Pediatric Restorative Dentistry

Latest Revision
2022

How to Cite: American Academy of Pediatric Dentistry. Pediatric restorative dentistry. The Reference Manual of Pediatric Dentistry. Chicago, IL: American Academy of Pediatric Dentistry; 2025:473-86.

Abstract

This best practice provides clinicians with guidance to form decisions about restorative dentistry, including when treatment is necessary and which techniques and materials are appropriate for restorative dentistry in pediatric patients. Not every caries lesion requires restoration, and restorative treatment of caries alone does not stop the disease process. Further, restorations have finite lifespans. Restorative approaches and supporting evidence for the excavation and restoration of deep caries lesions, including complete excavation, stepwise (ie, 2-step) excavation, partial (ie, 1-step) excavation, and no removal of caries prior to restoration, are discussed. Further research on long-term effectiveness of resin infiltration for small, noncavitated interproximal lesions is recommended. The evidence for and against the use of amalgam, composite, glass ionomer and resin-modified glass ionomer cements, compomers, stainless steel crowns, and anterior crowns has been summarized. Practitioners should familiarize themselves with such evidence to inform their clinical decisions regarding pediatric restorative dentistry.

This document was developed through a collaborative effort of the American Academy of Pediatric Dentistry Councils on Clinical Affairs and Scientific Affairs to offer updated information and guidance regarding restorative dental care for children.

KEYWORDS: DENTISTRY, OPERATIVE; DENTAL MATERIALS; DENTAL RESTORATION, PERMANENT; DENTAL RESTORATION, TEMPORARY; EVIDENCE-BASED DENTISTRY

Purpose

The American Academy of Pediatric Dentistry (**AAPD**) intends these recommendations to help practitioners make decisions regarding restorative dentistry, including when it is necessary to treat and what the appropriate materials and techniques are for restorative dentistry in children and adolescents.

Methods

These recommendations originally were developed by the Restorative Dentistry Subcommittee of the Clinical Affairs Committee and adopted in 1991.[1] The last revision by the Council on Clinical Affairs occurred in 2019.[2] A thorough review of the scientific literature in the English language pertaining to restorative dentistry in primary and permanent teeth was completed to revise the previous version. Electronic database searches using PubMed/MEDLINE, for the most part between the years 2012-2022, were conducted using the terms: *dental caries*, *intracoronal restorations*, *restorative treatment decisions*, *caries diagnosis*, *caries excavation*, *dental amalgam*, *glass ionomers*, *resin-modified glass ionomers*, *conventional glass ionomers*, *glass ionomer cements*, *atraumatic/alternative restorative technique* (**ART**), *interim therapeutic restoration* (**ITR**), *resin infiltration*, *resin-based composite*, *dental composites*, *compomers*, *full coverage dental restorations*, *stainless steel crowns* (**SSC**), *Hall technique*, *primary molars*, *preformed metal crowns* (**PMC**), *strip crowns*, *preveneered crowns*, *zirconia crowns*, *esthetic restorations*; parameters: humans, English, birth through age 18, clinical trials, randomized controlled clinical trials (**RCTs**). This search yielded 1,671 articles. Articles were screened by viewing titles and abstracts. Articles were chosen for review from these searches and from the references within selected articles. When data did not appear sufficient or were inconclusive, recommendations were based upon expert and/or consensus opinion by experienced researchers and clinicians.

Background

Historically, the management of dental caries was based on the belief that caries was a progressive disease that eventually destroyed the tooth unless there was surgical or restorative intervention.[3] It is now recognized that restorative treatment of dental caries alone does not stop the disease process and that restorations have a finite lifespan.[3] Conversely, some caries lesions may not progress and, therefore, may not need restoration.

Contemporary management of dental caries includes identification of an individual's risk for caries progression, understanding of the disease process for that individual, and active surveillance to assess disease progression.[3] Management with targeted preventive services and therapy such as silver

ABBREVIATIONS

AAPD: American Academy of Pediatric Dentistry. **ADA:** American Dental Association. **ART:** Alternative restorative technique. **BPA:** Bisphenol A. **FDA:** US Food and Drug Administration. **GIC:** Glass ionomer cement. **HT:** Hall technique. **ITR:** Interim therapeutic restoration. **MIH:** Molar-incisor hypomineralization. **MTA:** Mineral trioxide aggregate. **PMC:** Preformed metal crown(s). **RCTs:** Randomized controlled trials. **RMGIC:** Resin-modified glass ionomer cement(s). **SSC:** Stainless steel crowns.

diammine fluoride is supplemented by restorative therapy when indicated.[3-5]

Molar-incisor hypomineralization (**MIH**) is a developmental defect involving any number of the permanent first molars and possibly the permanent incisors as well. This condition presents esthetic and restorative challenges due to the range of clinical variation, including hypersensitivity, altered resin bond strength, potential for tooth structure loss, and a caries presentation that can be unusual.[6,7] Restorative treatment options and overall management of MIH depend on the degree of affected teeth, potential for breakdown of tooth structure, sensitivity, severity and quality of the dental defect in addition to patient preferences and behavior.[7,8]

Recommendations

When to restore

Among the objectives of restorative treatment are to repair or limit the damage from caries, protect and preserve the tooth structure, and maintain pulp vitality whenever possible. AAPD's *Use of Vital Pulp Therapies in Primary Teeth with Deep Caries Lesions*[9] and *Pulp Therapy for Primary and Immature Permanent Teeth*[10] state the treatment objective for a tooth affected by caries is to maintain pulpal vitality, especially in immature permanent teeth for continued apexogenesis.

Indications for restorative therapy have been examined only superficially because such decisions generally have been regarded as a function of clinical judgment.[11] Decisions for when to restore caries lesions should include at the least: clinical criteria of visual detection of enamel cavitations, visual identification of shadowing of the enamel, or radiographic recognition of enlargement of lesions over time.[3,12,13]

The benefits of restorative therapy include removing cavitations or defects to eliminate areas that are susceptible to caries, stopping the progression of tooth demineralization, restoring tooth structure and function, preventing the spread of infection into the dental pulp, and preventing the shifting of teeth due to loss of tooth structure. The risks of restorative therapy include reducing the longevity of teeth by making them more susceptible to fracture, recurrent lesions, restoration failure, pulp exposure during caries excavation, and future pulpal complications, in addition to the risk of iatrogenic damage to adjacent teeth.[14-16]

Primary teeth may be more susceptible to restoration failures than permanent teeth.[17] Additionally, before restoration of primary teeth, one needs to consider the length of time until tooth exfoliation.

Recommendations

- Management of dental caries should include identification of an individual's risk for caries progression, understanding of the disease process for that individual, and active surveillance to assess disease progression and intervention with appropriate preventive services, supplemented by restorative therapy when indicated.
- Decisions for when to restore caries lesions should include at the least: clinical criteria of visual detection of enamel cavitation, visual identification of shadowing of the enamel, or radiographic recognition of progression of lesions.

Deep caries excavation and restoration

Regarding the treatment of deep caries, 3 methods of caries removal have been compared to complete excavation, where all carious dentin is removed. Stepwise excavation is a 2-step caries removal process in which carious dentin is partially removed at the first appointment, leaving caries over the pulp, with placement of a temporary filling. At the second appointment, all remaining carious dentin is removed, and a final restoration placed.[18] Partial, or 1-step, caries excavation removes part of the carious dentin but leaves caries over the pulp, and subsequently places a base and final restoration.[19,20] No removal of caries before restoration of primary molars in children aged 3 to 10 years also has been reported.[21]

Evidence from multiple studies shows that frequency of pulp exposures in primary and permanent teeth is significantly reduced when using incomplete caries excavation compared to complete excavation in teeth with a normal pulp or reversible pulpitis. Two trials and a Cochrane review found that partial excavation resulted in significantly fewer pulp exposures compared to complete excavation.[22-24] One 5-year RCT evaluated the pulpal vitality of teeth treated with partial excavation compared to stepwise excavation and found that the success rate was significantly higher in partial excavation (80%) versus stepwise excavation (56%).[25] Two trials of stepwise excavation showed that pulp exposure occurred more frequently from complete excavation compared to stepwise excavation.[18,23] Evidence of a decrease in pulpal complications and postoperative pain after incomplete caries excavation compared to complete excavation in clinical trials is summarized in a meta-analysis.[26]

Additionally, a meta-analysis found the risk for permanent restoration failure was similar for incompletely and completely excavated teeth.[26] With regard to the need to reopen a tooth with partial excavation of caries, 1 RCT that compared partial (1-step) to stepwise excavation in permanent molars found higher rates of success in maintaining pulp vitality with partial excavation, suggesting there is no need to reopen the cavity and perform a second excavation.[19] Interestingly, 2 RCTs suggest that restoration without excavation can arrest dental caries as long as a good seal of the final restoration is maintained.[21,27]

Recommendations

- Multiple RCTs and systematic reviews determined that incomplete caries excavation, either partial (1-step) or stepwise (2-step) excavation, in primary and permanent teeth with normal pulps or reversible pulpitis results in fewer pulp exposures and fewer signs and symptoms of pulpal disease than complete excavation. Incomplete caries removal should be considered in primary and

permanent teeth with deep caries and normal pulp status or reversible pulpitis when complete caries removal is likely to result in pulp exposure.
- Two systematic reviews reported that the rate of restoration failure in permanent teeth is no higher after incomplete rather than complete caries excavation.
- Numerous studies concluded that partial (1-step) excavation followed by placement of final restoration leads to higher success in maintaining pulp vitality in permanent teeth than stepwise (2-step) excavation.

Resin infiltration

Resin infiltration is used primarily to arrest the progression of noncavitated interproximal caries lesions.[28,29] The aim of the resin infiltration technique is to allow penetration of a low viscosity resin into the porous lesion body of enamel caries.[28] Once polymerized, this resin serves as a barrier to acids and theoretically prevents lesion progression.[30,31]

A systematic review and meta-analysis that evaluated the effectiveness of enamel infiltration in preventing initial caries progression in proximal surfaces of primary and permanent teeth found infiltration was significantly more effective than placebo treatment.[32] In randomized clinical trials, resin infiltration, when used as an adjunct to preventive measures, was found to be more effective in reducing the radiographic progression of early or incipient proximal lesions on primary molars than preventive measures alone over a 24-month period.[33-36] Current ADA clinical practice guidelines for nonrestorative treatment for noncavitated interproximal caries lesions conditionally recommends enamel infiltration for treatment of these lesions, (low to very low certainty).[37] Few RCTs evaluate the long-term effectiveness of resin infiltration. An additional use of resin infiltration has been suggested to restore white-spot lesions. Based on a RCT, resin infiltration significantly improved the clinical appearance of such white-spot lesions and visually reduced their size.[38]

Recommendations

- Resin infiltration is indicated as an adjunct to preventive measures for primary and permanent teeth with small, noncavitated interproximal caries lesions to reduce lesion progression and for white-spot lesions to improve their clinical appearance.
- Further research regarding long-term effectiveness of resin infiltration is needed.

Dental amalgam

Dental amalgam contains a mixture of metals such as silver, copper, and tin, in addition to approximately 50% mercury.[39] Use of dental amalgam has declined, perhaps due to the controversy surrounding perceived health effects of mercury vapor, environmental concerns from its mercury content, and increased demand for esthetic alternatives.[40]

Two independent RCTs in children have examined the effects of mercury release from amalgam restorations and found no effect on the central and peripheral nervous systems and kidney function.[41,42] However, in 2009, the US Food and Drug Administration (**FDA**) issued a final rule that reclassified dental amalgam to a Class II device (having some risk) and designated guidance that included warning labels regarding: (1) possible harm of mercury vapors; (2) disclosure of mercury content; and (3) contraindications for persons with known mercury sensitivity.[39] Also in this final rule, the FDA noted information regarding dental amalgam and the long-term health outcomes in pregnant women, developing fetuses, and children under the age of 6 is limited.[39]

In 2020, the FDA published recommendations on the use of dental amalgam in certain populations considered high-risk, such as pregnant women, women planning to become pregnant, nursing women, children under 6 years old, and people with pre-existing neurological disease.[43] The FDA recommended providers avoid the use of dental amalgam in these high-risk populations and consider alternative restorative materials.[43] However, the ADA immediately reaffirmed that amalgam is a durable, safe, and effective restorative option and that the FDA's recommendations did not cite any new scientific evidence.[44] The ADA encourages providers to review all options for restorations with their patients and review the risks and benefits of amalgam.[44] Both organizations recommend that existing amalgam fillings in good condition should not be removed or replaced unless medically necessary.[43,44]

With regard to clinical efficacy of dental amalgam, results comparing longevity of amalgam to other restorative materials are inconsistent. Most meta-analyses, evidence-based reviews, and RCTs report comparable durability of dental amalgam to other restorative materials,[45-50] yet others show greater longevity for amalgam.[51,52] The comparability appears to be especially true when the restorations are placed in controlled environments such as university settings.[45]

Class I amalgam restorations in primary teeth have shown in a systematic review and 2 RCTs to have a success rate of 85% to 96% for up to 7 years, with an average annual failure rate of 3.2%.[17,49,52] Efficacy of Class I amalgam restorations in permanent teeth of children has been shown in 2 independent RCTs to range from 89.8% to 98.8% for up to 7 years.[49,51]

With regard to Class II restorations in primary molars, a 2015 systematic review recommended that amalgam could be utilized in preparations that do not extend beyond proximal line angles.[53] For Class II restorations in permanent teeth, 1 meta-analysis and 1 evidence-based review conclude that the mean annual failure rates of amalgam and composite are equal at 2.3%.[45,48] The meta-analysis comparing amalgam and composite Class II restorations in permanent teeth suggests that higher replacement rates of composite in general practice settings can be attributed partly to general practitioners' confusion of marginal staining for marginal caries and their subsequent premature replacements.[45] Otherwise, this meta-analysis concludes that the median success rate of composite and amalgam are statistically equivalent after 10 years, at 92% and 94% respectively.[45]

The limitation of many of the clinical trials that compare dental amalgam to other restorative materials is that the study period often is short (24 to 36 months), at which time interval all materials reportedly perform similarly.[54-58] Some of these studies also may be at risk for bias, due to lack of true randomization, inability of blinding of investigators, and, in some cases, financial support by the manufacturers of the dental materials being studied.

Recommendations

- Dental amalgam may be used to restore Class I and Class II cavity restorations in primary and permanent teeth.
- Providers should review the risks and benefits of amalgam restorations with patients.

Composites

Resin-based composite restorations were introduced in dentistry about a half century ago as an esthetic restorative material[59,60], and composites increasingly are used in place of amalgam for the restoration of caries lesions.[45,61] Composites consist of a resin matrix and chemically-bonded fillers.[45] They are classified according to their filler size, because filler size affects physical properties, polishability/esthetics, polymerization depth, and polymerization shrinkage.[62] Hybrid resins combine a mixture of particle sizes for improved strength while retaining esthetics. [63] The smaller filler particle size allows greater polishability and esthetics, while larger size provides strength. Flowable resins have a lower volumetric filler percentage than hybrid resins.[64]

Several factors contribute to the longevity of resin composites, including operator experience, restoration size, and tooth position.[51] Resins are technique sensitive and require longer placement time than amalgams.[65] In cases where isolation or patient cooperation is in question, resin-based composite may not be the restorative material of choice.[65,66] Additionally, composite may not be the ideal restorative material for primary posterior teeth requiring large multisurface restorations or high-risk patients with poor oral hygiene, numerous carious teeth, and demineralization.[65]

Bisphenol A (**BPA**) and its derivatives are components of resin-based dental sealants and composites. Trace amounts of BPA derivatives are released from dental resins through salivary enzymatic hydrolysis and increase from baseline at 24 hours posttreatment but return to baseline by 14 days and remain at baseline 6 months after treatment.[67] Evidence is accumulating that certain BPA derivatives may pose health risks attributable to their endocrine-disrupting properties, but no established thresholds for safety and exposure have been determined.[67] BPA exposure reduction is achieved by cleaning filling surfaces with pumice and cotton roll and rinsing. Additionally, potential exposure can be reduced by using a rubber dam.[68] Considering the proven benefits of resin-based dental materials and minimal exposure to BPA and its derivatives, continued use of these products, while taking precautions to minimize BPA exposure, has been recommended.[69]

There is strong evidence from a meta-analysis of 59 RCTs of Class I and II composite and amalgam restorations showing an overall success rate about 90% after 10 years for both materials, with rubber dam use significantly increasing restoration longevity.[45] Strong evidence from RCTs comparing composite restorations to amalgam restorations showed the main reason for restoration failure in both materials was recurrent caries.[49,51,68]

In primary teeth, there is strong evidence that composite materials for Class I restorations are successful.[17,49] One RCT showed success of Class II composite restorations in primary teeth that were expected to exfoliate within 2 years.[56] Another RCT comparing total caries removal versus selective caries removal with composite restorations showed a statistically significant higher survival rate with total caries removal after 36 months (81% to 57%).[70] In permanent molars, composite replacement after 3.4 years was no different than amalgam,[49] but after 7 to 10 years the replacement rate was higher for composite.[66] Secondary caries rate was reported as 3.5 times greater for composite versus amalgam.[51] A meta-analysis concluded that etching and bonding of enamel and dentin significantly decreases marginal staining and detectable margins in composite restorations.[45] Regarding different types of composites (ie, packable, hybrid, nanofilled, macrofilled, microfilled), evidence showing similar overall clinical performance for these is strong.[71-74]

Recommendations

- Resin-based composites can be used as Class I and Class II restorations in primary and permanent molars.
- Evidence from a meta-analysis shows enamel and dentin bonding agents decrease marginal staining and detectable margins for the different types of composites.
- Precautions should be used in conjunction with placement of resin-based composites to help minimize BPA exposure.

Glass-ionomer cements (GIC)

Glass-ionomers cements have been used in dentistry as restorative cements, cavity liner/base, and luting cement since the early 1970s.[75] Originally, glass-ionomer materials had long setting times and low fracture strength and exhibited poor wear resistance.[76] Advancements in conventional glass ionomer formulation led to better properties, including the formation of resin-modified glass ionomers. These products showed improvement in handling characteristics, decreased setting time, increased strength, and improved wear resistance.[77,78] All glass ionomers have several properties that make them favorable for use in children including chemical bonding to both enamel and dentin, thermal expansion similar to that of tooth structure, biocompatibility, uptake and release of fluoride, and decreased moisture sensitivity when compared to resins.[76]

Fluoride is released from glass ionomer and taken up by the surrounding enamel and dentin, resulting in teeth that are less susceptible to acid challenge.[79,80] Glass ionomers can act as a reservoir of fluoride, as uptake can occur from dentifrices, mouth rinses, and topical fluoride applications.[81,82] This fluoride protection, useful in patients at high risk for caries, has led to

the use of glass ionomers as luting cement for SSCs, space maintainers, and orthodontic bands.[83]

One RCT showed the overall median time from treatment to failure of conventional glass-ionomer restored primary teeth was 1.2 years.[52] Based on findings of a systematic review and meta-analysis, conventional glass ionomers have not been recommended for Class II restorations in primary molars.[84,85] Conventional glass-ionomer restorations have other drawbacks such as poor anatomical form and marginal integrity.[86,87] Composite restorations were more successful than GICs where moisture control was not a problem.[85]

Resin-modified glass-ionomer cements (**RMGIC**), with the acid-base polymerization supplemented by a second, light-cure polymerization, have been shown to be efficacious in primary teeth.[88] Based on a meta-analysis, RMGIC is more successful than conventional glass ionomer as a restorative material.[85] A systematic review supports the use of RMGIC in small to moderate sized Class II cavities.[84] Class II RMGIC restorations are able to withstand occlusal forces on primary molars for at least 1 year.[85] Because of fluoride release, RMGIC may be considered for Class I and Class II restorations of primary molars in a high caries risk population.[87] Conditioning dentin improves the success rate of RMGIC.[84] According to 1 RCT, cavosurface beveling leads to high marginal failure in RMGIC restorations and is not recommended.[68]

With regard to permanent teeth, a meta-analysis review reported significantly fewer caries lesions on single-surface glass ionomer restorations in permanent teeth after 6 years as compared to restorations with amalgam.[87] Data from a meta-analysis show that RMGIC is more caries preventive than composite resin with or without fluoride.[89] Another meta-analysis showed that cervical restorations (Class V) with glass ionomers may have a good retention rate but poor esthetics.[45] For Class II restorations in permanent teeth, 1 RCT showed unacceptable high failure rates of conventional glass ionomers, irrespective of cavity size.[91] However, a high dropout rate in this study limits significance.[91]

Silver diammine fluoride (**SDF**) application has been used prior to or in conjunction with GIC and RMGIC restorations in primary and permanent teeth. A systematic review and meta-analysis that evaluated the influence of SDF on the dentin bonding of adhesive materials included 11 and 10 studies, respectively.[92] The systematic review found that prior application of SDF does not have a negative effect on the bond strength between glass ionomer cement and dentin.[92] Another systematic review of 13 studies that examined the effect of SDF application on the bond strength between dentin and adhesives and dentin and glass-ionomer cements was inconclusive due to the inconsistent results from the included studies.[93] Further research examining the effect of SDF application to the bond strength of glass ionomers, as well as the advantages of its use prior to the application of glass ionomers, is needed.

Glass ionomers can be utilized for caries control in patients with high caries risk and for restoration repair.[76] Other applications of glass ionomers in which fluoride release has advantages are for ITR and ART. These procedures have similar techniques but different therapeutic goals. ITR may be used in very young patients,[94] uncooperative patients, or patients with special health care needs[50] for whom traditional cavity preparation or placement of traditional dental restorations is not feasible or needs to be postponed. Additionally, ITR may be used for caries control in children with multiple open caries lesions, prior to definitive restoration of the teeth.[95] In-vitro, leaving caries-affected dentin does not jeopardize the bonding of glass ionomercements to the primary tooth dentin.[96] ART, endorsed by the World Health Organization and the International Association for Dental Research, is a means of restoring and preventing caries in populations that have little access to traditional dental care and functions as definitive treatment.[97]

According to a meta-analysis, single-surface ART restorations had a high survival percentage over the first 3 years in primary teeth and over the first 5 years in permanent teeth.[98] One RCT supported single-surface restorations irrespective of the cavity size and also reported higher success in non-occlusal posterior ART compared to occlusal posterior ART.[99] With regard to multisurface ART restorations, there is conflicting evidence. Based on a meta-analysis, ART restorations presented similar survival rates to conventional approaches using composite or amalgam for Class II restorations in primary teeth.[100,101] Multisurface ART restorations in primary teeth exhibited a medium survival percentage over 2 years.[98] A recent RCT that compared modified ART to preformed metal crowns on primary teeth reported major failures on 21% of modified ART restorations at 6 months and 34% at 12 months.[102] More research is needed on the survival percentage of multisurface ART restorations in permanent teeth.

Recommendations

- GICs may be used for Class I restorations in primary teeth.
- RMGICs may be used for Class I restorations, and expert opinion supports Class II restorations in primary teeth.
- Evidence is insufficient to support the use of conventional or RMGICs as long-term restorative material in permanent teeth.
- ITR/ART using high-viscosity glass-ionomer cements may be used as single surface temporary restoration for both primary and permanent teeth. Additionally, ITR may be used for caries control in children with multiple open caries lesions, prior to definitive restoration of the teeth.
- Further research examining the effect of SDF application on the bond strength of glass ionomers to dentin is needed.

Compomers

Polyacid-modified resin-based composites, or compomers, were introduced into dentistry in the mid-1990s. They contain 72% (by weight) strontium fluorosilicate glass and the average particle size is 2.5 μm.[103] Moisture is attracted to both acid functional monomer and basic ionomer-type in the material. This moisture can trigger a reaction that releases fluoride and buffers acidic environments.[104,105] Considering the ability to release fluoride, esthetic value, and simple handling properties, compomer can be useful in pediatric dentistry.[103]

Based on a 2007 RCT, the longevity of Class I compomer restorations in primary teeth was not statistically different compared to amalgam, but compomers were found to need replacement more frequently due to recurrent caries.[49] In Class II compomer restorations in primary teeth, the risk of developing secondary caries and failure did not increase over a 2-year period in primary molars.[57,106] Compomers also have reported comparable clinical performance to composite with respect to color matching, cavosurface discoloration, anatomical form, and marginal integrity and secondary caries.[107,108] Compomers are available in a variety of nonconventional colors which, when polymerized, can cause varying pulp chamber temperatures.[109,110] Most RCTs showed that compomer tends to have better physical properties compared to GIC and RMGIC in primary teeth, but no significant difference was found in cariostatic effects of compomer compared to these materials.[52,106,111-114]

Recommendations

- Compomers can be an alternative to other restorative materials in the primary dentition in Class I and Class II restorations.
- There is not enough data comparing compomers to other restorative materials in permanent teeth of children.

Bioactive materials

A recently recognized category of materials is termed bioactive. Bioactive restorative materials release ions (typically calcium, fluoride, or phosphate[115]) yet, at times, antibacterial monomers, silver particles, or strontium particles.[116] The materials also can absorb ions at their surface. Although they may not meet true ionic equilibrium, the ion exchange still can help prevent adjacent tooth demineralization and enhance remineralization.[117,118]

Bioactive dental restorative materials are available for sealants, adhesive bonding agents, cements, resin-based restorations, GIC and RMGIC restorations, as well as pulp capping agents. Since each bioactive material interacts with hard tissue differently, a modified surface treatment may be required.[119]

Recommendations

- Bioactive materials can be used for remineralization and pulp capping.
- Further research examining the basic properties and long-term effect of bioactive materials and comparing bioactive materials to other restorative materials is needed.

Preformed metal crowns

Preformed metal crowns (**PMC**), also known as SSC, are prefabricated crown forms that are adapted to individual teeth and cemented with a biocompatible luting agent. PMC have been indicated for the restoration of primary and permanent teeth with extensive caries, cervical decalcification, or developmental defects (eg, hypoplasia, hypocalcification), when failure of other available restorative materials is likely (eg, interproximal caries extending beyond line angles, patients with bruxism), following pulpotomy or pulpectomy, for restoring a primary tooth that is to be used as an abutment for a space maintainer, for the intermediate restoration of fractured teeth, and for definitive restorative treatment for high caries-risk children.[120] They are used more frequently in patients who exhibit high caries risk and whose treatment is performed under sedation or general anesthesia.[121-123]

Very few prospective RCTs compare outcomes for PMC to intracoronal restorations.[124,125] A Cochrane review and additional studies, including 2 systematic reviews, concluded that the majority of clinical evidence for the use of PMC has come from nonrandomized and retrospective studies.[17,121-123] However, this evidence suggests that PMC showed greater longevity than amalgam restorations,[17] despite possible study bias of placing SSCs on teeth more damaged by caries.[122,123,126] Five studies which retrospectively compared Class II amalgams to PMC showed an average 5-year failure rate of 26% for amalgam and 7% for PMC.[122] SSC were shown in a recent retrospective study to have a higher survival rate compared to multisurface restorations and may be considered when treating multisurface caries in children younger than 4 years old in order to avoid possible retreatment.[127]

A 2-year RCT regarding restoration of primary teeth that had undergone a pulpotomy procedure found a nonsignificant difference in survival rate for teeth restored with PMC (95%) versus RMGIC/composite restoration (92.5%).[124] A 1-year RCT comparing primary molars treated with mineral trioxide aggregate (**MTA**) pulpotomies and restored with either multisurface composite restorations or PMC showed no difference in radiographic success over a 12-month follow-up period.[125] However, the pulpotomized teeth with multisurface composite restorations had more marginal change and required more maintenance than those with PMC, and a majority turned gray up to 12 months later even with the use of white MTA.[125] A systematic review on the use of SSC determined that the reported outcomes of primary teeth with pulpal therapy are best in teeth treated with SSC.[120]

With regards to gingival health adjacent to PMC, a 1-year RCT showed no difference in gingival inflammation between PMC and composite restorations after pulpotomy.[123] Yet, a 2-year randomized clinical study showed more gingival bleeding for PMC versus composite/glass ionomer restorations.[124] Inadequately contoured crown and residues of set cement remaining in contact with the gingival sulcus have been suggested as reasons for gingivitis associated with PMC, and a preventive regime including oral hygiene instruction

has been recommended for incorporation into the treatment plan.[122]

An RCT on PMC versus cast crowns placed on permanent teeth[128] found no difference between the 2 restoration types for quality and longevity after 24 months. A recent retrospective cohort study that focused on longterm clinical outcomes of SSCs compared to amalgam and composite restorations in permanent teeth on special needs populations concluded that posterior permanent teeth restored with SSCs can be expected to last for 10 years and represent a viable treatment option for severely carious or fractured posterior permanent teeth.[129] The remaining evidence is case reports and expert opinion concerning indications for use of PMC on permanent molars. The indications include teeth with severe genetic/developmental defects, grossly carious teeth, and traumatized teeth, along with tooth developmental stage or financial considerations that require semi-permanent restoration instead of a permanent cast restoration.[121,126,128] The main reasons for PMC failure reportedly are crown loss[17,130,131] and perforation[131].

A recent method of providing PMC is known as the Hall technique (**HT**).[132] The HT calls for cementation of an SSC over a caries-affected primary molar without local anesthetic, caries removal, or tooth preparation. A less invasive management procedure for treating carious primary teeth, HT involves caries control by managing the activity of the biofilm.[133] In

Table 1. EVIDENCE OF EFFICACY OF VARIOUS DENTAL MATERIALS/TECHNIQUES IN PRIMARY TEETH WITH REGARD TO CARIES LESION CLASSIFICATIONS

	Class I	Class II	Class III	Class IV	Class V
Amalgam	Strong evidence	Strong evidence	No data	No data	Expert opinion
Composite	Strong evidence	Strong evidence	Expert opinion	No data	Evidence in favor
Glass ionomer	Strong evidence α	Evidence against β	Evidence in favor γ	No data	Expert opinion γ
RMGIC	Strong evidence	Expert opinion δ	Expert opinion	No data	Expert opinion
Compomers	Evidence in favor	Evidence in favor	No data	No data	Expert opinion
SSC	Evidence in favor ε	Evidence in favor ε	No data	No data	No data
Anterior ϕ crowns	N/A	N/A	Expert opinion	Expert opinion	Expert opinion

Strong evidence – based on well-executed randomized control trials, meta-analyses, or systematic reviews; **Evidence in favor** – based on weaker evidence from clinical trials; **Expert opinion** – based on retrospective trials, case reports, in vitro studies and opinions from clinical researchers; **Evidence against** – based on randomized control trials, meta-analysis, systematic reviews.

RMGIC=resin modified glass ionomer cement.
SSC=stainless steel crown.
N/A=not available.
α Evidence from ART trials.
β Conflicting evidence for multisurface ART restorations.
γ Preference when moisture control is an issue.
δ Small restorations; life span 1-2 years.
ε Large lesions.
ϕ Strip crowns, stainless steel crowns with/without facings, zirconia crowns.

Table 2. EVIDENCE OF EFFICACY OF VARIOUS DENTAL MATERIALS/TECHNIQUES IN PERMANENT TEETH WITH REGARD TO CARIES LESION CLASSIFICATIONS

	Class I	Class II	Class III	Class IV	Class V
Amalgam	Strong evidence	Strong evidence	No data	No data	No data
Composite	Strong evidence	Evidence in favor	Expert opinion	No data	Evidence in favor
Glass ionomer	Strong evidence α	Evidence against	Evidence in favor β	No data	Expert opinion β
RMGIC	Strong evidence	No data	Expert opinion	No data	Evidence in favor
Compomers	Evidence in favor γ	No data	Expert opinion	No data	Expert opinion
SSC	Evidence in favor δ	Evidence in favor δ	No data	No data	No data
Anterior ϕ crowns	N/A	N/A	No data	No data	No data

Strong evidence – based on well executed randomized control trials, meta-analyses, or systematic reviews; **Evidence in favor** – based on weaker evidence from clinical trials; **Expert opinion** – based on retrospective trials, case reports, in vitro studies and opinions from clinical researchers; **Evidence against** – based on randomized control trials, meta-analysis, systematic reviews.

RMGIC=resin modified glass ionomer cement.
SSC=stainless steel crown.
N/A=not available.
α Evidence from ART trials.
β Preference when moisture control is an issue.
γ Evidence from studies in adults.
δ For children and adolescents with gross caries or severely hypoplastic teeth.
ϕ Strip crowns, stainless steel crowns with/without facings.

essence, bacteria sealed into the tooth and denied of substrate will die rather than result in caries progression, and the best way of producing an effective marginal seal is with a crown.[134]

Using HT may reduce discomfort from local anesthetic and caries removal at the time of treatment compared to fillings,[132] but it may add the discomfort of placement of separator bands prior to the SSC, as well as the pain from biting the crown into place.[135] In a randomized split mouth clinical trial with general dentists as providers, sealing in caries by using HT significantly outperformed the general dentists' standard restorations to restore caries interproximally and was more effective in the long term.[136] HT may be considered a treatment modality for carious primary molars when traditional SSC technique is not feasible due to limitations such as poor cooperation or barriers to care.[102] Additional studies that compare this technique to traditionally-placed PMC using long-term follow-ups, radiographic assessment, and caries removal are needed.[102,137]

SSC continue to offer the advantage of full coverage to combat recurrent caries and provide strength as well as long-term durability with minimal maintenance, which are desirable outcomes for caries management for high-risk children.[120]

Recommendations

- Retrospective studies reported greater longevity of PMC restorations compared to amalgam or resin-based restorations for the treatment of caries lesions in primary teeth. Therefore, use of SSC is indicated for high-risk children with large or multi-surface cavitated or non-cavitated lesions on primary molars, especially when children require advanced behavioral guidance techniques[138] including general anesthesia for the provision of restorative dental care.
- PMC may be indicated in permanent teeth as a semi-permanent restoration for the treatment of severe enamel defects or grossly carious teeth.
- Further research comparing HT to traditionally-placed PMC is needed.

Posterior esthetic crowns in primary teeth

The interest by clinicians and patients in esthetic options for full coverage restoration of primary posterior teeth is increasing.[139,140] Scientific studies that evaluate esthetic options for restoring posterior primary teeth with large caries lesions are not widely reported in the literature. While opened-faced SSC or preveneered SSC are not ideal based on minimum evidence, zirconia crowns are an option that has been used by pediatric dentists. Several preformed pediatric zirconia crowns are available on the market, and brands differ in material composition, fabrication, surface treatment, retentive feature, and cementation method.[141] More circumferential tooth reduction is needed for proper fit and placement of zirconia crowns compared to SSC[142] and, for proper retention, the minimum abutment height is 2 mm[143]. The indications for the preformed esthetic crowns are generally the same as those of the preformed SSCs but with consideration of esthetics.[144] Clinical parameters between zirconia crowns and SSC are similar except for retention and gingival health; SSC have comparatively better retention and zirconia crowns have relatively better gingival health.[144,145]

Recommendation

- Evidence is limited on the use of zirconia crowns as esthetic crowns for primary posterior teeth. When SSC would otherwise be indicated, zirconia crowns may be considered in lieu of SSC to due to esthetic considerations.

Anterior esthetic restorations in primary teeth

With increasing demand for esthetic considerations for children by their parents, treatment of dental caries of primary anterior teeth remains one of the biggest challenges in pediatric dentistry.[146] Esthetic restoration of primary anterior teeth can be especially challenging due to: the small size of the teeth; close proximity of the pulp to the tooth surface; relatively thin enamel; lack of surface area for bonding; and issues related to child behavior.[147]

Most evidence for the clinical techniques utilized to restore primary anterior teeth is regarded as expert opinion. While a lack of strong clinical data does not preclude the use of these techniques, it points out the strong need for well-designed, prospective clinical studies to validate their use.[147]

Class III (interproximal) restorations of primary incisors can be prepared with labial or lingual dovetails to incorporate a large surface area for bonding to enhance retention.[147] Resin-based restorations are appropriate for anterior teeth that can be adequately isolated from saliva and blood. RMGIC have been suggested for this category, especially when adequate isolation is not possible.[76,148,149] Patients considered at high risk for caries may be better served with placement of full tooth coverage restorations.[147,149]

Class V (cervical) cavity preparations for primary incisors are similar to those in permanent teeth. Due to the young age of children treated and associated cooperation difficulty, it is sometimes impossible to isolate teeth for the placement of composite restorations. In these cases, GIC or RMGIC is suggested.[148,149]

Full coronal restoration of carious primary incisors may be indicated when: (1) caries is present on multiple surfaces, (2) the incisal edge is involved, (3) cervical decalcification is extensive, (4) pulpal therapy is indicated, (5) caries may be minor, but oral hygiene is very poor, or (6) the child's behavior makes moisture control very difficult.[147] Currently, full coronal restorations of primary teeth are bonded to existing tooth structure or cemented in place.[147] Resin strip crowns are bonded to the tooth, and 2 retrospective studies show that 80% are retained after 3 years.[150,151] Resin strip crowns are esthetic, and parental satisfaction is high. They are technique sensitive and require sufficient tooth structure to provide surface area for bonding. Hemorrhage or saliva can interfere with bonding of the materials, and hemorrhage can affect the color of the crown.[141,147]

Preveneered SSC also are among the options of restoring primary anterior teeth with full coronal coverage. Three retrospective studies report excellent clinical retention of this type of crowns, yet a high incidence of partial or complete loss of the resin facings.[152,153] The crimping of preveneered SSC on the metal side does not affect the fracture resistance.[154] Preveneered SSC have the concerns of color stability and surface roughness changes,[155] so long-term clinical studies are required to establish their comparative effectiveness. Preformed SSC and opened-faced SSC are still options for treatment on primary anterior teeth, but published studies reporting their effectiveness and use are sparse[156] given the availability of more esthetic and easier-to-use alternatives.

Preformed zirconia crowns have been available in pediatric dentistry since 2010.[147] Zirconia crowns are strong, esthetic, and biocompatable.[147,157] Zirconia crowns placed in a university clinic displayed survival probability at 12, 24 and 36 months of 93%, 85%, and 76% respectively.[158] Parental esthetic satisfaction has been shown to be higher for zirconia crowns than resin strip crowns or preveneered SSC.[157] Disadvantages of zirconia crowns include a steep learning curve for dentists and, since the crowns cannot be adjusted, the tooth must be reduced in order to fit the crown. The amount of tooth reduction is greater than that required for an SSC and reduction of 1.5 to 2 mm with a feather margin is required to passively seat the zirconia crown.[142]

Recommendations

- Resin-based composites may be used as a treatment option for Class III and Class V restorations in the primary and permanent dentition.
- Expert opinion finds the use of RMGIC as a treatment option for Class III and Class V restorations for primary teeth, particularly in circumstances where adequate isolation of the tooth to be restored is difficult.
- Expert opinion suggests that strip crowns, preveneered SSC, preformed SSC, opened-faced SSC, and zirconia crowns are treatment options for full coronal coverage restorations in primary anterior teeth.

References

1. American Academy of Pediatric Dentistry. Guidelines for pediatric restorative dentistry 1991. In: American Academy of Pediatric Dentistry Reference Manual 1991-1992. Chicago, IL: American Academy of Pediatric Dentistry; 1991:57-9.
2. American Academy of Pediatric Dentistry. Best practices for restorative dentistry. The Reference Manual of Pediatric Dentistry. Chicago, IL: American Academy of Pediatric Dentistry; 2019:340-52.
3. American Academy of Pediatric Dentistry. Caries-risk assessment and management for infants, children, and adolescents. The Reference Manual of Pediatric Dentistry. Chicago, IL: American Academy of Pediatric Dentistry; 2022:266-72.
4. Urquhart O, Tampi MP, Pilcher L, et al. Nonrestorative treatments for caries: Systematic review and network meta-analysis. J Dent Res 2019;98(1):14-26.
5. American Academy of Pediatric Dentistry. Policy on the use of silver diamine fluoride for pediatric dental patients. The Reference Manual of Pediatric Dentistry. Chicago, IL: American Academy of Pediatric Dentistry; 2022:72-5.
6. Giuca MR, Lardani L, Pasini M, Beretta M, Gallusi G, Campanella V. State-of-the-art on MIH. Part. 1 Definition and aepidemiology. Eur J Paediatr Dent 2020;21 (1):80-2.
7. Somani C, Taylor GD, Garot E, Rouas P, Lygidakis NA, Wong FSL. An update of treatment modalities in children and adolescents with teeth affected by molar incisor hypomineralisation (MIH): A systematic review. Eur Arch Paediatr Dent 2022;23(1):39-64. Available at: "https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8927013/". Accessed June 30, 2022.
8. Martignon S, Bartlett D, Manton DJ, Martinez-Mier EA, Splieth C, Avila V. Epidemiology of erosive tooth wear, dental fluorosis and molar incisor hypomineralization in the American continent. Caries Res 2021;55(1):1-11.
9. Dhar V, Marghalani AA, Crystal YO, et al. Use of vital pulp therapies in primary teeth with deep caries lesions. Pediatr Dent 2017;39(5):E146-E159.
10. American Academy of Pediatric Dentistry. Pulp therapy for primary and immature permanent teeth. The Reference Manual of Pediatric Dentistry. Chicago, IL: American Academy of Pediatric Dentistry; 2022:415-23.
11. Bader JD, Shugars DA. Understanding dentists' restorative treatment decisions. J Pub Health Dent 1992;52(2): 102-11.
12. Ismail AI, Sohn W, Tellez M, et al. The international caries detection and assessment system (ICDAS): An integrated system for measuring dental caries. Community Dent Oral Epidemiol 2007;35(3):170-8.
13. Beauchamp J, Caufield PW, Crall JJ, et al. Evidence-based clinical recommendations for the use of pit-and-fissure sealants: A report of the American Dental Association Council on Scientific Affairs. J Am Dent Assoc 2008; 139(3):257-68.
14. Downer MC, Azli NA, Bedi R, Moles DR, Setchell DJ. How long do routine dental restorations last? A systematic review. Brit Dent J 1999;187(8):432-9.
15. Lenters M, van Amerongen WE, Mandari GJ. Iatrogenic damage to the adjacent surface of primary molars in three different ways of cavity preparation. Eur Archives Paediat Dent 2006;1(1):6-10.
16. Slayton RL. Clinical decision-making for caries management in children: An update. Pediatr Dent. 2015;37(2): 106-10.
17. Hickel R, Kaaden C, Paschos E, Buerkle V, García-Godoy F, Manhart J. Longevity of occlusally-stressed restorations in posterior primary teeth. Am J Dent 2005;18(3):198-211.

References continued on the next page.

18. Bjørndal L, Reit C, Bruun G, et al. Treatment of deep caries lesions in adults: Randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy. Eur J Oral Sci 2010; 118(3):290-7.
19. Maltz M, Garcia R, Jardim JJ, et al. Randomized trial of partial vs. stepwise caries removal: 3-year follow-up. J Dent Res 2012;91(11):1026-31.
20. Maltz M, Jardim JJ, Mestrinho HD, et al. Partial removal of carious dentine: A multicenter randomized controlled trial and 18-month follow-up results. Caries Res 2013; 47(2):103-9.
21. Innes NP, Evans DJ, Stirrups DR. Sealing caries in primary molars: Randomized control trial, 5-year results. J Dent Res 2011;90(12):1405-10.
22. Lula EC, Monteiro-Neto V, Alves CM, Ribeiro CC. Microbiological analysis after complete or partial removal of carious dentin in primary teeth: A randomized clinical trial. Caries Res 2009;43(5):354-8.
23. Orhan AI, Oz FT, Orhan K. Pulp exposure occurrence and outcomes after 1- or 2-visit indirect pulp therapy vs. complete caries removal in primary and permanent molars. Pediatr Dent 2010;32(4):347-55.
24. Ricketts D, Lamont T, Innes NPT, Kidd E, Clarkson JE. Operative caries management in adults and children (Review). Cochrane Database Syst Rev 2013;3:CD003808.
25. Maltz M, Koppe B, Jardim JJ, et al. Partial caries removal in deep caries lesions: A 5-year multicenter randomized controlled trial. Clin Oral Investig 2018;22(3):1337-43.
26. Schwendicke F, Dorfer CE, Paris S. Incomplete caries removal: A systematic review and meta-analysis. J Dent Res 2013;92(4):306-14.
27. Mertz-Fairhurst EJ, Curtis JW, Jr, Ergle JW, Rueggeberg FA, Adair SM. Ultraconservative and cariostatic sealed restorations: Results at year 10. J Am Dent Assoc 1998; 129(1):55-66.
28. Paris S, Hopfenmuller W, Meyer-Lueckel H. Resin infiltration of caries lesions: An efficacy randomized trial. J Dent Res 2010;89(8):823-6.
29. Meyer-Lueckel H, Bitter, K, Paris S. Randomized controlled clinical trial on proximal caries infiltration: Three-year follow-up. Caries Res 2012;46(6):544-8.
30. Dorri M, Dunne SM, Walsh T, Schwendicke F. Microinvasive interventions for managing proximal dental decay in primary and permanent teeth. Cochrane Database Syst Rev 2015;(11):CD010431.
31. Lee J, Chen JW, Omar S, Kwon SR, Meharry M. Evaluation of stain penetration by beverages in demineralized enamel treated with resin infiltration. Oper Dent 2016;41 (1):93-102.
32. Faghihian R, Shirani M, Tarrahi M, Zakizade M. Efficacy of the resin infiltration technique in preventing initial caries: A systematic review and meta-analysis. Pediatr Dent 2019;49(2):88-94.
33. Bagher SM, Hegazi FM, Finkelman M, et al. Radiographic effectiveness of resin infiltration in arresting incipient proximal enamel lesions in primary molars. Pediatr Dent 2018;40(3):195-200.
34. Jorge RC, Ammari MM, Soviero VM, Souza IPR. Randomized controlled clinical trial of resin infiltration in primary molars: 2 years follow-up. J Dent 2019;90:103184.
35. Sarti CS, Vizzotto MB, Filgueiras LV, Bonifácio CC, Rodrigues JA. Two-year split-mouth randomized controlled clinical trial on the progression of proximal carious lesions on primary molars after resin infiltration. Pediatr Dent 2020;42(2):110-5.
36. Tellez M, Gomez J, Kaur S, Pretty IA, Ellwood R, Ismail AI. Non-surgical management methods of noncavitated carious lesions. Community Dent Oral Epidemiol 2013;41(1): 79-96.
37. Slayton RL, Urquhart O, Araujo M, et al. Evidence-based clinical practice guideline on nonrestorative treatments for carious lesions. J Am Dent Assoc 2018;149(10):837-49.
38. Senestraro SV, Crowe JJ, Wang M, et al. Minimally invasive resin infiltration of arrested white-spot lesions. J Am Dent Assoc 2013;144(9):997-1005.
39. US Department of Health and Human Services. Final Rule. Federal Register 75: Issue 112 (Friday, June 11, 2010). Available at: "https://www.federalregister.gov/documents/2010/06/11/2010-14083/dental-devices-classification-of-dental-amalgam-reclassification-of-dental-mercury-designation-of". Accessed March 12, 2022.
40. Beazoglou T, Eklund S, Heffley D, Meiers, J, Brown LJ, Bailit H. Economic impact of regulating the use of amalgam restorations. Public Health Rep 2007;122(5):657-63.
41. Belliger DC, Trachtenberg F, Barregard L, et al. Neuropsychological and renal effects of dental amalgam in children: A randomized clinical trial. J Am Med Assoc 2006;295(15):1775-83.
42. DeRouen TA, Martin MD, Leroux BG, et al. Neurobehavioral effects of dental amalgam in children: A randomized clinical trial. J Am Med Assoc 2006;295(15): 1784-92.
43. US Food and Drug Administration. Recommendations About the Use of Dental Amalgam in Certain High-Risk Populations: FDA Safety Communication. Available at: "https://www.fda.gov/medical-devices/safety-communications/recommendations-about-use-dental-amalgam-certain-high-risk-populations-fda-safety-communication". Accessed January 30, 2022.
44. American Dental Association. ADA reaffirms that dental amalgam is 'durable, safe, effective' restorative material. Available at: "https://www.ada.org/publications/ada-news/2020/september/ada-reaffirms-that-dental-amalgam-is-durable-safe-effective-restorative-material". Accessed January 30, 2022.
45. Heintze SD, Rousson V. Clinical effectiveness of direct Class II restorations–A meta-analysis. J Adhes Dent 2012; 14(5):407-31.

46. Mickenautsch S, Yengopal V. Failure rate of high-viscosity GIC based ART compared with that of conventional amalgam restorations–Evidence from an update of a systematic review. J South African Dent Assoc 2012;67 (7):329-31.
47. Yengopal V, Harnekar SY, Patel N, Siegfried N. Dental fillings for the treatment of caries in the primary dentition Review). Cochrane Database of Syst Rev 2009;(2): CD004483.
48. Manhart J, Chen H, Hamm G, Hickel R. Buonocore Memorial Lecture. Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition. Oper Dent 2004;29(5):481-508.
49. Soncini JA, Meserejian NN, Trachtenberg F, Tavares M, Hayes C. The longevity of amalgam versus compomer/ composite restorations in posterior primary and permanent teeth: Findings from the New England Children's Amalgam Trial. J Am Dent Assoc 2007;138(6):763-72.
50. Mandari GJ, Frencken JE, van't Hof MA. Six-year success rates of occlusal amalgam and glass-ionomer restorations placed using three minimal intervention approaches. Caries Res 2003;37(4):246-53.
51. Bernardo M, Luis H, Martin MD, et al. Survival and reasons for failure of amalgam versus composite posterior restorations placed in a randomized clinical trial. J Am Dent Assoc 2007;138(6):775-83.
52. Qvist V, Laurberg L, Poulsen A, Teglers PT. Eight-year study on conventional glass ionomer and amalgam restorations in primary teeth. Acta Odontol Scand 2004;62(1): 37-45.
53. Fuks AB. The use of amalgam in pediatric dentistry: New insights and reappraising the tradition. Pediatr Dent 2015; 37(2):125-32.
54. de Amorim RG, Leal SC, Mulder J, Creugers NH, Frencken JE. Amalgam and ART restorations in children: A controlled clinical trial. Clin Oral Investig 2014;18(1):117-24.
55. Kavvadia K, Kakaboura A, Vanderas AP, Papagiannoulis L. Clinical evaluation of a compomer and an amalgam primary teeth class II restorations: A 2-year comparative study. Pediatr Dent 2004;26(3):245-50.
56. Fuks AB, Araujo FB, Osorio LB, Hadani PE, Pinto AS. Clinical and radiographic assessment of Class II esthetic restorations in primary molars. Pediatr Dent 2000;22(5): 479-85.
57. Duggal MS, Toumba KJ, Sharma NK. Clinical performance of a compomer and amalgam for the interproximal restoration of primary molars: A 24 month evaluation. Brit Dent J 2002;193(6):339-42.
58. Donly KJ, Segura A, Kanellis M, Erickson RL. Clinical performance and caries inhibition of resin-modified glass ionomer cement and amalgam restorations. J Am Dent Assoc 1999;130(10):1459-66.
59. Leinfelder KF. Posterior composite resins. J Am Dent Assoc 1988;117(4):21E-26E.
60. Minguez N, Ellacuria J, Soler JI, Triana R, Ibaseta G. Advances in the history of composite resins. J Hist Dent 2003;51(3):103-5.
61. Lynch CD, Opdam NJ, Hickel R, et al. Guidance on posterior resin composites: Academy of Operative Dentistry – European Section. J Dent 2014;42(4):377-83.
62. Dhar V, Hsu KL, Coll JA, et al. Evidence-based update of pediatric dental restorative procedures: Dental materials. J Clin Pediatr Dent 2015;39(4):303-10.
63. Burgess JO, Walker R, Davidson JM. Posterior resin-based composite: Review of the literature. Pediatr Dent 2002;24(5):465-79.
64. Pallav P, De Gee AJ, Davidson CL, Erickson RL, Glasspoole EA. The influence of admixing microfiller to small-particle composite resins on wear, tensile strength, hardness and surface roughness. J Dent Res 1989;68(3):489-90.
65. Donly KJ, García-Godoy F. The use of resin-based composite in children: An update. Pediatr Dent 2015;37(2): 136-43.
66. Antony K, Genser D, Hiebinger C, Windisch F. Longevity of dental amalgam in comparison to composite materials. GMS Health Technol Assess 2008;13(4):Doc12.
67. Marzouk T, Sathyanarayana S, Kim AS, Seminario AL, McKinney CM. A systematic review of exposure to bisphenol A from dental treatment. JDR Clin Trans Res 2019;4(2):106-15.
68. Alves dos Santos MP, Luiz RR, Maia LC. Randomised trial of resin-based restorations in Class I and Class II beveled preparations in primary molars: 48-month results. J Dent 2010;38(6):451-9.
69. Fleisch AF, Sheffield PE, Chinn C, Edelstein BL, Landrigan PJ. Bisphenol A and related compounds in dental materials. Pediatrics 2010;126(4):760-8.
70. Liberman J, Franzon R, Guimarles LF, Casagrande L, Haas AN, Araujo FB. Survival of composite restorations after selective or total caries removal in primary teeth and predictors of failures: A 36-months randomized controlled trial. J Dent 2020;93:103268.
71. Dijken JW, Pallesen U. A six-year prospective randomized study of a nano-hybrid and a conventional hybrid resin composite in Class II restorations. Dent Mater 2013;29 (2):191-8.
72. Krämer N, García-Godoy F, Reinelt C, Feilzer AJ, Frankenberger R. Nanohybrid vs. fine hybrid composite in extended Class II cavities after six years. Dent Mater 2011; 27(5):455-64.
73. Shi L, Wang X, Zhao Q, et al. Evaluation of packable and conventional hybrid resin composites in Class I restorations: Three-year results of a randomized, double-blind and controlled clinical trial. Oper Dent 2010;35(1):11-9.
74. Ernst CP, Brandenbusch M, Meyer G, Canbek K, Gottschalk F, Willershausen B. Two-year clinical performance of a nanofiller vs a fine-particle hybrid resin composite. Clin Oral Investig 2006;10(2):119-25.

References continued on the next page.

75. Wilson AD, Kent BE. A new translucent cement for dentistry. The glass ionomer cement. Br Dent J 1972;132 (4):33-5.
76. Berg JH, Croll TP. Glass ionomer restorative cement systems: An update. Pediatr Dent 2015;37(2):116-24.
77. Mitra SB, Kedrowski BL. Long-term mechanical properties of glass ionomers. Dent Mater 1994;10(2):78-82.
78. Douglas WH, Lin CP. Strength of the new systems. In: Hunt PR, ed. Glass Ionomers: The Next Generation. Philadelphia, PA: International Symposia in Dentistry, PC; 1994:209-16.
79. Tam LE, Chan GP, Yim D. In vitro caries inhibition effects by conventional and resin-modified glass ionomer restorations. Oper Dent 1997;22(1):4-14.
80. Tyas MJ. Cariostatic effect of glass ionomer cements: A 5-year clinical study. Aust Dent J 1991;36(3):236-9.
81. Forsten L. Fluoride release and uptake by glass-ionomers and related materials and its clinical effect. Biomaterials 1998;19(6):503-8.
82. Donly KJ, Nelson JJ. Fluoride release of restorative materials exposed to a fluoridated dentifrice. ASDC J Dent Child 1997;64(4):249-50.
83. Donly KJ, Istre S, Istre T. In vitro enamel remineralization at orthodontic band margins cemented with glass ionomer cement. Am J Orthod Dentofacial Orthop 1995;107(5): 461-4.
84. Chadwick BL, Evans DJ. Restoration of Class II cavities in primary molar teeth with conventional and resin modified glass ionomer cements: A systematic review of the literature. Eur Arch Paediatr Dent 2007;8(1):14-21.
85. Toh SL, Messer LB. Evidence-based assessment of tooth-colored restorations in proximal lesions of primary molars. Pediatr Dent 2007;29(1):8-15.
86. Daou MH, Tavernier B, Meyer JM. Two-year clinical evaluation of three restorative materials in primary molars. J Clin Pediatr Dent 2009;34(1):53-8.
87. Mickenautsch S, Yengopal V, Leal SC, Oliveira LB, Bezerra AC, Bonecker M. Absence of carious lesions at margins of glass-ionomer and amalgam restorations: A meta-analysis. Eur J Paediatr Dent 2009;10(1):41-6.
88. Sidhu SK, Nicholson JW. A review of glass-ionomer cements for clinical dentistry. J Funct Biomater 2016;7 (3):16.
89. Yengopal V, Mickenautsch S. Caries-preventive effect of resin-modified glass-ionomer cement (RM-GIC) versus composite resin: A quantitative systematic review. Eur Arch Paediatr Dent 2011;12(1):5-14.
90. Heintze SD, Ruffieux C, Rousson V. Clinical performance of cervical restorations–A meta-analysis. Dent Mater 2010;26(10):993-1000.
91. Frankenberger R, García-Godoy F, Kramer N. Clinical performance of viscous glass ionomer cement in posterior cavities over two years. Int J Dent 2009;2009:781462.
92. Fröhlich TT, Rocha RO, Botton G. Does previous application of silver diamine fluoride influence the bond strength of glass ionomer cement and adhesive systems to dentin? Systematic review and meta-analysis. Int J Paediatr Dent 2020;30(1):85-95.
93. Jiang M, Mei ML, Wong MCM, Chu CH, Lo ECM. Effect of silver diamine fluoride solution application on the bond strength of dentine to adhesives and to glass ionomer cements: A systematic review. BMC Oral Health 2020;20 (1):40.
94. Wambier DS, dos Santos FA, Guedes-Pinto AC, Jaeger RG, Simionato MR. Ultrastructural and microbiological analysis of the dentin layers affected by caries lesions in primary molars treated by minimal intervention. Pediatr Dent 2007;29(3):228-34.
95. Dulgergil DT, Soyman M, Civelek A. Atraumatic restorative treatment with resin-modified glass ionomer material: Short-term results of a pilot study. Med Princ Pract 2005; 14(4):277-80.
96. Alves FB, Lenzi TL, Guglielmi Cde A, et al. The bonding of glass ionomer cements to caries-affected primary tooth dentin. Pediatr Dent 2013;35(4):320-4.
97. Frencken JE. Evolution of the ART approach: Highlights and achievements. J Appl Oral Sci 2009;17Suppl(spe): 78-83.
98. de Amorim RG, Frencken JE, Raggio DP, Chen X, Hu X, Leal SC. Survival percentages of atraumatic restorative treatment (ART) restorations and sealants in posterior teeth: An updated systematic review and meta-analysis. Clin Oral Investig 2018;22(8):2703-25.
99. Frencken JE, van't Hof MA, Taifour D, Al-Zaher I. Effectiveness of ART and traditional amalgam approach in restoring single surface cavities in posterior teeth of permanent dentitions in school children after 6.3 years. Community Dent Oral Epidemiol 2007;35(3):207-14.
100. Raggio DP, Hesse D, Lenzi TL, Guglielmi CAB, Braga MM. Is atraumatic restorative treatment an option for restoring occluso-proximal caries lesions in primary teeth? A systematic review and meta-analysis. Int J Paediatr Dent 2013;23(6):435-43.
101. Tedesco TK, Calvo AF, Lenzi TL, et al. ART is an alternative for restoring occlusoproximal cavities in primary teeth – Evidence from an updated systematic review and meta-analysis. Int J Paediatr Dent 2017;27(3):201-9.
102. Ebrahimi M, Sarraf Shirazi A, Afshari E. Success and behavior during atraumatic restorative treatment, the Hall technique, and the stainless steel crown technique for primary molar teeth. Pediatr Dent 2020;42(3):187-92.
103. Nicholson JW. Polyacid-modified composite resins ('compomers') and their use in clinical dentistry. Dent Mater 2007;23(5):615-22.
104. Cildir SK, Sandalli N. Fluoride release/uptake of glass-ionomer cements and polyacid-modified composite resins. Dent Mater J 2005;24(1):92-7.

105. Peng D, Smales RJ, Yip HK, Shu M. In vitro fluoride release from aesthetic restorative materials following recharging with APF gel. Aust Dent J 2000;45(3):198-203.
106. Daou MH, Attin T, Göhring TN. Clinical success of compomer and amalgam restorations in primary molars: Follow up in 36 months. Schweiz Monatsschr Zahnmed 2009;119(11):1082-8.
107. Attin T, Opatowski A, Meyer C, Zingg-Meyer B, Mönting JS. Class II restorations with a polyacid-modified composite resin in primary molars placed in a dental practice: Results of a two-year clinical evaluation. Oper Dent 2000; 25(4):259-64.
108. Attin T, Opatowski A, Meyer C, Zingg-Meyer B, Buchalla W, Mönting JS. Three-year follow up assessment of Class II restorations in primary molars with a polyacid-modified composite resin and a hybrid composite. Am J Dent 2001; 4(3):148-52.
109. Ertuğrul CÇ, Ertuğrul IF. Temperature change in pulp chamber of primary teeth during curing of coloured compomers: An in vitro study using pulpal blood microcirculation model. Peer J 2019;8(7):1-14.
110. Bakkal M, Yılmaz B, Durmus A, Durmus Z, Ozalp S. Polymerization characteristics of colored compomers cured with different LED units. J Appl Biomater Funct Mater 2019;17(1):1-9.
111. Welbury RR, Shaw AJ, Murray JJ, Gordon PH, McCabe JF. Clinical evaluation of paired compomer and glass ionomer restorations in primary molars: Final results after 42 months. Br Dent J 2000;189(2):93-7.
112. Baba MG, Kirzioglu Z, Ceyhan D. One-year clinical evaluation of two high-viscosity glass-ionomer cements in class II restorations of primary molars. Aust Dent J 2021;66(1):32-40.
113. Sagmak S, Bahsi E, Ozcan N, Satici O. Comparative evaluation of antimicrobial efficacy and fluoride release of seven different glass-ionomer-based restorative materials. Oral Health Prev Dent 2020;18(1):521-8.
114. Francois P, Fouquet V, Attal JP, Dursun E. Commercially available fluoride-releasing restorative materials: A review and a proposal for classification. Materials (Basel) 2020; 1813(10):2313.
115. Skrtic D, Antonucci JM. Bioactive polymeric composites for tooth mineral regeneration: Physiochemical and cellular aspects. J Functional Biomater 2011;2(3):271-307.
116. Slowikowski L, John S, Finkleman M, et al. Fluoride ion release and recharge over time in three restoratives. J Dent Res 2014;93(Spec Iss A):268.
117. May E, Donly KJ. Fluoride release and re-release from bioactive restorative material. Am J Dent 2017;30(6): 305-8.
118. Donly KJ, Liu JA. Dentin and enamel demineralization inhibition at restoration margins of Vitremer, Z 100 and Cention N. Am J Dent 2018;31(3):166-8.
119. Xu S, Wu Zhang MD. Evaluating bonding agent's effect in microleakage of a bioactive restorative material with thermocycling and pH challenge test. Taiwan J Pediatr Dent 2019;19(4):133-42.
120. Seale NS, Randall R. The use of stainless steel crowns: A systematic literature review. Pediatr Dent 2015;37(2): 147-62.
121. Attari N, Roberts JF. Restoration of primary teeth with crowns: A systematic review of the literature. Eur Arch Paediatr Dent 2006;7(2):58-62.
122. Randall RC. Preformed metal crowns for primary and permanent molar teeth: Review of the literature. Pediatr Dent 2002;24(5):489-500.
123. Innes NP, Ricketts D, Evans DJ. Preformed metal crowns for decayed primary molar teeth. Cochrane Database Syst Rev 2007;(1):CD005512.
124. Atieh M. Stainless steel crown versus modified open-sandwich restorations for primary molars: A 2-year randomized clinical trial. Int J Paediatr Dent 2008;18(5): 325-32.
125. Hutcheson C, Seale NS, McWhorter A, Kerins C, Wright J. Multi-surface composite vs stainless steel crown restorations after mineral trioxide aggregate pulpotomy: A randomized controlled trial. Pediatr Dent 2012;34(7): 460-7.
126. Randall RC, Vrijhoef MM, Wilson NH. Efficacy of preformed metal crowns vs. amalgam restorations in primary molars: A systematic review. J Am Dent Assoc 2000;131 (3):337-43.
127. Wu E, Yang YJ, Munz SM, Hsia CC, Boynton JR. Restorations versus stainless steel crowns in primary molars. A retrospective split-mouth study. Pediatr Dent 2021;43(4): 290-5.
128. Zagdwon AM, Fayle SA, Pollard MA. A prospective clinical trial comparing preformed metal crowns and cast restorations for defective first permanent molars. Eur J Paediatr Dent 2003;4(3):138-42.
129. Sigal AV, Sigal MJ, Titley KC, Andrews PB. Stainless steel crowns as a restoration for permanent posterior teeth in people with special needs: A retrospective study. J Am Dent Assoc 2020;151(2):136-44. Erratum in: J Am Dent Assoc 2020;151(12):890.
130. Sonmez D, Duruturk L. Success rate of calcium hydroxide pulpotomy in primary molars restored with amalgam and stainless steel crowns. Br Dent J 2010;208(9):E18.
131. Roberts JF, Attari N, Sherriff M. The survival of resin modified glass ionomer and stainless steel crown restorations in primary molars, placed in a specialist paediatric dental practice. Br Dent J 2005;198(7):427-31.
132. Innes NP, Stirrups DR, Evans DJ, Hall N, Leggate M. A novel technique using preformed metal crowns for managing carious primary molars in general practice – A retrospective analysis. Br Dent J 2006;200(8):451-4; discussion 444.
133. Santamaria RM, Innes NPT, Machiulskiene V, et al. Alternative caries management options for primary molars: 2.5-year outcomes of a randomised clinical trial. Caries Res 2018;51(6):605-14.
134. Welbury RR. The Hall Technique 10 years on: Its effect and influence. Br Dent J 2017;222(6):421-2.
135. Page LA, Boyd DH, Davidson SE, et al. Acceptability of the Hall Technique to parents and children. N Z Dent J 2014;110(1):12-7.

References continued on the next page.

136. Innes NP, Evans DJ, Stirrups DR. Sealing caries in primary molars: Randomized control trial, 5-year results. J Dent Res 2011;90(12):1405-10.
137. Fontana M, Gooch BF, Junger ML. The Hall technique may be an effective treatment modality for caries in primary molars. J Evid Based Dent Pract 2012;12(2): 110-2.
138. American Academy of Pediatric Dentistry. Behavior guidance of the pediatric dental patient. The Reference Manual of Pediatric Dentistry. Chicago, IL: American Academy of Pediatric Dentistry; 2022:321-39.
139. Holsinger DM, Wells MH, Scarbecz M, Donaldson M. Clinical evaluation and parental satisfaction with pediatric zirconia anterior crowns. Pediatr Dent 2016;38(3):192-7.
140. Davette J, Brett C, Catherine F, Gary B, Gary F. Wear of primary tooth enamel by ceramic materials. Pediatr Dent 2016;38(7):519-22.
141. Alrashdi M, Ardoin J, Liu JA. Zirconia crowns for children: A systematic review. Int J Paediatr Dent 2022;32 (1):66-81.
142. Clark L, Wells MH, Harris EF, Lou J. Comparison of amount of primary tooth reduction required for anterior and posterior zirconia and stainless steel crowns. Pediatr Dent 2016;38(1):42-6.
143. Jing L, Chen JW, Roggenkamp C, Suprono MS. Effect of crown preparation height on retention of a prefabricated primary posterior zirconia crown. Pediatr Dent 2019;41 (3):229-33.
144. Donly KJ, Sasa I, Contreras CI, Mendez MJC. Prospective randomized clinical trial of primary molar crowns: 24-month results. Pediatr Dent 2018;40(4):253-8.
145. Taran PK, Kaya MS. A comparison of periododontal health in primary molars restored with prefabricated stainless steel and zirconia crowns. Pediatr Dent 2018;40 (5):334-9.
146. Hamrah MH, Mokhtari S, Hosseini Z, et al. Evaluation of the clinical, child and parental satisfaction with zirconia crowns in maxillary primary incisors: A systematic review. Int J Dent 2021;2021:7877728. Available at: "https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8275371/". Accessed October 17, 2022.
147. Waggoner WF. Restoring primary anterior teeth: Updated for 2014. Pediatr Dent 2015;37(2):163-9.
148. Croll TP, Bar-Zion Y, Segura A, Donly KJ. Clinical performance of resin-modified glass ionomer cement restorations in primary teeth. A retrospective evaluation. J Am Dent Assoc 2001;132(8):1110-6.
149. Donly KJ. Restorative dentistry for children. Dent Clin North Am 2013;57(1):75-82.
150. Kupietzky A, Waggoner WE, Galea J. Long-term photographic and radiographic assessment of bonded resin composite strip crowns for primary incisors: Results after 3 years. Pediatr Dent 2005;27(3):221-5.
151. Ram D, Fuks AB. Clinical performance of resin-bonded composite strip crowns in primary incisors: A retrospective study. Int J Paediatr Dent 2006;16(1):49-54.
152. Shah PV, Lee JY, Wright JT. Clinical success and parental satisfaction with anterior preveneered primary stainless steel crowns. Pediatr Dent 2004;26(5):391-5.
153. Roberts C, Lee JY, Wright JT. Clinical evaluation of and parental satisfaction with resin-faced stainless steel crowns. Pediatr Dent 2001;23(1):28-31.
154. Gupta M, Chen JW, Ontiveros JC. Veneer retention of preveneered primary stainless steel crowns after crimping. J Dent Child 2008;75(1):44-7.
155. Truong K, Chen JW, Lee S, Riter H. Changes of surface properties of composite preveneered stainless steel crowns after prophy polishing to remove stains. Pediatr Dent 2017; 39(2):17-24E.
156. Roshan D, Curzon MEJ, Fairpo CG. Changes in dentists' attitudes and practice in paediatric dentistry. Eur J Paediatr Dent 2003;4(1):21-7.
157. Gill A, Garcia M, An SW, et al. Clinical comparison of three esthetic full-coverage restorations in primary maxillary incisors at 12 months. Pediatr Dent 2020;42(5): 367-72.
158. Seminario A, Garcia M, Spiekerman C, et al. Survival of zirconia crowns in primary maxillary incisors at 12-, 24-, and 36-month follow-up. Pediatr Dent 2019;41(5): 385-90.