survival rate composite resin vs amalgam

The final follow-up period for this category ranged from 9 months to 13 years (**Table S2**). The survival rate for composite resin restorations varied from 54 to 100% whereas for amalgam restorations, it further broadly varied from 48 to 100%. Three studies (Bernardo et al., 2007; da Silva Pereira et al., 2020; Kemaloglu et al., 2016) reported the survival/success rate. Two studies (Opdam et al., 2010; Rho et al., 2013) reported the percentage of clinically acceptable restorations. Two studies (Palotie et al., 2017; Rho et al., 2013) reported the median survival time. Three studies (Bernardo et al., 2007; Kopperud et al., 2012; Palotie et al., 2017) reported the mean annual failure rate. Another two studies (Laske et al., 2016; Opdam et al., 2010) calculated the annual failure rate. One study (Soncini et al., 2007) reported only the percentage of restoration failure. All the included studies reported the outcomes of statistical tests with respect to this parameter.

As the nine studies that compared composite resin restorations with amalgam restorations had varied outcomes and no consistent trend could be identified, it is worth highlighting specific details of the individual studies.

A significantly better longevity of amalgam restorations compared to composite resin restorations was observed in three studies (Bernardo et al., 2007; Kopperud et al., 2012; Rho et al., 2013). Another study (Soncini et al., 2007) reported a significantly better performance of amalgam restorations with respect to repair but not for replacement in both follow-up periods. For both aspects, a better performance was observed in amalgam restorations. In the study, repairs were found to be seven times more frequent in composite resin restorations compared to amalgam restorations. Interestingly, amalgam restorations showed a significantly longer survival time yet a nonsignificantly lower number of clinically acceptable restorations compared to composite resin restorations in Rho et al. (2013).

In contrast, two other studies (Laske et al., 2016; Opdam et al., 2010) reported significantly better longevity in composite resin restorations. During the first five years of the study by Opdam et al. (2010), the annual failure rate was slightly but not significantly lower in amalgam restorations compared to composite resin restorations. In this study, the risk for caries was further differentiated. Interestingly, no significant difference was found between both types of restorations in high caries risk and low caries risk groups at five years follow-up. At twelve years follow-up, no significant difference was found in the high caries risk group; however, a significant difference was found in the low caries risk group and combined caries risk group, where composite resin restorations showed significantly better survival.

Finally, three other studies (da Silva Pereira et al., 2020; Kemaloglu et al., 2016; Palotie et al., 2017) found rather comparable outcomes, all of which were nonsignificant. Kemaloglu et al. (2016) reported a 100% success rate in both types of restorations, albeit with a small sample size and only three years of follow-up. Palotie et al. (2017) reported similar outcomes for restorations comparing amalgam and composite resin in molar teeth, although the data for premolars was not comparable as amalgam constituted only 2%. Da Silva Pereira et al. (2020) found a comparable performance, despite the sample size of amalgam restorations being six times more than that of composite resin restorations.

3.1.2 Survival rate composite resin vs glass ionomer cement

The final follow-up period for this category ranged from 2 to 10 years (**Table 3**). The survival rate for composite resin varied from 96.9 to 100% whereas for glass ionomer cement restoration the survival range was broader and varied from 54.3 to 100%. All the included studies reported the outcomes of statistical tests with respect to this parameter.

Table 3. Survival of composite resin (comp-res) vs glass ionomer cement (glass-ion-c). CE = clinical efficacy, NR = not reported; n.s. = not significant, RE = radiographic efficacy, y = year.

STUDY	FOLL-UP	SURVIVAL/SUCCESS RATES (%)		P VALUE
		COMP-RES	GLASS-ION-C	
BALKAYA, 2020	2 y	100	54.3	< 0.05
GURGAN, 2020	10 y	100 (throughout)	10 y: 100	n.s.
			4 y: 96	
ROZNIATOWSKI, 2020	2 y	CE: 100	CE: 95.83	n.s.
		RE: 100	RE: 93.75	n.s.
		Overall: 100	Overall: 91.67	< 0.05
HATIRLI, 2021	2 y	100	96	n.s.
UZEL, 2022	2 y	1 y: 100	1 y: 100	n.s.
		2 y: 100	2 y: 97.1	
BAYAZIT, 2023	4 y	96.9	90.6	n.s.

While five studies showed similar outcomes, Balkaya and Arslan (2020) found a markedly different outcome. The study reported a drastically and significantly lower survival rate of glass ionomer cement restorations, as 16 out of 35 restorations required repair and replacement at the end of two years. In three other studies (Bayazıt et al., 2023; Hatirli et al., 2021; Uzel et al., 2022) a slight nonsignificant lower survival rate was consistently observed in the glass ionomer cement restorations. Interestingly, a study by Gurgan et al. (2020), with the longest follow-up period, reported 100% survival for both types of restorations at the ten-year follow-up, although after four years it dropped to 96% for glass ionomer cement restoration.

In Rozniatowski et al. (2021), the efficacy of the restorative materials was further differentiated into clinical and radiographic efficacy and was assessed separately as well as together. No significant difference was found when reported individually, while a significant difference was found when the overall efficacy was considered.

Overall, the studies reveal that composite restorations have consistently better longevity compared to glass ionomer cement restorations, although the differences were comparatively low and not significant in the majority of the studies.

3.2 Secondary outcome

The secondary outcome parameters are secondary / recurrent caries, loss of retention / restoration loss, postoperative sensitivity / pain, marginal defect / loss of adaptation, marginal discoloration, wear / loss of anatomic contour, poor color match / loss of surface luster, loss of surface texture / stain, fracture of tooth, fracture of restoration, loss of contact point and primary caries.

3.2.1 Secondary caries composite resin vs amalgam

The percentage of secondary or recurrent caries as the cause of restoration failure among the different studies revealed broad ranges for both types of restorations, with values ranging from 6.6 to 74% for composite resin restorations and 3.7 to 69.2% for amalgam restorations (**Table 4**).

Table 4. Secondary/recurrent caries for composite resin (comp-res) vs amalgam. A = alpha score, AM = amalgam, B = bravo score, BL = baseline, CR = composite resin, HCR = high caries risk, LCR = low caries risk, mo = month, nr = number of restorations, NR = not reported, n.s. = not significant, OR = odds ratio, y = year. (*) Calculated from the published data available in the study.

STUDY	SECONDARY/RECURRENT CARIES % (nr/total)								P VALUE
	COMP-RES				AMALGAM				
BERNARDO, 2007	12.7 (113/892)				3.7 (32/856)				< 0.001
SONCINI, 2007	52 (58/112)				44 (24/55)				n.s.
OPDAM, 2010	Combined: 6.6 (49/747)				Combined: 5.7 (69/1202)				NR
	HCR		LCR		HCR		LCR		
	19		1.8		14		3.6		
KOPPERUD, 2012	74* (284/384)				69.2* (9/13)				NR
RHO, 2013	OR for AM/CR – 0.623								n.s.
KEMALOGLU, 2016	BL	6 mo	1 y	3 y	BL	6 mo	1 y	3 y	n.s.
	A - 100, B - 0				A - 100, B - 0				
AL-AMSAR, 2023	26 (15/57)				16 (42/261)				< 0.05

Rho et al. (2013) did not report the failure percentage but rather calculated the odds ratio for this parameter, indicating that amalgam restorations have a 0.623 times lower risk of failure due to secondary caries compared to composite resin restorations. However, this risk reduction compared to composite resin restorations was not significant.

While seven studies assessed this parameter, only four reported the outcomes of the statistical tests regarding this parameter, which were inconsistent. Two studies (Al-Asmar et al., 2023; Bernardo et al., 2007) found a significant difference between the types of restorations, with less failure due to secondary caries in the amalgam restorations. In contrast, two other studies (Rho et al., 2013; Soncini et al., 2007) reported no significant differences but observed a slightly lower failure rate due to secondary caries in amalgam restorations. Kemaloglu et al. (2016) reported no failures or changes in this outcome.

In Opdam et al. (2010), the risk for caries was further differentiated. The outcome percentage was analyzed for both high caries risk and low caries risk groups for both types of restorations. It was shown that composite resin restorations have a higher failure due to this parameter in the high caries risk group, while they have a lower failure due to this parameter in the low caries risk group compared to amalgam restorations.

Overall, studies that reported failures indicate that restoration failure due to secondary caries was consistently slightly higher in composite resin restorations compared to amalgam restorations. However, despite this consistency, a significant difference was observed only in a minority of the included studies.

3.2.2 Secondary caries composite resin vs glass ionomer cement

Among the six studies that assessed this parameter, only Uzel et al. (2022) reported secondary or recurrent caries as the cause of failure in glass ionomer cement restorations (**Table S5**). No significant difference was found between both types of restorations in this parameter. Additionally, no changes were observed in the percentage of Bravo scores across different follow-up periods.

Meanwhile, Hatirli et al. (2021) showed slight but nonsignificant changes in the FDI scores over the different follow-up periods. Composite resin restorations showed changes only at the two-year follow-up, whereas glass ionomer cement restorations showed further changes at the one-year and two-year follow-up periods.

Overall, the majority of studies reported no failure or changes due to secondary caries. However, among the studies that did report failure or changes, glass ionomer cement restorations exhibited a slightly higher risk of failure compared to composite resin restorations.

3.2.3 Loss of retention composite resin vs amalgam

The percentage of loss of retention or loss of restoration being the cause of restoration failure among different studies revealed that composite resin restoration failure ranged from 1 to 8.1% whereas for amalgam restoration, failure ranged from 2 to 15.3% (**Table 6**). Rho et al. (2013) did not report the failure percentage but calculated the odds ratio for this parameter and reported that amalgam restorations have 0.837 times lower risk of failure due to loss of retention compared to composite resin restorations. However, this risk reduction compared to composite resin restoration was not significant.

While Soncini et al. (2007) found a comparable outcome and Kemaloglu et al. (2016) found no failure or changes, Kopperud et al. (2012) found a higher failure rate in amalgam restorations. Four studies assessed this parameter, and two of them reported the outcomes of the statistical tests, which showed no significant differences between both types of restorations. Overall, the results are inconsistent, and no clear trend can be observed.

Table 6. Loss of retention/restoration loss for composite resin (comp-res) vs amalgam. A = alpha score, AM = amalgam, B = bravo score, BL = baseline, CR = composite resin, mo = month, nr = number of restorations, NR = not reported, n.s. = not significant, OR = odds ratio, y = year. (*) Calculated from the published data available in the study.

STUDY	RETENTION/RESTORATION LOSS % (nr/total)								P VALUE
	COMP-RES				AMALGAM				
SONCINI, 2007	1 (1/112)				2 (1/55)				n.s.
KOPPERUD, 2010	8.1* (31/384)				15.3* (2/13)				NR
RHO, 2013	OR for AM/CR – 0.837								n.s.
KEMALOGLU, 2016	BL	6 mo	1 y	3 y	BL	6 mo	1 y	3 y	n.s.
	A - 100, B - 0				A - 100, B - 0				

3.2.4 Loss of retention composite resin vs glass ionomer cement

The percentage of loss of retention or loss of restoration being the cause of composite resin restoration failure ranged from 0 to 4%, whereas for glass ionomer cement restoration, failure ranged more broadly from 2.9 to 28.6% (**Table S7**). Rozniatowski et al. (2021) did not report failure percentages but calculated mean values, which showed significantly higher failure in glass ionomer cement restorations. The study reported the failure of two glass ionomer cement restorations after one year due to this parameter.

All six studies reported the outcomes of the statistical tests with respect to this parameter, in which only one study (Balkaya & Arslan, 2020) found a significant difference. In Balkaya and Arslan (2020), no failure was reported due to this parameter in composite resin restoration, whereas failure was seen in glass ionomer cement restorations in one-year and two-year follow-ups, leading to a significant difference with retention loss being higher in glass ionomer cement restorations than composite resin restorations. Similarly, in Uzel et al. (2022), no failure was reported in composite resin restorations, whereas no significant failure was seen in glass ionomer cement restorations at the two-year follow-up.

Gurgan et al. (2020) reported no failure due to this parameter in class I composite resin restoration, class I glass ionomer cement restoration, and class II composite resin restoration, whereas failure was reported in class II glass ionomer cement restoration at three-year and four-year follow-up periods. Meanwhile, Hatirli et al. (2021) showed slight nonsignificant changes in the FDI scores over different follow-up periods. Composite resin showed changes at one-year and two-year follow-up periods, while two glass ionomer cement restorations showed changes and were found unacceptable (Score 4) at one-year and two-year follow-up periods, leading to a 96% success rate for glass ionomer cement restoration.

Bayazıt et al. (2023) reported failure due to this parameter in composite resin restoration at the four-year follow-up, while slightly higher but nonsignificant failure was seen at one-year and four-year follow-up in glass ionomer cement restoration.

Overall, the studies reveal that, in tendency, restoration failure due to loss of retention was consistently slightly higher in glass ionomer cement restorations compared to composite resin restorations but was significant only in one of the included studies.

3.2.5 Postoperative sensitivity composite resin vs amalgam

The percentage of postoperative sensitivity or pain being the cause of restoration failure amongst the different studies revealed that composite resin restoration failure ranged from 1.3 to 12%, whereas for amalgam restoration, failure ranged from 0 to 7% (**Table 8**).

Table 8. Postoperative sensitivity/pain for composite resin (comp-res) vs amalgam. AM = amalgam, BL = baseline, CR = composite resin, HCR = high caries risk, LCR = low caries risk, mo = month, nr = number of restorations, NR = not reported, n.s. = not significant, OR = odds ratio, y = year. (*) Calculated from the published data available in the study.

STUDY	POSTOPERATIVE SENSITIVITY/PAIN % (nr/total)				P VALUE
	COMP-RES		AMALGAM		
OPDAM, 2010	Combined risk: 3.5 (26/747)		Combined risk: 2.5 (30/1202)		NR
	HCR	LCR	HCR	LCR	
	3.9	3.3	4.8	1.9	
KOPPERUD, 2012	1.3* (5/384)		0		NR
RHO, 2013	OR for AM/CR – 0.778				n.s
KEMALOGLU, 2016	-				BL, 6 mo, 1 y: n.s. 3 y: < 0.05
AL-AMSAR, 2023	12 (7/57)		7 (19/261)		< 0.05

Rho et al. (2013) did not report the failure percentage but calculated the odds ratio for this parameter and stated that amalgam restorations have 0.778 times lower risk of failure due to postoperative sensitivity compared to composite resin restorations. However, this risk reduction was not significant.

Five studies assessed this parameter, but only three studies reported the outcomes of the statistical tests. In Kemaloglu et al. (2016), there was no significant difference in this parameter at the baseline, six months, and at the one-year follow-up period. However, at the three-year follow-up, a significant difference was noted, where amalgam restorations had increasing postoperative sensitivity compared to composite resin restorations.

Although the difference is slight, Al-Asmar et al. (2023) reported a significantly higher failure rate due to pain or sensitivity in composite resin restorations compared to amalgam. In their study, two out of seven restorations expressing this parameter were found to have a history of replacement of amalgam restorations less than a year after they were placed, making it an actual 9% of composite restorations that were initially placed, suffering from this parameter, thereby further reducing the difference between the types of restorations.

Opdam et al. (2010) reported the percentage for both high caries risk and low caries risk groups for both types of restorations, showing that amalgam restorations have higher failure due to this parameter in the high caries risk group and lower failure due to this parameter in the low caries risk group compared to composite resin restorations.

Overall, studies that reported failures reveal that, in tendency, restoration failure due to postoperative sensitivity was consistently slightly higher in composite resin restorations compared to amalgam restorations but was found to be significant in only one of the included studies.

3.2.6 Postoperative sensitivity composite resin vs glass ionomer cement

Among the six studies that assessed this parameter, no study reported postoperative sensitivity or pain as the cause of composite resin or glass ionomer cement restoration failure in their final follow-up period (**Table S9**).

Meanwhile, Kharma et al. (2018) reported slight, nonsignificant changes in Bravo scores in composite resin restoration at the three-month follow-up period compared to baseline, while no changes were observed in glass ionomer cement restorations throughout.

Hatirli et al. (2021) showed slight, nonsignificant changes in the FDI scores over the different follow-up periods. Composite resin restoration showed changes at the two-year follow-up, and glass ionomer cement restorations showed changes at the one-year and two-year follow-up periods.

Uzel et al. (2022) showed slight, nonsignificant changes in composite resin restoration at the one-year follow-up, whereas glass ionomer cement restorations showed changes only at the one-year and eight-month follow-up periods.

Bayazıt et al. (2023) reported changes in composite resin restoration at the four-year follow-up, while restoration changes were observed at the one-year and four-year follow-ups in glass ionomer cement restoration. In the same study, failure was reported in one glass ionomer cement restoration at the baseline period, which was then, according to the author, endodontically treated as the pain did not subside. No failures were reported thereafter.

3.2.7 Marginal defect composite resin vs amalgam

Kopperud et al. (2012) reported that the percentage of marginal defect or loss of adaptation was the cause of composite resin restoration failure in 2.3% of cases, whereas for amalgam restoration failure, the percentage was 0% (**Table 10**). Rho et al. (2013) did not report the failure percentage but calculated the odds ratio for this parameter, stating that amalgam restorations have 0.647 times lower risk of failure due to poor marginal adaptation compared to composite resin restorations. However, this risk reduction was not significant when compared to composite resin restorations.

Table 10. Marginal defect/loss of adaptation for composite resin (comp-res) vs amalgam. A = alpha score, AM = amalgam, B = bravo score, BL = baseline, CR = composite resin, mo = month, nr = number of restorations, NR = not reported, n.s. = not significant, OR = odds ratio, y = year. (*) Calculated from the published data available in the study.

STUDY	MARGINAL DEFECT/ADAPTATION % (nr/total)								P VALUE
	COMP-RES				AMALGAM				
KOPPERUD, 2012	2.3* (9/384)				0				NR
RHO, 2013	OR for AM/CR – 0.647								n.s
KEMALOGLU, 2016	BL	6 mo	1 y	3 y	BL	6 mo	1 y	3 y	NR
	A - 100		A - 90	A - 80	A - 100		A - 90	A - 85	
	B - 0		B - 10	B - 20	B - 0		B - 10	B - 15	

While three studies assessed this parameter, only one study reported the outcomes of the statistical test, which showed no significant difference between the two types of restorations. In the study by Kemaloglu et al. (2016), no failures were reported, but slightly higher Bravo scores were observed at three-year follow-up periods in composite resin restorations compared to amalgam restorations.

Overall, studies reveal that restoration failure due to marginal defects was consistently slightly higher in composite resin restorations compared to amalgam restorations, but this difference was found to be nonsignificant.

3.2.8 Marginal defect composite resin vs glass ionomer cement

The percentage of marginal defect or loss of marginal adaptation as cause of restoration failure among different studies revealed that glass ionomer cement restoration failure ranged from 2.9% to 6.3% whereas for composite resin restoration, no failure was reported (**Table S11**). Rozniatowski et al. (2021) did not report failure percentages but calculated mean values, which showed significantly higher failure rates in glass ionomer cement restorations. The study reported failures in two glass ionomer cement restorations after one year due to the suspicion of recurrent caries/presence of a marginal gap observed during radiographic evaluation.

All seven studies reported the outcomes of the statistical tests regarding this parameter, with only two studies (Balkaya & Arslan, 2020; Rozniatowski et al., 2021) finding a significant difference. Balkaya and Arslan (2020) reported a significantly higher failure rate in glass ionomer cement restorations, with two restorations failing at the one-year follow-up and one restoration failing at the two-year follow-up period. Similarly, Uzel et al. (2022) reported no failure in composite resin restorations; no significant failure was observed in glass ionomer cement restorations at the two-year follow-up.

Kharma et al. (2018) is the only study that reported no failures for this parameter. All other studies showed changes in Bravo scores over different follow-up periods. No significant differences were observed in them.

Overall, the studies reveal that restoration failure due to marginal defects was slightly higher in glass ionomer cement restorations compared to composite resin restorations, but statistically significant in only a minority of the included studies.

3.2.9 Marginal discoloration composite resin vs amalgam

The percentage of marginal discoloration causing restoration failure amongst different studies revealed that composite resin restoration failure ranged from 0.3 to 26% whereas for amalgam restoration, failure ranged from 0 to 19% due to this parameter (**Table 12**).

While three studies assessed this parameter, only one study reported the statistical test outcomes, which are inconsistent. Kemaloglu et al. (2016) found no failures but observed higher Bravo scores at one-year and three-year follow-up periods in composite resin restoration compared to amalgam restoration. Although the difference is slight, Al-Asmar et al. (2023) reported a significantly higher failure rate due to marginal discoloration in composite resin restoration compared to amalgam.

Overall, the studies reveal a tendency for restoration failure due to marginal discoloration to be slightly higher in composite resin restorations compared to amalgam restorations, with significance noted in only one of the included studies.

Table 12. Marginal discoloration for composite resin (comp-res) vs amalgam. A = alpha score, B = bravo score, BL = baseline, mo = month, nr = number of restorations, NR = not reported, y = year. (*) Calculated from the published data available in the study.

STUDY	MARGINAL DISCOLORATION % (nr/total)								P VALUE
	COMP-RES				AMALGAM				
KOPPERUD, 2012	0.3* (1/384)				0				NR
KEMALOGLU, 2016	BL	6 mo	1 y	3 y	BL	6 mo	1 y	3 y	NR
	A - 100		A - 80	A - 70	A - 100		A - 95	A - 95	
	B - 0		B - 20	B - 30	B - 0		B - 5	B - 5	
AL-AMSAR, 2023	26 (15/57)				19 (49/261)				< 0.05

3.2.10 Marginal discoloration composite resin vs glass ionomer cement

Only two studies reported marginal discoloration as the cause of restoration failure. Balkaya and Arslan (2020) found that one glass ionomer cement restoration failed due to this parameter at a two-year follow-up period, with no failures in composite resin restorations (**Table S13**). Rozniatowski et al. (2021) did not report the failure percentage but calculated the mean values, which showed significantly higher failure rates in glass ionomer cement restorations. The study reported failure in one glass ionomer cement restoration after one year due to this parameter.

All other studies showed changes in Bravo scores over different follow-up periods. All seven studies reported the outcomes of statistical tests with respect to this parameter, in which only three studies (Bayazıt et al., 2023; Hatirli et al., 2021; and Rozniatowski et al., 2021) found a significant difference. Hatirli et al. (2021) reported a significant increase in marginal discoloration in composite resin restorations compared to glass ionomer cement restorations after two years, but not during the six-month and one-year follow-up periods. In Gurgan et al. (2020), a significant difference was observed between class I and class II of glass ionomer cement restorations at the six-year and ten-year follow-up periods. Compared to class I glass ionomer cement restorations, class II restorations showed a significantly higher risk of failure due to this parameter. Bayazıt et al. (2023) reported a significantly higher marginal discoloration in glass ionomer cement restorations compared to composite restorations according to the data provided by the study.

Overall, the studies reveal that, in tendency, restoration failure due to marginal discoloration was slightly higher in glass ionomer cement restorations compared to composite resin restorations, but significant in a minority of the included studies.

3.2.11 Wear composite resin vs amalgam

According to Al-Asmar et al. (2023), the percentage of wear or loss of anatomic contour causing composite resin restoration failure was found to be 4%, whereas it was 1% for amalgam restoration failure, showing a significant difference between the two types of restorations (**Table 14**). Rho et al. (2013) did not report the failure percentage but calculated the odds ratio for this parameter, revealing that amalgam restorations have 0.804 times lower risk of failure due to wear compared to composite resin restorations. However, this risk reduction was not significant.

Table 14. Wear/Loss of anatomic contour for composite resin (comp-res) vs amalgam. A = alpha score, AM = amalgam, B = bravo score, BL = baseline, CR = composite resin, mo = month, nr = number of restorations, NR = not reported, n.s. = not significant, OR = odds ratio, y = year.

STUDY	WEAR/ANATOMIC CONTOUR % (nr/total)								P VALUE
	COMP-RES				AMALGAM				
RHO, 2013	OR for AM/CR – 0.804								n.s.
KEMALOGLU, 2016	BL	6 mo	1 y	3 y	BL	6 mo	1 y	3 y	NR
	A - 100		A - 95	A - 75	A - 100		A - 85	A - 50	
	B - 0		B - 5	B - 25	B - 0		B - 15	B - 50	
AL-AMSAR, 2023	4 (2/57)				1 (3/261)				< 0.05

Out of the three studies that assessed this parameter, only the above two studies reported the outcomes of the statistical test, which are contradictory. In Kemaloglu et al. (2016), higher bravo scores can be noticed at one-year and three-year follow-up periods in amalgam restoration compared to composite resin restoration.

Overall, the studies reveal that, in tendency, restoration failure due to wear was slightly higher in composite resin restorations compared to amalgam restorations but was significant in only one of the included studies.

3.2.12 Wear composite resin vs glass ionomer cement

The percentage of wear or loss of anatomic contour causing restoration failure across different studies revealed that composite resin restoration failure ranged from 0 to 4.2%, whereas for glass ionomer cement restoration, failure ranged from 0 to 4.8% (**Table S15**). All five studies reported the outcomes of the statistical tests for this parameter, with only two studies (Balkaya & Arslan, 2020; Hatirli et al., 2021) finding a significant difference. Balkaya and Arslan (2020) reported a significantly higher failure rate due to this parameter in glass ionomer cement restorations, with two restorations and one restoration failing at one-year and two-year follow-up periods, respectively. Hatirli et al. (2021) reported a significant increase in wear and loss of anatomic contour in glass ionomer cement restorations compared to composite resin restorations. Meanwhile, Bayazıt et al. (2023) found that one composite restoration failed due to this parameter during the four-year follow-up period, with no failures in glass ionomer cement restorations. No significant difference was found between the two types of restoration.

Overall, the studies reveal that, in tendency, the risk of restoration failure due to wear or loss of anatomic contour was slightly higher in glass ionomer cement restorations compared to composite resin restorations, but significant only in a minority of the included studies.

3.2.13 Poor color match composite resin vs amalgam

Due to obvious aesthetic differences and reasons, only one study, Al Asmar et al. (2023) evaluated this parameter, which reported a predictable outcome of higher failure rates attributable to poor color match in 34% of the amalgam restorations and 14% of the composite restorations. The study did not report the outcome of the statistical test for this parameter.

3.2.14 Poor color match composite resin vs glass ionomer cement

While no other study reported poor color match as the cause of restoration failure, Balkaya and Arslan (2020) reported a significantly higher failure rate due to this parameter in glass ionomer cement restorations compared to composite resin restorations across all follow-up periods (**Table S16**).

All other studies showed changes in Bravo scores over various follow-up periods. All five studies reported the outcomes of the statistical tests with respect to this parameter, and only two studies (Balkaya & Arslan, 2020; Bayazıt et al., 2023) found a significant difference. Incorrect data reporting was identified and confirmed by Kharma et al. (2018), but no significant difference was found between the two types of restorations for this parameter.

Gurgan et al. (2020) reported no failure and an overall nonsignificant difference between both types of restorations for this parameter. However, the study found a significant difference in glass ionomer cement restorations after ten years when compared to the baseline and also observed a significant difference between both types of restorations in the Bravo scores of class II restorations, where the Bravo scores for glass ionomer cement restorations were significantly higher than those of composite restorations.

For Uzel et al. (2022), no changes were reported in composite resin restorations, whereas changes were observed in glass ionomer cement restorations at the one-year and two-year follow-ups. No significant difference was found between the two types of restorations.

Bayazıt et al. (2023) reported a significantly higher color match in composite restorations compared to glass ionomer cement restorations.

Overall, the studies reveal that the risk of restoration failure due to poor color match was slightly higher in glass ionomer cement restorations compared to composite resin and significant in half of the included studies.

3.2.15 Loss of surface texture composite resin vs amalgam

No study reported loss of surface texture or staining as the cause of composite resin or amalgam restoration failure. In contrast, Kemaloglu et al. (2016) reported no failure but slightly higher Bravo scores due to surface texture loss at one-year and three-year follow-up periods in composite resin restorations compared to amalgam restorations (**Table 17**).

Table 17. Loss of surface texture/staining for composite resin (comp-res) vs amalgam. A = alpha score, B = bravo score, BL = baseline, mo = month, n.s. = not significant, y = year.

STUDY	SURFACE TEXTURE / STAINING (%)								P VALUE
	COMP-RES				AMALGAM				
	BL	6 mo	1 y	3 y	BL	6 mo	1 y	3 y	
KEMALOGLU, 2016	A - 100		A - 65	A - 35	A - 100		A - 75	A - 40	n.s.
	B - 0		B - 35	B - 65	B - 0		B - 25	B - 60	

3.2.16 Loss of surface texture loss composite resin vs glass ionomer cement

The percentage of loss of surface texture or staining as the cause of restoration failure among the various studies revealed that glass ionomer cement restoration failure ranged from 5.9% to 9.5%, whereas for composite resin restoration, no failure was reported (**Table S18**). All other studies showed changes in Bravo scores over different follow-up periods. All five studies reported the outcomes of the statistical tests with respect to this parameter, where only three studies (Balkaya & Arslan, 2020; Hatirli et al., 2021; Kharma et al., 2018) found a significant difference. Although Kharma et al. (2018) reported no failures, the authors found a significant decrease in surface texture over the different follow-up periods in glass ionomer cement restorations compared to composite resin restorations. Balkaya and Arslan (2020) reported a significantly higher failure rate due to surface texture loss in glass ionomer cement restorations compared to composite resin restorations in one-year and two-year follow-up periods. Similarly, in Uzel et al. (2022), no failure was reported in composite resin restorations, whereas no significant failure was seen in glass ionomer cement restorations at the two-year follow-up. Hatirli et al. (2021) reported a significant decrease in surface luster in glass ionomer cement restorations compared to composite resin restorations. The study also reported changes in surface staining between the two types of restorations, which were nonsignificant.

Overall, the studies reveal that the risk of restoration failure due to loss of surface texture was consistently slightly higher in glass ionomer cement restorations compared to composite resin restorations and was found to be significant in the majority of the studies.

3.2.17 Fracture of restoration composite resin vs amalgam

The percentage of fractured restoration as the cause of failure among the different studies revealed that composite resin restoration failure ranged from 0.9% to 11%, whereas amalgam restoration failure ranged from 0% to 15% (**Table 19**). Of the five studies that assessed this parameter, three reported statistically inconsistent outcomes. Two studies (Bernardo et al., 2007; Opdam et al., 2010) found comparable outcomes, which were nonsignificant according to Bernardo et al. (2007).

Table 19. Fracture of restoration for composite resin (comp-res) vs amalgam. FOR = fracture of restoration, FOT = fracture of tooth, HCR = high caries risk, LCR = low caries risk, nr = number of restorations, NR = not reported, n.s. = not significant. (*) Calculated from the published data available in the study.

STUDY	FRACTURE OF RESTORATION % (nr/total)				P VALUE
	COMP-RES		AMALGAM		
BERNARDO, 2007	1.8 (16/892)		1.9 (16/856)		n.s.
SONCINI, 2007	2 (2/112)		5 (3/55)		n.s.
OPDAM, 2010	Combined: 0.9 (7/747)		Combined: 0.9 (11/1202)		NR
	HCR	LCR	HCR	LCR	
	1.5	0.7	1.2	0.8	
KOPPERUD, 2012	5.2* (20/384)		0		NR
AL-AMSAR, 2023	Overall: 11 (6/57)		Overall: 15 (38/261)		< 0.05
	11 (FOR)		14 (FOR)		
	0 (FOT)		1 (FOT)		

Two other studies (Al-Asmar et al., 2023; Soncini et al., 2007) found slightly higher failure rates in amalgam restorations compared to composite resin restorations, reported as nonsignificant in Soncini et al. (2007) and significant in Al-Asmar et al. (2023). Interestingly, Kopperud et al. (2012) is the only study that reported a higher percentage of failure due to restoration fracture in composite resin restorations compared to amalgam restorations. The study reported significant failure in restorations made with Filtek Z100 (92 restorations) compared to other resin composites, and a significant failure was found in restorations that used Ana-single-bond (94 restorations) compared to other bonding agents. Opdam et al. (2010) reported the outcome percentages for both high caries risk and low caries risk groups for both types of restorations, showing that composite resin restorations had slightly higher failure rates in the high caries risk group but slightly lower failure rates in the low caries risk group compared to amalgam restorations. Overall, the results are inconsistent, and no clear trend can be observed.

3.2.18 Fracture of tooth composite resin vs amalgam

The percentage of fractured tooth being the cause of failure amongst different studies revealed that composite resin restoration failure ranged from 0.3 to 1.3%, whereas for amalgam restoration, failure ranged from 5.9 to 15.3% (**Table 20**). No studies reported outcomes of the statistical test on this parameter. Opdam et al. (2010) reported the outcome percentage for both high caries risk and low caries risk groups for both types of restorations, which show that amalgam restorations have higher failure rates due to this parameter in both high caries risk and low caries risk groups compared to composite resin restorations.

Overall, the studies reveal that restoration failure due to fracture of the tooth was slightly higher in amalgam restorations compared to composite resin restorations.

Table 20. Fracture of tooth for composite resin (comp-res) vs amalgam. HCR = high caries risk, LCR = low caries risk, nr = number of restorations, NR = not reported. (*) Calculated from the published data available in the study.

STUDY	FRACTURE OF TOOTH % (nr/total)				P VALUE
	COMP-RES		AMALGAM		
OPDAM, 2010	Combined: 1.3 (10/1202)		Combined: 5.9 (71/747)		NR
	HCR	LCR	HCR	LCR	
	2.4	0.9	5.2	6.1	
KOPPERUD, 2012	0.3* (1/384)		15.3* (2/13)		NR

3.2.19 Loss of contact point composite resin vs amalgam

The percentage of loss of contact point or poor contact point being the cause of failure amongst different studies revealed that composite resin restoration failure ranged from 0.3 to 7%, whereas for amalgam restoration, failure ranged slightly more from 0 to 8% (**Table 21**). While Kopperud et al. (2012) reported the failure of one composite resin restoration and no failure in amalgam restorations, Al-Asmar et al. (2023) reported a slight and significantly higher failure due to this parameter in amalgam restorations, where there were more overhangs (13 restorations) than open contacts (7 restorations). In composite resin restorations, the number of overhangs and open contacts were equal.

Overall, the outcomes of these two studies are contradictory, but in both studies, there was no significant difference between the two types of restorations.

Table 21. Loss of contact point for composite resin (comp-res) vs amalgam. NR = not reported. (*) Calculated from the published data available in the study

STUDY	CONTACT POINT % (no/total)		P VALUE
	COMP-RES	AMALGAM	
KOPPERUD, 2012	0.3* (1/384)	0	NR
AL-AMSAR, 2023	7 (4/57)	8 (20/261)	< 0.05

3.2.20 Loss of contact point composite resin vs glass ionomer cement

Only one study reported findings on the loss of contact point or poor contact point parameter. Balkaya and Arslan (2020) reported a significantly higher failure rate due to this parameter in glass ionomer cement restoration compared to composite resin restoration at one-year and two-year follow-up period (**Table 22**).

3.2.21 Primary caries composite resin vs amalgam

The percentage of primary caries as the cause of failure among different studies revealed that composite resin restoration failure ranged from 1.6% to 38.5%, whereas for amalgam restoration, failure ranged from 0% to 40% (**Table 23**).

Opdam et al. (2010) reported the outcome percentage for both high caries risk and low caries risk groups for both types of restorations, indicating that composite resin restoration has a slightly higher failure rate due to this outcome parameter in both high caries risk and low caries risk groups compared to amalgam restoration.

Table 22. Loss of contact point for composite resin (comp-res) vs glass ionomer cement (glass-ion-c). A = alpha score, B = bravo score, BL = baseline, C = charlie score, y = year. (*) Calculated from the published data available in the study.

STUDY	CONTACT POINT (%)						P VALUE
	COMP-RES			GLASS-ION-C			
	BL	1 y	2 y	BL	1 y	2 y	
BALKAYA, 2020	A - 100	A - 100	A - 100	A - 100	A - 84.4*	A - 66.6*	< 0.05
	B - 0	B - 0	B - 0	B - 0	B - 0	B - 23.8*	
	C - 0	C - 0	C - 0	C - 0	C - 15.6*	C - 9.5*	

While two studies (Kopperud et al., 2012; Opdam et al., 2010) report a higher failure rate due to this parameter in composite resin restorations compared to amalgam restorations, one study (Soncini et al., 2007) reported a higher failure in amalgam restorations, which was nonsignificant.

Overall, the studies reveal that, in tendency, restoration failure due to primary caries is slightly higher in composite resin restorations compared to amalgam restorations.

Table 23. Primary caries for composite resin (comp-res) vs amalgam. HCR = high caries risk, LCR = low caries risk, nr = number of restorations, NR = not reported, n.s. = not significant. (*) Calculated from the published data available in the study.

STUDY	PRIMARY CARIES % (nr/total)				P VALUE
	COMP-RES		AMALGAM		
SONCINI, 2007	33 (37/112)		40 (22/55)		n.s.
OPDAM, 2010	Combined: 1.6 (12/747)		Combined: 1.1 (13/1202)		NR
	HCR	LCR	HCR	LCR	
	3.9	0.7	3.2	0.5	
KOPPERUD, 2012	38.5* (5/13)		0		NR

3.3 Summary of the primary and secondary outcomes

To obtain an overview of the primary outcome, an attempt was made to compare data from studies that reported success or survival rates (**Figure 2**). The total reported percentages were divided by the number of studies that reported them, which is presented in the bar charts below.

Primary outcome composite resin vs amalgam The calculated average shows a comparable outcome with a slightly higher survival or success rate in amalgam restorations compared to composite resin restorations (**Figure 2, left**). This aligns with the analysis of the primary outcome, although an inconsistent trend was observed. Amalgam restorations performed slightly better in four out of nine studies, while in three studies both restorations were comparable, and in two studies composite restorations performed better.

Primary outcome composite resin vs glass ionomer cement The calculated average shows a slightly higher survival or success rate in composite resin restorations compared to glass ionomer cement restorations (**Figure 2, right**). This aligns with the analysis of the primary outcome.

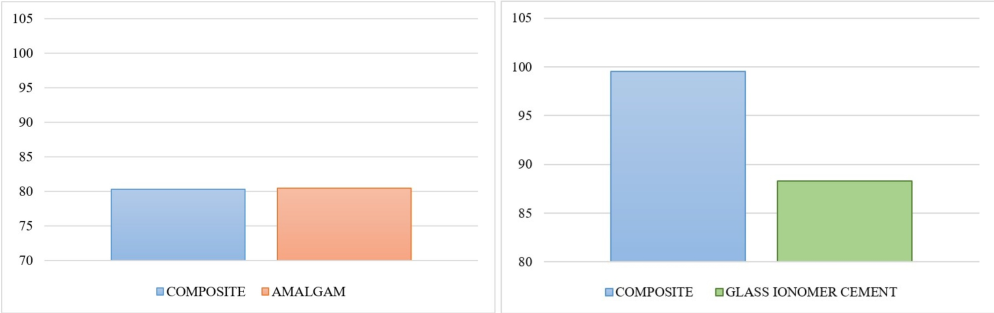

Figure 2. Left: Comparison of longevity between composite resin and amalgam restorations. Right: Comparison of longevity between composite resin and glass ionomer cement restorations.

To assess the secondary outcomes, an attempt was made to compare data from studies that reported absolute failures in each type of restoration (**Figures 3 and 4**). All absolute failures and the total number of restorations for a specific secondary outcome were added. The totals were then divided and converted into percentages, as presented in the bar charts below.

Secondary outcome composite resin vs amalgam The bar chart results align with the overall tendencies found for each secondary outcome above, except for loss of retention, postoperative sensitivity, marginal discoloration, fracture of restoration, and loss of contact point (**Figure 3**). This is due to the pooled effect and higher weightage of one type of restoration. Detailed analysis revealed no consistent trend in loss of retention, fracture of restoration, and loss of contact point parameters, whereas postoperative sensitivity and marginal discoloration parameters showed a higher failure tendency in composite resin restorations.

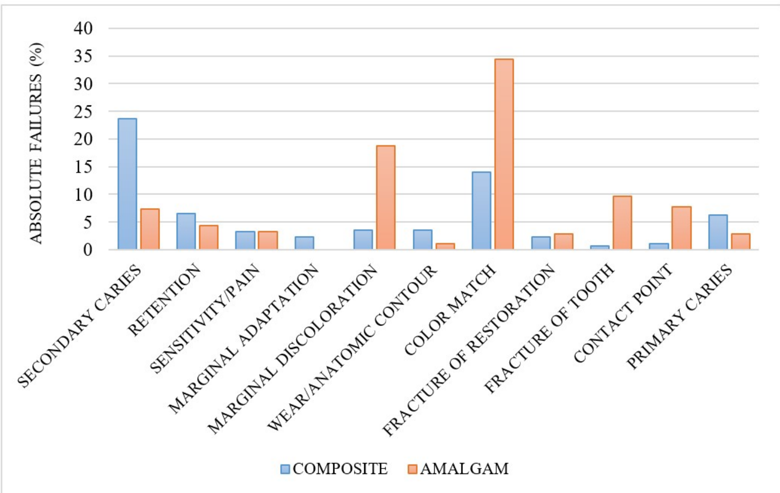

Figure 3. Comparison of secondary outcomes between composite resin and amalgam restorations.

As shown in the chart, drastic differences were observed between the restorations in the following secondary outcomes: secondary caries, marginal discoloration, poor color match, fracture of the tooth, and loss of contact point. Slight differences were noted in the following secondary outcomes: loss of retention, marginal defects, wear, and primary caries. The rest of the secondary outcomes were comparable.

Secondary outcome composite resin vs glass ionomer cement The bar chart results align with the overall tendencies for each secondary outcome detailed in the analysis above (**Figure 4**). Firm conclusions could not be drawn from this chart as absolute failures were reported by only one study in the starred bars and by two studies in other secondary outcomes, except for loss of retention in glass ionomer cement restorations, which had five studies reporting absolute failures. Nevertheless, an overall tendency could be observed. Glass ionomer cement restorations showed a higher risk of failure in all the mentioned secondary outcomes, although the failed restorations ranged from one to six in total.

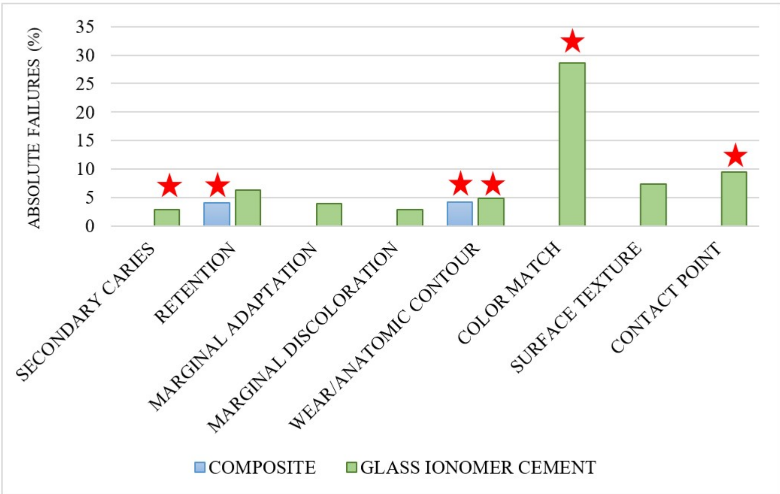

Figure 4. Comparison of secondary outcomes between composite resin and glass ionomer cement restorations. (*) Results from a single study as no other studies reported absolute failures of the restorations due to the mentioned secondary outcome.

To review the distribution of reasons for restoration failure, the data calculated for the above bar chart was organized for each restoration type (**Figures 5-7**). Due to the pooled effect, a different trend may be observed. Overall, composite resin restorations had a slightly higher tendency to fail in half of the secondary outcomes analyzed when compared to amalgam restorations but showed a less significant difference in most outcomes. Meanwhile, glass ionomer cement restorations demonstrated a slightly higher tendency to fail compared to composite resin restorations but showed a less significant difference in the majority of outcomes.

Reasons for restoration failure This data is collected from the composite resin restorations compared to amalgam restorations (**Figure 5**). Since most of the composite resin restorations were successful in the majority of studies comparing them to glass ionomer cement restorations, data from this group was not considered. **Figure 5** identifies secondary caries, poor color match, loss of retention, and primary caries as the primary reasons for the failure of composite resin restorations. These findings differ slightly from the detailed analysis, which reported consistent failure due to secondary caries, primary caries, postoperative sensitivity, marginal defects, and marginal discoloration. This discrepancy is due to the pooled effect and higher weightage of one type of restoration. **Figure 6** highlights poor color match, marginal discoloration, tooth fracture, and loss of contact point as the main reasons for the failure of amalgam restorations. The detailed analysis, however, indicates a slightly higher tendency for failure due to poor color match and tooth fracture. **Figure 7** reveals that poor color match, contact point loss, surface texture loss, and retention loss are the leading reasons for the failure of glass ionomer cement restorations. The detailed analysis confirms a consistent failure due to the loss of retention and surface texture.

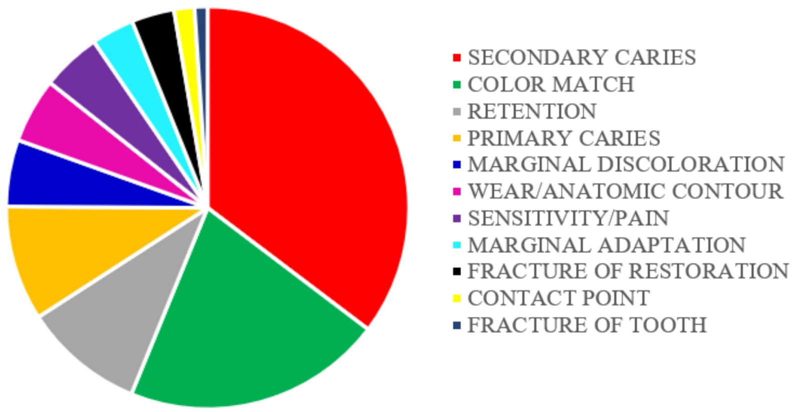

Figure 5. Distribution of reasons for failure in composite resin restorations.

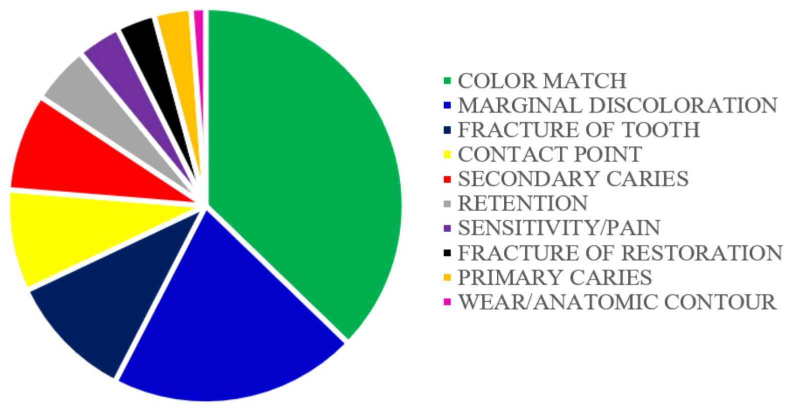

Figure 6. Distribution of reasons for failure in amalgam restorations.

3.4 Risk factors influencing the longevity of direct restorations in posterior permanent teeth

In addition to the primary and secondary outcome parameters, the included studies have also aimed to identify other factors that could pose a risk or contribute to the failure of restorations (**Table S24**). All the included studies reported risk factors with respect to composite resin restorations or amalgam restorations, except for Laske et al. (2016), which included glass ionomer cement restorations and compomer restorations as well, and Uzel et al. (2022), which reported risk factors with respect to glass ionomer cement restorations.

Only those factors evaluated by three or more studies are mentioned in the table. Other factors that were reported by single studies and found significant differences include evalua-

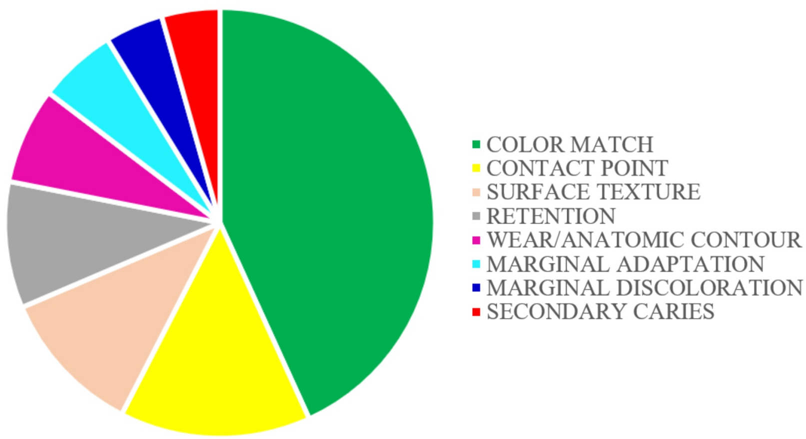

Figure 7. Distribution of reasons for failure in glass ionomer cement restorations.

tor, practice type, diagnosis, presence of removable dentures, endodontically treated teeth, bond type, composite type, and geographical location. Factors reported by a single study that found no significant difference were systemic diseases and graduation time.

In various studies, it has been found that as the number of surfaces involved or the size of the cavity increases, there is a significantly higher risk of restoration failure. This consistent trend highlights the critical role these factors play in the longevity of dental restorations.

When examining the location of the tooth, findings are inconsistent across different studies. Laske et al. (2016), Palotie et al. (2017), and da Silva Pereira et al. (2020) observed a higher risk of restoration failure in the mandibular arch compared to the maxillary arch, although this difference was statistically significant in only one study. Notably, Bernardo et al. (2007) found a significantly higher risk of composite resin restoration failure due to secondary caries in both arches. Conversely, Rho et al. (2013) noted higher restoration failure in the maxillary arch compared to the mandibular arch, but this finding was not statistically significant.

Regarding the type of tooth, there is a consistent observation that molars have a higher failure rate compared to premolars. This trend was significant in the majority of studies, except for those by Opdam et al. (2010), Kopperud et al. (2012) and da Silva Pereira et al. (2020). Furthermore, Balkaya & Arslan (2020), who compared composite resin restorations with glass ionomer cement restorations, found no significant difference in failure rates between premolars and molars.

The findings on gender differences in restoration failure are inconsistent among studies. Rho et al. (2013) and Laske et al. (2016) reported a significantly higher restoration failure rate in males compared to females. However, da Silva Pereira et al. (2020) observed a higher failure rate in males, which was not statistically significant, and Kopperud et al. (2012) found no significant gender difference.

Age consistently appears as a significant factor, with studies showing higher restoration failure rates in children and elders compared to young adults. This age-related trend underscores the need for tailored dental care strategies for different age groups.

Poor oral hygiene and high caries risk are consistently associated with higher restoration failure rates. Studies consistently demonstrate this correlation, with Al-Asmar et al. (2023) also reporting a higher rate of composite resin restoration replacements in patients with poor oral hygiene.

Lastly, the findings regarding the operator are inconsistent. Kopperud et al. (2012) and da Silva Pereira et al. (2020) found no significant difference among operators. However, Rho et al. (2013) identified significant differences within the operator group (student, resident, professor), with higher restoration failure rates observed among residents and professors.

Overall, risk factors like the number of surfaces involved or size of cavity, type of tooth, age and caries risk or oral hygiene have shown a consistent association or influence on restoration longevity.

4 Discussion

A total of seventeen studies were selected for comparison and evaluation in this systematic review based on the PICOS elements along with the set inclusion and exclusion criteria mentioned above (see **Figure 1** and **Table S1**). Ten studies compared composite resin restorations with amalgam restorations, and seven studies compared composite resin restorations with glass ionomer cement restorations.

The clinical efficacy of direct restorative materials has been evaluated in many clinical trials. However, the results of these evaluations remain controversial, as reported in various studies and reviews comparing different studies. The comparison of different types of direct restorative materials by different studies and authors was challenging for several reasons, as also observed and reported by Manhart et al. (2002). Firstly, there were wide variations in the study characteristics, particularly in sample size and follow-up duration. Secondly, the outcome parameters varied among the studies, and some parameters were not well-defined or well-assessed, with different statistical methods being used to determine the results. Thirdly, improvements or modifications in materials could have occurred over time, different material brands were used, and different clinical protocols or procedures were followed in various studies. Apart from the study design itself, internal factors such as patient-, dentist-, and oral-related factors varied among the studies. Nevertheless, despite these limitations, certain trends were observed by comparing the outcomes of different clinical studies with the same objective, while also considering the drawbacks identified in these studies.

4.1 Longevity

To evaluate the clinical effectiveness of different restorative materials, the primary outcome studied in this review was longevity. Longevity is a major decision-making factor when choosing a restorative material (Fernandes et al., 2015). Unknown to most patients and some clinicians, dental restorations have a finite longevity and are likely to be repaired or replaced at some point in time (Aliaga et al., 2015). The prognosis of a restoration is related to the condition in which it was performed, including the accuracy of diagnosis and treatment, oral hygiene level, caries risk, parafunctional habits, the number of surfaces involved, depth of the cavity, etc. With the increase in the use of amalgam alternatives, it is important for clinicians to be informed about the longevity, indications, and risks associated with using a particular restorative material for a given clinical situation (Dutra et al., 2015).

For easier discussion, composite resin versus amalgam restorations will be considered as group 1, whereas composite resin versus glass ionomer cement restorations will be considered as group 2.

4.1.1 Composite resin vs. amalgam

One of the most controversial and inconclusive topics concerns the longevity and performance of composite resin restorations compared to amalgam restorations. Comparing different included studies, the survival or success rate for composite resin restorations varied from 54 to 100%, whereas for amalgam restorations, it varied more broadly from 48 to 100%. Considering the data reported by the studies, the results are inconsistent. However, there is a slight tendency towards better longevity for amalgam restorations compared to composite resin restorations.

Considering all study characteristics, including sample size distribution, follow-up period, evaluation method, and risk factors, as well as the trend observed from comparing all the data provided by the studies included in this parameter, the author of this review finds and suggests that amalgam restorations, when properly executed, tend to exhibit better longevity compared to composite resin restorations due to their superior mechanical properties. However, composite resin restorations can perform similarly to amalgam restorations if carried out accurately, especially when the conditions required for the material to achieve maximum strength, retention, and bonding to the tooth structure are understood. This is particularly true for patients with low caries risk, good oral hygiene, and minimal or absent parafunctional habits. It is crucial to note that once a composite resin restoration begins to fail, its deterioration tends to be rapid, necessitating periodic follow-up and early detection to allow for timely repair or replacement.

Sample size and distribution. An important point to note is that when the sample size is equal but too small (Kemaloglu et al., 2016) or too different to compare effectively (Al-Asmar et al., 2023; da Silva Pereira et al., 2020; Kopperud et al., 2012; Laske et al., 2016; Opdam et al., 2010; Palotie et al., 2017), the power of the study may be limited, which may prevent reliable extrapolation of findings and thus provide inconclusive or unreliable results. Hence, these studies should be interpreted cautiously. Unsurprisingly, out of the ten included studies, the majority had more composite resin restorations compared to amalgam restorations, except for three studies (Al-Asmar et al., 2023; da Silva Pereira et al., 2020; Opdam et al., 2010). This reflects the shift towards minimally invasive, adhesive dentistry and the phasedown of dental amalgam.

Follow-up period. While most of the studies in this group had at least five-years of follow-up, Kemaloglu et al. (2016) is the only study with a shorter follow-up period of three years. It is reported that short-term studies have limited reliability since most restorative materials perform well in the initial years, and it may take several years for differences to become apparent. However, such studies are also essential to detect early catastrophic failures, which can then be excluded or improved upon (Opdam et al., 2014). For example, two of the longer follow-up studies (Laske et al., 2016; Opdam et al., 2010) of twelve years reported significantly better survival for composite resin restorations, whereas Palotie et al. (2017), the longest follow-up study in this group at thirteen years, reported comparable performance between the two restorative materials. Soncini et al. (2007), with a five-year follow-up, suggested that differences in replacement rates could become significant with longer follow-up, as there was a widening gap observed in the survival analysis curves along with a significant difference in repair rates.

Further points noted during analysis. Opdam et al. (2010) is the only study that assessed the materials in different caries risk categories for posterior permanent teeth. In the same study, a decrease in the annual failure rate (AFR) of composite resin restorations was noticed at the twelve-year follow-up compared to the five-year follow-up, whereas a double increase in the AFR of amalgam restorations was noticed at the twelve-year follow-up compared to the five-year follow-up. The study also found the highest survival of composite resin restorations in low caries risk patients.

Rho et al. (2013) reported that despite the significant difference in longevity favoring amalgam restorations, the clinical performance was comparable and showed no significant differences, suggesting a rapid progression of composite resin restoration failure. Apart from the findings already presented, Laske et al. (2016) also reported that glass ionomer cement restorations (with an AFR of 13.9%) and compomer restorations (with an AFR of 13.2%) have shorter survival compared with amalgam restorations (with an AFR of 5.2%) and composite resin restorations (with an AFR of 4.6%).

While considering the limitations or drawbacks, Laske et al. (2016) suggested that the effect of indication bias must be assumed. Palotie et al. (2017) went deeper into comparison by investigating the effect of two surfaces and three surfaces on the longevity of the materials and found that composite resin restorations are significantly affected by the increasing number of restored tooth surfaces. Comparing the survival rates of the restorative materials found in the studies, it was noticed that Rho et al. (2013) and Laske et al. (2016) have reduced rates compared to other studies. This could be due to the retrospective, practice-based nature of the study, which involved restorations from the 1990s. While Rho et al. (2013) used modified USPHS criteria for evaluation, Laske et al. (2016) collected the data from electronic patient files.

4.1.2 Composite resin vs glass ionomer cement

Comparing different included studies, the survival or success rate for composite resin varied from 96.9% to 100%, whereas for glass ionomer cement restorations, the survival range was broader and varied from 54.3% to 100%. Considering the data reported in the studies, overall, composite resin restorations consistently performed slightly better compared to glass ionomer cement restorations, although this was nonsignificant in the majority of the included studies, except for Rozniatowski et al. (2021).

Meanwhile, taking into account all the study characteristics such as sample size, follow-up period, risk factors, etc., along with the trend found from comparing all the data provided by the studies included in this parameter, the author of this review finds and suggests that composite resin restorations, when carried out correctly, have consistently and slightly better longevity compared to glass ionomer cement restorations due to their superior mechanical properties. However, glass ionomer cement restorations, when carried out correctly, have the capacity to perform similarly to composite resin restorations as observed from the studies and, in fact, have better performance compared to composite resin restorations in certain clinical situations such as uncooperative children, elderly, high caries risk, difficulty in isolation, etc.

Sample size and distribution. Unlike in group 1, the samples here were distributed more or less equally in all the studies. Unfortunately, the sample size was smaller. As mentioned previously, when the sample size is too small, it is difficult to ascertain whether it is a true effect or chance variation, i.e., if the same result would be produced when repeated in other studies.

Follow-up period. Except for Gurgan et al. (2020), all the other included studies had a short follow-up period (less than five years). As mentioned previously, it can take some years for differences to start showing up in the performance of the restorative materials.

Therefore, short-term studies have limited reliability and further studies with large-sized samples and long follow-ups are required for more reliable outcomes. However, such studies are also useful to see if the restorative materials have early failure, which was indeed seen in the majority of the included studies, consistently in glass ionomer cement restorations.

Further points noted during analysis. As seen in the results, Balkaya and Arslan (2020) was the only study that reported a drastically lower survival rate for glass ionomer cement restoration. An attempt was made by the author of this review to further understand the reason for the higher failure of glass ionomer cement restorations in Balkaya and Arslan (2020). After comparing the restoration procedure executed, cavity class types, and patient risk categories included in the different selected studies, a few possible reasons for the lower survival rate of glass ionomer cement restorations in Balkaya and Arslan (2020) were noted down.

Firstly, the study included only class II cavities. While Rozniatowski et al. (2021) also included only class II, Gurgan et al. (2020) and Uzel et al. (2022) included both class I and II, and the other two studies (Bayazıt et al., 2023; Haitrili et al., 2021) included only class I. Secondly, no other study disinfected their cavity with 0.2 % chlorhexidine gluconate as was done in Balkaya and Arslan (2020). Thirdly, while extremely poor oral hygiene and severe periodontitis cases were excluded, it is still not clear if high caries risk patients were excluded or not, whereas the majority of the other included studies excluded high caries risk patients. Fourthly, the study mentioned the use of calcium hydroxide as a cavity liner or base in deep cavities, which was not reported to be used in other studies except for one other study (Gurgan et al., 2020). Fifthly, the outcome could also be different depending on the operator's skill. All these factors could be considered and assessed in future studies to ascertain if a true association is present or not.

Meanwhile, according to the author of this review, Gurgan et al. (2020) reported an incorrect conclusion, i.e., a 100% survival rate for glass ionomer cement restoration despite having two failed restorations (reducing the survival rate to 96%) after four years, which was then lost during the ten-year follow-up. The author of this review argues that the survival rate should continue to be reported as 96% at the ten-year follow-up while no other failures were reported. It is also worth mentioning that this is the only study in the group that went further to understand the difference between the performance of two materials in two different cavity class types (class I and class II) for each of the secondary outcomes assessed.

Bayazıt et al. (2023) mentioned that patients with high caries activity were included in the study, which is probably why the survival rates for both materials were lower compared to the majority of the studies in this group. Rozniatowski et al. (2021) is the only study in this group that went further to assess the clinical and radiographic efficacy of both restorative materials separately, which shows the importance of radiographic follow-up and evaluation apart from clinical evaluation.

The author of this review was also intrigued by the wide variations between the survival rates of composite resin restorations in group 1 (composite resin vs amalgam) and group 2 (composite resin vs glass ionomer cement). The author proposes that this could be due to better controlled studies with small-sized groups and short follow-ups in group 2. Additionally, most of the studies in group 2 excluded patients with parafunctional habits and poor oral hygiene, and all the studies used absolute or relative isolation.

4.2 Secondary outcomes influencing longevity

For easier discussion, composite resin versus amalgam restorations will be considered as group 1, whereas composite resin versus glass ionomer cement restorations will be considered as group 2.

Secondary Caries. In group 1, composite resin restorations consistently showed a slightly higher failure rate due to secondary caries, but this was significant only in a minority of the included studies. In group 2, glass ionomer cement restorations exhibited a slightly higher risk of failure due to secondary caries in the studies that reported changes or failures, which were nonsignificant.

In group 1, while a higher failure rate due to secondary caries was observed in composite resin restorations across all studies, Bernardo et al. (2007) was the only study that reported the risk of developing secondary caries to be 3.5 times higher in composite resin restorations than in amalgam restorations. The study indicated that the risk of developing secondary caries in composite resin restorations was relatively higher for both arches, for molars, for restorations involving up to three surfaces, and for all restoration sizes. No significant differences were found in the risks concerning premolars or restorations involving four or more surfaces, probably due to small sample sizes. The increased risk of failure in high caries risk patients, particularly for composite resins, can be seen in Opdam et al. (2010), which reported a 2.5 times higher risk of failure in the high caries risk group compared to the low caries risk group. Meanwhile, Kemaloglu et al. (2016) was the only study in this parameter that reported no failures or changes. The author of this review proposes that this could be due to the use of bonding agents in amalgam restorations, relative isolation of both restorations, exclusion of participants with poor oral hygiene, or the operator's skill. These factors should be considered and assessed in future studies to determine if a true association is present.

Although direct comparisons cannot be made, studies such as Leinfelder (2000) and Manhart et al. (2002) have reported that faster caries progression was observed adjacent to composite resin restorations compared to amalgam restorations. This is attributed to some components in composite resins that promote bacterial *Streptococcus mutans* growth. Many studies (Bourbia et al., 2013; De Fucio et al., 2009; Demarco et al., 2012; Kuper et al., 2015; Opdam et al., 2007; Park et al., 2012) have reported a higher failure of composite resin restorations in poorly isolated or poorly restored teeth, in high caries risk patients, or in those with poor oral hygiene habits. These studies also highlight higher failure rates in children, teenagers, and elderly patients who are unable to maintain adequate oral hygiene. Conversely, studies such as Zhang et al. (2016) have found that novel composite resins do not accumulate more biofilm compared to amalgam or glass ionomer cements. Efforts are underway to make composite resins smarter and antimicrobial (Manhart et al., 2002; Sun et al., 2021). Further *in vivo* trials on human teeth are necessary to derive conclusive results. Meanwhile, reduced failures were observed in amalgam restorations, with only two studies reporting failures or changes in glass ionomer cement restorations due to this outcome measure. This is possibly because amalgam is said to have a bacteriostatic action due to the release of silver ions and an antimicrobial effect due to mercury, which likely lowers biofilm formation. Glass ionomer cements are known for their fluoride-releasing properties, which provide a bacteriostatic effect by reducing the bacterial load in saliva (Zhang et al., 2016). In the instances of failures seen in amalgam and glass ionomer cement restorations, factors such as poor oral hygiene, loss of adhesion, marginal defects, and rough surfaces accumulating plaque may contribute.

Loss of retention. In group 1, no clear trend or significant differences could be observed, whereas in group 2, glass ionomer cement restorations consistently showed slightly higher restoration failure due to loss of retention, although this was significant in only one of the included studies.

AlHumaid et al. (2018) have stated that a 95% and 90% retention rate after six and 18 months, respectively, is required for restorations to be accepted according to the American Dental Association guidelines. Considering this guideline, in group 1, amalgam restorations in Kopperud et al. (2012) exhibited a failure rate of 15.3%, whereas in group 2, glass ionomer cement restorations in Balkaya and Arslan (2020) demonstrated a failure rate of 28.6% due to loss of retention.

In group 1, Kemaloglu et al. (2016) was the only study in this parameter that reported no failures or changes, with possible reasons discussed in the above secondary outcome. In group 2, the lowest retention was reported by Balkaya and Arslan (2020) in glass ionomer cement restorations. The study proposed that this could be due to the inability to effectively apply a protective coating to the proximal wall of the glass ionomer cement restoration, leaving the proximal area unprotected from moisture contamination during the initial hardening phase, which can lead to the dissolution of the glass ionomer cement.

Additionally, glass ionomer cement could adhere to the metal matrix, causing slight pull or loss of the material upon removal of the matrix. This may create micro-cracks or poor adaptation of the material to the tooth margins, eventually leading to loss of retention. Apart from the reasons mentioned by the study, other possible causes for higher failure rates of glass ionomer cement restorations speculated by the author of this review have already been discussed in the primary outcome.

Meanwhile, according to Gurgan et al. (2020), Class II glass ionomer cement restorations had failures due to loss of retention at three and four-year follow-ups but not in the final follow-up period due to the dropout of these patients. The author of this review has argued that the failure percentage should have continued to be the same until the final follow-up period if no other failures were observed.

Considering the materials' established properties, a properly placed amalgam with retentive features and sufficient bulk to prevent fracture is regarded as the most retentive. In amalgam restorations, loss of retention could happen due to less retentive features in the prepared cavity, a lack of bonding to the tooth structure, or insufficient bulk. On the other hand, composite resins bond micromechanically to the tooth with the help of an adhesive and are found to have better bonding to enamel than to dentine. In composite resin restorations, loss of retention could occur due to polymerization shrinkage leading to stress, microleakage and secondary caries, a high configuration factor of the prepared cavity, or the use of weaker adhesive systems. However, composite resins can perform similarly to amalgam because of the adhesive system that reinforces the tooth structure (Bernardo et al., 2007; Opdam et al., 2010). Meanwhile, glass ionomer cements bond chemically to both enamel and dentine, with better adherence to enamel. In glass ionomer cement restorations, loss of retention could occur due to porosities in the set cement, desiccation, water absorption during the initial setting phase, low compressive strength, fracture resistance, and abrasion resistance.

Postoperative Sensitivity/Pain. In group 1, composite resin restorations consistently exhibited slightly higher restoration failure due to postoperative sensitivity or pain, but this was significant in only one of the included studies. In contrast, no failures were reported in either of the two restorative types in group 2.

In group 1, postoperative sensitivity could be higher in composite resins due to various factors such as operative trauma (excessive heating and drying of the tooth structure), contamination if isolation is not provided, use of etchants, polymerization shrinkage leading to stress and loss of adhesion or marginal leakage. The metal alloy in amalgam is known to be a good conductor of heat and cold. Therefore, deep cavities without a base, close to the pulp, can irritate the nerve and cause sensitivity or pain. Moreover, since amalgam does not bond to the tooth, microleakage at the tooth-restoration interface could be another cause. Another possible reason could be excessive drilling of the tooth for retention and extension for prevention philosophy.

In alignment with this, Kemaloglu et al. (2016) was the only study that reported an opposite outcome compared to other studies in this parameter. Kemaloglu et al. (2016) found a significant increase in postoperative sensitivity in amalgam restorations in the third year. The study suggested that this could be due to differences in etchant composition (citric acid and ferric chloride for amalgam restorations), primer composition (acetone for amalgam restorations), the number of application steps between the two restorative types (multi-step for amalgam restorations), and the increased thermal conduction of amalgam since the restorations were base-free.

In group 2, Bayazıt et al. (2023) reported a failure of glass ionomer cement restoration at the baseline, which was then endodontically treated as the pain did not subside. This could have occured due to an incorrect diagnosis or the treatment procedure. The lack of failures due to sensitivity or pain in glass ionomer cements could be due to their bioactivity, as discussed in the above secondary outcome.

Glass ionomer cements do have a high pH during the initial setting phase, but because the molecule size is large and has a high molecular weight, penetration into the dentinal tubules is difficult. However, slightly higher Bravo scores in glass ionomer cement restorations were reported by the studies. This could be due to loss of adhesion, marginal defects, the technique of preparing the cavity, depth of the prepared cavity, etc.

Marginal defect. In group 1, composite resin restorations exhibited consistently slightly higher failure due to marginal defects. This difference was nonsignificant in the majority of the included studies. In group 2, glass ionomer cement restorations tended to show slightly higher failure due to marginal defects, which was significant only in a minority of the included studies.

Marginal adaptation should be considered one of the critical factors in the success of a restoration, as several secondary outcomes such as secondary caries, loss of retention, postoperative sensitivity or pain, marginal discoloration, fracture of the restoration, and loss of contact area can be initiated due to poor marginal seal or adaptation. Therefore, a dentist has to strive for a high-quality marginal seal, if not a perfect one.

As discussed previously regarding secondary outcomes, in composite resins, the lack of enamel at gingival margins for bonding, ineffective etching of all tooth surfaces and margins, weak adhesive systems, contamination, polymerization shrinkage, the difference in coefficients of thermal expansion between the material and tooth structure, and accumulated fatigue from continuous occlusal forces could contribute to defects formed at the margins. Consequently, different placement methods, preparation and finishing techniques are being developed and used to achieve a better marginal seal. Certain properties, such as creep and corrosion, have been identified as potential reasons for marginal defects in amalgam. Despite these properties being possible reasons, studies like Mahler et al. (2009) and Osborne (2006) suggest that the corrosion products and creep expansion seal the marginal gaps and improve marginal adaptation, reducing failures due to marginal defects in amalgam restorations. In group 2, studies reporting the failure of glass ionomer cement restorations were observed to have included class II cavities except for Gurgan et al. (2020), which also included class II cavities but reported no failure. Other studies reporting no failure included only class I cavities. Balkaya and Arslan (2020) reported a failure rate of 6.3% at one-year follow-up and a reduced rate of 4.8% at two-year follow-up, potentially due to dropouts. The author of this review argues that once a failure is reported, it should continue to be monitored in subsequent observation periods, even if there were dropouts of those failed cases.

The tendency for higher failure of glass ionomer cement restorations could be attributed to reasons previously discussed regarding secondary outcomes, including the lack of protective coating at margins, especially in proximal areas, moisture contamination during the initial hardening phase, and adherence of the material to the metal matrix.

Marginal discoloration. In group 1, composite resin restorations consistently exhibited a slightly higher restoration failure due to marginal discoloration compared to amalgam restorations. This was significant in only one of the included studies. In group 2, glass ionomer cement restorations tended to show slightly higher failure due to marginal discoloration, which was significant in only a minority of the included studies.

Studies like Demarco et al. (2012) and Signori et al. (2022) have noted that confusion can arise between marginal discoloration and secondary caries, leading to overestimation of either. While various methods exist for detecting secondary caries or marginal discoloration, visual inspection is the most commonly used, often leading to confusion.

Marginal discoloration of composite resins can be attributed to material properties (such as type of composite, filler particle size, etc.), restoration techniques (such as cavity type, margin finish lines, frequency and duration of etching the tooth, effective isolation, adhesive system, polymerization method, finishing and polishing, polymerisation shrinkage, leading to stress, marginal gaps, and discoloration, etc.), diet, and oral hygiene habits. In amalgam, marginal discoloration may be observed due to the penetration of corrosion products. Nevertheless, the tendency for failure due to marginal discoloration in amalgam restorations was less than that of composite resin restorations. This could be due to intrinsic pigmentation caused by amalgam on the tooth structure.

In glass ionomer cement, factors such as water sorption, high porosity, cavity type, margin finish lines, marginal gaps, diet, and oral hygiene habits may contribute to marginal discoloration. Gurgan et al. (2020) also mentioned that compared to class I restorations, class II restorations showed a significantly higher risk of failure due to this parameter. Meanwhile, two other studies (Balkaya & Arslan, 2020; Rozniatowski et al., 2021) which included only class II restorations reported higher failure rates for glass ionomer cement restorations. Bayazıt et al. (2023) included high caries risk patients. These studies seem to support the aforementioned possible reasons for glass ionomer cements; there is a higher risk of failure in proximal cavities of glass ionomer cement restorations and in patients with poor oral hygiene habits.

Wear. In group 1, composite resin restorations showed a slightly higher tendency for restoration failure due to wear or loss of anatomic contour, which was significant in only one of the included studies. In group 2, glass ionomer cement restorations showed a slightly higher tendency for restoration failure due to wear or loss of anatomic contour, which was significant in only a minority of the included studies.

Wear presents itself as a consequence of occlusal interaction and is significant, especially in posterior teeth with large cavities. Low wear resistance can lead to outcomes such as the loss of contact points, loss of retention, fractures, postoperative sensitivity or pain, and secondary caries due to marginal gaps. Restorative materials, as well as tooth structures, wear over time. Therefore, a material with similar characteristics and wear resistance to enamel is preferred.

In composite resins, wear resistance depends on the composition and characteristics of the filler particles, opposing tooth factors, and the presence or absence of parafunctional habits. Meanwhile, although amalgam has high wear resistance, it can also experience wear over time, particularly due to corrosion. Compared to amalgam, both adhesive materials cannot accommodate the strain. Glass ionomer cements are known to have low wear resistance. The improved variant, along with resin coating, claims to provide better wear resistance. As only one study reported absolute failure and other studies reported slightly higher Bravo scores, it appears that the high viscosity glass ionomer cement, used in the majority of studies, performs better than conventional glass ionomer cement regarding wear resistance. Resin coatings promise to provide a protective layer yet can also wear out over time. Further improvements are needed as studies still indicate a higher risk of failure in glass ionomer cement restorations.

Poor color match. In group 1, only one study assessed this outcome and reported that amalgam restorations showed higher restoration failure due to poor color match. In group 2, glass ionomer cement restorations showed slightly higher restoration failure due to poor color match, which was significant in half of the included studies.

Color stability is crucial in anterior teeth or in patients with high aesthetic expectations who require a natural appearance of the filling even in posterior teeth. In group 1, possibly due to obvious aesthetic differences, no other included study assessed this outcome. Composite resins have a superior advantage in this aspect; however, long-term color stability remains a concern as these restorations can become stained or discolored over time, depending on the material composition, accuracy of shade matching, etching frequency and duration, polymerization method, finishing and polishing, diet, oral hygiene habits, and smoking habits. Meanwhile, amalgam is aesthetically unappealing, which is a primary reason for its decline in demand amidst the increasing focus on aesthetics. Corrosion products can eventually discolor the rest of the tooth structure, giving it a grey-black appearance. High viscosity glass ionomer cements offer more translucency and color options compared to conventional ones. Nevertheless, in group 2, Gurgan et al. (2020) reported that, compared to the baseline, there was a significant color change in glass ionomer cement restorations. A significant change was also observed in class II glass ionomer cements compared to class II composite resin restorations. Factors such as the nature of the reinforcing particle, exposure of the material to external factors during the initial setting phase, solubility, porosity of the set material, water absorption, continuous maturation, diet, oral hygiene habits, and smoking habits are possible contributors to color changes.

Loss of surface texture. In group 1, no failures were reported in either of the two restoration types, whereas in group 2, glass ionomer cement restorations showed consistently higher restoration failure due to loss of surface texture, significant in the majority of the included studies. In group 1, although no failures were reported, slightly higher Bravo scores were observed in composite resin restorations, which was not significant. Wear and surface texture can be interrelated and, therefore, the reasons are similar. Factors such as material composition, filler size, the use of matrix bands, polymerization method, finishing and polishing, nature of the opposing tooth or restoration, oral hygiene habits, and the presence or absence of parafunctional habits may influence the surface texture of composite resin restorations. The surface texture of amalgam may depend on carving, polishing, wear, and corrosion. Increased surface roughness in glass ionomer cement restorations was observed in several studies (Balkaya & Arslan, 2020; Hatirli et al., 2021; Kharma et al., 2018; Uzel et al., 2022), possibly due to low wear resistance, loss of resin coating, brushing, or occlusal forces.

Restoration and Tooth Fracture. In group 1, no clear trend could be observed for restoration failure due to restoration fracture. However, amalgam restorations showed higher restoration failure due to tooth fracture.

In group 1, the failure due to restoration fracture is almost comparable between the two restorative types, with a slight increase in amalgam restorations. It is worth mentioning that the risk of fracture in composite resin was comparable or slightly less, due to the adhesive system that reinforced the tooth-restoration system and the higher elasticity or lower brittleness of the material. Traditional amalgams cannot strengthen the tooth structure and, moreover, the dimensional changes could eventually lead to gaps, cracks, or fractures. Additionally, extensive tooth preparation for the retention of amalgam restorations weakens the tooth structure, causing more fractures in teeth restored with amalgam.

Opdam et al. (2010) reported that in low caries risk groups, more amalgam restorations failed due to tooth fracture and cracked tooth syndrome. Meanwhile, Kemaloglu et al. (2016) reported no tooth fractures in amalgam restorations. According to their study, this is due to the use of bonded amalgams, which increased the fracture resistance at the tooth-restoration interface. Kopperud et al. (2012) reported a significant failure in restorations made with Filtek Z100 (92 restorations) compared with other resin composites and also a significant failure in restorations using Ana-Single-Bond (94 restorations) compared to other bonding agents. This likely explains the higher failure rate in composite resin restorations due to restoration fractures. At the same time, their study also reported a higher failure rate in amalgam restorations due to tooth fractures.

A higher risk of restoration fracture can be seen in composite resins when the number of surfaces or the size and depth of the cavity increase, as adhesion is affected in these cases. Other risk factors such as dietary and parafunctional habits need to be considered. Many studies discuss a potential increase in composite resin restoration fractures when glass ionomer cement is used as a base or liner, or when certain types of etch techniques are used.

In group 2, three studies (Balkaya & Arslan, 2020; Hatirli et al., 2021; Rozniatowski et al., 2021) reported retention and fracture together, which was already analyzed when discussing retention outcomes. Glass ionomer cement restorations have low fracture resistance, and increasing the cavity size leads to a higher risk of fractures.

Loss of contact point. In group 1, no clear trend or significant difference could be reported in this aspect, but there was no great difference between the two restorative types. However, in group 2, only one study assessed this outcome and reported a significantly higher restoration failure in glass ionomer cement restorations.

Building a proximal wall with a good marginal seal is one of the most challenging tasks for a dentist. Natural proximal contour is necessary for both the teeth and the periodontium to minimize food impaction, inflammation, plaque accumulation, etc. It seems that the contour of the contact point or area largely depends on the restoration technique rather than the material alone. It depends on the operator's knowledge and skill, whether a matrix system or interdental wedge was used, the complete adaptation of the chosen matrix system with the help of interdental wedges, the location of the gingival margin of the prepared cavity, the fracture resistance of the material, etc.

In the case of amalgam, a strong condensing force can be used against the prepared walls, matrix, and adjacent tooth. However, in the case of adhesive materials, due to their viscoelastic nature, difficulties can arise in doing the same. Studies suggest that higher failure rates in glass ionomer cement restorations due to loss of contact points or altered shapes of contact areas may be due to the inability to apply resin coating at the proximal surface, contamination during the initial setting phase, adherence to the matrix band, etc.

Primary caries In group 1, composite resin restorations showed consistently slightly higher restoration failures due to secondary caries compared to amalgam restorations. This outcome is similar to secondary caries. Only one study (Soncini et al., 2007) reported a different outcome with a slightly higher rate of primary caries in amalgam restorations compared to composite resin restorations, but this was found to be nonsignificant as well.

4.3 Risk factors

While assessing different outcome measures, it was understood that numerous factors are associated with a restoration's success or longevity. The survival of restorations depends not only on material-related factors but also on patient-, oral-, and dentist-related factors. Therefore, it is important for dentists to know which material can be best used in the clinical situation presented to them.

Material-related factors such as strength, fracture resistance, wear resistance, abrasion resistance, type of bonding to the tooth structure, bond strength, complexity level of the technique, caries-initiating or inhibiting effects, composition, and concentration of certain components, are found to be associated with or are expected to affect the aforementioned secondary outcomes. With respect to dentist-related factors, the outcome may be related to the operator's knowledge, skill, accuracy, experience, decision-making threshold for repair or replacement, practice organization and type, and the time since graduation. Oral-related factors include the location and type of the tooth, the number of surfaces and size of the prepared cavity, the depth of the prepared cavity, the position of the prepared cavity margins, the quality of the remaining tooth structure, the nature of opposing teeth, existing prostheses, caries risk, periodontal condition, and quality of saliva. Meanwhile, patient-related factors such as age, gender, oral hygiene habits, parafunctional habits, other general habits, systemic diseases, socioeconomic status, individual expectations and needs, and cooperation during and after treatment, may be related to the outcome.

Some of the included studies have assessed or reported a few of the above-mentioned risk factors, which were tabulated by the author of this review to identify tendencies and significance. Overall, risk factors such as the number of surfaces involved, the size of the cavity, the type of tooth, age, and caries risk or oral hygiene have shown a consistent association or influence on the longevity or performance of direct restorations.

Bernardo et al. (2007) reported higher survival rates for single-surface and small-sized cavities in both amalgam and composite resin restorations, but this was found to be non-significant. Composite resin restorations with four or more surfaces had the lowest survival rates among all. The study also reported that amalgam restorations performed better irrespective of these factors. Meanwhile, Al-Asmar et al. (2023) reported higher failure rates in large-sized amalgam restorations compared to small-sized amalgam restorations. Soncini et al. (2007) observed a significant increase in the need for replacement with increasing size of the restoration, the highest failure rates being in large-sized composite resin restorations and small-sized amalgam restorations. Opdam et al. (2010) reported significantly better survival in both three-surface and four or five-surface composite resin restorations after twelve years, although such differences were absent at five years. Premolars offered better survival of restorations compared to molars, especially in composite resins, as the cavities are usually smaller, the intensity of occlusal forces is less, and access is easier. Accessibility is an important factor for dentists when it comes to composite resin restorations, as the procedure is technique-sensitive, and for patients in terms of performing oral hygiene.

Significantly higher failure rates were observed in 1) medium or large-sized compared to small-sized, two or more surfaces compared to one surface, and class II compared to class I restorations (likely due to the direct effect of occlusal forces), 2) molars compared to premolars (likely due to a larger surface area), 3) children, teenagers, and the elderly compared to young adults (likely due to neglect or incapacity in performing oral hygiene), and 4) high caries risk or poor oral hygiene compared to low caries risk or good oral hygiene (likely due to higher plaque accumulation and bacterial load).

Although direct comparisons cannot be made, these findings are in line with other studies. Sunneg et al. (2009) found that class II restorations were most often replaced, especially with composite resin, followed by class I and class IV, and that the longevity of composite resin restorations was lower in high caries risk patients compared to low or moderate caries risk patients.

Burke and Lucarotti (2009) reported similar findings with respect to cavity type, noting an increase in the potential for fracture as teeth became heavily restored. They also mentioned that restorations placed in older patients had less longevity. Simecek et al. (2009) reported that caries risk and the number of involved surfaces affect the longevity of restorations, especially with composite resins.

Noaman and Fattah (2021) reported a synergistic relationship between secondary caries development and restoration replacement related to caries risk and oral hygiene level, particularly in class II cavities. Correa et al. (2012) reported similar findings with respect to caries risk and cavity characteristics.

Similarly, McCracken et al. (2013) reported that old age and higher numbers of surfaces are significant risk factors associated with restoration failure. Kim et al. (2013) also reported a significant influence of various factors such as cavity classification, type of tooth, type of restorative material, gender, age, and operator. They stated that the controversy could be resolved if materials were compared according to cavity classification and emphasized the importance of timely check-ups and repair of composite resin restorations.

Demarco et al. (2012) found that secondary caries, which were absent during the initial follow-up in composite resin restorations, appeared between the five- and seven-year follow-up. This supports the findings reported in the discussion on the primary outcome (longevity of composite resin restorations) that regular follow-up and timely intervention are required for better survival of composite resin restorations.

The study evaluated different risk factors influencing the longevity of restorations, with the majority including patient-related risk factors such as the number of restored surfaces, type of tooth, caries risk, parafunctional habits, periodontal status, age, general health, and endodontic treatment. Although studies have found such associations, regardless of the type of material used, restorative procedures carried out in high caries risk patients could be unsatisfactory.

Apart from the risk factors mentioned by the studies, the author of this review sought to determine if any other common factors or trends were present. Out of the ten included studies in group 1, two studies used a rubber dam and one study used a cotton roll and suction for isolation. This aspect was noted since composite resin is said to be technique-sensitive and most affected by moisture contamination. Bernardo et al. (2007) found a significant difference between the materials that were performed under isolation, whereas Soncini et al. (2007) and Kemaloglu et al. (2016) found no significant difference.

In group 2, all the studies used either rubber dam or cotton roll isolation, which could be one of the reasons for the better performance of composite resin restorations in this group. Kharma et al. (2018) is the only study in this group that used a rubber dam and also reported no failures. Although direct comparisons cannot be made, a study by Jardim et al. (2020) found no significant difference in the longevity of amalgam restorations and composite resin restorations when performed under a rubber dam. Meanwhile, a systematic review by Heintze and Rousson (2012) found a significant impact on the longevity of restorative materials when a rubber dam was used. Therefore, the impact of isolation and type of isolation needs to be examined further when comparing the two materials.

Opdam et al. (2010) discussed the use of cavity liners. Without a cavity liner, composite resin restorations showed fewer fractures. Bernardo et al. (2007) and Soncini et al. (2007) also did not use liners, which resulted in fewer fractures of composite resin restorations. On the other hand, da Silva Pereira et al. (2020) used a cavity liner and found no significant difference between the two restorative types. The materials used by different studies were cross-checked for availability in the market and were found to be in use to the present date. No tendency for higher failure could be found with respect to the brand or composition of the material, etching technique, or finishing and polishing technique, although some studies have mentioned their influence on the longevity of the restorations. This was examined since failure can also occur due to operative processes involving adherence to the 'extension for prevention' principle, aspiration of odontoblasts, heat and friction, lubricant contamination, disinfection of the prepared cavity, use of certain restorative materials, iatrogenic damage, etc.

Clinical practice has shifted towards prevention rather than cure and repair rather than replace restorations as much as possible. When it comes to repairing, composite resin restorations are easier to repair than amalgam restorations. Studies have reported a significant increase in the survival time of restorations when monitoring, repairing, or refurbishing is performed rather than replacing. Replacement is now considered as the last resort (Wilson et al., 2016; Schwendicke et al., 2016). However, this decision-making process can be challenging and widely varied depending on the scenario presented in clinical practice, along with dentist and patient-related factors. Prime importance is given to preventing the need for restorations with the help of critical examination of all tooth surfaces and the use of advanced caries detection techniques; using less aggressive caries excavation and tooth reduction methods; sealing and bonding the restorations well; and regularly monitoring the restored teeth. Regardless of the method opted for, re-treatment is a disadvantage as it requires time, further removal of tooth structure, materials, and costs more or less the same as the original restoration.

Treatment cost is another factor that has not been discussed by the included studies. However, using the New England Children's Amalgam Trials, Khangura et al. (2018) observed that amalgam restorations were more economical with better longevity when compared to composite resin restorations that took relatively more time to be placed, were more expensive, and had slightly less longevity. Correa et al. (2012) also discussed the cost-effectiveness of the materials, with amalgam restorations being more economical. The study mentioned the possible influence of companies investing in the development of composite resin materials. Therefore, the role of the market should also be taken into account by dentists, who must carefully navigate the multiple options present, sticking to materials backed by sufficient trials. Insurance companies and their policies also seem to influence the choice of material opted for by the patient or dentist.

Finally, there is an ongoing debate regarding the biocompatibility of these direct restorative materials and environmental safety, which needs to be addressed and resolved. Further studies are required to explore all these factors and the possibility of their influence on the performance or longevity of direct restorations. As discussed above, many factors are related to the patient, oral conditions, and dentist rather than the material itself. Therefore, dentists need to focus on these factors, with a strong emphasis on preventing dental diseases.

4.4 Strength, limitations and future research

To the author's best knowledge, no systematic review has been published in the last sixteen years comparing the clinical effectiveness of amalgam, composite resin, and glass ionomer cement in posterior permanent teeth based on the extensive list of primary and secondary outcome measures mentioned in this review, along with the assessment of risk factors. As dentistry increasingly embraces minimally invasive techniques, direct restorations will gain importance due to the smaller cavity sizes, enabling alternative materials to perform better. Therefore, this review aims to provide readers with an overview of the clinical effectiveness of the three direct restorative materials, identify the risk factors influencing their performance, and compile information on the clinical studies conducted on this topic so far.

This review highlights the evident lack of high-quality clinical studies or trials with head-to-head comparisons, inclusion of large-sized groups to account for high dropout rates, adequate random sequence generation and allocation sequence concealment, follow-up periods of at least five years, low risk of bias, and homogeneity between datasets. An improvement is required in the overall reporting of results, as errors were found, necessitating contact with the authors. Only the corrected data from these communications have been included in this review. Since effectiveness varies across materials, considering clinically relevant differences due to material properties, additional risk factors, and outcomes may provide better insights and aid clinicians in the decision-making process. Caries risk and parafunctional habits should be noted because they are associated with increased susceptibility to restoration failure. For better comparisons and conclusions, studies should report the size, depth, and cavity classification along with the type of teeth involved. Dentists need to document the reasons for placing or replacing restorations to improve diagnostic and treatment planning skills and for investigative and practice-based studies. To enhance dental service and patient care, it is crucial to identify and record potential risk factors for restoration failure. Many studies assess failure or survival based on routine clinical observations and dentists' judgments during follow-ups, rather than following standard criteria such as USPHS or FDI criteria, which can introduce bias.

Meta-analyses and systematic reviews are considered the highest quality of scientific evidence. In this study, a systematic review was conducted using various study types, including randomized clinical trials, retrospective, prospective, and cross-sectional studies. Discussing the study types used in a comparative review is important as the quality and reliability of outcomes vary depending on the study type, such as university-based versus practice-based research networks, longitudinal versus cross-sectional, and short-term versus long-term (Bayne, 2007).

As many studies have indicated, randomized clinical trials are considered the best study design for comparing treatments. However, limitations such as research cost, time commitment, number and skill of investigators, changes in materials or brands, and impractically long follow-up periods exist (Manhart et al., 2002). Additionally, not all research questions may be answered. Results from such studies may not accurately reflect general dental practice conditions. These studies often use specific criteria such as USPHS or FDI for a limited number of restorations, which are then evaluated and compared in detail by calibrated practitioners. Ideally, these studies show the potential of the restorative material under examination (Laske et al., 2019). Conversely, practice-based studies are less controlled and may have biases, confounding factors, and data pollution; thus, careful interpretation of results is necessary (Laske et al., 2016). To determine the survival time of many restorations over a long period, cross-sectional or retrospective studies based on available dental practice records seem more suitable. Cross-sectional surveys differ from controlled clinical trial studies, where clinicians operate under near-ideal conditions that meet the investigated materials' indications (Manhart et al., 2002).

It has been reported that in clinical trials, longevity turns out to be comparable when direct comparisons are made. However, in cross-sectional retrospective studies, the longevity of amalgam restorations is found to be approximately twice that of composite resin restorations. This discrepancy is possibly due to the better training of operators and more motivated patients in clinical trials, where restorations are performed without time constraints. In contrast, cross-sectional studies involve operators with varying skill levels and diverse patient populations with all types of risks (Opdam et al., 2007). Regardless, in both study types, results heavily depend on the dentists' skills and require consideration of confounding factors.

For a clear survival analysis of restorations, recording the date of placement and the date of failure or the end of the follow-up period is important. Failure may be defined differently by various stakeholders involved in the treatment—patients, operators, insurance companies, researchers, and governments—depending on their perspectives and interests. Anusavice (2012) defines success as a restoration on which no intervention has occurred and survival as a restoration still functioning and (partially) in place. In studies assessing survival, repairs may not be considered failures, whereas in studies assessing success, they may be. Consequently, survival rates appear higher when repairs are not counted as failures (Demarco et al., 2012).

Laske et al. (2019) mentioned that annual failure rates are preferred as an outcome measure because they can be calculated for all observation times, whereas median survival can be calculated only after at least 50% of the restorations have failed. The study also reports significant variations in failure rates when success and survival were distinguished for direct restorations along with other restoration-related variables. Furthermore, the annual failure rates varied widely among different studies evaluating the same type of restoration. This calculation was problematic as the progression of restoration failure was not a linear function (Manhart et al., 2002). Opdam et al. (2011) indicated that restorations prone to early failure show a lower median survival time compared to those prone to late failure, thus not providing a true measure of overall restoration longevity. Kaplan-Meier analysis is considered the gold standard for evaluating the longevity of restorations as it utilizes information from both failed and non-failed restorations optimally. Unfortunately, only a few studies employ this method. The study also found that survival data calculated from the median age of failed restorations differ from those derived from Kaplan-Meier analysis. Although Kaplan-Meier analysis is preferred, and median survival time often underestimates the longevity of restorations, it is considered the best available data for comparing the longevity of different restorative materials in various clinical settings (Opdam et al., 2011). Thus, using different study designs is essential for obtaining a comprehensive understanding.

While randomized clinical studies often portray higher survival rates, they can also lead to overestimation of failure rates due to stringent criteria (Laske et al., 2019). A restoration might be classified as failed due to marginal discolorations, exposed dentine surfaces, or lack of proximal contact, even if it is still functioning well and may continue to do so for years. Such restorations might need repairs, and considering these minor interventions demands a separate analysis. Besides using predefined criteria, considering the patient's perspective is also valuable. While a dentist might see marginal discoloration as a failure, a patient may not. Clear and unified definitions of outcome measures and evaluation criteria would facilitate better comparisons of studies.

Conclusions

Establishing the effectiveness of direct restorative materials, namely dental amalgam, composite resin, and glass ionomer cement, is a multifactorial process. This systematic review evaluated their efficacy in light of recurrent influencing secondary outcomes and risk factors affecting permanent posterior teeth restorations.

While it was observed that amalgam restorations demonstrated slightly better longevity, composite resins and glass ionomer cement restorations performed equally well under certain conditions. It was observed that the primary causes of failure varied among the three restorative materials. Four recurring risk categories were also identified in this review.

This review provides insights for both clinical trials and dental practices. Future clinical trials can ensure more accuracy and homogeneity by including details regarding patient characteristics or oral condition, the reason for placing or replacing a restoration, the date of placement along with failure or end of follow-up period where applicable, clearly defined outcome measures, and evaluation criteria, along with other standardized study characteristics.

Meanwhile, dentists should properly assess the clinical situation, striving to provide holistic, multifaceted care rather than narrowly focused care. This approach entails taking into account the appropriate indications, challenges posed by material properties, common reasons for failure of the selected restorative material, and other multiple risk factors.

While focus is often placed on material-related factors, patient-, oral-, and dentist-related factors significantly impact performance and longevity. Each direct restorative material has distinct advantages and disadvantages. An ideal restorative material that meets all criteria and exhibits long-lasting performance has yet to be discovered.

Acknowledgements

Not applicable.

Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Consent for publication

Not applicable.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

Author notes

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