

TOOTH-COLORED DENTAL RESTORATIVE MATERIALS IN PRIMARY DENTITION

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ABSTRACT

Restoration of decayed primary teeth is very important and significant not only for the maintenance of health and psychics of the child but also for the physiological development of permanent dentition. Esthetic materials were formulated for permanent teeth restoration, but they can also be used for the treatment of primary dentition, especially in minimally invasive techniques, atraumatic tooth restoration, and preventive interventions. Composite resins, glass ionomers, resin modified glass ionomers, and compomers are the materials of choice in the form of direct filling. Findings of individual authors on success of esthetic primary teeth restoration are, however, different and further well-founded clinical trials and experimental studies are necessary. Opinions on the decision-making process when choosing a restorative material are very similar and can be formulated in the following way: To receive reliable results with esthetic material restoration in primary dentition three conditions have to be present: isolation, cooperation, and time. Microscopic structure peculiarities of primary enamel and dentin and time until tooth exfoliation have to be taken into consideration too. One has to state, however, that the longevity of tooth-colored materials has not been found higher than that of amalgam. That is why dentists should consider the diagnosis, ease of material placement, oral hygiene, caries risk, esthetic demands, and financial aspects when choosing a restorative material for primary teeth.

ABBREVIATIONS USED

Bis-GMA – bisphenol-A – glycidyl methacrylate
HEMA – hydroxyl ethyl methacrylate
GIC – Glass ionomer cement
RMGIC – resin modified glass ionomer cement

Table 1

Classification of composites based on filler size (adapted according to 6)

Classification	Filler material (% weight content)	Average particle size (µm)
Macrofilled	Glass particles (78 %)	1–35 (conventional)
Microfilled	Amorphous silica (35 %–63 %)	0.01–0.1 (mean diameter 0.04)
Hybrid	Glass particles and fillers (>80 %)	5, conventional plus microfiller (two sizes)
Micro-Hybrid	Glass particles and microfillers(>80 %)	0.4–0.8
Nanofilled	Zirconium/silica or silica nanofillers and clusters (N/A)	5–20 nm Zr/Si or 75nm Si

INTRODUCTION

Restoration of decayed primary teeth is very important and significant not only for the healthy development and psychics of the child but also for the physiological development of permanent dentition. The choice of restorative materials for primary teeth is large at the present time. Whereas several years ago the only possibility was amalgam, today there are various alternatives at the dentist's disposal [1]. Increased attention to minimal intervention, combined with increased requests for more esthetical appearance, has created much broader use of newer restorative materials when treating dental caries in primary teeth. Amalgams have a known quality with long-proven history and research. They have been proven more economical for the dentist and the patient. Amalgams are easily completed and the margins are easily identifiable when carving. Radiographically, amalgams are easily distinguished from the tooth structure and enable the dentist to identify recurrent decay and margins. Amalgams have a long shelf life and easy storage of materials. Amalgam restoration has also been known for superior interproximal contacts and superior marginal integrity that becomes tighter with age. It also has a superior wear rate and can be extremely long-lasting [2]. The operative technique with amalgam is based on mechanistic principles. The box-shaped cavity preparation is not tooth-friendly to either healthy enamel or dentin, and the crown is weakened [3]. Marginal disintegration of amalgam fillings is material inherent and ultimately limits the longevity of restorations. A thickness of the amalgam filling less than 2 mm, particularly in Class II, commonly results in bulk fracture, dislodgment, or a combination of the two [4]. The esthetics of the amalgam filling is, however, unsatisfactory and can cause dark staining of the tooth and a tattoo of the gingival and buccal mucosa. Esthetically acceptable materials have been formulated in recent years and steadily improved especially as regards their physical properties. Esthetic ma-

terials were developed for permanent teeth restoration, but they can also be successfully used for the treatment of primary dentition, especially in minimally invasive techniques, atraumatic tooth restoration, and preventive interventions. Composite resins, glass ionomers, resin modified glass ionomers, and compomers are the materials of choice in the form of direct filling. Indirect filling (inlays), composite resins or ceramics are not used for primary teeth restoration.

Composite resin

In the early fifties, R. L. Bowen developed a polymer based on dimethacrylate chemistry. This polymer, generally known as bis-GMA or Bowen's resin, was made from a combination of bisphenol-A and glycidyl methacrylate. Since the advent of Bowen's resin, inorganic fillers were added to overcome the problem of shrinkage, thermal expansion, and low strength [5]. Current composite formulations contain high and low molecular weight monomers, inorganic fillers, silane coupling agents, polymerization inhibitors, initiators, and ultraviolet stabilizers. The high molecular weight monomers undergo polymerization via free radical addition to form rigid drops-linked polymers. Inorganic fillers serve multiple purposes in composites. Fillers occupy the spaces in between the resin matrix, which helps to reduce shrinkage upon polymerization. Fillers also impart greater strength, hardness, low water absorption, lower wear and greater esthetics upon polishing, and confer radiopacity as they contain barium, strontium or zinc [5].

Composites can be classified according to:

1. Type of fillers (quartz, fused silica, many types of glasses including aluminosilicates or borosilicates)
2. Size of fillers (macrofilled, microfilled) (Table 1)
3. The amount of filler used (percentage by weight or volume)
4. Method of curing (chemical activation and visible light activation)

Table 2

Evolution of dental bonding adhesives (adapted according to 48). Progression of dental adhesives

1960s and 1970s: First and Second Generations Did not recommend dental etching. Relied on adhesion to smear layer. Weak bond strength.	1980s: Third Generation Acid etching of dentin. Separate primer. Increased bond strength. Margin staining caused clinical failure over time.
Early 1990s: Fourth Generation Hybrid layer of dentin and collagen. Dental seal. Concept of wet bonding introduced. Technique sensitive.	Mid 1990s: Fifth Generation Combined primer and adhesive in one bottle. Maintained high bond strengths. Unit-dose packaging introduced.
Late 1990s, early 2000s: Sixth Generation Self-etching primers. Reduced incidence of post-treatment sensitivity. Bond strengths lower than fourth-and fifth-generation.	Late 2002: Seventh Generation All-in-One. Combines etching, priming and bonding. Single solution. Good bond strength and margin sealing.

Macrofilled composite resins were very hard and rough, which made them difficult to polish, and they tended to cause enamel abrasion. The surfaces often became rougher with wear and attracted plaque. Microfillers were then developed in 1970s. They were composed of colloidal silica 0.04 μm in size. These fillers rendered the composite more polishable and less shrinkage and higher wear resistant than the macrofillers. However, they have poor mechanical properties (use in low stress area). Hybrid composites combine glass particles with fillers of various sizes (aluminosilicates, quartz or barium aluminosilicate silica glasses). Hybrid composites are easier to polish and have better wear resistance than the microhybrid composite resins. Nanofilled composite resins can be excellently polished and have good mechanical properties [6].

Anchoring of a composite filling into the tooth structure was made possible by a revolutionary method – acid etching [7, 8]. The surface enamel is smooth and has little potential for bonding by micromechanical attachment. On treatment by certain acids, however, the structure of enamel may be modified considerably. Chemical treatment by acid etching enhances the topography of enamel, changing it from a low-reactive surface to a surface that is more susceptible to adhesion. The demineralization is selective because of the morphological disposition of the prisms [9]. Acid etching removes approximately 10 μm of enamel surface and creates a morphologically porous layer 5–50 μm deep [10]. The surface free energy is doubled [11] and, as a result, the low viscosity fluid resin contacts the surface and is attracted to these microporosities through capillarity [12]. Therefore, resin tags are formed into micropo-

rosities of conditioned enamel and provide a resistant long-lasting bond by micromechanical interlocking with this tissue [13, 14, 15]. The type of resin applied to the etched enamel depends on the specific application used. For composite resins the mixed material may be applied directly to the etched enamel surface. The resin from the composite flows into the etched enamel and sets, forming rigid tags which retain the filling. More frequently, however, low viscosity resins, the so-called bonding resins enhancing the adhesive bond strength, are used. They consist of a resin similar to that used in composite material but contain no filler particles. It is fully fluid and readily flows into the etched enamel surface. Bonding readily occurs at the unfilled resin-to-composite interface. The resulting shear bond strength achieved between etched enamel and restorative resins is 16–20 MPa.

Dentin adhesives

In most clinical situations, however, the restoration is bonded to the enamel and dentin. To interact with this intrinsically moist tissue, an adhesive system was needed that could diffuse under this condition. Formulation of dentin adhesives underwent a complicated development (Table 2). The most significant factor that limits bonding in the absence of any form of dentin pretreatment is the presence of the dentin smear layer. The smear layer is formed by the process of cavity preparation and extends over the whole prepared surface of the dentin and into the dentinal tubules (smear plug). A smear layer is present on the surface of freshly cut dentin irrespective of the method of mechanical tooth preparation. It is now

Table 3

Composition of glass ionomer cements

Powder/liquid materials	
Powder	Sodium aluminosilicate glass with about 20 % CaF or other minor additives
Liquid	Aqueous solutions of acrylic acid/itaconic acid copolymer or aqueous solutions of maleic acid polymer and tartaric acid in some products to control setting characteristics
Powder/water materials	
Powder	Sodium aluminosilicate glass with about 20 % CaF or other minor additives + vacuum-dried polyacid (acrylic, maleic or copolymers)
Liquid	Water (added by dropper) or dilute aqueous solution of tartaric acid

recognized that in order to form an effective bond and seal between a restorative resin and the dentin the smear layer must be removed, disturbed or modified in some way, which allows access to dentin. The liquids used for dentin pretreatment prior to bonding are called conditioners. They are generally acid solutions. Many acid solutions have been employed as conditioners. It is advantageous if the acid used for dentin conditioning can also be used for acid etching enamel [16]. The conditioning stage can be viewed as the first of three stages – the other two being priming and bonding. Having conditioned the dentin in order to remove or modify the smear layer the next stage is the priming stage. This stage is a key stage in the procedure as it is designated to change the chemical nature of the dentin surface and to overcome the normal repulsion between the hydrophilic dentin and the hydrophobic resin. Most adhesive systems that use the total-etch technique (etching with 37% phosphoric acid) have in their formulation low-viscosity hydrophilic monomers diluted in organic solvents with a high potential of volatilization to displace the moisture of the conditioned dentin. The primer components (e.g. hydroxyl ethyl methacrylate – HEMA) are called bipolar because they have 2 functional groups (hydrophilic and hydrophobic). The hydrophilic end has the ability to interact even under moist conditions and the hydrophobic end has chemical affinity with the methacrylate group of the bonding resin matrix or with the composite resin [17]. Some adhesives contain inorganic filler particles to increase the film thickness and cohesive strength. After priming the nature of the dentin surface is significantly changed; it becomes more hydrophobic and ready to accept the resin-based bonding agent. The bonding agent is normally a fluid resin able to flow over and wet the primed surface to complete the formation of an effective bond. Efficient dentin conditioning removes the smear layer and smear plug and also

causes a significant decalcification of the intertubular dentin to a depth of a few microns. The decalcification process leaves a three-dimensional collagenous network which can be infiltrated by the primer and resin to form a resin infiltrated/reinforced hybrid layer. The need to shorten the time-consuming application led to a simplification of the procedures for conditioners, primers and bonding agents, and to techniques combining these procedures into one. Dentin adhesives are currently classified into two major categories: etched-and-rinsed and self-etched adhesives based on the mechanisms by which they interact with the smear layer [18]. The etched-and-rinsed types remove the smear layer before application of the resin, while the self-etched adhesives incorporate the smear layer into a hybrid coating [19]. The original self-etched systems included two steps: application of an acidic self-etching primer followed by a separate bonding step. The self-etch adhesive system relies on the use of non-rinse acidic methacrylate monomers that simultaneously etch and prime the dentin, so that the disrupted smear layer is incorporated into the hybrid layer [20]. Recently, one-step self-etch adhesives have been developed that combine the conditioner, primer, adhesive resin and water into a single application. Self-etch systems are in general less technique sensitive than etch-and-rinse systems that utilize separate etching and rinsing steps [19]. When bonded to primary dentin [21], significant differences were found in bond strength between etch-and-rinse and two-step self-etch adhesives.

Glass Ionomer Restorative Materials (GIC)

Glass ionomer restorative materials have been available since the early 1970s and were derived from silicate cements and polycarboxylate cements (Table 3). GICs are classical water-based cements with an acid/base setting reaction of aluminium

silicate glass and a polyalkenoic acid [22, 23, 24]. Like many dental cements, the properties of glass ionomers are critically dependent upon the powder/liquid ratio. The powder/liquid ratio should be high in order to optimize strength and solubility, but there should be sufficient free polyacid available to form a bond with the tooth substance. The variability of material properties with the powder liquid ratio and the difficulties of mixing by hand suggest that there are definite advantages to be gained by using the materials in the encapsulated form. One of the most important properties of these materials is their ability to adhere to both enamel and dentin, but the precise mechanism of bonding is still somewhat unclear. One theory is that polyacid molecules chelate with calcium at the tooth surface. Support for this mechanism stems from the fact that the formation of the interfacial calcium polyalkenoate salt would involve a reaction similar to that thought to occur during the setting of the cement. Also, the significantly greater bond achieved with enamel than with dentin suggests that it is the calcium of the tooth substance that is involved in bond formation. Another theory is that the outer layers of apatite on the tooth surface become solubilized in the presence of acid. As more apatite dissolves and as the cement begins to set the pH begins to rise. This may cause a re-precipitation of the complex mixture of calcium phosphate (from apatite) and calcium salts of the polyacid onto the tooth surface. Thus, the polyacid chains would be bound to a re-precipitated layer on the tooth surface. This mechanism could operate on enamel and dentin surfaces and thus could also be supported by bond strength data. It has been suggested that in the case of dentin there may also be some bonding between carboxylic acid groups of the cement and reactive groups within collagen, either by hydrogen bonding or by metallic ion bridging. The fluoride release and the ion-exchange adhesion with both tooth structures have been reported to be the main advantages of this particular group of materials (25). However, the evidently low water resistance, moisture susceptibility, and inferior flexural strength characteristics lead to the development of several modifications in the field of conventional GICs [26, 27, 28]. Metal reinforced glass ionomer cements were formulated to improve the mechanical properties of the cements and to increase their wear resistance [29, 30, 31]. Further development of glass ionomer cements focused on a higher powder-to-liquid ratio, a lower water content, and smaller glass particles leading to high viscosity glass ionomer cements, which should be packable like amalgam and reveal enhanced flexural strength characteristics. Clinical studies, however, have not proved the results of the previous promising in vitro studies [32, 33].

Giomers

This group of materials is more correctly described as composites with active filler particles. The material unites the

chemistries of composite and GIC in an effort to combine the advantages of both materials, whilst minimizing the limitations of each. The material is composed of pre-reacted GIC particles within a resin matrix. Giomers can be subdivided into two distinct groups of materials, namely those in which the glass ionomer particles have been surface reacted and those which have been fully reacted. Surface pre-reacted glass ionomer giomers are suitable for composite indications, whilst fully pre-reacted glass ionomer giomers are used in dentin adhesive systems, fissure sealants, and as restorative material for nonloaded-bearing areas [34].

Compomers

Compomer is a polyacid-modified composite resin [35, 36, 37]. Compomer is made predominantly from resin composite (90%) with the addition of a polyacid-modified molecule similar to that found in traditional GIC. Compomers are initially light-cured, but subsequently absorb water, allowing for an acid-based reaction to set the polyacid-modified molecule. Consequently, the material shrinks, initially due to polymerization contraction, and expands subsequently as water is absorbed. The addition of a polyacid-modified molecule makes the material more hydrophilic. Compomers are, therefore, relatively easy to handle and apt for preparation. A dentin-bonding agent is required for their successful placement. Physically, their properties are similar to those of a composite. The wear rates and fracture resistance are less than for a composite. Compomers and composites have the same advantages (38). Additional advantages of compomers include fluoride release and ease of handling [34].

Resin-modified glass ionomer

The chemistry of GIC has been incorporated into another modern material, namely the resin-modified glass ionomer cement (RMGIC). RMGICs most closely resemble conventional glass ionomer cements and are capable of setting by an acid-base mechanism. This is supplemented by a free radical polymerization reaction involving the monomer 2-hydroxyethyl methacrylate. The actual bonding mechanism of RMGICs to tooth tissues has been recently determined to be twofold, by micromechanical interlocking [39, 40] and by chemical interaction [41, 42]. Micromechanical interlocking is achieved by impregnation of a partially demineralized layer on the top of the dentin substrate with a high-molecular-weight polycarboxyl-based polymer [18] similar to the hybrid layer in resin-based interfaces. Chemical interaction in the form of gel-phase between polyalkenoic acids and calcium was demonstrated not only on hydroxyapatite blocks [41] but also on enamel and dentin [42]. The physical presence of the gel-phase attached to the tooth surface suggests that the resulting calcium polycarboxylate salt is stable in this particular

system [43]. RMGICs develop self-adhesion to tooth tissue, which is enhanced if the tooth surface is conditioned and left moist prior to application of the material. The resin-based systems are command-cured, although it is important to understand that the acid-base reaction for the traditional glass-ionomer cement proportion of the material (ca 80%) is really how the material cures and sets (44). This reaction is water dependent and takes several days for the process to be complete. More correctly, therefore, resin-modified glass-ionomer cements are initially photostabilized rather than light-cured. RMGICs are able to release fluorides. The materials have, however, disadvantages linked to their inferior properties when compared with composites, the most important being poor structure strength and wear rate, marginal chipping, and exogenous discoloration.

Tooth-colored materials have been used more and more frequently for restoration of primary dentition in recent years [45, 46, 21, 26, 32, 33, 35–38]. The findings of individual authors are, however, different and further well-founded clinical trials and experimental studies are necessary. Opinions on the decision-making process when choosing a restorative material are very similar and can be formulated in the following way: To receive reliable results with esthetic material restoration in primary dentition one must have three conditions in place: isolation, cooperation, and time. Microscopic structure peculiarities of the primary enamel and dentin and time until tooth exfoliation have to be taken into consideration too. As regards clinical application, composite resin can be used for restoration of primary incisors for class III, IV and V, and of primary molars for class I and II cavities if the patient is cooperative, because a resin composite material requires more time and more steps with great technique sensitivity to be effective. The conventional hand-mixed powder and water glass-ionomer cements have limited application and are used only as luting cements for preformed metal crowns and as temporary dressings. Resin-modified glass ionomers are becoming very popular in pedodontic practice, especially for class I and II restorations in primary molars. They can also be used for class V cavities and atraumatic restorative techniques or as a base material in deep-cavity preparations. Compomers need acid etching and bonding, both procedures which demand increased time and good patient compliance. They have been shown to be durable over a three-year period when used in approximal primary molar cavities. Therefore, they can be used in class I and II primary molar cavities and in class V cavities. One has to state, however, that the longevity of tooth-colored materials has not been found higher than that of amalgam [46]. That is why dentists should consider the diagnosis, ease of material placement, oral hygiene, caries risk, esthetic demands, and financial aspects when choosing a restorative material for primary teeth [47].

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