Clinical effectiveness of direct anterior restorations—A meta-analysis

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ABSTRACT

Objectives. This is the first meta-analysis on the efficacy of composite resin restorations in anterior teeth. The objective of the present meta-analysis was to verify whether specific material classes, tooth conditioning methods and operational procedures influence the result for Class III and Class IV restorations.

Material and methods. The database SCOPUS and PubMed were searched for clinical trials on anterior resin composites without restricting the search to the year of publication. The inclusion criteria were: (1) prospective clinical trial with at least 2 years of observation; (2) minimal number of restorations at last recall = 20; (3) report on drop-out rate; (4) report of operative technique and materials used in the trial, and (5) utilization of Ryge or modified Ryge evaluation criteria. For the statistical analysis, a linear mixed model was used with random effects to account for the heterogeneity between the studies. p-Values smaller than 0.05 were considered to be significant.

Results. Of the 84 clinical trials, 21 studies met the inclusion criteria, 14 of them for Class III restorations, 6 for Class IV restorations and 1 for closure of diastemata; the latter was included in the Class IV group. Twelve of the 21 studies started before 1991 and 18 before 2001. The estimated median overall success rate (without replacement) after 10 years for Class III composite resin restorations was 95% and for Class IV restorations 90%. The main reason for the replacement of Class IV restorations was bulk fractures, which occurred significantly more frequently with microfilled composites than with hybrid and macrofilled composites. Caries adjacent to restorations was infrequent in most studies and accounted only for about 2.5% of all replaced restorations after 10 years irrespective of the cavity class. Class III restorations with glass ionomer derivate suffered significantly more loss of anatomical form than did fillings with other types of material. When the enamel was acid-etched and no bonding agent was applied, significantly more restorations showed marginal staining and detectable margins compared to enamel etching with enamel bonding or the total etch technique; fillings with self-etching systems were in between of these two outcome variables. bevelling of the enamel was associated with a significantly reduced deterioration of
the anatomical form compared to no bevelling but not with less marginal staining or less detectable margins. The type of isolation (absolute/relative) had a statistically significant influence on marginal caries which, however, might be a random finding.

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1. Introduction

Perfect anterior restorations act as an advertisement for the skills of the dental professional. Most operative interventions in anterior teeth are accomplished with the direct placement of composite resins. The skill of the dentist in achieving a natural anatomical shape and color match with the adjacent teeth are prerequisites to achieving a pleasing aesthetic result, which can also be assessed easily by the patients themselves. Type of composite resin, methods and materials to condition the tooth structure (enamel etching, self-etching, no etching) as well as the operative procedure (bevelling of enamel margin, rubber dam application) may also influence both the aesthetic results and the longevity of the restoration.

Before the development of composite resins and the acid-etch technique of the enamel, carious lesions in anterior teeth were mainly restored with silicate cement, which required a retentive preparation pattern [1]. Restorations that involve the proximal part of an anterior tooth but not the incisal edge are defined as Class III restorations.

In the early days, the building up of fractured teeth was only possible with indirect restorations, such as full-coverage crowns, because bonding to the remaining tooth substance had not yet been established as an operative procedure. Already in the nineteen-fifties, the enamel etch technique with phosphoric acid was developed by Buonocore [2]. However, it took about 20 years until this technique has been introduced into clinical dentistry. This technique made it possible to directly restore fractured anterior teeth with composite resin, to close diastemata or to build up worn teeth. Restorations that involve a part of the incisal edge are defined as Class IV restorations.

At that time, there was a dispute as to whether it is necessary to place an unfilled resin bonding material on the etched enamel or whether high-viscosity resin composites could be placed directly on the etched enamel. The operative procedures have been gradually simplified and the materials improved since then. First, the application times of both enamel etching and rinsing were reduced from 60 to 30s [3], dentin bonding agents made liners superfluous and increased the bonding strength to the tooth structure [4]. Then, self-etching adhesive systems were introduced [5]. Capable of establishing a bond to both the enamel and dentin, these materials streamlined the operative procedure because they eliminated the need for a separate rinsing step.

Most contemporary dental composite resins still contain a monomer which was already developed in the late 1950s of the last century by M. Bowen [6]: it is called Bisphenol-A glycidylmethacrylate or simply Bis-GMA or Bowen’s resin Microfilled composites and later hybrid and nano-hybrid composites replaced the macrofilled composites, which were the first dental resins on the market [7]. Polymerization curing lights were first introduced at the end of 1970s of last century [8]. They allowed these materials to be cured on demand, which facilitated the customization of anterior restorations, because they could be built up step-by-step with several layers that have different optical properties.

With the reduction of caries prevalence in most countries, the prevalence of Class III restorations due to proximal caries has also dropped. However the prevalence of traumatic injuries to anterior teeth has significantly increased over the last 20 years due to an increase in sports activities undertaken during leisure time. In some countries, particularly in Scandinavia, children and adolescents have nowadays more teeth damaged by traumatic injuries than by caries [9]. The restoration of fractured teeth (Class IV) with composite is usually the first treatment option.
The question arises as to how effective such a treatment is in terms of aesthetics, function and longevity. In the databases SCOPUS and PubMed no meta-analysis or systematic review on the efficacy of Class III or Class IV restorations has been found. There are several systematic reviews on posterior composite restorations [10–15] and cervical restorations [16,17]. However, it is inadequate to extrapolate from the longevity of posterior composite restoration to that of anterior restorations.

The aim of this review was to systematically evaluate prospective clinical trials on anterior resin composite restorations without restricting the search to the publication year or the type of resin or adhesive system used.

The following factors affecting the clinical outcome were to be specifically evaluated:

- type of cavity (Class III, Class IV)
- type of enamel/dentin conditioning
- type of resin composite
- operative techniques:
  • bevelling of enamel
  • absolute versus relative isolation

These factors were to be assessed by the following outcome criteria:

- time elapsed until replacement and reason for replacement (marginal caries, fracture of filling, retention loss, etc.)
- color match and surface texture
- marginal integrity and marginal staining
- anatomical form (shape)
- chipping and fracture

The following hypotheses were examined:

1. Class IV restorations mostly suffer from chippings and fractures and have a reduced longevity compared to Class III restorations.
2. The type of composite resin does not influence the overall longevity of Class III restorations.
3. Class IV restorations with hybrid composites show a better longevity than Class IV restorations with microfilled composites.
4. Restorations based on glass ionomer derivates have a reduced longevity compared to composite resin restorations and compomers.
5. Enamel etching with phosphoric acid reduces the number of restorations that show marginal discoloration and defective marginal integrity compared to self-etching systems and compared to those restorations that were placed with enamel etching but without bonding agent.
6. The type of isolation or bevelling of the enamel does not influence the clinical outcome.
7. Hybrid and microfilled composites show a better color match than microfilled composites.
8. Hybrid composites maintain their anatomical form more effectively than microfilled composites, compomers and glass ionomer derivates.

2. Materials and methods

2.1 Selection of clinical trials on class III/IV restorations

Prospective clinical studies on Class III/IV restorations in permanent teeth were searched in the databases PubMed (search period 1966–2012, search time December 2012). The search terms were “anterior” (or “Class III”) or “anterior” (or “Class IV” or “trauma”) and “composite” and “clinical trial”.

The inclusion criteria were as follows:

1. Prospective clinical trial for Class III or Class IV cavities or diastema closures.
2. Minimal duration of 2 years.
3. Minimal sample size at last recall: 15 restorations per material.
4. The study had to report on the following outcome variables: marginal discoloration, marginal integrity, caries adjacent to restorations, material fractures, color match and anatomical form. The variables “surface texture”, “surface staining” were optional variables.
5. The study had to report on the materials and hard tissue conditioning technique used (etching of enamel with phosphoric acid yes/no, dentin/enamel bonding agent).
6. The study had to report on the operative technique (bevelling of enamel, preparation, isolation technique, type of curing).

Clinical studies on direct composite veneers and studies that used composite materials to correct the vertical dimension were not included in the meta-analysis. Studies with experimental materials that were never launched on the market were not taken into account. There was no restriction with regard to the publication year.

As far as the materials are concerned, studies with polyacid-modified resin composites (compomers or PAMRC) and resin-modified glass ionomer cements (RMGIC) were also included.

The restorative materials and adhesive systems (AS) were grouped as follows:

Restorative material (RM)
1 = macrofiller
2 = microfiller
3 = hybrid
4 = polyacid-modified resin composite (compomer)
5 = resin-modified glass ionomer cements (RMGIC)

Adhesive system (AS)
1 = enamel etch + enamel bonding
2 = enamel etch + no bond
3 = enamel etch–3 steps
4 = enamel etch–2 steps
5 = self-etch–2 steps
6 = self-etch–1 step
7 = no etch + no bond
To further reduce the number of categories and to increase the statistical power, four adhesive classes were defined:

1 = enamel etch with phosphoric acid + bonding
2 = enamel etch with phosphoric acid + no bonding
3 = self-etch
4 = no etch + no bond

The following binary variables were considered, where the percentage of the category given in brackets will be analyzed in what follows:

1. MD marginal discoloration (not visible).
2. MI marginal integrity (no clinically detectable margins (with explorers).
3. CAR caries adjacent to restorations (no caries).
4. F material fracture (no chipping, no bulk fracture; alternatively with slight chipping or fracture).
5. AF anatomical form (good/very good).
6. C color match (good/very good).
7. ST surface texture (good/very good).
8. R retained restoration.

For most of these variables (MD, MI, F, C, ST and AF) the data were originally graded into three categories (1 = good or very good, corresponds to Ryge criterion “Alpha”; 2 = acceptable or repairable, corresponds to Ryge criteria “Beta” or “Charlie”; 3 = unacceptable which needs replacement, corresponds to Ryge criterion “Delta”), but since the category 3 occurred only rarely, the variables were dichotomized for the analysis, as given above. However, category 3 was taken into account when defining and analyzing the longevity of a restoration. The percentage of restorations still in function refers to those restorations which did not have to be replaced due to one (or more) of the following reasons:

1. CAR = caries adjacent to restorations (secondary or marginal caries)
2. F = material fracture
3. R = loss or partial loss of restoration
4. C = unacceptable color match
5. MI = unacceptable marginal integrity
6. AF = unacceptable anatomical form

To assess the possible influence of the polishing system, the various polishing methods were categorized in the following way:

1 = disc
2 = silicone instrument
3 = stone
4 = disc + glaze
5 = etch + bonding

3. Statistical analysis

All the clinical outcomes could be expressed as percentages of restorations retaining a given property across the defined period of time, for example the percentage of restorations without a visible marginal discoloration, the percentage of restorations with a good or a very good anatomical form, or the percentage of restorations which did not need replacement, as defined above. To permit a comparison of the rate of deterioration among the various experiments, the percentages observed at the various points of time were divided by the percentage observed at baseline for those experiments where the latter was below 100%.

Let $Y(t)$ be a percentage measured at time $t$ (expressed in years). To model the rate of deterioration, we were looking for a model where $Y(t)$ is a decreasing function of $t$ ranging from $Y(t) = 100\%$ down to $0\%$ for large values of $t$. A linear model of the form $Y(t) = 100 - \beta t$
would for example not be convenient since it would have become negative for large values of \( t \), which was not sensible in our context. We considered instead a deterioration model of the form \( Y = 100 \times \exp(-\lambda \times t^\alpha) \) with positive values of \( \alpha \) and \( \lambda \), which is equivalent to stating that \( \log(-\log(Y/100)) = \beta + \alpha \times \log(t) \), with \( \beta = \log(\lambda) \).

To study how the deterioration process depends on a given factor of interest, we then considered the following statistical model for our empirical percentages \( Y(t) \):

\[
\log(-\log(Y(t)/100)) = \beta_j + \alpha \times \log(t) + \text{study effect} + \text{experiment effect} + \text{random error}.
\]

In this model, \( \beta_j \) is a fixed parameter characterizing the rate of deterioration for the level \( j \) of the factor of interest, such that the higher the parameter, the faster the deterioration (a value of \( \beta_j = -2 \) indicates for example a faster deterioration than a value of \( \beta_j = -3 \)). The parameter \( \alpha \) characterizes the shape of the deterioration which does not depend on the factor of interest. A random experiment effect was included to account for the obvious dependencies among the repeated percentages observed in the same experiment along time, while a random study effect was included to account for the fact that the subjects involved in different experiments from the same study were partly the same (split-mouth design).

Fig. 2 – Estimated median percentage of Class III restorations across the studies and experiments with good or very good surface texture in relation to the type of restorative material and to the observation time.

Fig. 3 – Estimated median percentage of Class III restorations across the studies and experiments with adequate anatomical form in relation to the type of restorative material and to the observation time.

Fig. 4 – Estimated median percentage of restorations across the studies and experiments without material chipping/fracture to the restoration in relation to the type of restorative material. (Left) Class III, (right) Class IV.
In our model, the deterioration curve is thus assumed to be different from study to study and from experiment to experiment. Figs. 1–9 below show some of our fitted models as $Y = 100 \times \exp(-\lambda_{j} \times t \times \alpha)$, with $\lambda_{j} = \exp(\beta_{j})$, which can be interpreted as a median deterioration curve for the level $j$ of the factor of interest (estimated over all studies and experiments).

Such a linear mixed model could be fitted using the restricted maximum likelihood method implemented in the routine lme, which can be found in the package nlme from the statistical software R. In this routine, it was also possible to weight each empirical percentage by the corresponding number of restorations (the denominator of the percentage). To test for the statistical significance of the factor of interest, a maximum likelihood ratio test was used, with the number of levels of the factor of interest minus one as number of degrees of freedom. $p$-Values smaller than 0.05 were considered to be significant.

4. Results

4.1. Study search

The initial search revealed 85 clinical studies on Class III/IV anterior restorations. However, only 21 studies met the criteria to be included in the review, 14 of them for Class III restorations, 6 for Class IV and 1 for diastema closure; the latter was included in the group of Class IV restorations (Table 1). Furthermore, prospective studies that missed to report on one or several of the clinical outcome variables listed above, e.g. color match or marginal staining, were also included, which led to more statistical power.

The most frequent reasons for exclusion were (in descending order according to frequency):

1. No differentiation between restorations of Class III, IV, V (I, II)
2. Short duration (less than 2 years)
3. Retrospective study
4. Pooled data for different materials
5. Other indication (e.g. restoration of worn incisors)
6. Case reports

The specific characteristics of each clinical trial that is included in the final analysis are listed in Table 1.

4.2. Structure of included studies

The 21 studies included in the review contain 53 in vivo experiments with 22 different composites, 3 componers and 2 glass ionomer derivates. Fifteen different adhesive systems were used to fabricate the restorations. Twelve of the included 21 studies started before 1991 and 18 before 2001. The type of adhesive and composite/restorative material is listed in Table 1. Eighty-five per cent of the experiments had an observation period of 2–5 years. For 27 experiments data on the ratio of maxillary versus mandibular anterior restorations are reported; the mean ratio was 96% with a range from 88 to 100%. In Tables 2 and 3 the frequency of studies as well as the number of restorations at baseline in relation to the hard tissue conditioning method and the different groups of restorative materials are listed.

Out of the 58 experiments, enamel was bevelled in 31 experiments, and absolute isolation (rubber dam) was applied in 29 experiments (Tables 2 and 3). For 13 experiments there was no description on the type of isolation.
4.3. **Outcome variables**

The curves presented in the figures below refer to the estimated median percentage of deterioration (across studies and experiments) for the binary outcomes, in relation to time and to various factors of interest, and differentiated between Class III and Class IV restorations. If there is no graph for Class IV restorations, there were not enough data to run the model. Curves were plotted for the longest observation time of the corresponding factor levels. The parameters \( \alpha \) and \( \beta_j \), as well as the number of experiments (nexp) and the number of observed percentages (nobs) are also provided for each factor level, together with a \( p \)-value from a maximum likelihood ratio test. As usual in a statistical study, the result might not be statistically significant despite large differences among the curves, due to a high between-study variability and/or to the small number of studies involved. On the other hand, statistical significance might have been achieved despite a seemingly small difference among the curves in case of a low between-study variability.

The decrease of restorations with good or very good color match was dependent on the type of composite material. Compomers and hybrid composites showed a better color match than microfilled and macrofilled composites in Class

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**Fig. 7** – Estimated median percentage of restorations across the studies and experiments without marginal staining in relation to the adhesive technique and adhesive system and to the observation time. (Left) Class III, (right) Class IV.

**Fig. 8** – Estimated median percentage of Class III restorations across the studies and experiments without detectable margins in relation to the composite material (left) and the adhesive technique (right).
III restorations (Fig. 1); the difference, however, was not statistically significant. Class III restorations with glass ionomer derivates exhibited the most rapid deterioration in color match compared to the other materials; the difference to the other materials was, however, not statistically significant. In Class IV restorations hybrid composites showed a significantly better color match than microfilled composites ($p=0.002$), which performed significantly better than macrofilled composites ($p=0.022$). The type of polishing system did not have a significant influence on the color match.

As far as surface texture is concerned, Class III restorations with hybrid composites and compomers showed a statistically significant less rapid deterioration than restorations with microfilled and macrofilled composites ($p=0.017$) (Fig. 2). Restorations with glass ionomer derivates demonstrated the worst deterioration in surface texture. The deterioration was significantly worse than that of compomers ($p=0.001$). The type of polishing system did not have a significant influence on the surface texture.

The loss of anatomical form was material-dependent. Class III restorations with macrofilled and hybrid composites were affected to a lower degree by impaired anatomical form than restorations that were fabricated with other restorative materials (Fig. 3); the difference, however, was only significant between macrofilled and microfilled composites ($p=0.003$) as well as between macrofilled or hybrid composites and glass ionomer cements ($p=0.006$ and $p=0.003$ respectively). The bevelling of the cavity was associated with a significant reduction in the deterioration of the anatomical form compared to not bevelling the margins ($p=0.039$).

Significantly more Class IV restorations showed chippings and fractures that resulted in the replacement of the restoration than did Class III restorations ($p=0.0001$). Class IV restorations with hybrid composites showed significantly less fractures than Class IV restorations with macrofilled composites ($p=0.0001$) (Fig. 4); the latter showed significantly more chippings/fractures than macrofilled composites ($p=0.0001$). For Class III restorations there was no statistically significant difference between the materials.

The frequency of caries adjacent to restorations (CAR) was low in most studies with a median prevalence of about 2.5% after 10 years in both Class III and Class IV restorations and this rate did not differ very much across the studies (Fig. 5). The occurrence was not dependent on the type of compositive material, the type of enamel and dentin conditioning or the bevelling of the cavity. However, Class III restorations that were placed without a rubber dam were associated with a significantly higher frequency of caries adjacent to restorations than those restorations that were placed with a rubber dam ($p=0.024$) (Fig. 6).

The decrease of restorations with no marginal staining was dependent on the tooth conditioning technique. Restorations with etched enamel and treated with either an enamel or a dentin bonding agent showed less marginal discoloration than all the other groups, including those restorations whose enamel was etched but not coated with a bonding agent (Fig. 7). The difference was, however, only statistically significant between the groups “enamel etch and bond” and “no etch and no bond” ($p=0.008$). The variables “bevelling of enamel” and “type of isolation” did not influence the result significantly.

As far as the outcome variable marginal integrity is concerned there was a significant more rapid decrease in no detectable margins for Class III microfilled composite restorations than for Class III macrofilled restorations ($p=0.001$) (Fig. 8). The type of tooth conditioning method was not statistically significant. The variables “bevelling of enamel” or “type of isolation” did not influence the result significantly.

The reasons for restoration replacement were predominantly bulk fractures of Class IV restorations and caries at the restorative margins. A very small number of restorations...
### Table 1 – Clinical studies and their characteristics that are included in the meta-analysis.

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<td>1977</td>
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<td></td>
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<td>161</td>
<td>27</td>
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<td>Roberts</td>
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<td>Shey</td>
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<td>19</td>
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<td></td>
<td>[54]</td>
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<td>25</td>
<td>19</td>
<td>2</td>
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<tr>
<td></td>
<td>[25]</td>
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<td>29</td>
<td>17</td>
<td>3</td>
<td>No</td>
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<tr>
<td></td>
<td>[25]</td>
<td>1990</td>
<td>22</td>
<td>21</td>
<td>3</td>
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<tr>
<td>Peumans</td>
<td>[55,56]</td>
<td>1997</td>
<td>61</td>
<td>61</td>
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<tr>
<td>van Dijken</td>
<td>[28]</td>
<td>2010</td>
<td>43</td>
<td>40</td>
<td>12</td>
<td>Yes</td>
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</table>
was replaced due to retention loss, unacceptable color match or unacceptable marginal integrity. The replacement rate for Class III fillings with glass ionomer cements and microfilled composites was significantly higher compared to macrofilled and hybrid composites (p = 0.014 and p = 0.017 respectively) (Fig. 9). For Class IV restorations significantly more restorations were replaced when microfilled composites were used compared to macrofilled and hybrid composites (p = 0.0001).

The overall median success rate of composite restorations (excluding glass ionomer) after 10 years was about 95% for Class III restorations and 90% for Class IV restorations.
The type of tooth conditioning, bevelling of the enamel or the type of isolation (absolute/relative) did not have a significant influence on the investigated outcome variables.

Table 4 summarizes the clinical performance of the five different groups of restorative materials in relation to certain outcome variables specified above.

5. Discussion

Meta-analyses are considered a valid method to combine the results from clinical trials that were selected according to predefined criteria and to extract data in order to draw

---

**Table 2 – Number of experiments and sample size at baseline in relation to the tooth conditioning technique and the cavity class (‘number of experiments’).**

<table>
<thead>
<tr>
<th>Cavity Class</th>
<th>Number of experiments</th>
<th>Number of restorations at baseline</th>
<th>Rubber dam</th>
<th>Bevelling of enamel*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Class III</td>
<td>Enamel etching + enamel bonding</td>
<td>9</td>
<td>459</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Enamel etching-3 steps</td>
<td>4</td>
<td>130</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Enamel etching-2 steps</td>
<td>3</td>
<td>115</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Enamel etching + no bonding</td>
<td>12</td>
<td>387</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Self-etch-2 steps</td>
<td>2</td>
<td>83</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Self-etch-1 step</td>
<td>2</td>
<td>144</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Glass ionomer</td>
<td>4</td>
<td>113</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>No etch + no bond</td>
<td>2</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Class IV</td>
<td>Enamel etching + enamel bonding</td>
<td>12</td>
<td>642</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Enamel etching-3 steps</td>
<td>2</td>
<td>104</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Enamel etching + no bonding</td>
<td>1</td>
<td>52</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: Some studies did not report on rubber dam placement, which explains the difference between total number of experiments and the number of experiments with rubber dam yes/no.

**Table 3 – Number of experiments and sample size at baseline in relation to the type of restorative material and the cavity class (‘number of experiments’).**

<table>
<thead>
<tr>
<th>Cavity Class</th>
<th>Number of experiments</th>
<th>Number of restorations at baseline</th>
<th>Rubber dam</th>
<th>Bevelling of enamel*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Class III</td>
<td>Macrofiller</td>
<td>7</td>
<td>270</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Microfiller</td>
<td>12</td>
<td>478</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Hybrid</td>
<td>11</td>
<td>462</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Compomer</td>
<td>4</td>
<td>178</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Glass ionomer</td>
<td>4</td>
<td>113</td>
<td>3</td>
</tr>
<tr>
<td>Class IV</td>
<td>Macrofiller</td>
<td>9</td>
<td>592</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Microfiller</td>
<td>2</td>
<td>54</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Hybrid</td>
<td>4</td>
<td>152</td>
<td>2</td>
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</tbody>
</table>

---

**Table 4 – Clinical performance of composite resin materials in relation to the type of resin material.**

<table>
<thead>
<tr>
<th>Composite resin</th>
<th>Number of experiments</th>
<th>Color match</th>
<th>Surface texture</th>
<th>Anatomical form</th>
<th>Material chipping</th>
<th>Material fracture (replacement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class III</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macrofiller</td>
<td>7</td>
<td>–</td>
<td>+/-</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microfiller</td>
<td>12</td>
<td>+/-</td>
<td>+/-</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid</td>
<td>11</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compomer</td>
<td>4</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass ionomer</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class IV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macrofiller</td>
<td>9</td>
<td>–</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Microfiller</td>
<td>2</td>
<td>+/-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hybrid</td>
<td>4</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

++ = very good, + = good, +/- = acceptable, - = bad, - - = very bad.
conclusions about the efficacy of a therapeutic intervention - in this case the longevity of restorative materials and their operative technique to restore anterior teeth. However, there is no consensus as to which statistical method should be applied to conduct a meta-analysis. In the present study, a linear mixed model with random effects was considered to account for both the heterogeneity between the studies and the repeated observations across time within an experiment to be the most appropriate approach.

This is the first meta-analysis on the efficacy of anterior restorations. However, most of the included studies were carried out between 1980 and 2000 and there were only 6 studies on Class IV restorations. As this is the first systematic review or meta-analysis of that kind, also studies that evaluated resin materials that are no longer available on the market, such as macrofilled materials, had been included. Likewise, studies that did not use an enamel or dentin conditioning agent, had also been taken into consideration as the clinical result of this kind of study may shed light on the correlation of marginal gap and marginal caries. A similar approach has been carried out in a recent meta-analysis on the effectiveness of posterior Class I/II resin restorations [15].

Hybrid composite restorations demonstrated the best overall performance (good color match, small number of fractures). Macrofilled composites exhibited a significantly less favourable color match and microfilled composites showed significantly more fractures in Class IV restorations and a significant loss of anatomical shape. Especially glass ionomer derivates were marred by several shortcomings and may not be the first choice as permanent filling material to restore defects of the anterior teeth.

Some of the clinical phenomena can be explained by material-inherent properties. The rapid deterioration of the color match of the self-curing macrofilled materials (e.g. Concise and Adaptic) is related, first, to the initiators of the self-curing mechanism (e.g. amines), which are not very color-stable, and second to the higher amount of monomers contained in them compared to the hybrid and microfilled composites [18,19]. The fact that the early macrofilled and microfilled composites were available in only a limited range of shades explains why in some experiments a significant percentage of restorations did not show a good color match even at baseline (see Table 1). Contemporary micro-hybrid and nano-hybrid composites are available in a variety of different shades with different degrees of opacity and translucency and are ideal for aesthetic restorations of anterior teeth. However, studies that evaluate these more recent generations of composite resins in anterior teeth do not appear to have been published.

Composite resin materials that are used to build up incisal edges must be very fracture-resistant as high shear forces during chewing stress the restoration. The meta-analysis showed that significantly more Class IV restorations exhibited chippings and fractures that required the replacement of the restoration than Class III restorations. In fact the median replacement frequency was twice for Class IV than for Class III after 10 years (10% versus 5%). Class IV restorations with microfilled composites showed significantly more chippings and fractures than those with hybrid and macrofilled composites. The overall success rate of Class IV restorations, however, would have been increased only partly if the microfilled restorations had been excluded, as three times more restorations with hybrid composites were included in the meta-analysis than restorations with microfilled composites (see Table 2). The flexural strength of self-curing macrofilled composites is comparable to that of contemporary hybrid composites (>100 MPa) [20,21] and explains why these two types of materials exhibited a similar fracture frequency. Similar to the composites for posterior Class II restorations, a low flexural strength of the resin material is correlated with a high incidence of chipping and fractures of incisal edgebuild-ups (Class IV). For Class II restorations the ISO standard requires a minimum flexural strength of 80 MPa after 1 week of water storage [22]. Clinical studies on Class II restorations with a material that had a flexural strength of about 60 MPa showed more than 20% fractures after only 2 years [23,24]. A minimum value of flexural strength has not been specified for Class IV restorations. A clinical trial [25], whose results are also included in this meta-analysis, has shown that materials with a flexural strength of about 70 MPa such as Durafill [21,26] produced about 30–35% more fractures in Class IV restorations within 3 years than materials with a flexural strength of well above 100 MPa such as Estilux MF [27]. It appears reasonable to demand that materials for Class IV restorations should offer a flexural strength of at least 100 MPa. Microfilled composites fall short of this value by far [21] and are therefore not suitable for this indication, as has been demonstrated in the present meta-analysis. Also resin-modified glass ionomer cements and comomers do not have the mechanical strength to withstand the shear forces in Class IV cavities. A long-term clinical study, whose data on glass ionomer derivates and compomers were not included in the present analysis due to the low number of restorations in each material group, has shown high fractures rates for these materials in Class IV cavities [28]. Fracture toughness is another important physical parameter that needs to be considered and is closely related to flexural strength. Materials in stress-bearing regions should have a fracture toughness of at least 1.2 MPa√m [25].

Marginal discoloration and detectable margins are the only clinically measurable signs for the evaluation of the marginal seal of direct restorations. As most often 100% of the visible margin of Class III/IV restorations is located in the enamel, the bonding to enamel is crucial for the prevention of marginal discoloration and for a good seal. Enamel etching with 37% phosphoric acid is the best method to establish a microrretentive pattern that allows a good bonding to ground enamel: the bond strength to cut enamel conditioned with a phosphoric acid etching systems is superior to self-etching systems [29]. Besides the conditioning method, the orientation of the enamel prisms is of importance. A study has shown that the micro-shear bond strength was higher if enamel was cut in an oblique direction to the orientation of the prisms compared to a parallel direction [30]. The bevelling of the enamel margin prior to conditioning, however, did not significantly influence the frequency of marginal discoloration in the present meta-analysis, even though there was a tendency of less marginal staining when the enamel had been bevelled. For all subgroups there was a rapid increase in the restorations with stained margins. The reason for the insignificant difference between bevelled and non-bevelled margin in relation to marginal
staining might be the fact that in most studies only a short bevel was prepared. Nowadays, it is often recommended to prepare a very broad (=long) bevel, especially on the labial surface, to make the transition between restoration and enamel almost invisible. The broad bevel may also reduce the number of restorations with marginal staining in the long run. A broad bevel may also increase the fracture resistance of Class IV resin restorations as a laboratory study has shown [31]. But no systematic clinical trials have addressed these topics so far. Yet, the advantages of a broad bevel in anterior restorations has been questioned recently [32].

Another interesting and unexpected result of this review was that the overall longevity of the anterior composite resin restorations included in these studies did not significantly depend on the type of enamel and dentin conditioning system used, at least not over a period of 5 years. If, however, the enamel was not etched with either phosphoric acid or a self-etching primer, there was a rapid increase in the number of restorations that showed marginal staining as it the case with posterior restorations that do not include an enamel conditioning agent according to a meta-analysis [15]; however, marginal gaps alone are apparently no risk indicator for the development of caries at the restorative margin. Restorations that included the application of an enamel etchant but not an enamel bonding agent showed more marginal staining over time than restorations with enamel etching and enamel bonding.

There was a clear tendency that fillings with self-etching primers had a higher prevalence of marginal staining than fillings with enamel etching. General practitioners are in general advised to use phosphoric acid etching on enamel as this technique helps to reduce the occurrence of marginal staining. Marginal discoloration is usually linked to irregularities in the margin such as gaps, cracks, ditching, etc. Therefore, it is more appropriate to clinically evaluate marginal adaptation than marginal fractures, marginal gaps, etc., as considerable differences exist between the assessments of marginal adaptation by different evaluators [33–35].

As the median prevalence of marginal discoloration in restorations with enamel etching and bonding was about seven times higher than that of marginal caries after 5 years and as the existence of marginal gaps or imperfections is usually necessary for the development of marginal discoloration, this is an indication that (1) small marginal gaps per se are not responsible for causing marginal caries and (2) marginal staining is not indicative of marginal caries. Nevertheless, practitioners should try to reduce the risk for marginal staining by etching the enamel with 37% phosphoric acid. This operative procedure contributes to a less premature replacement of restorations as general practitioners often associate marginal staining with caries at the margins [34–36].

The placement of rubber dam was related to less marginal caries of direct anterior restorations. This is, however, probably a random finding as the number of included studies is relatively low and the individual results might be biased by the fact that marginal discoloration could have been confounded with marginal caries in some cases. In a recently published meta-analysis on the longevity of Class II composite resin restorations there was not less marginal caries in those studies that used rubber dam [15]. However, significantly less bulk fractures were observed in restorations placed with rubber dam compared to those placed without. It has been speculated as to whether contamination during placement could have resulted in a mechanically compromised composite material or the overall quality of the restoration was higher in those studies where dentists used rubber dam. The present meta-analysis on anterior restorations did not yield such an influence of rubber dam on the occurrence of fractures. Bulk fractures occurred almost invariably in Class IV restorations (s. Fig. 4). As only in 5 of the 7 included studies of Class IV restorations rubber dam has been placed the influence of rubber dam cannot be thoroughly assessed. Also moisture control is easier in the anterior region than in the posterior region.

The marginal integrity did not depend on the tooth conditioning system or method, which confirms the fact that detectable margins are not necessarily combined with stained margins. There was not even a difference between acid etching and no etching in Class III restorations. As, however, these two methods were not evaluated in the same study, this result may be explained by different levels of calibration, which also may explain differences between studies that used the same tooth conditioning method.

This variability with regard to the outcome variables between different studies when applying the same operational procedures and materials may be explained by (1) differences between different operators, and/or (2) differences when applying the evaluation criteria. Usually the very gross Ryge criteria or modifications of these criteria were applied or are still applied in clinical trials. In 2007, more refined and better structured clinical assessment criteria were published and approved by the FDI [34,35]. The Ryge criteria do not take into account the extension of certain outcome criteria, e.g. the percentage of margin with staining or caries, or the extension of fractures. Therefore, the FDI criteria included a semi-quantitative approach for certain criteria to be able to better differentiate between clinical phenomena.

6. Conclusions

- The absolute failure rate of anterior restorations in general was relatively low.
- Class IV restorations showed more fractures than Class III restorations, which confirms hypothesis No. 1. Class IV restorations with hybrid composites showed less fractures than microfilled composites, which confirms hypothesis No. 3.
- The overall performance of hybrid composites was better than that of microfilled composites.
- There was a consistent decrease in color match independent of the type of material. Therefore, hypothesis No. 7 had to be rejected.
- When the enamel was etched with phosphoric acid, less discoloration at the restorative margins was observed compared to restorations that involved other conditioning systems. Caries adjacent to the restoration was infrequent and not related to any factor evaluated except for the type of isolation: restorations that were placed with a rubber dam showed less caries at the margins than restorations that
were placed without a rubber dam which, however, may be caused by additional confounding factors (staining, etc.).

- Bevelling of enamel had no significant influence on the outcome variables except for the anatomical form, which might be a random finding.

- As most of the studies were carried out between 1980 and 2000 and as there are only few studies on Class IV restorations, more clinical trials with contemporary resin materials especially in Class IV cavities are warranted.

For clinicians the implications of the present meta-analysis are as follows:

1. Adhesive system: The dentist should select an adhesive system which includes or allows the inclusion of enamel conditioning with 37% phosphoric acid. This reduces the occurrence of marginal discoloration which, in turn, may reduce the temptation to prematurely replace restorations e.g. due to the confusion between stained margin and caries at the margin or due to aesthetic reasons.

2. Restorative material: Hybrid composites can be used for both Class III and Class IV restorations, while microfilled composites, composites and glass ionomer cements showed more shortcomings (fractures, impaired esthetics).

Operative procedures: The additional bevelling of the enamel did not result in less marginal staining or improved marginal integrity. Whether a (long) bevel improves aesthetics or increases the fracture resistance of Class IV restorations has not been systematically investigated. Absolute isolation with a rubber dam is not a prerequisite for long-lasting anterior restorations if adequate relative isolation can be ensured.

REFERENCES


