How to Intervene in the Caries Process: Dentin Caries in Primary Teeth

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Abstract
For an ORCA/EFCD consensus, this review systematically assessed available evidence regarding interventions performed and materials used to manage dentin carious lesions in primary teeth. A search for systematic reviews (SRs) and randomized clinical trials (RCTs) with a follow-up of at least 12 months after intervention was performed in PubMed, LILACS, BBO, and the Cochrane Library. The risk of bias tool from the Cochrane Collaboration and the PRISMA Statement were used for assessment of the included studies. From 101 screened articles, 2 SRs and 5 RCTs, which assessed the effectiveness of interventions in terms of pulp vitality and success of restoration, and 10 SRs and 1 RCT assessing the success of restorative materials were included. For treatments involving no carious tissue removal, the Hall technique showed lower treatment failure for approximal carious lesions compared to complete caries removal (CCR) and filling. For the treatment of deep carious lesions, techniques involving selective caries removal (SCR) showed a reduction in the incidence of pulp exposure. However, the benefit of SCR over CCR in terms of pulp symptoms or restoration success/failure was not confirmed. Regarding restorative materials, preformed metal crowns (PMCs) used to restore multisurface lesions showed the highest success rates compared to other restorative materials (amalgam, composite resin, glass ionomer cement, and compomer), and in the long term (12–48 months) these were also less likely to fail. There is limited evidence supporting the use of PMCs to restore carious lesions with single cavities. Among nonrestorative options, silver diammine fluoride was significantly more effective in arresting caries than other treatments for treating active carious lesions of different depths. Considerable heterogeneity and bias risk were observed in the included studies. Although heterogeneity observed among the studies was substantial, the trends were similar. In conclusion, less invasive caries approaches involving selective or no caries removal seem advantageous in comparison to CCR for patients presenting with vital, symptomless, carious dentin lesions in primary teeth. There is evidence in favor of PMCs for restoring multisurface carious lesions in primary molars.

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Introduction

Since caries is no longer seen as an infectious disease [Kidd, 2011], the possibilities for lesion management have evolved. For existing dentin caries in primary teeth, management includes a wide range of approaches, in-
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Inclusion those where carious tissue removal is not involved, such as nonrestorative cavity control (NRCC) [Gruythuysen et al., 2011; Schwendicke et al., 2016; Santamaria et al., 2018], the use of silver fluoride products (mainly silver diammine fluoride [SDF]) [Chibinski et al., 2017; Richards, 2017], and the Hall technique (HT) [Innes et al., 2015; Santamaria and Innes, 2018]. On a wider scope, management techniques involving caries removal include those in which carious tissue is selectively removed, such as the (one-step) selective caries removal (SCR), stepwise caries removal (i.e., selective dentin carious tissue removal at the first step and in a second visit selective removal to firm dentin) [Ricketts et al., 2013; Bjørndal, 2018], and the nonselective caries removal (non-SCR), involving removal of all demineralized dentin in the cavity to reach hard dentin, leaving no softened dentin. This technique is no longer recommended [Innes et al., 2016, 2018].

The decision around when to use which treatment approach should follow the modern view of carious lesion management, which emphasizes controlling/inactivating the carious process using less invasive management approaches, avoiding initiation of the cycle of restoration, maintaining as much as possible of the affected dental tissue, and preserving the tooth for as long as possible [Schwendicke et al., 2016].

The number of clinical studies and reviews assessing and comparing the effectiveness of these diverse techniques and materials has increased over the last years. Despite the current scientific evidence regarding caries management in primary teeth, there is still no agreement on the most effective approach/material in terms of clinical success to treat primary teeth with dentin involvement; there is even a debate whether the outcomes should be on a tooth, child, or quality of life level. The aim of this systematic review (SR), therefore, is to systematically assess the current state of knowledge regarding interventions performed and materials used to manage carious lesions with dentin involvement in primary vital teeth, diagnosed clinically or radiographically.

Materials and Methods

This review asked the following PICO questions:

1. Are minimal invasive carious lesion management approaches (caries control and minimal operative interventions) more effective in terms of absence of signs or symptoms of pulpal disease or success of restorations or lesion arrestment than the conventional therapy (non-SCR and restoration) for managing dentin carious lesions of different depths in primary teeth?

2. What is the success/failure rate of different materials used for managing asymptomatic dentin carious lesions (occlusal or approximal) in primary teeth regarding integrity of the restoration or lesion arrest?

This study followed the PRISMA Statement recommendation [Moher et al., 2009]. No further review registration was performed as the topic was provided to the authors by the joined chairs of the ORCA/EFCD consensus workshop on how to intervene in the caries process.

Search Strategy

We included meta-analyses, SRs, and in the case of no studies for these levels of evidence, also randomized clinical trials (RCTs). We excluded studies in which caries removal was assisted by chemomechanical agents and compared to complete caries removal (CCR).

We defined the search strategy based on the combination of different predefined MeSH terms of the PubMed database. For details regarding the search terms used in English, see Table 1. Citations from: MEDLINE/PubMed, Cochrane Library, and MEDLINE via Ovid up to March 2019 were retrieved. Moreover, other electronic databases such as LILACS (Latin American & Caribbean Health Sciences Literature), and BBO (Brazilian Library in Dentistry) were also used to identify eligible papers. We included studies performed in humans and published in English and Spanish. Records from all database searches were analyzed using Mendeley software (version 1.19.3).

Inclusion Criteria

Participants

Children 3–12 years of age, primary dentition.

Intervention

PICO Question 1. Only studies that compared a minimum of one of the following treatment approaches to non-SCR/CCR were included:

- No carious tissue removal – such as NRCC (i.e., the carious lesion is opened to allow access to the lesion for brushing, allowing continuous removal of the biofilm and remineralization using fluoride products and advising a sensible diet) [Gruythuysen et al., 2011; Schwendicke et al., 2016; Santamaria et al., 2018];
- Caries arresting methods (e.g., SDF or other remineralization agents), and sealing techniques including those with no caries removal using filling materials or preformed metal crowns (PMCs) (the HT; where the carious lesion is separated from the oral environment and substrate by putting in a PMC, consequently slowing or stopping the caries process [Innes et al., 2015; Santamaria and Innes, 2018];
- SCR (at one visit) – that includes [Machiulskiene et al., 2020]:
- SCR to soft dentin: the excavation of carious dentin from the peripheral walls of a deep carious lesion (excavated to hard dentin), followed by selective removal of soft dentin from the pulpal wall; or
- SCR to firm/leathery dentin: the excavation to firm/leathery dentin (physically resistant to hand excavation) in the pulpal aspect of the cavity. Periphery of the cavity should be excavated to hard dentin. Stepwise caries excavation is the excavation of dentin carious tissue removal and temporary filling at the first step and in a second visit some months later, selective removal to firm dentin. CCR to reach hard dentin is no longer recommended and considered as overtreatment.

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− No caries treatment or extraction.
− Comparator/control intervention (non-SCR): that is, CCR to sound enamel and clear sound dentin (hard dentin) at one visit, usually using rotary instruments followed by restoration.

**PICO Question 2.** All types of materials used for restoration (i.e., amalgam [AMG], glass ionomers [self-setting or light-cured], composite resin [CR], compomer [CP], all types of PMCs), and management (i.e., fluoride products and SDF) of dentin carious lesions in primary teeth, independently of the extension of the lesion and type of cavity.

− Outcome: overall success of treatment (i.e., the absence of clinical signs or symptoms of pulpal pathology (or pain), or carries arrestment, or restoration success [satisfactory appearance of restoration, needlessness for retreatment]). We also reported subjective assessment of treatment by participants (children’s parents/guardians), regardless of the outcome measure or any adverse events (e.g., gingival inflammation) or safety issues (e.g., allergies) related to the interventions.
− Follow-up: at least 12 months after intervention.

**Critical Appraisal**

Four investigators (R.M.S., M.H.A., A.F.G.Z., and G.G.) independently performed the search and identified the articles for potential inclusion. Data from all included studies were extracted and assessed using designed data extraction forms (Tables 2, 3). A fifth investigator (G.F.G.) resolved disagreements.

Two reviewer teams (R.M.S./M.H.A./M.S.M. and A.G.F.Z./G.G./G.F.G.) estimated the risk of bias using the guidelines outlined by the Cochrane “risk of bias” tool [Higgins et al., 2011]. Seven criteria were considered for each included study: sequence generation, allocation concealment, masking of participants and personnel, masking of outcome assessment, incomplete outcome data, selective outcome reporting, and “other bias.” Each criterion was judged as “low,” “high,” or “unclear” risk of bias.

**PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)** was used for analysis of the reporting of SRs [Moher et al., 2009]. PRISMA assessment was performed in duplicate by the 2 reviewer teams. We considered all 27 included items and considered the sum of positive answers as the final score, with higher scores indicating better reporting quality. The risk of bias...
Table 2. Overview of the included systematic reviews for PICO 1 (n = 2) and PICO 2 (n = 10) on how to intervene in the caries process in carious primary teeth with dentin involvement

| Study ID | Intervention/control | Primary outcome | Data bases searched/up to | Included studies/participants/mode of analysis | Main results |
|----------|----------------------|-----------------|---------------------------|-----------------------------------------------|--------------|
| Tedesco et al. [2018] | All available approaches to treat dentin caries lesions in primary teeth. ART, HT, UTC, NRCC, sealer, IWT, fluoride application (SDF, NaF) conventional PMCs. | Pain relief as reported by the patient (survival of restoration was reported as secondary outcome) | MEDLINE/PubMed, Web of Science, Scopus, Grey literature (OpenSGL, OpenGrey) | 15 RCTs for systematic review and 13 for meta-analysis | Crowns placed on primary molar teeth with decay, or that have had pulp treatment, are likely to reduce the risk of major failure or pain in the long term compared to fillings. Crown fitted using the HT may reduce discomfort at the time of treatment compared to fillings (RR 0.56, 95% CI 0.36–0.87; 312 teeth). Crowns fitted using the HT may reduce discomfort at the time of treatment compared to fillings (RR 0.56, 95% CI 0.36–0.87; 312 teeth). Reduced risk of failure in crowns group (RR 0.81 vs. 0.69; 162 teeth) | |
| Innes et al. [2015] | Preformed crowns of any material placed using any method (incisal or no tooth caries material removal), or any pulp therapy prior to crown placement. Control: Another crown, or another method for managing carious tissue | Failure rate or failure rate as a secondary outcome | Cochrane Oral Health Group Trials Register, Cochrane Central Register of Controlled Trials, MEDLINE via Ovid, EMBASE via Ovid, US National Institutes of Health Trials Register, WHO International Clinical Trials Registry Platform for ongoing trials | 5 RCTs | 483 patients (926 restorations) Age of participants: 3–10 years RRs and CIs, meta-analysis, and forest plots | |
| Santos et al. [2016] | Intervention and control: Different adhesive materials used for restorations of primary teeth (CR, GIC, RMGIC, SRGIC, and CP) | Restoration survival and clinical performance | PubMed, Web of Science, LILACS, Science Information (Clinical Trials – US National Institute of Health, National Institute for Health and Clinical Excellence) | 11 RCTs | 5,483 patients (926 restorations) Age of participants: 3–10 years Meta-analysis, RRs and 95% CIs | Crowns placed on primary molar teeth with decay, or that have had pulp treatment, are likely to reduce the risk of major failure or pain in the long term compared to fillings. Reduced risk of failure in crowns group (RR 0.81 vs. 0.69; 162 teeth) | |

For PICO 1:
- **Stepwise excavation:** Reduced risk of pulp exposure (RR 0.31, 95% CI 0.17–0.57, p < 0.005).
  - All exposures occurred during the second stage of caries removal.
  - Signs or symptoms of pulpal disease during excavation.
- **Complete caries removal:** No statistically significant difference was found between CR vs. CP regarding median survival rate (p < 0.05).

For PICO 2:
- **Restorations vs. non-restorations:** No statistically significant difference was found between CR vs. CP regarding median survival rate (p < 0.05).
- **Crowns vs. fillings:** Reduced risk of failure in crowns group (RR 0.18, 95% CI 0.04–0.67; 312 teeth).
Table 2 (continued)

| Study ID | Intervention/control | Primary outcome | Data bases searched/up to | Included studies/participants/mode of analysis | Main results |
|----------|----------------------|-----------------|---------------------------|-----------------------------------------------|--------------|
| Duangthip et al. [2016] | Intervention and control: Comparisons between restorative approaches with different materials, cavity preparation, and removal techniques; restorative and nonrestorative approaches | Survival rates, failure rates, or longevity of restorations | PubMed, Cochrane Collaboration, EMBASE, 2014 | 8 trials reported in 9 articles: 0.594 patients (1,637 restorations) | There is great variation in the success rate of restorations, depending on the lesion extension, material, and operative technique used. CR and CP class I and III restorations show favorable success rates (86%) irrespective of the operative techniques (2-year follow-up). CP, AMG, and GIC class II restorations show highly variable success rates (63–80%). Provisional or interim GIC restoration performed in a field setting is less effective on caries arrest compared to nonsurgical approach using SDF solution. There was insufficient evidence to make recommendations. |
| Doeri et al. [2017] | Intervention: ART (hand instruments and lesions sealed with adhesive restorative materials, GICs with different viscosities or resins) Control: Conventional restorative treatment | Restoration failure (lost or deficient restorations) | The Cochrane Oral Health Group's Trials Register, The Cochrane Central Register of Controlled Trials, MEDLINE via OVID, EMBASE, LILACS/BIROME, BBO/BIROME, Clinical trials database (clinicaltrials.gov), WHO International Clinical Trials Registries Platform, February, 2017 | 15 studies = 11 trials included data on primary teeth: Primary teeth: 1,682 children Age of participants: 3–13 years | ART/HVGIC may increase the risk of restoration failure when compared to conventional fillings using HVGIC on multi-surface carious primary molars, over a follow-up period from 12 to 24 months (OR 11.11, 95% CI 0.54–2.29), though the findings were considered unreliable due to the low quality of evidence. Comparisons of ART vs. CCR using composite or RMGIC were downgraded to high risk of bias. |
| Aeem et al. [2017] | Intervention: Esthetic preformed crowns (CR-strip crowns, open-face PMCs, pre-veneered PMCs, zircon crowns) Control: Conventional restorative materials (AMG, CP, GIC, RMGIC, CP) or other types of crowns | Failure or clinical effectiveness of restorations | PubMed via MEDLINE, Cochrane central register, March, 2016 | 5 RCTs (reported in 7 papers): 5 studies reported on primary molars (NuSmile), 1 study reported on primary teeth (CR-strip crowns (3M, Filtek), pre-veneered PMCs (NuSmile), and zircon crowns (Zirkor) | Considerable heterogeneity of included studies, with high risk of bias. Data from a single study comparing zirconia crowns placed on primary incisors and compared with pre-veneered PMCs and CR strip crowns were excluded due to the limited follow-up period (6 months). |
| Chibinski et al. [2017] | Intervention: Silver diamine fluoride (SDF) for controlling caries progression Control: Conventional active treatments (ART) or placebos | Caries arrestment | PubMed, Cochrane, LILACS/BIROME, March, 2013 | 11 RCTs, 8 of which reported on primary teeth: 0.2732 children (only primary teeth included) Age of participants: 2–15 years | The arrestment of caries at 12 months promoted by SDF was 66% higher (93% CI 41–91%, p < 0.00001) than by other active materials, but it was 134% higher (95% CI 67–85%, p < 0.00001) than by placebos. Overall, the caries arrestment was 89% higher (93% CI 49–138%, p < 0.00001) than using active materials/placebos. The protocol of application of the majority of the studies was a single application of SDF at baseline. No heterogeneity was detected. The evidence was graded as high quality. The use of SDF is 89% more effective in controlling/arresting caries than other treatments (ART) or placebos. |
| de Amorim et al. [2018] | Intervention/control: ART restorations with HVGIC Control: AMG, CR | Survival rates of ART restorations | PubMed, EMBASE, LILACS/BIROME, CNKI/VIP, February, 2017 | 43 publications in primary and permanent teeth: 9 studies reported on primary teeth and 4 on mixed dentition | The survival percentages and standard errors of single-surface and multiple-surface ART restorations in primary posterior teeth over the first 2 years were 94.3% (±1.5) and 65.4% (±0.9), respectively. Reported ART/HVGIC survival rates match those of conventional treatment with a amalgam and resin composite restorations. |
Table 2 (continued)

| Study ID | Intervention/control | Primary outcome | Data bases searched/up to | Included studies/participants/analysis mode of analysis | Main results |
|----------|----------------------|-----------------|---------------------------|--------------------------------------------------------|--------------|
| Pires et al. [2018] | Intervention: Use of any restorative material according to conventional treatment Control: AMG, CP, CR, GIC, RMGIC | Survival rate (number of failures based on clinical criteria) | Clinical Trials Cochrane PubMed/EMBASE Scopus TRIP January 2017 | 17 RCTs ◊ 863 children (2,687 restorations) | Restorations of primary molars with conventional GIC showed increased risk of failure than CP, RMGIC, AMG, and CR. Risk of bias was low in most studies (45–60% of all items across studies) Pediatric dentists should avoid conventional glass ionomer cement for restoring primary molars |}
| Chisini et al. [2018] | Intervention and control: Class I or II restorations, or crown restorations performed with different restorative materials or techniques | Longevity of restorations | PubMed Scopus Web of Science Cochrane LILACS/EMRO 2017 | 31 studies (most of the included studies were RCTs) ◊ 3330 children (1,2047 restorations) | Overall failure rate of restorations (n = 12,047) was 12.5%. A high variation on AFR was detected (0–29.9%) CR showed the lowest AFRs (7.1–12.9%). PMCs had the highest success rate (96.1%). 36% of studies reported that restorations were carried out exclusively using rubber dam Class I restorations and restorations placed using rubber dam presented better AFR. The main reason for restoration failure was secondary caries (36.5%) |

AMG, Amalgam; AFR, annual failure rate; ART, atraumatic restorative treatment; CI, confidence interval; CR, composite resin; CP, comomer; CCR, conventional caries removal; ECC, Early childhood caries; GIC, glass ionomer cement; HT, Hall technique; HV/GIC, high-viscosity glass ionomer cement; IMT, interim restorative treatment; NaF, sodium fluoride; N.M, not mentioned; NRCG, non-restorative cavity control; PMG, preferred metal crown; RCT, randomized controlled clinical trial; RMGIC, resin-modified glass ionomer cement; RR, risk ratio; SCR, selective caries removal; SDF, silver diamine fluoride; SRGIC, silver-reinforced glass ionomer cement; UCT, ultraconservative treatment; WHO, World Health Organization.
ART and removal of biofilm from accessible large cavities), HT, IRT (interim restorative treatment), CCR, and so on (Table 2). Only data on primary teeth were extracted. Further details of the included SRs (n = 2) and RCTs (n = 5) are presented in Tables 2 and 3.

Selective Carious Tissue Removal

In the included studies, SCR was considered for the treatment of deep carious lesions: lesions defined as radiographically extending into the inner third or quarter of dentin, or clinically assessed at risk of pulpal exposure. The SR by Ricketts et al. [2013] reported a significant risk reduction for pulpal exposure for one-step SCR (RR 0.23, CI 0.08–0.69) and stepwise caries removal (RR 0.31, 95% CI 0.17–0.57) compared to CCR for the treatment of deep carious lesions. In addition, there were no differences in pulpal symptoms between SCR and CCR (RR 0.27, 95% CI 0.05–1.60, p = 0.15) in the middle term (12 months). However, for this comparison the quality of evidence was considered low. In addition, there was insufficient evidence to determine whether there was a difference in restoration failure between SCR and CCR. For this review, it should be considered that the extension of the SCR (to soft or firm/leathery dentin) might have varied throughout the included studies. Furthermore, the exact indication of the carious tissue removal extension was not noted in the paper.

An RCT [Franzon et al., 2015] which compared the 2-year clinical and radiographic outcomes of SCR (to leathery dentin) and CCR performed in deep carious primary molars showed no statistical benefit of SCR (66%) over CCR (86%) in terms of restoration survival (p = 0.03). However, the mean incidence of pulp exposure during excavation was significantly lower in SCR (2%) compared to CCR (27.5%; p < 0.01). When pulp exposure during caries excavation and restoration failure – according to the modified United States Public Health Service (USPHS) Criteria [Franzon et al., 2015] – were considered together as the outcome, there was no significant difference in success rates between SCR (64%) and CCR (61%; p = 0.10).

A further study by Phonghanyudh et al. [2012] assessed the integrity and 1-year survival of the restoration (resin-modified glass ionomer cement [RMGIC]) for SCR (selective or complete soft dentin caries removal by hand excavation) versus CCR (rotary instruments) of lesions located in ≥1/3 of dentin. No significant differences were reported in overall success (teeth without restoration failure, absence of pulp symptomatology, etc.) of SCR versus CCR. In terms of cavity type, the cumulative survival rate of Class I restorations was higher (92–100%) than that of Class II restorations (79 and 88%).

No Carious Tissue Removal

The SR by Ricketts [2013] reported its findings based on a single study [Innes et al., 2007]. In this study asymptomatic carious lesions radiographically in ≤ or >1/2 way through dentin were included. Lesions were located on the occlusal (32%) and approximal surfaces (68%). The reported dmft of the study population was 2.47. After 2 years, no dentinal caries removal using the HT showed lower failure in terms of absence of signs and symptoms of irreversible pulpitis (2%; p < 0.000) or loss of restoration (5%; p < 0.000) in comparison to CCR and filling (15 and 46%, respectively). Restorations placed in the control group were mainly multisurface fillings restored with conventional GIC (69%).

The SR and meta-analysis by Tedesco et al. [2018] showed that when caries arrestment is considered as the primary outcome, there are no differences in the success rates of dentin carious lesions (International Caries Detection and Assessment System [ICDAS] codes 4–5) treated with no carious tissue removal and sealed with resin materials compared to techniques involving caries removal (selective to firm/leathery dentin or CCR; RR 7.89, 95% CI 0.39–160.91). However, for this comparison the quality of evidence was considered low due to the overall high risk of bias in the included studies. In addition, this review showed that for asymptomatic dentin carious lesions on occluso-proximal surfaces, without considering the lesion depth, the HT showed the best results in terms of restoration success, followed by the NRCC, and then treatment modalities involving CCR and conventional restoration (CP, high-viscosity GIC [HVGIC], CR, AMG, etc.).

In the RCT by Mijan et al. [2014], asymptomatic dentin carious lesions of different depths (moderate-to-deep lesions close to pulp) treated with 3 treatment modalities ART/HVGIC, UCT, and CCR/AMG were compared. In the UCT, no caries removal was performed; however, small cavities were restored with ART/HVGIC, including SCR, and medium/large cavities were left open for daily supervised brushing. The results of this trial showed no difference in the tooth survival (absence of signs and symptoms of irreversible pulpitis) of primary molars treated according to the 3 interventions over the 3.5-year period (90.9 ± 2.0% with CCR, 90.4 ± 2.4% with ART, and 88.6 ± 1.9% with UCT; p = 0.13). In addition, Mijan et al. [2014] reported that tooth survival for molars was higher for Class I cavities than
Table 3. Summary of included randomized clinical trials for PICO 1 \((n = 5)\) and PICO 2 \((n = 1)\) on how to intervene in the caries process in carious primary teeth with dentin involvement

| Study ID          | Study type/setting/country                  | Sample distribution/age               | Intervention                                                                 | Control                                                                 | Surfaces involved/lesion depth                        | Follow-up period, months | Dropout, % | Main outcomes                                                                                      |
|-------------------|--------------------------------------------|---------------------------------------|------------------------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------|--------------------------|------------|-----------------------------------------------------------------------------------------------|
| PICO 1: Management approaches for dentin carious lesions in primary teeth | | | | | | | | | |
| Franzon et al. [2015] | Split-mouth RCT University clinic/ chairside Brazil | 51 children, 124 teeth SCR 38 children, 67 teeth CCR 31 children, 37 teeth Age 3–8 years (mean 5.6 years; SD 16 months) | SCR (feather), CaOH₂ applied to the pulpal wall and composite restoration | CCR, CaOH₂ applied to the pulpal wall and composite restoration | Occlusal and occlusal-proximal lesions Dentin caries (inner quarter) | 24 2 | Overall success (restoration and pulp status): SCR 64% CCR 61% (p = 0.10) Restoration success: SCR 66% CCR 86% (p = 0.03) Pulp exposure: SCR 2% CCR 27.5% (p < 0.01) Pulp vitality: SCR 92% CCR 98% (p > 0.05) |
| Santamaria et al. [2018] | 3-Arm parallel group RCT University clinic/ chairside Germany | 169 children/teeth HT 52 NRCC 52 CCR 65 Age 3–8 years (mean 5.6 years; SD 1.5 months) | Hall technique, Non-restorative cavity control | CCR and compomer restoration | Occlusal and occlusal-proximal lesions Dentin caries (ICDAS codes 3–5) | 30 16 | Overall success: HT 92.5% CCR 67% NRCC 70% Minor failures: HT 5% CCR 3.4% NRCC 21% (p = 0.013) Major failures: HT 2.5% CCR 3.4% | |
| Phonghanyudh et al. [2012] | 2-Centered parallel-group RCT Dental clinics in hospitals/ chairside Thailand | 276 children/teeth SCR 92 ART 92 CCR 92 Age 6–11 years (mean 7.7 years; SD 1.4 months) | SCR: Selective soft caries removal at EDJ by spoon excavation and RMGIC filling ART: Complete soft caries removal by spoon excavation and RMGIC filling | CCR and low-speed handpiece used and RMGIC filling | Occlusal and occlusal-proximal lesions Dentinal caries (≥1/3 of dentin) | 12 2.5 | Overall restoration success: SCR 83% ART 80% CCR 79% (p = 0.05) Overall pulp success: SCR 99% ART 100% CCR 98% (p > 0.05) Pulpal symptoms: SCR 1% ART 2% CCR 2% |
| van Gemert-Schriks et al. [2008] | Longitudinal RCT Primary school Rain forest of Suriname (South America) | 380 children Group 1 = 96 (full treatment) Group 2 = 91 (extractions) Group 3 = 96 (ART) Group 4 = 97 (no treatment) Age 5–7 years (mean 6.1 years; SD 0.5 years) | Group 2: Carious primary teeth with pulpal involvement were extracted Group 3: Carious cavities without possible pulp involvement were restored with ART Group 4: No treatment | All primary teeth with or without pulpal involvement | | 24 6.6 | Overall pulpal symptoms: 156/323 (48.3%) Overall abscess/fistula: 49/156 (30.2%) Overall root remnants = 49/156 (30.2%) Overall root caries: 49/156 (30.2%) Pulpal symptoms: Group 1: 14/80 (17.5%) Group 2: 14/73 (19.1%) Group 3: 55/82 (67.1%) Group 4: 17/55 (31.5%) Group 5: 73/88 (82.9%) Abscess/fistula: Group 1: 14/80 (17.5%) Group 2: 14/73 (19.1%) Group 3: 55/82 (67.1%) Group 4: 17/55 (31.5%) Group 5: 73/88 (82.9%) |
| Mijan et al. [2014] | 3-Arm parallel group RCT302 children/341 teeth Primary schools/ chairside Brazil | 246 children CCR 120 UCT 126 ART 52 Group 1 = 120 (ART) Group 2 = 126 (UCT) Group 3 = 52 (CCR) Age 6–7 years (mean SD): CCR 6.7 (0.4) ART 6.9 (0.4) UCT 6.9 (0.4) | Group 1: ART and extractions Group 2: Carious primary teeth ART and extractions | All primary teeth with or without pulpal involvement | Occlusal and occlusal-proximal lesions Small, medium, and large cavitated dentine carious lesions without pulp involvement | 42 12.2 | Overall survival: CCR 90.9% ART 90.4% UCT 88.6% with (p = 0.13) Pulpal exposure: CCR 37 (40.7%) ART 6 (11.2%) UCT 26 (48.1%) |

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The 2.5-year report by Santamaria et al. [2018] assessed the pulp symptomatology and failure of restoration of approximal asymptomatic dentin carious lesions of different depths (ICDAS codes 3–5) treated with 2 non-caries removal techniques (NRCC and HT) vs. CCR with CP filling. Results showed significant higher success (caries arrest/restoration intact and absence of signs of pulp pathology) for teeth treated with the HT ($p = 0.013$). No significant differences were reported when NRCC and CCR with fillings were compared ($p = 0.81$).

The study was performed in a high caries risk population ($\text{dmft} > 5$).

No Treatment of Carious Lesions or Extraction

For no carious treatment, only 1 RCT was included [van Gemert-Schriks et al., 2008]. This study compared 4 different interventions: (1) full dental treatment (ART and extractions), (2) only extractions, (3) only restorations using ART, and (4) no treatment. No additional preventive oral health interventions were reported. After 24 months, pulpal involvement was present in 48.3% of the participants. Broken down by interventions, pulpal involvement was 17.5%, 19.2%, 67.1%, and 82.9%, respectively, for the 4 interventions. However, the comparison between arms in this study may have been compromised since all teeth presenting with pulp involvement were extracted. In terms of caries increment, children treated with ART showed an increment in the dmft level from 5.48 ± 3.2 at baseline to 6.35 ± 2.6 after 2 years ($p < 0.001$).

### Table 3 (continued)

| Study ID | Study type/setting/country | Sample distribution/age | Intervention | Control | Surfaces involved/lesion depth | Follow-up period, months | Dropout, % | Main outcomes |
|----------|---------------------------|--------------------------|--------------|---------|-------------------------------|--------------------------|-----------|---------------|
| PICO 2: Materials for management of dentin carious lesions in primary teeth | Donly et al. [2018] | Split-mouth RCT University Clinic and Pediatric Dental Clinic/USA | NuSmile® aesthetic primary molar crowns | PMGs | Primary molars exhibiting carious lesions radiographically and clinically that warranted a full-coverage restoration | 24 | 22 | 70 crowns were evaluated |

The order from lowest to highest probability of failure was RMGIC, CR, AMG, and GIC. The AUC for network meta-analysis showed lower risk of failure for network meta-analysis (AUC, 0.732) compared to CR (AUC, 0.302) and GIC (AUC, 0.251). An SR and meta-analysis [Pires et al., 2018] compared the success/failure rates of different restorative materials (AMG, CR, CP, RMGIC) placed in primary molars (2,687 teeth) in Class I and II cavities. The network meta-analysis showed higher risk of failure for GIC compared to CP (RR 2.64, 95% CI 1.29–5.38), RMGIC (RR 3.25, 95% CI 1.58–6.75), AMG (RR 2.25, 95% CI 1.17–4.51), and CR (RR 3.27; 95% CI 1.55–7.15). The order from lowest to highest probability of failure was RMGIC, CR, AMG, and GIC.
A further SR by Duangthip et al. [2016] assessed the effectiveness of different approaches/materials for the treatment of dentin caries in primary teeth. The subgroup analysis demonstrated that CR and CP Class I and III restorations show favorable success rates (86–91%) over a 2-year period, while CP, AMG, and GIC Class II restorations show highly variable success rates (63–80%). Similarly, the SR by Chisini et al. [2018] reported that independently of the material, Class I restorations fail less (7.6%) than Class II (14.7%). In addition, restorations placed under rubber dam show a better success rate than those placed without it (93.6 vs. 77.5%).

An SR and meta-analysis on ART restorations from de Amorim et al. [2018] showed for primary posterior teeth that the mean survival rates of single-surface ART/HVGIC restorations were significantly higher (94.3 ± 1.5%) over 2 years compared to multiple-surface ART/HVGIC restorations (65.4 ± 3.9%). However, these rates were considered similar when compared to AMG resto-
rations in primary molars. On the other hand, the SR by Dorri et al. [2017] showed that ART/HVGIC may increase the risk of restoration failure when compared to conventional fillings using composite and AMG on multisurface carious primary molars, over a follow-up period from 12 to 24 months (OR 1.11, 95% CI 0.54–2.29). However, the findings were considered unreliable due to the low quality of evidence.

Three included SRs [Innes et al., 2015; Aiem et al., 2017; Chisini et al., 2018] and 1 RCT [Donly et al., 2018] reported on preformed crowns for restoring single and predominantly multisurface carious primary teeth. There was a wide variation in the studies related to treatment setting (chairside or general anesthesia), use of local anesthesia, number of operators, extension of the lesion surfaces involved, and so on. In general, these studies reported that in the long-term (12–48 months) PMCs were less likely to fail than conventional fillings (AMG, CR, GIC, RMGIC, and CP). Based on a single study [Innes et al., 2007], it was reported that there was no statistically significant relationship between Class I GIC restorations and the risk of a “minor” failure (restoration failure or reversible pulpitis, $p = 0.272$), but for Class II GIC restorations the relationship was significant ($p = 0.018$). The SR by Aiem et al. [2017] also compared different types of esthetic preformed crowns (NuSmile®, Pedo Pearls®, and Kinder Krowns®) for treating multisurface carious primary molars. The results of this review were inconclusive due to the overall high risk of bias with significantly dissimilar outcome measures used.

A recently published RCT [Donly et al., 2018] assessed the clinical success of zirconia crowns compared to PMCs for restoring primary molars using a split-mouth design. Fifty pairs of teeth requiring crowns were evaluated over a 2-year period. The size or extension of the carious lesions was not reported. After 2 years, 70 crowns (70%) were assessed (zirconia crowns = 36 [51%], PMC = 34 [49%]). There were no failures in any of the groups. The authors concluded that zirconia crowns perform comparably to PMCs for restoration of primary molars.

An SR and meta-analysis by Chibinski et al. [2017] aimed to evaluate the caries-arresting effect of SDF compared to active treatments or placebos for treating active caries lesions of different depths (moderate-to-deep lesions close to pulp). The authors reported that caries arrest at 12 months using SDF was 66% higher (RR 1.66, 95% CI 1.41–1.96) than that by other active material (GIC restorations and fluoride varnish). In this SR, the evidence was graded as high quality.

Secondary Outcomes

The SR from Ricketts et al. [2013] reported on patient, parent/caregiver, and dentist perception outcomes during treatment when non-caries removal (HT) and CCR were compared. No dentinal caries removal using the HT was preferred by 77% of children, 83% of parents/caregivers, and 81% dentists compared to CCR and restoration. Most children (89%) were assessed by the dentist as experiencing “no pain, discomfort” to “mild, not significant” during the intervention, compared to 78% in the CCR group.

The study from Santamaria et al. [2015] showed more child-related, negative behavior when CCR and restoration (37%) was performed compared to NRCC (21%) and HT (13%). Pain intensity was rated as “low” in all treatment modalities. NRCC and HT were rated as “easy” to perform for most dentists (>77%), compared to 50% in the non-SCR and CP filling arm. There were no significant differences in parents’ rating their child’s level of comfort.

Innes et al. [2015] reported that in the long term (12–24 months), PMCs were less likely to cause pain than fillings. In addition, children had more discomfort with fillings than PMCs. Apparently, there is an increased risk of gingival bleeding from crowns compared to fillings in the short and long term.

Adverse events were not reported in the included studies.

Study Outcome Summary of Findings and Assessment of Heterogeneity

PICO 1

- For treatment of asymptomatic moderate-to-deep lesions, the HT involving no carious tissue removal showed lower restoration failure for multisurface cavities, when compared to CCR and restoration [Ricketts et al., 2013; Santamaria et al., 2018; Tedesco et al., 2018].
- Considering arrestment of lesions, the available evidence endorsing the similarity between sealing dentin carious lesions with resin materials without carious tissue removal and interventions involving caries tissue removal (selective to firm/leathery dentin or CCR) is limited, and low in terms of quality [Tedesco et al., 2018].
- The NRCC [in Mijan et al., 2014, presented as UCT] showed comparable results with CCR and filling for treatment of asymptomatic moderate-to-deep dentin lesions [Mijan et al., 2014; Santamaria et al., 2018].
However, treatment success was superior when daily toothbrushing with fluoridated toothpaste and biofilm removal was supervised. The evidence for this technique is very limited, and low in terms of quality.

- Concerning treatment of deep carious lesions (lesions extending into the inner third or quarter of dentin), SCR, one-step, and stepwise caries removal showed reduction in the incidence of pulp exposure in asymptomatic, vital, carious deciduous teeth over CCR [Ricketts et al., 2013; Franzon et al., 2015]. However, the superiority of one over the other in terms of pulp symptoms could not be confirmed.
- There is extremely limited evidence for no treatment or extraction of teeth with dentin carious lesions, and so far, these approaches cannot be recommended.

PICO 2
- There is great variation in the success rate of restorations, depending on the lesion extension, material, and operative technique used.
- Irrespective of the technique used (standard or HT), PMCs were shown to have the highest success rates compared to other filling materials and were less likely to fail than fillings [Innes et al., 2015; Aiem et al., 2017; Chisini et al., 2018].
- Considering only filling materials, probability of failure was ranked from lowest to highest: RMGIC, CR, CP, AMG, and conventional GIC [Chisini et al., 2018; Pires et al., 2018], with a single SR and meta-analysis [Santos et al., 2016] reporting no significant differences between CR, CP, and RMGIC regarding restoration survival over a 2-year period. The results of the included SRs and meta-analysis were similar. However, some clinical heterogeneity was observed among the included studies regarding caries risk of participants, isolation technique used, criteria for restoration assessment, different material brands, and so on. This could indicate some degree of bias that could compromise mainly the ranking and, therefore, the interpretation of findings.
- In general, conventional GIC showed increased failure risk than other filling materials (e.g., CP, RMGIC, AMG, and CR) [Dorri et al., 2017; Chisini et al., 2018; Pires et al., 2018].
- Considering the type of carious lesion (occlusal or approximal), there was no significant relationship between Class I GIC restorations and the risk of restoration failure or reversible pulpitis. However, a significant relationship between restoration failure and Class II GIC restorations was reported [Innes et al., 2015].
- ART/HVGIC may increase the risk of restoration failure, essentially in multisurface cavities. In contrast, ART/HVGIC was demonstrated to be an adequate management option for treating single-surface carious lesions in primary teeth [de Amorim et al., 2018]. In addition, when conventional restorations were put in comparison, ART/HVGIC survival rates showed resemblance with those of conventional treatment of AMG and resin composite restorations [de Amorim et al., 2018]. In contrast, the conflicting results by Dorri et al. [2017] could be due to the low quality of evidence, and thus were considered unreliable.
- Regardless of the material used, survival of single-surface restorations is considerably greater than that of multisurface restorations over a 2-year period [Duangthip et al., 2016; Chisini et al., 2018]. Moreover, utilization of rubber dam showed better success rates of restorations than those placed without it [Chisini et al., 2018].
- Regarding esthetic PMCs for restoring carious front teeth, there is still inconclusive evidence supporting its use over other techniques (i.e., strip crowns), primarily due to the limited follow-up (<12 months). For primary molars, evidence from a single RCT [Donly et al., 2018], showed that zirconia crowns are comparable to PMCs for restoration of primary molars. However, the high risk of bias reported in the included SR (including 4 studies) [Aiem et al., 2017] prevents us from making recommendations on their effectiveness compared to PMCs.
- SDF was demonstrated to be significantly more effective in arresting caries than other treatments (fluoride varnish application and GIC restorations) or placebos for treating active caries lesions of different depths [Chibinski et al., 2017].

Quality Assessment

Considerable heterogeneity was observed in the included SRs and RCTs regarding to subject characteristics, depth of treated lesions, extension of cavities, restorative materials used, and outcome measures; however, the trends were similar. In addition, the databases searched and reporting of effect scores differed considerably among the SRs.

Most studies were found to have considerable risk of bias (Fig. 2; Table 4). All SRs reported quality of evidence as either poor or low-to-moderate level. Regarding the risk of bias of SRs, the estimated risk of bias according to
PRISMA was low for PICO 1 (100%). For PICO 2, most of included SRs presented low risk of bias (>80%), with 3 studies presenting a substantial (52%) [Aiem et al., 2017] or moderate (74%) [Duangthip et al., 2016; Chisini et al., 2018] risk of bias (Table 4).

Grading the “Body of Evidence”

Most included SRs were considered to have a low potential risk of bias. Estimation of the risk of bias related to the reporting and methodological quality of the included SRs is presented in Table 4.

Discussion

This systematic literature review aimed to assess an appropriate intervention during the caries process of dental lesions in terms of treatment approach (PICO 1) and material used (PICO 2) in primary teeth. Comparison of different methods of SCR, non-SCR, and treatment approaches, as well of the different materials used for restorations from the selected articles, were summarized based on their benefits and limitations to concur on appropriate approaches to treat caries in primary teeth. Eligible published studies including PICO 1 (2 SRs and 5 RCTs) and PICO 2 (10 SRs and 1 RCT) that strictly met the inclusion criteria were incorporated in the analysis. Mean age varied from 5.6 to 7.7 years within the clinical trials, and from 3 to 13 years within the SRs.

Most RCTs were identified as having considerable risk of bias. Randomization was reported for all studies, occasionally without detailed clarification. On the other hand, many studies did not report on allocation concealment and blinding of participants. In general, the most frequently downgraded domains were performance and detection bias (blinding of participants/personnel or outcome). However, blinding in some of the studies could not be assured due to the dissimilarities of compared techniques and materials used (e.g., techniques with caries removal vs. no caries removal; PMCs vs. direct restorations, etc.), and the associated procedures were specific enough to identify the allocation to a certain intervention.
Table 4. Estimated risk of bias according to the PRISMA Statement for reporting the included systematic reviews for PICO 1 \((n = 2)\) and PICO 2 \((n = 10)\) on how to intervene in the caries process in carious primary teeth with dentin involvement

| Study No. | Quality criteria PICO I | Quality criteria PICO II |
|-----------|-------------------------|------------------------|
| 1         | Defined outcome criteria of interest | + + + + + + + + + + + + |
| 2         | Describes the rationale | + + + + + + + + + + + + |
| 3         | Describes the focused (PICO[S]) question/hypothesis | + + + + + + + + + + + + |
| 4         | Describes if a protocol was developed “a priori” | + + + + – + + + + + + |
| 5         | Protocol registration/publication | + + + + + – + + + + + + |
| 6         | Presented eligibility criteria (in/exclusion criteria) | + + + + + + + + + + + + |
| 7         | Presents the full search strategy | + + + + + + + + – + + + + |
| 8         | Various databases searched | + + + + + + + + + + + + |
| 9         | Performed (hand) search in additional sources (e.g., grey literature or trial) | + + + + + – + – – – – – |
| 10        | Review selection by more than 1 reviewer | (1)+ (2)+ (2)+ (2)+ (3)+ (2)+ (2)+ (2)+ (2)+ (2)+ |
| 11        | Non-English papers included | + + + + + – + – + + + – |
| 12        | Provide details on the performed study selection process/flow chart | + + + + + + + + + + + |
| 13        | Report included study characteristics | + + + + + + + + + + + + |
| 14        | Provide data of the selected studies on the outcome measures of interest | + + + + + + + + + + + + |
| 15        | Data were extracted by more than 1 reviewer | + + + + + + + + + + + + |
| 16        | Contacted authors for additional information | + + + + + + + – + + + – |
| 17        | Report heterogeneity of the included studies | + + + + + + + – + + – + |
| 18        | Estimated risk of bias in individual studies | + + + + + + + + + + + + |
| 19        | Performed a meta-analysis | + + + + + + + – + + + – |
| 20        | Performed a descriptive analysis | + + + + + + + + + + + + |
| 21        | Describe additional sub-analysis | + + + + + + + + + + + + |
| 22        | Grading of the obtained evidence | + + + + + + + – + + + – |
| 23        | Present limitations of the systematic review | + + + + + + + + + + + + |
| 24        | Provide a conclusion that responds to the objective | + + + + + + + + + + + + |
| 25        | Publication bias assessed | + + + + + + + – + + + – |
| 26        | Funding source | + + + + + + + + + + + + |
| 27        | Conflict of interest statement | + + + + + + + – + + + – |

For the quality assessment score, individual items with a positive rating were summed to obtain an overall percentage score.
It was disappointing to have downgraded some clinical studies because these were not satisfactory in a risk of bias protocol that is essentially not applicable for this kind of studies. The protocols used for risk of bias assessment should consider and acknowledge the limitations of clinical treatment modalities. Another example of possible bias in the included studies was the variability of caries diagnostic methods and indices (dmft/DFMT, ICDAS, etc.) for treatment assessment (USPHS, own developed criteria, etc.), often without reporting calibration of examiners. The considerable risk of bias of some included studies and the heterogeneity in comparisons and outcomes (Table 3) hindered the ability to perform a meta-analysis to complete recommendations. Related to the review process, a potential risk of bias was that one of the review authors (R.M.S.) carried out one of the included studies. However, the author was not involved in the data extraction, assessment of risk of bias, or outcome analysis for this study.

Recent consensus meeting reports stated terminology and recommendations on carious tissue removal in primary and permanent teeth [Schwendicke et al., 2016; Machiulskiene et al., 2020]. In the present review, one of the causes of heterogeneity within the included studies was the depth of caries removal (i.e., the amount of tissue left or removed). Thus, what authors termed complete caries removal might not always be complete, or even SCR. Caries removal varied between studies (soft to firm dentin), generally due to the diverse and inhomogeneous use of criteria for assessing the remaining dentin tissue after carious removal. Added to this is the fact of the subjective nature of the selective removal of carious tissue and the instinctive reliance of clinicians in terms of the type of carious dentin layer that is reached. This variation might have impacted whether the pulp was exposed during caries removal. This is particularly evident in the studies which were conducted before the consensuses were published. However, our results show that particularly in the treatment of deep carious lesions in primary teeth, it seems advantageous to use techniques which involve SCR (to soft or to firm/leathery dentin) in order to reduce pulp exposure.

From the included studies there is insufficient evidence to determine whether it is necessary to re-enter as in the stepwise caries removal technique. However, an SR and meta-analysis [Schwendicke et al., 2013] (not included in present review due to pooled data reporting of primary and permanent teeth) that compared one-step incomplete and stepwise caries removal with complete caries removal showed risk reduction for pulp exposure and pulpal symptoms for both management techniques. In the present review, the reported risk of failure for both techniques seemed to be comparable, but due to limited quality of data for this outcome, conclusions could not be drawn.

We did not address the effect of SCR on the adhesion of the restorative materials or bonding techniques, or how carious tissue removal was performed (hand, mechanical, chemomechanical, etc.). Although there is still insufficient evidence to recommend any single method/technique for caries management, studies which involved no carious tissue removal such as the HT and sealing with resin-based materials [Ricketts et al., 2013; Tedesco et al., 2018] reported no adverse consequences when caries was left, and the lesion sealed. Findings of 2 RCTs [Borges et al., 2012; Hesse et al., 2014] included in Tedesco et al. [2018] showed a notable similarity in efficacy of sealing with resin materials regarding arrestment of asymptomatic occlusal carious lesions when compared to techniques involving carious tissue removal (SCR to firm/leathery dentin [Hesse et al., 2014] or CCR [Borges et al., 2012]), and the possibility of avoiding CCR for dentin carious primary teeth. This may indicate that entering the carious lesion may not be necessary and that rather an accurate pulp diagnosis and adequate lesion sealing contribute to treatment success.

In addition, techniques involving no caries removal or restoration of the affected teeth (NRCC and UCT) showed similar results to complete caries removal and restoration in terms of signs or symptoms of pulp damage. Treatment success was higher when daily toothbrushing was supervised. However, data on these management approaches were of a limited quality and inconclusive. The use of NRCC is considered as an advantageous method to control carious lesion progression, to change patient/parents’ behavior, and to promote oral health [Gruythuysen et al., 2011]. However, it seems to have limited clinical success, and this may limit its applicability to general situations. In general, we still need to understand the factors that support or reduce the success of NRCC, and some of these would seem to be closely related to our capacity as clinicians to change patient behavior or to aspects related to the patient and his/her family context. Further prospective long-term studies on this management technique are required, probably supplementing the caries arrestment with the use of silver fluoride agents. In the included SR [Chibinski et al., 2017], SDF showed superiority in terms of caries arrest when compared to other fluoride treatments or placebos, and the quality of this evidence was graded as high. Over-
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all, there is consistent evidence from high-quality SRs [Rosenblatt et al., 2009; Gao et al., 2016; Chibinski et al., 2017] showing the effectiveness of SDF for caries arrest in cavitated lesions in primary and permanent teeth. In general, SDF offers multiple advantages for the treatment of pediatric patients such as easy application, noninvasiveness, safety, and so on. In addition, the use of SDF buys the dentist some time until more traditional restorative methods can be utilized, if required. However, it also presents disadvantages such as the permanent black staining of the carious lesions, which can be a concern for more esthetic-oriented parents/children.

Irrespective of the technique used – standard (i.e., caries removal and tooth preparation) or HT – PMCs had the highest success rates compared to other filling materials and were less likely to fail than fillings. In general, there is evidence in favor of PMCs for the restoration of carious primary molars. Zirconia primary molar crowns show promise in terms of restoration success for the treatment of primary molars compared to PMCs [Donly et al., 2018]. However, an included review [Aiem et al., 2017] contained conflicting data based on RCTs with a high risk of bias and notably different outcomes. In addition, the cost of zirconia primary molar crowns could limit their use in daily practice, mainly considering that in many countries restorations with esthetic crowns are not covered by the statutory insurance, thus costs should be covered either by the patient or his private additional insurance. The cost-benefit of zirconia crowns for parents and health systems as compared to PMCs should also be considered in further studies. Among direct restorative materials, there is evidence against conventional GIC for the restoration of multisurface cavitated primary carious teeth as it showed increased failure risk. RMGIC, on the other hand, had the lowest failure risk followed by CR, CP, AMG, and GIC. Regarding ART using HVGICs, there is weak evidence supporting its use for the treatment of multisurface carious lesions in primary teeth. Irrespective of the material used, single-surface restorations fail less than multisurface restorations over a 2-year period [Chisini et al., 2018; Pires et al., 2018].

Whilst the technique and material per se are important for treatment success, an accurate diagnosis of the carious lesion and pulpal status are crucial and can impact the results. Authors of included studies in this review reported the inclusion of asymptomatic primary teeth with no clinical or radiographic signs of pulp injury. Thus, in daily practice for managing patients with reported pain, or other signs or symptoms of irreversible pulpitis, another treatment modality should be considered, which involves pulp management (pulpotomy or pulpectomy) or extraction and the use of space maintainers. In addition, patients included in most studies were individuals with high caries risk (dmft >3), presenting a high number of restored surfaces. This factor, although often included in clinical studies, is rarely considered as a variable of analysis and this may influence the survival of restorations. Patients’ caries risk has been shown in permanent teeth to significantly influence the longevity of restorations [Demarco et al., 2012].

In general, the management of carious lesions in primary teeth is challenging. In contrast to treatment in adults, pediatric dentistry has to consider factors such as age, cognitive development, pain perception and ability to describe it, child and parents’ cooperation, type of treatment, and so on. These play a central role in the selection and provision of dental treatment. To conclude, for disease control or restoration longevity, there is no single ideal therapy for managing dentin caries in pediatric patients. The current evidence shows that in symptomless, carious primary teeth, less invasive techniques involving SCR and those involving no caries removal (SDF application or the HT) could be advantageous in terms of reduction of pulp exposure or restoration failure, as compared to nonselective caries removal. In addition, for treatment of multisurface carious lesions the use of PMCs is recommendable.

Further Recommendations

Dental practitioners should consider the use of more conservative techniques involving selective or no caries removal (HT) or without restoration (SDF) over total caries removal for patients presenting with vital, symptomless, carious lesions in primary teeth. Studies using NRCC reinforced by the use of SDF and compared to other treatment approaches are needed.

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Statement of Ethics

This study followed the PRISMA Statement recommendation. No further review registration was performed as the topic was provided to the authors by the joined chairs of the ORCA/EFCD Consensus workshop on how to intervene in the caries process.

Conflict of Interest Statement

R.M.S., M.H.A., G.G., M.S.M., and G.F.G. declare that they have no conflict of interest. A.G.F.Z. has received research grants from Colgate, NIDCR, Greenmark, Delta Dental, and Calcivis, and is a consultant on product development by Colgate, GreenMark, and Calcivis.

Author Contributions

A.G.F.Z. and R.M.S.: designed and planned the search strategies. R.M.S., M.H.A., G.G., and A.G.F.Z.: identified studies from PubMed and screened for eligibility and inclusion. R.M.S., M.H.A., M.S.M., and A.G.F.Z.: summarized the studies and analyzed the results. R.M.S. and A.G.F.Z.: wrote a first draft of the manuscript that was complemented and revised by G.F.G., M.H.A, M.S.M, and G.G.

References

Aiem E, Small-Faugeron V, Muller-Bolla M. Aerobic preformed paediatric crowns: systematic review. Int J Paediatr Dent. 2017 Jul; 27(4):273–82.
Bjørndal L. Stepwise Excavation. Monogr Oral Sci. 2018;27:68–81.
Borges BC, De Souza Bezerra Araújo RF, Dantas RF, De Arai Lucena A, De Assunção Pinheiro IV. Efficacy of a non-drilling approach to manage non-cavitated dentin occlusal caries in primary molar: a 12-month randomized controlled clinical trial. Int J Paediatr Dent. 2012 Jan;22(1):44–51.
Chibinski AC, Wambier LM, Feltrin J, Loguerquito AD, Wambier DS, Reis A. Silver Diamine Fluoride Has Efficacy in Controlling Caries Progression in Primary Teeth: A Systematic Review and Meta-Analysis. Caries Res. 2017; 51(5):527–41.
Chisini LA, Collares K, Cademartori MG, de Oliveira LJ, Conde MC, Demarco FF, et al. Restorations in primary teeth: a systematic review on survival and reasons for failures. Int J Paediatr Dent. 2018 Mar;28(2):123–39.
de Amorim RG, Frencken JE, Raggio DP, Chen X, Hu X, Leal SC. Survival percentages of traumatic restorative treatment (ART) restorations and sealants in posterior teeth: an updated systematic review and meta-analysis. Clin Oral Investig. 2018 Nov;22(8):2703–25.
Demarco FF, Corrêa MB, Cenci MS, Moraes RR, Opdam NJ. Longevity of posterior composite restorations: not only a matter of materials. Dent Mater. 2012 Jan;28(1):87–101.
Donly KJ, Sasa I, Contreras CI, Mendez MJ. Prospective Randomized Clinical Trial of Primary Molar Crowns: 24-Month Results. Pediatr Dent. 2018 Jul;40(4):253–8.
Dorri M, Martinez-Zapata MJ, Walsh T, Marinho VC, Sheiham Deceased A, Zaroc O. Traumatic restorative treatment versus conventional restorative treatment for managing dental caries. Cochrane Database Syst Rev. 2017 Dec;12:CD008072.
Duangthip D, Jiang M, Chu CH, Lo EC. Restorative approaches to treat dentin caries in preschool children: systematic review. Eur J Paediatr Dent. 2016 Jun;17(2):113–21.
Franzon R, Opdam NJ, Guimaêraes LF, Demarco FF, Casagrande L, Haas AN, et al. Randomized controlled clinical trial of the 24-months survival of composite resin restorations after one-step incomplete and complete excavation on primary teeth. J Dent. 2015 Oct;43(10):1235–41.
Gao SS, Zhao IS, Hiraishi N, Duangthip D, Mei ML, Lo EC, et al. Clinical Trials of Silver Diamine Fluoride in Arresting Caries among Children: A Systematic Review. JDR Clin Trans Res. 2016 Oct;1(3):201–10.
Gruythuyser Rj, van Strijp AJ, van Palesten Helderman WH, Frankenmolen FW. [Non-restorative treatment of cavities in temporary dentition: effective and child-friendly]. Ned Tijdschr Geneeskd. 2011;155(42):A3489.
Hesse D, Bonifácio CC, Mendes FM, Braga MM, Imparato JC, Raggio DP. Sealing versus partial caries removal in primary molars: a randomized clinical trial. BMC Oral Health. 2014 May;14(1):58.
Higgins JP, Altman DG, Gotzsche PC, Juni P, Moher D, Oxman AD, et al.; Cochrane Bias Methods Group; Cochrane Statistical Methods Group. The Cochrane Collaboration’s tool for assessing risk of bias in randomised trials. BMJ. 2011 Oct;343:d5928.
Innes N, Schwendicke F, Frencken J. An Agreed Terminology for Carious Tissue Removal. Monogr Oral Sci. 2018;27:155–61.
Innes NP, Evans DJ, Stirrups DR. The Hall Technique; a randomized controlled clinical trial of a novel method of managing carious primary molars in general dental practice: acceptability of the technique and outcomes at 23 months. BMC Oral Health. 2007 Dec;7(1):18.
Innes NP, Frencken JE, Bjørndal L, Maltz M, Manton DJ, Ricketts D, et al. Managing Carious Lesions: Consensus Recommendations on Terminology. Adv Dent Res. 2016 May; 28(2):49–57.
Innes NP, Ricketts D, Chong LY, Keightley AJ, Lamont T, Santamaria RM. Preformed crowns for decayed primary molar teeth. Cochrane Database Syst Rev. 2015 Dec;12:CD008512.
Kidd E. The implications of the new paradigm of dental caries. J Dent. 2011 Dec;39 Suppl 2:S3–8.
Machulskiene V, Campus G, Carvalho J, Dige I, Ekstrand K, Jablonski-Momeni A, et al. Terminology of Dental Caries and Dental Caries Management: Consensus Report of a Workshop Organized by ORCA and Cariology Research Group of IADR. Caries Res. 2020; 54(1):7–14.
Mijan M, de Amorim RG, Leal SC, Mulder J, Oliveira L, Creugers NH, et al. The 3.5-year survival rates of primary molars treated according to three treatment protocols: a controlled clinical trial. Clin Oral Investig. 2014 May;18(4):1061–9.
Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009 Jul; 6(7):e1000097.
Phonghanyudh A, Phantomuvit P, Songpaisan Y, Petersen PE. Clinical evaluation of three caries removal approaches in primary teeth: a randomised controlled trial. Community Dent Health. 2012 Jun;29(2):173–8.
Pires CW, Pedrotti D, Lenzi TL, Soares FZ, Ziegelmans PK, Rocha RO. Is there a best conventional material for restoring posterior primary teeth? A network meta-analysis. Braz Oral Res. 2018 Mar;32(2):e10.
Richards D. The effectiveness of silver diamine fluoride in arresting caries. Evid Based Dent. 2017 Oct;18(3):70.

Santamaria et al.
Ricketts D, Lamont T, Innes NP, Kidd E, Clarkson JE. Operative caries management in adults and children. Cochrane Database Syst Rev. 2013 Mar;(3):CD003808.

Rosenblatt A, Stamford TC, Niederman R. Silver diamine fluoride: a caries "silver-fluoride bullet". J Dent Res. 2009 Feb;88(2):116–25.

Santamaria R, Innes N. Sealing Carious Tissue in Primary Teeth Using Crowns: The Hall Technique. Monogr Oral Sci. 2018;27:113–23.

Santamaria RM, Innes NP, Machiulskiene V, Evans DJ, Alkilzy M, Splieth CH. Acceptability of different caries management methods for primary molars in a RCT. Int J Paediatr Dent. 2015 Jan;25(1):9–17.

Santamaria RM, Innes NP, Machiulskiene V, Schmoeckel J, Alkilzy M, Splieth CH. Alternative Caries Management Options for Primary Molars: 2.5-Year Outcomes of a Randomised Clinical Trial. Caries Res. 2018 Jan;51(6):605–14.

Santos AP, Moreira IK, Scarpelli AC, Pordeus IA, Paiva SM, Martins CC. Survival of Adhesive Restorations for Primary Molars: A Systematic Review and Metaanalysis of Clinical Trials. Pediatr Dent. 2016 Oct;38(5):370–8.

Schwendicke F, Dörfer CE, Paris S. Incomplete caries removal: a systematic review and meta-analysis. J Dent Res. 2013 Apr;92(4):306–14.

Schwendicke F, Frencken JE, Bjørndal L, Maltz M, Manton DJ, Ricketts D, et al. Managing Carious Lesions: Consensus Recommendations on Carious Tissue Removal. Adv Dent Res. 2016 May;28(2):58–67.

Tedesco TK, Gimenez T, Floriano I, Montagner AF, Camargo LB, Calvo AF, et al. Scientific evidence for the management of dentin caries lesions in pediatric dentistry: A systematic review and network meta-analysis. PLoS One. 2018 Nov;13(11):e0206296.

van Gemert-Schriks MC, van Amerongen WE, ten Cate JM, Aartman IH. The effect of different dental treatment strategies on the oral health of children: a longitudinal randomised controlled trial. Clin Oral Investig. 2008 Dec;12(4):361–8.

Yengopal V, Harneker SY, Patel N, Siegfried N. Dental fillings for the treatment of caries in the primary dentition. Cochrane Database Syst Rev. 2009 Apr;(2):CD004483.