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# Longevity of posterior composite restorations: Not only a matter of materials

Flávio F. Demarco<sup>a,\*</sup>, Marcos B. Corrêa<sup>a</sup>, Maximiliano S. Cenci<sup>a</sup>,  
Rafael R. Moraes<sup>a</sup>, Niek J.M. Opdam<sup>b</sup>

<sup>a</sup> Graduate Program in Dentistry, School of Dentistry, Federal University of Pelotas, RS, Brazil

<sup>b</sup> Department of Restorative and Preventive Dentistry, Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands

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## ABSTRACT

Resin composites have become the first choice for direct posterior restorations and are increasingly popular among clinicians and patients. Meanwhile, a number of clinical reports in the literature have discussed the durability of these restorations over long periods. In this review, we have searched the dental literature looking for clinical trials investigating posterior composite restorations over periods of at least 5 years of follow-up published between 1996 and 2011. The search resulted in 34 selected studies. 90% of the clinical studies indicated that annual failure rates between 1% and 3% can be achieved with Class I and II posterior composite restorations depending on several factors such as tooth type and location, operator, and socioeconomic, demographic, and behavioral elements. The material properties showed a minor effect on longevity. The main reasons for failure in the long term are secondary caries, related to the individual caries risk, and fracture, related to the presence of a lining or the strength of the material used as well as patient factors such as bruxism. Repair is a viable alternative to replacement, and it can increase significantly the lifetime of restorations. As observed in the literature reviewed, a long survival rate for posterior composite restorations can be expected provided that patient, operator and materials factors are taken into account when the restorations are performed.

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## 1. Introduction

Direct restorations have been largely employed to restore posterior teeth due to their low cost and less need for the removal of sound tooth substance when compared to indirect restorations, as well as to their acceptable clinical performance [1–4]. Despite the fact that both amalgam and composite resin are considered suitable materials for restoring Class I and Class II cavities, some advantages can be related to composite restorations such as better esthetics; their adhesive

properties, resulting in reduced preparation size [5]; and reinforcement of the remaining dental structure [6]. A clinical study has shown that painful vital teeth with incomplete fractures can be treated successfully by replacing the amalgam fillings with bonded composite restorations [7]. On the other hand, posterior composite restorations have been shown to produce higher failure rates due to secondary caries [8,9]. However, although used in many practices around the world, amalgam is facing its demise, leaving resin composite as the most likely material for posterior restorations for widespread use in the near future.

\* Corresponding author at: Graduate Program in Dentistry, Federal University of Pelotas, Rua Gonçalves Chaves 457, 96015-560 Pelotas, RS, Brazil. Tel.: +55 53 3222 6690x135; fax: +55 53 3222 6690x135.

E-mail addresses: [flavio.demarco@pq.cnpq.br](mailto:flavio.demarco@pq.cnpq.br), [ffdemarco@gmail.com](mailto:ffdemarco@gmail.com) (F.F. Demarco).

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Even though acceptable survival rates are achieved with Class I and II restorations in dental health care, the replacement of failing restorations is still a relevant issue. Dentists still spend a significant amount of time replacing restorations, contributing to the repetitive restorative cycle described by Elderton [10]. Factors related to the patient, operator, tooth, cavity size, and materials have been reported in the literature as potentially relevant for restoration failures [2,3,8,11–13], although evidence of this is still limited.

Despite the considerable differences in properties among commercial composites as found in laboratory analysis [14–20], *in vitro* tests are limited in predicting the clinical survival of composite restorations. Due to the constant influx of new posterior restorative materials on the market and the need for manufacturers to prove the clinical safety of their new materials, there has been an emphasis on relatively short-term clinical studies with a limited number of restorations, mostly placed in low-risk patients. In those studies, differences in performance are seldom found, as most materials perform well on a short-term basis, with a few exceptions [21,22].

To estimate how long posterior composite restorations last, long-term studies are needed to identify modes of failure and possible reasons for these failures. In a comparative amalgam–composite study after 5 years, no differences in performance were found; after 12 years, however, the composite showed significantly better performance [12]. Given the considerable differences between (non-bonded) amalgam and composite and the fact that, after 5 years, no differences in performance were observed, it is not likely that the majority of composite restorations will show different longevity when investigated before at least 5 years of clinical service. Because of limited observation times of most clinical studies [4], limited information is available on the performance determinants and reasons for the failure of posterior composite restorations in the long term. Although the rapid evolution of composites makes it difficult for long-term evaluations to be conducted using materials still available in the market, the good results shown with previous and presently available materials in clinical studies [3,4,12] foster the question of whether new materials are actually improvements, and the authors tend to conclude that this is not likely. This means that, based on the available long-term studies, especially studies with observation times exceeding 5 years, an expectation regarding the long-term behavior of posterior composite restorations can be made. In the present article, we aim to review and discuss, with an emphasis on the available long-term literature, the longevity of posterior composite restorations, and the main factors associated with restoration failures.

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## 2. Methods and results

### 2.1. Selection of papers

To investigate the longevity of composite restorations as reported in clinical studies in the dental literature, a PubMed search for articles that evaluated longitudinal data for posterior resin composite restorations published between 1996 and 2011 was performed. The terms used in the search were

‘posterior composite restorations’ and ‘survival’ or ‘longevity’ or ‘failure’. After selecting only papers reporting clinical longevity studies of composite restorations with evaluation periods of at least 5 years, a total of 34 papers reporting on varied materials, techniques, and methods of evaluation was found. The selected papers included prospective and retrospective clinical studies, as well as longevity studies based on secondary data. Excluded for longevity assessment were cross-sectional studies as these are considered to deliver unreliable data with respect to longevity [23]. The selected papers were searched for the reported longevity outcome, expressed in annual failure rates (AFRs) or median survival, and factors associated with composite failure as mentioned by the respective authors.

### 2.2. Longevity of posterior composite restorations

From Table 1, the following conclusions regarding the longevity of posterior composite restorations can be made: on average, the AFRs of Class I and II posterior composite restorations placed in vital teeth vary between 1% and 3%. This is in accordance with the results reported in the most recent review published by Manhart et al. [4]. For endodontically treated teeth, the AFRs vary from 2% to 12.4%.

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## 3. Aspects that influence longevity

### 3.1. Clinical

Clinical related factors play an important role in restoration longevity and causes of failure. Several studies have indicated that the position of the tooth in the mouth or the tooth type directly affects restoration longevity, with restorations in premolars showing better performance than those in molars [2,3,24–26]. One paper reported a risk of restoration failure twice as high for molars compared to premolars [24]. One study with a 22-year observation time found the risk of failure of restorations placed in lower molars to be 3 times higher than the risk of failure in upper premolars [3]. However, a study on large restorations of 3 or more surfaces did not find differences between the longevity in molars and premolars [12].

The findings mentioned above are explained by the knowledge that restorations placed in molar teeth are subjected to higher masticatory stresses than restorations placed in premolars. Similarly, cavity size, cavity type, and the number of restored surfaces are related to the failure risk. In this context, multi-surface restorations, extensive cavities, and Class II restorations, are more likely to fail than single-surface and Class I restorations [2,3,9,13,24,26–29]. One study showed that Class II restorations have a relative risk of failure of 2.8 compared to Class I restorations, and that restorations with 3 or more surfaces have a relative risk of failure of 3.3 in relation to single-surface restorations [2]. Another study calculated that every surface more resulted in an increased risk of failure of 40% [24].

Two papers reported an increased risk of failure with a higher number of restored teeth per patient [9,13]. These patients may be considered to have a higher risk of caries,

**Table 1 – Results from the literature search: clinical trials with follow-up periods of at least 5 years published between 1996 and 2011.**

Author, year	Evaluation period/study design <sup>a</sup>	Materials tested	Evaluated restorations	AFR <sup>b</sup> /outcome/survival rate of composite	Factors associated with composite failure
Da Rosa Rodolpho et al., 2011 [3]	22 years, RL	Composite	Class I and II	AFR: between 1.5% and 2.2%	Tooth type, cavity size, material
Opdam et al., 2010 [12] Fokkinga et al., 2008 [104]	12 years, RL 17 years, PL	Composite vs. amalgam Composite	Large Class II Endodontically treated teeth with or without a prefabricated metal post	AFR: 1.68% AFR: 2.8% (restoration level) and 1.2% (tooth level)	Caries risk No factors associated
Bernardo et al., 2007 [8] Opdam et al., 2007 [24]	7 years, PL 9 years, RL	Composite vs. amalgam Composite	Class I and II Class II with a total-etch technique or with glass-ionomer lining	AFR: 2.1% AFR: 1.3% (total-etch) and 3.3% (glass-ionomer lining)	Secondary caries Presence of a lining, caries risk
Opdam et al., 2007 [13]	5 and 10 years, RL	Composite vs. amalgam	Class I and II	AFR: 1.7% (5 years) and 1.8% (10 years)	Amount of restored surfaces
Soncini et al., 2007 [9]	5 years, PL	Amalgam vs. composite/composer	Children aged 6–10 with more than one posterior restoration	AFR: 2.98%	Number of restorations, cavity size
Lindberg et al., 2007 [105]	9 years, PL	Composite/composite-composer open sandwich	Class II	AFR: 1.1%	No factors associated
Gordan et al., 2007 [55] Da Rosa Rodolpho et al., 2006 [2]	8 years, PL 17 years, RL	Composite Composite	Class I and II Class I and II	AFR: 0% AFR: 2.4%	Not investigated Tooth, cavity type, cavity size
Burke et al. and Lucarotti et al., 2005 [27–29,37]	Up to 10 years, RS	Amalgam, composite and glass-ionomer	Class I and II	AFR: 8.4% (5 years) and 5.7% (10 years)	Operator: age, country of qualification, employment status; Clinical: cavity size, root filling; Patient: age, charge-paying status, practice assiduity
Nagasiri et al., 2005 [106]	5 years, RL	Composite, amalgam and OZE	Endodontically treated molars	AFR: 12.4%	Remaining coronal tooth structure
Mannocci et al., 2005 [107]	5 years, PL	Amalgam/composite with post, endodontically treated tooth	Class II	AFR: 2%	More root fracture with amalgam, more secondary caries with composite
Opdam et al., 2004 [40]	5 years, RL	Composite	Class I and II placed by dental students	AFR: 2.6%	Operator: year of graduation; Clinical: proximal contact status
Andersson-Wenckert et al. 2004 [30]	9 years, PL	Composite and glass-ionomer, open sandwich	Class II	AFR 3.2%	Not investigated
Coppola et al., 2003 [39]	5 years, RS	Composite vs. amalgam	Posterior restorations with 2 surfaces at least	Average longevity: 42 months	Dentist experience
Hayashi and Wilson, 2003 [108]	5 years, PL	Composite	Class I and II	AFR: 3.76%	Marginal deterioration, cavomarginal discoloration

- Table 1 (Continued)

Author, year	Evaluation period/study design <sup>a</sup>	Materials tested	Evaluated restorations	AFR <sup>b</sup> /outcome/survival rate of composite	Factors associated with composite failure
Pallesen and Qvist, 2003 [25]	11 years, PL	Composite, direct vs. indirect	Medium to large Class II	AFR: 1.45%	Tooth type
Turkun et al., 2003 [76]	7 years, PL	Composite	Class I and II	AFR: 0.82%	No factors associated
van Nieuwenhuysen et al., 2003 [26]	5-22 years, RL	Amalgam, composite and crowns	Posterior extensive restorations	Average survival time: 7.8 years	Clinical: tooth type, extension of restoration, pulpal vitality, use of base material; Patient: age, 3-year period of treatment
Busato et al., 2001 [109]	6 years, PL	Composite	Class I and II	AFR: 2.5%	Not investigated
Gaengler et al., 2001 [31]	10 years, PL	Composite with glass ionomer cement	Class I and II	AFR: 2.6%	Not investigated
Kohler et al., 2000 [51]	5 years, PL	Composite	Class II	AFR: 5.5%	Caries risk
van Dijken, 2000 [110]	11 years, PL	Composite, direct inlays/onlays and restorations	Class II	AFR: 1.6% (inlays/onlays) and 2.5% (direct restorations)	Tooth type
Wassel et al., 2000 [111]	5 years, PL	Composite, direct vs. inlay	Class I and II	AFR: 1.5%	Not investigated
Lundin and Koch, 1999 [112]	5 and 10 years, PL	Composite	Class I and II	AFR: 2% (5 years) and 2.1% (10 years)	Not investigated
Raskin et al., 1999 [41]	10 years, PL	Composite	Class I and II	AFR: 8.6%	Not investigated
Wilder et al., 1999 [113]	17 years, PL	Composite	Class I and II	AFR: 1.4%	Not investigated
Collins et al., 1998 [73]	8 years, PL	Composite	Class I and II	AFR: 1.71%	Not investigated
Mair, 1998 [74]	10 years, PL	Composite vs. amalgam	Class II	100% of success	Not investigated
Nordbo et al., 1998 [75]	10 years, PL	Composite	Saucer-shaped Class II	AFR: 3.0%	Not investigated

Studies using secondary data are highlighted in gray.

<sup>a</sup> R: retrospective; P: prospective; L: longitudinal; S: secondary data acquisition.

<sup>b</sup> AFR: annual failure rate.

which would explain the higher rates of restoration failures observed in these patients.

The type of the substrate on which the composite is placed could also affect the restoration longevity. The use of a glass-ionomer base under an adhesive restoration was shown to decrease restoration survival compared with total-etch restorations [24], with fracture as the main reason for failure. It is not yet clear, however, whether thickness and type of glass-ionomer cements play a role in the failure behavior. Other clinical studies in which a base of glass-ionomer was used also showed increased failure by fracture over time [2,3,26,30,31], but the absence of a restorative control group placed using total-etch bonding procedure in those studies or a lack of specifications for the applied liner makes it impossible to draw more definitive conclusions. It is also possible that extensive layers of calcium hydroxide linings and the amount of soft carious tissue left behind might affect the strength and longevity of composite restorations. Although there is clinical evidence that the removal of soft decayed tissue is not necessary to stop a caries process once a well-sealed restoration is placed [32,33], it remains questionable whether this will reduce the strength of the restorative complex and increase the amount of failure in the long term [34,35].

From Table 1, it can also be concluded that posterior composite restorations placed in endodontically treated teeth have a reduced survival rate, which is explained by the extensive loss of tooth substance that these teeth suffer.

### 3.2. Operator

It is generally acknowledged that the operator is probably the most important factor in the longevity of a dental restoration. However, evidence from clinical studies does not support this assumption. Clinical studies on posterior restorations and clinical procedures in which more than one operator was involved, do not reveal differences in study outcome among the operators [13,36]. It is likely that every dentist who is aware that his work is involved in a clinical trial will work as accurately as possible, resulting in fewer operator failures that could influence the study outcome.

However, secondary data studies suggest that the operator significantly influences the longevity of a restoration and mention relevant factors such as age, country of qualification and employment status [27–29,37]. Moreover, it is the dentist who decides whether a restoration needs to be replaced. From those secondary data studies, it is known that patients changing dentist have an increased chance that their restorations will be replaced [27–29,37]. Reduced lifetime for composite and amalgam restorations has been reported for patients changing dentists [38], being this effect accounted to the high level of variability in diagnostic decisions among clinicians. A more conservative approach toward restoration replacement would, therefore, lead to increased restoration longevity.

Technique-related aspects of a posterior restoration rely on the knowledge and sufficient skills of the operator. A study conducted by Coppola et al. [39] revealed that efficient working dentists produce restorations with a higher survival rate than inefficient working providers. In that study [39], a decision-making approach was used to measure relative efficiencies of operators by considering multiple inputs and

outputs regarding clinical decisions in order to identify the most efficient providers. Other study has shown that inexperienced undergraduate students were more closely associated with certain types of restoration failures than more experienced students [40].

In the past, dentists complained about difficulties in achieving adequate proximal contact when placing a posterior composite, and this was also found in a clinical study [41]. Nowadays, techniques have evolved in that respect, and the operator can now use several types of matrices and separation rings that result in even tighter contact than before the treatment [36,42,43].

The often-mentioned problems of post-operative sensitivity related to posterior composite restorations may be related to adhesive procedures having not been done properly due to the inappropriate selection of adhesive materials and techniques or the application of materials not in accordance with the manufacturers' instructions. It has been found in several studies that self-etch adhesives lead to less sensitivity [44–47], though, in recent literature, the sensitivity problem seems to be less prominent, which might be related to greater experience among dentists with increased knowledge concerning the proper application of state-of-art adhesive agents and increased use of self-etch materials. A relatively recent study on post-operative sensitivity found that this was mainly related to the cavity size and concluded that most sensitivity had disappeared over time [48].

Some clinicians tend to make restorations of very high quality when it comes to the color and anatomy of the restoration [49,50]. However, these restorations are never subjected to longevity evaluation, and it is unlikely that these esthetic quality aspects have any influence on posterior restoration survival in general. Moreover, these types of composite restorations, as inspiring they can be for the colleague dentist, are not feasible to place in everyday practice.

### 3.3. Patients

Although evidence is limited, it is likely that the type of patient and the oral environment play an important role in the survival of dental restorations. The caries risk of patients has been shown to significantly influence the longevity of restorations. Among the selected studies, several investigated the caries risk and found increased risk of failure of restorations placed in patients with caries risk [12,24,51]. Restorations in a high-caries risk group had a failure rate more than twice as high compared to low-risk patients [12]. In that study, the caries risk was established by the treating dentist based on the dental history and the expected risk of new lesion [52]. Another study that used a caries risk assessment also showed that high-caries risk patients have increased risk of failure of posterior composite restorations [53]. In a study on direct posterior restorations in children, those with a high DMFT index had an increased risk of restoration failure [35].

In investigating the prevalence of satisfactory posterior composite restorations in a birth cohort, a higher prevalence of unsatisfactory restorations at the age of 24 was observed in patients exhibiting a higher level of dental caries at the age of 15 [54]. Clinical prospective studies performed in university clinics that evaluate the longevity of restorations of



new materials are likely to include only motivated patients with good oral health and, consequently, low caries risk. This would explain why, in some prospective clinical trials, a high survival rate is found in the absence of secondary caries, or with very few restorations failing due to secondary caries [41,55], while cross-sectional studies have shown that caries are the most important reason for the replacement of composite and amalgam restorations [56–59]. Also, when restorations are performed in patients with a higher economic status in a private clinic, secondary caries do not seem to be a main reason for the failure of posterior composite restorations [2,3].

Tooth and restoration fracture also are important reasons for restoration failure. It is, therefore, likely that bruxing habits such as grinding and clenching play an important role in fatigue development in the tooth-restoration complex, resulting in fracture in the long term. The diagnosis of bruxism is not easy, and diagnostic tools for this are not always reliable [60]. Sometimes, it is mentioned in the inclusion criteria for a clinical study that “bruxing patients were excluded from the sample”, with no mention of the criteria used for such a diagnosis. A clinical 3-year study on the longevity of composite restorations placed in patients with severe tooth wear showed unfavorable results compared to ‘normal patients’, indicating that the destructive mouth habits of these patients (probably with bruxism) resulted in more failures [61]. In a study on cracked teeth [7], it was speculated that clenching habits might play a role in the etiology of cracked and fractured teeth, an important reason for the failure of amalgam restorations in particular [12]. Currently, no validated criteria are available to assess bruxing habits, either for grinding nor clenching; thus, conclusions regarding a direct relationship between bruxism and restoration failure, although such a relationship is very likely, are still not possible.

Post-operative sensitivity is a patient-related factor, such as pain experience and amount of discomfort, that can vary between patients. In the past, post-operative sensitivity was acknowledged as an important problem for dentists working with composite restorations. However, as mentioned previously, post-operative sensitivity is more closely related to the adhesive system [46] or restorative technique approach [62] and is a less prominent problem in recent literature.

Esthetic demand from the patient is a further factor determining restoration longevity. High demand for esthetic perfectionism is likely to result in more restorations being replaced for esthetic reasons. However, in a retrospective clinical study less than 1% of large amalgam restorations were replaced due to esthetic reasons [12], and no posterior composite restorations were replaced due to esthetic reasons. Therefore, with respect to the longevity of posterior composite restorations, failure due to esthetic reasons seems to be very rare.

### 3.4. Socioeconomic

In addition to clinical variables, patient demographic, socioeconomic and behavioral variables may also affect the longevity of posterior restorations. Very few studies have investigated the association between these variables, but the findings suggest that such factors can play an important

role in the longevity of restorations. Burke et al. [11] analyzed data from General Dental Services in England and Wales between 1991 and 2002, involving a total of 503,965 restorations. While survival analysis showed no difference between genders, the age of the patients was significant, with older patients having a shorter interval before re-intervention.

As dental caries are strongly associated with social determinants experienced during the life course [63–65], it is possible that social determinants can also influence the longevity of restorations by the same pathway. However, this remains to be established, because most investigations on restoration longevity have focused on materials and techniques or cavity preparation features [2–4,66]. In addition, most of the clinical trials reporting the longevity of posterior restorations are carried out in university clinical settings [67] and population-based studies are very rare [11]. However, several retrospective studies have been conducted in general practices including at least some at-risk patients [2,3,9,12,13,24,51,68]. Moreover, many of the studies that analyzed patient factors used a statistical approach considering the tooth restoration as the unique unit of analysis. To analyze the influence of socioeconomic factors on restoration longevity, one should consider the fact that variation between subjects is great, and it is also important to consider the existing variation between the teeth of the same patient. A recent study in 24-year-old subjects from a birth cohort [54] used a multilevel statistical approach to consider variables at both the patient and tooth levels. This study showed that the socioeconomic trajectory from birth to age 15 was associated with posterior restoration failure, even after adjustment by tooth-level variables. People who had always lived in the poorest stratum of the population had more restoration failures than those who lived in the richest layer (odds ratio: 3.14; CI 95% 1.6–3.84) [54].

Other findings shown by a series of studies [27–29,37] have corroborated the idea that socioeconomic and behavioral variables act directly on the longevity of posterior restorations. The charge-paying status of the patient had an association with survival for charge-payers being slightly higher over 11 years than for non-payers. Also, a strong relationship between attendance frequency and survival time was observed, with restorations of more frequent attenders performing less well than those of less frequent attenders.

### 3.5. Material

*In vitro* studies on the properties of resin composites for the restoration of posterior teeth have shown considerable differences among commercially available materials. Differences in flexural and compressive strength [15–18,69], elastic modulus [14,16–18], fracture strength and toughness [19,70], hardness [15,16,69,71], and wear resistance [15,20,70,72], among others, have been shown to be significantly different among materials when laboratory techniques were used to compare the restoratives. Despite these considerable differences, which were usually considered to be a result of differences in organic matrix components, filler loading, or particle morphology/size, only minor differences in the clinical behavior of composite restorations placed with different

composite materials are often described in clinical studies [22,25,73–76].

A restriction in clinical trials is that long observation times are hardly feasible. As a result, most prospective clinical studies comparing different composites report short follow-up periods, showing no differences among the materials under investigation. A recent retrospective study, however, has shown that, after 22 years, differences in filler characteristics between composites affected their clinical performance [3], as superior longevity was observed for a higher filler-loaded composite (midfilled) compared with a minifilled material when restorations were evaluated in the long term. This study was the first to indicate that the physical properties of the composite may have some impact on restoration longevity. Fracture being the main reason for failure indicates that the midfilled composite, which has higher elastic modulus and hardness than the minifilled material, was less sensitive to long-term fatigue.

However, when the same population group was assessed after a 17-year follow-up [2], no significant differences among the materials could be observed, indicating that differences in clinical performance between composite materials with different properties may be significant only when the late failing behavior of composite restorations is taken into consideration. At the same time, it remains to be discussed whether these significant differences found after 22 years are relevant from the perspective of dental health care. Given the finding that, in most clinical studies, AFRs between 1% and 3% have been found for the composites used, one can speculate as to whether any relevant improvement in material properties can be made that would have a clinical impact. In other words, the resin composite materials for use in posterior teeth marketed in the last two decades may have a quality standard that is sufficient to fulfill the clinical requirements in most cases.

Nevertheless, numerous resin-based materials to restore posterior teeth are introduced into the market each year, claiming improved properties and presenting innovations in organic and inorganic components. A significant concern regarding clinical trials to compare different restoratives is that while a given composite is being assessed after a few years of clinical service, the material might not be available in the market anymore. The major change in the inorganic formulation of composites for posterior restorations in the past decade was the introduction of nanofilled composites, created in an endeavor to provide a material with superior polish and gloss retention for the anterior and posterior areas. Clinical evaluations of nanocomposites compared with traditional hybrids are increasingly available in the literature [77–84], but the evaluation periods are still short (up to 5 years) to draw any significant conclusions. To date, no major clinical differences have been reported between nanofilled and hybrid materials, except for perceived better surface appearance/polish for nanofills [81,82]. It is not likely that these nanofilled materials would show superior performance compared to hybrids when used in everyday situations including patients at all levels of risk. The main question will be whether these innovative materials will meet the standards that are, in the meantime, set by the available, mainly hybrid composites, showing that an AFR of 1–3% is feasible for the average Class II posterior composite restoration.

Microfilled composites, in contrast to hybrids, are generally not recommended for use in posterior restorations due to their lower fracture strength. Microfilled resin composites use an ‘organic filler’ approach, whereby inorganic particles and resin are cured, crushed and added to resin to produce the final composite material. The overall amount of filler that can be incorporated into these composites is limited, resulting in higher coefficients of thermal expansion and lower elastic moduli compared with conventional hybrids [85,86]. Even though a clinical study investigating posterior restorations limited in size showed favorable results for a microfilled composite [73], the same material showed poor clinical performance when used in large restorations and patients with tooth wear [61].

One of the most comprehensive studies on the impact of the formulation of restorative composites on their clinical performance was published in 2001 [87]. The effect of organic matrix components, filler composition and filler silanization were all addressed by clinically using experimental composites. The authors found that the resin formulation was a significant factor affecting wear, with a UDMA/TEGDMA-based formulation showing significantly higher wear resistance, while the silane and filler were not significant factors. However, the paper concentrated only on the wear of the restoratives, and the wear of current posterior composite restorations is not a clinical problem (see the following section of the paper). Nowadays, wear may be a problem mainly for patients with bruxing and clenching habits [88]. These patients may be served best with a wear-resistant composite when their lost tooth substances are to be replaced. However, results indicating the clinical performance of composite restorations placed in patients with severe tooth wear are limited.

Current changes in the organic phase of dental composites focus on reducing the polymerization shrinkage and stress associated with methacrylate-based materials [89,90]. A low-shrinkage, silorane-based resin composite was recently introduced, but clinical trials with this material are too recent and scarce to indicate any improvement in restoration longevity [68]. Likewise, as with the nanofilled composites, it can hardly be imagined that these materials will show superior performance compared to the current hybrid composites in terms of survival considering the main reasons for failure reported in the following section of the paper. Recent developments in cariology indicate that marginal leakage, often considered an important phenomenon negatively influencing restoration performance, is not relevant for secondary caries development [91,92]. However, there is always room for innovation [93], and novel materials might lead to clinical benefits even if they do not extend the survival of restorations, especially if new materials are designed to make the placement of resin-based composite restorations a less stressful and less technique-sensitive experience [94].

The material properties of the restorative composite for the posterior area, therefore, seem to have a minor effect on the longevity of restorations, provided that hybrid materials are used, as these materials have been shown to perform well to excellently when used in posterior composite restorations. Negative exceptions include some novel materials that turned out to be unacceptable shortly after being marketed [21,22],

which is a reason that short-term clinical trials of a minimum of 3 years are still needed before a dentist can use a material in a posterior restoration in a responsible way. Meanwhile, clinicians are advised to stick with hybrid materials, which can be considered the ‘gold standard’ for posterior composite restorations.

Other factors related to the restorative complex might influence the clinical behavior of composite fillings. The use of a lining material, as previously mentioned, has been shown to significantly affect the longevity of restorations [24,26]. Due to the possible increased risk of fatigue in the long term, a base or lining of glass-ionomer cement should not be applied when possible. The selection of an appropriate bonding agent, although significantly affecting the survival of Class V restorations [95], is usually described as having marginal to no [62,96–98] or a relatively low [44–46] impact on the clinical performance of posterior restorations. However, a well-performing dental adhesive may aid in reducing post-operative sensitivity. It is, therefore, advised that, when placing a posterior composite restoration, clinicians should use a ‘gold standard’ adhesive such as three-step, etch-and-rinse, or two-step, self-etch bonding agents.

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#### 4. Main reasons for failure

Table 2 shows the main causes of failure reported by the studies included in this review (Table 1). The two main causes of failure identified were fracture (restoration or tooth) and secondary caries. In a previous review, it was shown that early failures were more closely related to fractures, while studies with long periods of observation showed a trend to find more caries-related failures [1]. However, according to the present review, the same conclusion cannot be drawn since most long-term studies (more than 10 years of follow-up) showed a higher incidence of failure due to fracture than to caries [2,3,25]. Similarly, some of the 5–7-year follow-up studies showed higher proportions of failure due to secondary caries [8,9,51] than to fracture. Therefore, factors such as patient caries risk, the clinical setting of the study, and the socioeconomic characteristics of the population under study would be more determinant for the reasons for failure than the clinical age of the evaluated restorations [3,12,54]. Regarding secondary caries, a recurrent problem in the literature is the lack of standardized criteria for diagnosis among studies, which could directly affect their outcomes [92,99]. Few studies have addressed the specific criteria used for secondary caries diagnosis.

Other reported failure causes, such as failure due to endodontic reasons, pain, post-operative sensitivity, and esthetic reasons could be considered minor reasons for failure since they are individually related to less than 5% of the observations in the different studies shown in the tables. Also, some studies, especially reports published before 2000, pointed out marginal discoloration and marginal defects as cause of failure, responsible for 1–10% of the observations depending on the report. The study conducted by Raskin et al. [41] evaluating posterior composite restorations after 10 years

of clinical service is remarkable in that respect, as it found an AFR of 8.6%, which is very high compared to other studies. Moreover, the majority of the restorations were considered to have failed due to the loss of anatomic form, also seldom found as a reason for failure in other studies. It is remarkable that fracture was not found and that only two cases of secondary caries were found. This indicates that either the investigated material was extremely sensitive to wear or the applied criteria for the evaluation of restorations were mainly used for producing results in research rather than indicating that a restoration was really clinically unacceptable and needed to be replaced in the short term. However, wear and loss of anatomic form are seldom considered to be causes of failure in more recent studies. Since the revised studies had distinct purposes and used different evaluation tools and criteria for restoration assessment, certain variations in the attributed failure causes listed in Table 2 are not surprising.

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#### 5. Repair as an alternative to replacement

Failed restorations or restorations presenting small defects are routinely treated by replacement by most clinicians. Because of this, for many years, the replacement of defective restorations has been reported as the most common treatment in general dental practice, and it represents a major part of oral health care in adults [100]. When a restoration is replaced, a significant amount of sound tooth structure is removed and the preparation is enlarged [100,101]. Moreover, the general cost of a replacement may be higher than the cost of alternative treatments, such as the repair or resurfacing of restorations. These alternative treatments are reported to increase the longevity of amalgam and composite restorations [26,100–102]. Despite the promising results of these more conservative treatments, very few longitudinal studies have been published assessing repairs as an alternative to the replacement of restorations, and there are no studies with follow-ups longer than 7 years. Also, a recent publication showed that there is still room for improvement in teaching on the repair of restorations, especially composites, during undergraduate training [103].

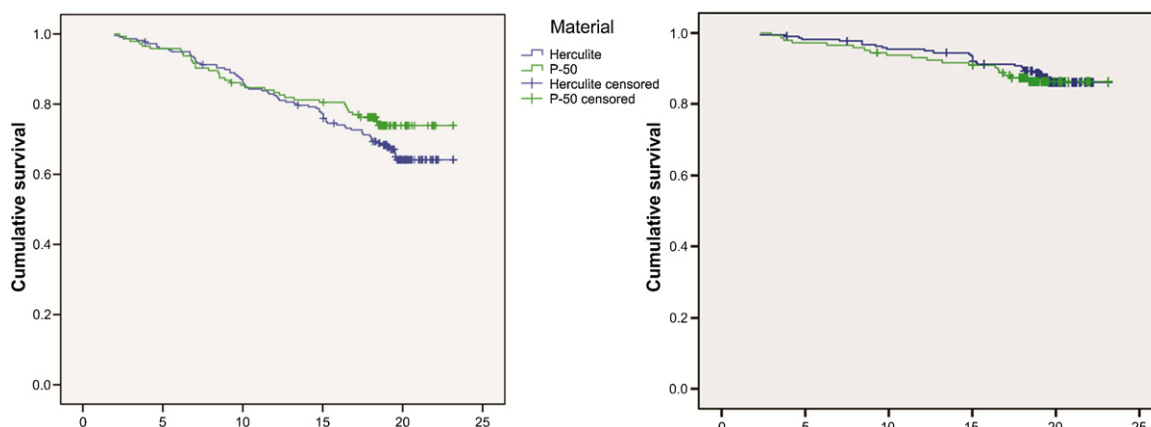
Our group has recently published an evaluation of up to 22 years of posterior composite restorations placed with two composites [3]. In that study, 61 of 110 failed restorations were repaired as an alternative to complete substitution. For statistical purposes in that publication, we considered both repaired and replaced restorations to be failures, and the AFR was 1.9% over 22 years (Fig. 1). However, when repaired restorations were considered successes instead of failures, the AFR decreased to 0.7%. These data corroborate the expressive impact of choosing more conservative treatments when dealing with restoration defects to prevent premature failures and improve restoration longevity. Fig. 2 shows representative pictures of a restoration evaluated on the 22-year follow-up study that was still clinically acceptable (Fig. 2A) or that have been repaired during the follow-up period (Fig. 2B). In the latter case, repair was considered an alternative to replacement, and the restoration was still clinically serviceable 7 years after being repaired.



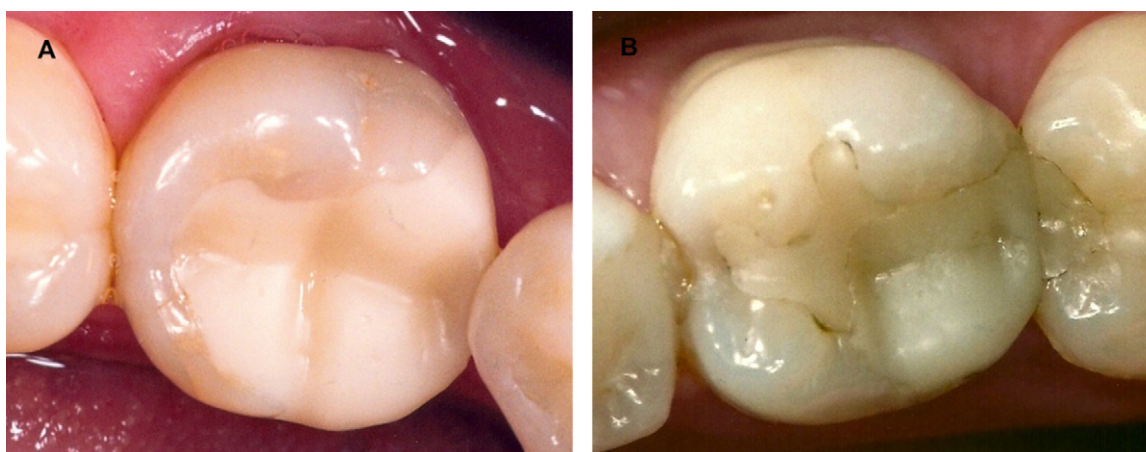
**Table 2 – Causes of failure of posterior composites according to the selected studies, shown in Table 1 recording clinical failures.**

Author, year	Period of evaluation	Type of restoration	Percentage of failure causes (in relation to the total number of evaluated restorations)					
			Restoration fracture	Secondary/primary caries	Tooth fracture	Endodontic treatment/pain	Esthetics	Extraction
Da Rosa Rodolpho et al., 2011 [3]	22 years		14.1	7.5	5.3	1.9	0.83	0.83
Opdam et al., 2010 [12]	12 years		0.9	8.2	1.4	3.5		
Bernardo et al., 2007 [8]	7 years		1.8	12.7				
Lindberg et al., 2007 [105]	9 years		2.3	5.9	0.7	2.2		
Opdam et al., 2007 [24]	9 years	Total-etch	1	7				
		Sandwich	22	13				
Opdam et al., 2007 [13]	5 and 10 years		0.61	5	1.3	1.4		1.1
Soncini et al., 2007 [9]	5 years		0.27	12.6				
da Rosa Rodolpho et al., 2006 [2]	17 years		18.8	7.8	1.8	1.8		3.9
Opdam et al., 2004 [40]	5 years		2.6	2.7	0.57	1.3		0.85
Pallesen and Qvist, 2003 [25]	11 years	Indirect composite	8.9	5.4	3.6			
		Direct composite	4.8	2.4				
Turkun et al., 2003 [76]	7 years			5.7				
Gaengler et al., 2001 [31]	10 years		1.5	2.6				
Kohler et al., 2000 [51]	5 years		1.6	9.5	1.6			
Van Dijken, 2000 [110]	11 years	Direct inlays/onlays	6.3	4.2	1.0			
		Direct composite	12.2	9.1				
Wassel et al., 2000 [111]	5 years	Indirect composite	1.6		1.6		3.1	
		Direct composite	3.1	1.6	4.7		1.6	
Raskin et al., 1999 [41]	10 years			3.3				
Wilder et al., 1999 [113]	17 years		2.3	3.5				
Nordbo et al., 1998 [75]	10 years			15.7				





**Fig. 1** – Kaplan–Meier survival curves for two composites evaluated over an up to 22-year observation period. When both repaired and replaced restorations were considered to be failures (left hand side graph), the AFR was 1.9%. On the other hand, when repaired restorations were considered to be successes (right hand side graph), the AFR decreased to 0.7%.



**Fig. 2** – Representative pictures of a restoration evaluated on the 22-year follow-up study [3] that was still clinically acceptable (A) or that have been repaired during the follow-up period (B). In (B), repair was considered an alternative to replacement and the restoration was still clinically serviceable 7 years after being repaired.

## 6. Overall considerations

Due to their esthetic properties and good clinical service, composites have become the preferred material for direct posterior restorations. When ‘gold standard’ hybrid composites are used, an AFR between 1% and 3% can be expected depending mainly upon factors other than material properties. The main reasons for the failure of posterior composite restorations are secondary caries and fracture. The failure of restorations related to the wear of these materials in the posterior region seems, nowadays, almost absent and may be restricted to bruxing and clenching patients. A review of the literature on long-term clinical trials of posterior composite restorations showed that the longevity of these restorations are influenced mainly by clinical variables (type, size, and location of the restoration), the quality and technique of the operator, socioeconomic factors such as income and type of dental service, demographic factors (age of patients) and behavioral aspects (caries prevalence).

There is little evidence that the material properties of the composite used are a relevant factor in restoration longevity, as it is only after extended periods of observation or in the presence of glass-ionomer cement base that significant differences in AFRs could be observed. Recent reports have shown satisfactory survival rates for posterior composite restorations, including hybrid materials that are no longer available in the market. Improvements in clinical performance should address the main reasons for failure. The main reasons for failure observed in clinical trials are still secondary caries and fracture (tooth or restoration), and neither may actually be a failure of the materials themselves. Secondary caries is a continuum of primary caries, being a failure of clinicians and patients to act effectively in the etiology of the disease, while fracture of the restoration or tooth can be related partially to the presence of a softer base under the restoration, such as a lining. To prevent fracture, the strongest materials with high fracture toughness should be used. Long-term clinical trials with nanofilled and low-shrinking composites, on the other hand, are still needed to prove their suitability to be

used in patients. Meanwhile, it is unlikely that these materials will provide a significant improvement, as good results are already achieved with the currently available posterior composite materials.

In conclusion, composite restorations have been shown to perform favorably in posterior teeth, with AFRs of 1–3%. To improve the success of these restorations, factors related to the patient and operator are of primary importance, indicating the need for prevention and a conservative approach toward restoration replacement. The improvement of material properties should address the prevention of secondary caries and a reduction in fracture incidence.

## REFERENCES

- [1] Brunthaler A, Konig F, Lucas T, Sperr W, Schedle A. Longevity of direct resin composite restorations in posterior teeth. *Clin Oral Investig* 2003;7:63–70.
- [2] da Rosa Rodolpho PA, Cenci MS, Donassollo TA, Loguercio AD, Demarco FF. A clinical evaluation of posterior composite restorations: 17-year findings. *J Dent* 2006;34:427–35.
- [3] Da Rosa Rodolpho PA, Donassollo TA, Cenci MS, Loguercio AD, Moraes RR, Bronkhorst EM, et al. 22-Year clinical evaluation of the performance of two posterior composites with different filler characteristics. *Dent Mater* 2011;27:955–63.
- [4] Manhart J, Chen H, Hamm G, Hickel R. Buonocore Memorial Lecture. Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition. *Oper Dent* 2004;29:481–508.
- [5] Cenci M, Demarco F, de Carvalho R. Class II composite resin restorations with two polymerization techniques: relationship between microtensile bond strength and marginal leakage. *J Dent* 2005;33:603–10.
- [6] Coelho-De-Souza FH, Camacho GB, Demarco FF, Powers JM. Fracture resistance and gap formation of MOD restorations: influence of restorative technique, bevel preparation and water storage. *Oper Dent* 2008;33:37–43.
- [7] Opdam NJ, Roeters JJ, Loomans BA, Bronkhorst EM. Seven-year clinical evaluation of painful cracked teeth restored with a direct composite restoration. *J Endod* 2008;34:808–11.
- [8] Bernardo M, Luis H, Martin MD, Leroux BG, Rue T, Leitao J, et al. Survival and reasons for failure of amalgam versus composite posterior restorations placed in a randomized clinical trial. *J Am Dent Assoc* 2007;138:775–83.
- [9] Soncini JA, Maserejian NN, Trachtenberg F, Tavares M, Hayes C. The longevity of amalgam versus compomer/composite restorations in posterior primary and permanent teeth: findings From the New England Children's Amalgam Trial. *J Am Dent Assoc* 2007;138:763–72.
- [10] Elderton RJ. Restorations without conventional cavity preparations. *Int Dent J* 1988;38:112–8.
- [11] Burke FJ, Lucarotti PS. How long do direct restorations placed within the general dental services in England and Wales survive? *Br Dent J* 2009;206:E2.
- [12] Opdam NJ, Bronkhorst EM, Loomans BA, Huysmans MC. 12-Year survival of composite vs. amalgam restorations. *J Dent Res* 2010;89:1063–7.
- [13] Opdam NJ, Bronkhorst EM, Roeters JM, Loomans BA. A retrospective clinical study on longevity of posterior composite and amalgam restorations. *Dent Mater* 2007;23:2–8.
- [14] Chung SM, Yap AU, Tsai KT, Yap FL. Elastic modulus of resin-based dental restorative materials: a microindentation approach. *J Biomed Mater Res B Appl Biomater* 2005;72:246–53.
- [15] de Moraes RR, Goncalves Lde S, Lancellotti AC, Consani S, Correr-Sobrinho L, Sinhoreti MA. Nanohybrid resin composites: nanofiller loaded materials or traditional microhybrid resins? *Oper Dent* 2009;34:551–7.
- [16] Ersoy M, Civelek A, L'Hotelier E, Say EC, Soyman M. Physical properties of different composites. *Dent Mater J* 2004;23:278–83.
- [17] Ilie N, Hickel R. Investigations on mechanical behaviour of dental composites. *Clin Oral Investig* 2009;13:427–38.
- [18] Rodrigues Junior SA, Zanchi CH, Carvalho RV, Demarco FF. Flexural strength and modulus of elasticity of different types of resin-based composites. *Braz Oral Res* 2007;21:16–21.
- [19] Shortall AC, Uctasli S, Marquis PM. Fracture resistance of anterior, posterior and universal light activated composite restoratives. *Oper Dent* 2001;26:87–96.
- [20] Turssi CP, Faraoni-Romano JJ, de Menezes M, Serra MC. Comparative study of the wear behavior of composites for posterior restorations. *J Mater Sci Mater Med* 2007;18:143–7.
- [21] Ernst CP, Martin M, Stuff S, Willershausen B. Clinical performance of a packable resin composite for posterior teeth after 3 years. *Clin Oral Investig* 2001;5:148–55.
- [22] Kramer N, Garcia-Godoy F, Frankenberger R. Evaluation of resin composite materials. Part II: in vivo investigations. *Am J Dent* 2005;18:75–81.
- [23] Opdam NJ, Bronkhorst EM, Cenci MS, Huysmans MC, Wilson NH. Age of failed restorations: a deceptive longevity parameter. *J Dent* 2011;39:225–30.
- [24] Opdam NJ, Bronkhorst EM, Roeters JM, Loomans BA. Longevity and reasons for failure of sandwich and total-etch posterior composite resin restorations. *J Adhes Dent* 2007;9:469–75.
- [25] Pallesen U, Qvist V. Composite resin fillings and inlays. An 11-year evaluation. *Clin Oral Investig* 2003;7:71–9.
- [26] Van Nieuwenhuysen JP, D'Hoore W, Carvalho J, Qvist V. Long-term evaluation of extensive restorations in permanent teeth. *J Dent* 2003;31:395–405.
- [27] Burke FJ, Lucarotti PS, Holder RL. Outcome of direct restorations placed within the general dental services in England and Wales (Part 2): variation by patients' characteristics. *J Dent* 2005;33:817–26.
- [28] Lucarotti PS, Holder RL, Burke FJ. Outcome of direct restorations placed within the general dental services in England and Wales (Part 3): variation by dentist factors. *J Dent* 2005;33:827–35.
- [29] Lucarotti PS, Holder RL, Burke FJ. Outcome of direct restorations placed within the general dental services in England and Wales (Part 1): variation by type of restoration and re-intervention. *J Dent* 2005;33:805–15.
- [30] Andersson-Wenckert IE, van Dijken JW, Kieri C. Durability of extensive Class II open-sandwich restorations with a resin-modified glass ionomer cement after 6 years. *Am J Dent* 2004;17:43–50.
- [31] Gaengler P, Hoyer I, Montag R. Clinical evaluation of posterior composite restorations: the 10-year report. *J Adhes Dent* 2001;3:185–94.
- [32] Maltz M, Oliveira EF, Fontanella V, Carminatti G. Deep caries lesions after incomplete dentine caries removal: 40-month follow-up study. *Caries Res* 2007;41:493–6.
- [33] Mertz-Fairhurst EJ, Curtis Jr JW, Ergle JW, Rueggeberg FA, Adair SM. Ultraconservative and cariostatic sealed restorations: results at year 10. *J Am Dent Assoc* 1998;129:55–66.

- [34] Hevinga MA, Opdam NJ, Frencken JE, Truin GJ, Huysmans MC. Does incomplete caries removal reduce strength of restored teeth? *J Dent Res* 2010;89:1270–5.
- [35] Trachtenberg F, Maserejian NN, Tavares M, Soncini JA, Hayes C. Extent of tooth decay in the mouth and increased need for replacement of dental restorations: the New England Children's Amalgam Trial. *Pediatr Dent* 2008;30:388–92.
- [36] Loomans BA, Opdam NJ, Roeters FJ, Bronkhorst EM, Burgersdijk RC, Dorfer CE. A randomized clinical trial on proximal contacts of posterior composites. *J Dent* 2006;34:292–7.
- [37] Burke FJ, Lucarotti PS, Holder R. Outcome of direct restorations placed within the general dental services in England and Wales (Part 4): influence of time and place. *J Dent* 2005;33:837–47.
- [38] Bogacki RE, Hunt RJ, del Aguila M, Smith WR. Survival analysis of posterior restorations using an insurance claims database. *Oper Dent* 2002;27:488–92.
- [39] Coppola MN, Ozcan YA, Bogacki R. Evaluation of performance of dental providers on posterior restorations: does experience matter? A data envelopment analysis (DEA) approach. *J Med Syst* 2003;27:445–56.
- [40] Opdam NJ, Loomans BA, Roeters FJ, Bronkhorst EM. Five-year clinical performance of posterior resin composite restorations placed by dental students. *J Dent* 2004;32:379–83.
- [41] Raskin A, Michotte-Theall B, Vreven J, Wilson NH. Clinical evaluation of a posterior composite 10-year report. *J Dent* 1999;27:13–9.
- [42] Loomans BA, Opdam NJ, Roeters FJ, Bronkhorst EM, Plasschaert AJ. The long-term effect of a composite resin restoration on proximal contact tightness. *J Dent* 2007;35:104–8.
- [43] Loomans BA, Opdam NJ, Roeters JF, Bronkhorst EM, Plasschaert AJ. Influence of composite resin consistency and placement technique on proximal contact tightness of Class II restorations. *J Adhes Dent* 2006;8:305–10.
- [44] Opdam NJ, Feilzer AJ, Roeters JJ, Smale I. Class I occlusal composite resin restorations: in vivo post-operative sensitivity, wall adaptation, and microleakage. *Am J Dent* 1998;11:229–34.
- [45] Opdam NJ, Roeters FJ, Feilzer AJ, Verdonchot EH. Marginal integrity and postoperative sensitivity in Class 2 resin composite restorations in vivo. *J Dent* 1998;26:555–62.
- [46] Perdigao J, Dutra-Correa M, Castilhos N, Carmo AR, Anauate-Netto C, Cordeiro HJ, et al. One-year clinical performance of self-etch adhesives in posterior restorations. *Am J Dent* 2007;20:125–33.
- [47] Unemori M, Matsuya Y, Akashi A, Goto Y, Akamine A. Self-etching adhesives and postoperative sensitivity. *Am J Dent* 2004;17:191–5.
- [48] Briso AL, Mestreneur SR, Delicio G, Sundfeld RH, Bedran-Russo AK, de Alexandre RS, et al. Clinical assessment of postoperative sensitivity in posterior composite restorations. *Oper Dent* 2007;32:421–6.
- [49] Deliperi S, Bardwell DN. Multiple cuspal-coverage direct composite restorations: functional and esthetic guidelines. *J Esthet Restor Dent* 2008;20:300–8.
- [50] Spreafico RC. Composite resin rehabilitation of eroded dentition in a bulimic patient: a case report. *Eur J Esthet Dent* 2010;5:28–48.
- [51] Kohler B, Rasmusson CG, Odman P. A five-year clinical evaluation of Class II composite resin restorations. *J Dent* 2000;28:111–6.
- [52] Alanen P, Hurskainen K, Isokangas P, Pietila I, Levanen J, Saarni UM, et al. Clinician's ability to identify caries risk subjects. *Community Dent Oral Epidemiol* 1994;22:86–9.
- [53] van Dijken JW, Sunnegardh-Gronberg K. Fiber-reinforced packable resin composites in Class II cavities. *J Dent* 2006;34:763–9.
- [54] Correa MB. Life course determinants of failure in posterior restorations: a multilevel approach. PhD thesis. Brazil: Graduate Program in Dentistry, Federal University of Pelotas; 2011.
- [55] Gordan VV, Mondragon E, Watson RE, Garvan C, Mjor IA. A clinical evaluation of a self-etching primer and a giomer restorative material: results at eight years. *J Am Dent Assoc* 2007;138:621–7.
- [56] Burke FJ, Cheung SW, Mjor IA, Wilson NH. Restoration longevity and analysis of reasons for the placement and replacement of restorations provided by vocational dental practitioners and their trainers in the United Kingdom. *Quintessence Int* 1999;30:234–42.
- [57] Qvist V, Qvist J, Mjor IA. Placement and longevity of tooth-colored restorations in Denmark. *Acta Odontol Scand* 1990;48:305–11.
- [58] Qvist J, Qvist V, Mjor IA. Placement and longevity of amalgam restorations in Denmark. *Acta Odontol Scand* 1990;48:297–303.
- [59] Sunnegardh-Gronberg K, van Dijken JW, Funegard U, Lindberg A, Nilsson M. Selection of dental materials and longevity of replaced restorations in Public Dental Health clinics in northern Sweden. *J Dent* 2009;37:673–8.
- [60] Abe S, Yamaguchi T, Rompre PH, De Grandmont P, Chen YJ, Lavigne GJ. Tooth wear in young subjects: a discriminator between sleep bruxers and controls? *Int J Prosthodont* 2009;22:342–50.
- [61] Bartlett D, Sundaram G. An up to 3-year randomized clinical study comparing indirect and direct resin composites used to restore worn posterior teeth. *Int J Prosthodont* 2006;19:613–7.
- [62] Perdigao J, Geraldini S, Hodges JS. Total-etch versus self-etch adhesive: effect on postoperative sensitivity. *J Am Dent Assoc* 2003;134:1621–9.
- [63] Peres MA, Peres KG, de Barros AJ, Victora CG. The relation between family socioeconomic trajectories from childhood to adolescence and dental caries and associated oral behaviours. *J Epidemiol Community Health* 2007;61:141–5.
- [64] Thomson WM. Dental caries experience in older people over time: what can the large cohort studies tell us? *Br Dent J* 2004;196:89–92.
- [65] Thomson WM, Poulton R, Milne BJ, Caspi A, Broughton JR, Ayers KM. Socioeconomic inequalities in oral health in childhood and adulthood in a birth cohort. *Community Dent Oral Epidemiol* 2004;32:345–53.
- [66] Demarco FF, Cenci MS, Lima FG, Donassollo TA, Andre Dde A, Leida FL. Class II composite restorations with metallic and translucent matrices: 2-year follow-up findings. *J Dent* 2007;35:231–7.
- [67] Wilson MA, Cowan AJ, Randall RC, Crisp RJ, Wilson NH. A practice-based, randomized, controlled clinical trial of a new resin composite restorative: one-year results. *Oper Dent* 2002;27:423–9.
- [68] Burke FJ, Crisp RJ, James A, Mackenzie L, Pal A, Sands P, et al. Two year clinical evaluation of a low-shrink resin composite material in UK general dental practices. *Dent Mater* 2011;27:622–30.
- [69] Borba M, Della Bona A, Cecchetti D. Flexural strength and hardness of direct and indirect composites. *Braz Oral Res* 2009;23:5–10.
- [70] Schultz S, Rosentritt M, Behr M, Handel G. Mechanical properties and three-body wear of dental restoratives and their comparative flowable materials. *Quintessence Int* 2010;41:e1–10.



- [71] de Moraes RR, Marimon JL, Schneider LF, Sinhoreti MA, Correr-Sobrinho L, Bueno M. Effects of 6 months of aging in water on hardness and surface roughness of two microhybrid dental composites. *J Prosthodont* 2008;17:323–6.
- [72] Moraes RR, Ribeiro Ddos S, Klumb MM, Brandt WC, Correr-Sobrinho L, Bueno M. In vitro toothbrushing abrasion of dental resin composites: packable, microhybrid, nanohybrid and microfilled materials. *Braz Oral Res* 2008;22:112–8.
- [73] Collins CJ, Bryant RW, Hodge KL. A clinical evaluation of posterior composite resin restorations: 8-year findings. *J Dent* 1998;26:311–7.
- [74] Mair LH. Ten-year clinical assessment of three posterior resin composites and two amalgams. *Quintessence Int* 1998;29:483–90.
- [75] Nordbo H, Leirskar J, von der Fehr FR. Saucer-shaped cavity preparations for posterior approximal resin composite restorations: observations up to 10 years. *Quintessence Int* 1998;29:5–11.
- [76] Turkun LS, Aktener BO, Ates M. Clinical evaluation of different posterior resin composite materials: a 7-year report. *Quintessence Int* 2003;34:418–26.
- [77] Cetin AR, Unlu N. One-year clinical evaluation of direct nanofilled and indirect composite restorations in posterior teeth. *Dent Mater J* 2009;28:620–6.
- [78] Dresch W, Volpato S, Gomes JC, Ribeiro NR, Reis A, Loguercio AD. Clinical evaluation of a nanofilled composite in posterior teeth: 12-month results. *Oper Dent* 2006;31:409–17.
- [79] Efes BG, Dorter C, Gomec Y. Clinical evaluation of an ormocer, a nanofill composite and a hybrid composite at 2 years. *Am J Dent* 2006;19:236–40.
- [80] Ernst CP, Brandenbusch M, Meyer G, Canbek K, Gottschalk F, Willershausen B. Two-year clinical performance of a nanofiller vs a fine-particle hybrid resin composite. *Clin Oral Investig* 2006;10:119–25.
- [81] Loguercio AD, Lorini E, Weiss RV, Tori AP, Picinatto CC, Ribeiro NR, et al. A 12-month clinical evaluation of composite resins in class III restorations. *J Adhes Dent* 2007;9:57–64.
- [82] Palaniappan S, Bharadwaj D, Mattar DL, Peumans M, Van Meerbeek B, Lambrechts P. Three-year randomized clinical trial to evaluate the clinical performance and wear of a nanocomposite versus a hybrid composite. *Dent Mater* 2009;25:1302–14.
- [83] Palaniappan S, Bharadwaj D, Mattar DL, Peumans M, Van Meerbeek B, Lambrechts P. Nanofilled and microhybrid composite restorations: five-year clinical wear performances. *Dent Mater* 2011;27:692–700.
- [84] Sadeghi M, Lynch CD, Shahamat N. Eighteen-month clinical evaluation of microhybrid, packable and nanofilled resin composites in Class I restorations. *J Oral Rehabil* 2010;37:532–7.
- [85] Kim KH, Park JH, Imai Y, Kishi T. Fracture toughness and acoustic emission behavior of dental composite resins. *Eng Fract Mech* 1991;40:811–9.
- [86] Papadogianis Y, Boyer DB, Lakes RS. Creep of conventional and microfilled dental composites. *J Biomed Mater Res* 1984;18:15–24.
- [87] Soderholm KJ, Lambrechts P, Sarrett D, Abe Y, Yang MC, Labella R, et al. Clinical wear performance of eight experimental dental composites over three years determined by two measuring methods. *Eur J Oral Sci* 2001;109:273–81.
- [88] Ferracane JL. Is the wear of dental composites still a clinical concern? Is there still a need for in vitro wear simulating devices? *Dent Mater* 2006;22:689–92.
- [89] Ferracane JL. Resin composite—state of the art. *Dent Mater* 2011;27:29–38.
- [90] Lu H, Trujillo-Lemon M, Ge J, Stansbury JW. Dental resins based on dimer acid dimethacrylates: a route to high conversion with low polymerization shrinkage. *Compend Contin Educ Dent* 2010;31(Spec no. 2):1–4.
- [91] Cenci MS, Tenuta LM, Pereira-Cenci T, Del Bel Cury AA, ten Cate JM, Cury JA. Effect of microleakage and fluoride on enamel-dentine demineralization around restorations. *Caries Res* 2008;42:369–79.
- [92] Mjor IA. Clinical diagnosis of recurrent caries. *J Am Dent Assoc* 2005;136:1426–33.
- [93] Moraes RR, Garcia JW, Barros MD, Lewis SH, Pfeifer CS, Liu J, et al. Control of polymerization shrinkage and stress in nanogel-modified monomer and composite materials. *Dent Mater* 2011;27:509–19.
- [94] Ferracane JL. Buonocore Lecture. Placing dental composites—a stressful experience. *Oper Dent* 2008;33:247–57.
- [95] Peumans M, Kanumilli P, De Munck J, Van Landuyt K, Lambrechts P, Van Meerbeek B. Clinical effectiveness of contemporary adhesives: a systematic review of current clinical trials. *Dent Mater* 2005;21:864–81.
- [96] Gallo JR, Burgess JO, Ripps AH, Walker RS, Winkler MM, Mercante DE, et al. Two-year clinical evaluation of a posterior resin composite using a fourth- and fifth-generation bonding agent. *Oper Dent* 2005;30:290–6.
- [97] Schoch M, Kramer N, Frankenberger R, Petschelt A. Direct posterior composite restorations with a new adhesive system: one-year results. *J Adhes Dent* 1999;1:167–73.
- [98] Turkun SL. Clinical evaluation of a self-etching and a one-bottle adhesive system at two years. *J Dent* 2003;31:527–34.
- [99] Kidd EA. Diagnosis of secondary caries. *J Dent Educ* 2001;65:997–1000.
- [100] Moncada G, Martin J, Fernandez E, Hempel MC, Mjor IA, Gordan VV. Sealing, refurbishment and repair of Class I and Class II defective restorations: a three-year clinical trial. *J Am Dent Assoc* 2009;140:425–32.
- [101] Gordan VV, Riley 3rd JL, Blaser PK, Mondragon E, Garvan CW, Mjor IA. Alternative treatments to replacement of defective amalgam restorations: results of a seven-year clinical study. *J Am Dent Assoc* 2011;142:842–9.
- [102] Fernandez EM, Martin JA, Angel PA, Mjor IA, Gordan VV, Moncada GA. Survival rate of sealed, refurbished and repaired defective restorations: 4-year follow-up. *Braz Dent J* 2011;22:134–9.
- [103] Blum IR, Lynch CD, Schriever A, Heidemann D, Wilson NH. Repair versus replacement of defective composite restorations in dental schools in Germany. *Eur J Prosthodont Restor Dent* 2011;19:56–61.
- [104] Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NH. Composite resin core-crown reconstructions: an up to 17-year follow-up of a controlled clinical trial. *Int J Prosthodont* 2008;21:109–15.
- [105] Lindberg A, van Dijken JW, Lindberg M. Nine-year evaluation of a polyacid-modified resin composite/resin composite open sandwich technique in Class II cavities. *J Dent* 2007;35:124–9.
- [106] Nagasiri R, Chitmongkolsuk S. Long-term survival of endodontically treated molars without crown coverage: a retrospective cohort study. *J Prosthet Dent* 2005;93:164–70.
- [107] Mannocci F, Qualtrough AJ, Worthington HV, Watson TF, Pitt Ford TR. Randomized clinical comparison of endodontically treated teeth restored with amalgam or

- with fiber posts and resin composite: five-year results. *Oper Dent* 2005;30:9-15.
- [108] Hayashi M, Wilson NH. Marginal deterioration as a predictor of failure of a posterior composite. *Eur J Oral Sci* 2003;111:155-62.
- [109] Busato AL, Loguercio AD, Reis A, Carrilho MR. Clinical evaluation of posterior composite restorations: 6-year results. *Am J Dent* 2001;14:304-8.
- [110] van Dijken JW. Direct resin composite inlays/onlays: an 11 year follow-up. *J Dent* 2000;28:299-306.
- [111] Wassell RW, Walls AW, McCabe JF. Direct composite inlays versus conventional composite restorations: 5-year follow-up. *J Dent* 2000;28:375-82.
- [112] Lundin SA, Koch G. Class I. II posterior composite resin restorations after 5 and 10 years. *Swed Dent J* 1999;23:165-71.
- [113] Wilder Jr AD, May Jr KN, Bayne SC, Taylor DF, Leinfelder KF. Seventeen-year clinical study of ultraviolet-cured posterior composite Class I and II restorations. *J Esthet Dent* 1999;11:135-42.