Materials for Restoration of Primary Teeth: 1. Conventional Materials and Early Glass Ionomers

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Abstract: **This paper demonstrates how the treatment of primary dentition may present the clinician with increased difficulties compared with the preparation and placement of restorations in adult dentition. Established dental materials (dental amalgam and conventional glass ionomer cements) and less well established alternative materials (copper cements) are reviewed. The use of amalgam to restore primary dentition is the subject of concern amongst the dental profession in terms of lack of adhesion and potential toxicity concerns, while the low tensile strength of traditional glass ionomer cements make them less suitable for the restoration of primary dentition.**

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Clinical Relevance: **This article reviews 'established' dental materials which have been employed with varying degrees of success for the restoration of primary dentition.**

The treatment of caries in the primary dentition is an integral part of general dental practice. Such restorations may present the clinician with problems different from those of preparing restorations in the adult dentition,[1] including variations in patient co-operation, potential difficulties in isolation and the different anatomy of primary teeth, with cavities tending to be wider and more shallow than in adult teeth. However, the masticatory and biting forces applied to restorations in primary teeth are lower than forces applied to restorations in the adult dentition and, given that primary teeth exfoliate, the need for restoration longevity is less. Prevention must also form an integral part of treatment, given that no restorative material is ideal.

Potential materials for the restoration of primary teeth should possess adequate physical characteristics to withstand the forces of occlusion so that restorations in primary teeth do not simply function as long-term provisionals.[2] Frankenberger has considered that the figure quoted by the American Dental Association (of maximum abrasion of 50 microns per year for materials for the restoration of primary molar teeth) is sufficient;[2] however, it has also been considered that the working characteristics of materials for primary teeth are of special importance, given the possible problems with patient compliance.[2] This is reflected in the loss rate of amalgam restorations placed in pre-school children being greater than that in children of school age.[3]

Traditionally, dental amalgam has been used for the restoration of primary teeth, but increasing concerns about its effect on the environment and some patient concerns regarding mercury toxicity have led to the increasing use of alternative materials. Additionally, the position taken by the German Federal Minister of Health to restrict the use of amalgam to stress-bearing fillings in permanent teeth, to bar the use of amalgam in pregnant women and as a core material, placed many patients and consumers in the post-amalgam age. However, Lutz suggested that this governmental decision was taken not on the basis of a scientific report, but rather under pressure from 'mercury fundamentalists' who had 'irreversibly vilified amalgam' and therefore 'blackmailed' the relevant authorities.[4]

A variety of restorative materials is presently available which adhere to, or are capable of being bonded to, tooth structure. The use of such materials may require removal of less tooth substance to provide retention than non-adhesive materials. For permanent teeth, resin-based composite (RBC) materials are increasingly used in the restoration of adult teeth,[5] because of the advantage of conservative cavity preparation, along with increasing public anxiety about amalgam toxicity, environmental concerns and aesthetics. However, primary enamel has a more pronounced prismless layer than permanent enamel,[6] which requires an increased etching time[7] and permanent tooth dentine is more mineralized than primary tooth dentine.[8] For this reason, the bond strength of RBC materials is less in primary teeth than in permanent teeth.[9] RBC materials may therefore be considered less appropriate for restoration of the primary dentition than the permanent dentition. However, other materials which adhere to tooth

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substance, such as glass ionomer, and its variants, and polyacid-modified resin (compomer) may be considered appropriate and will be discussed in depth in these articles, along with more conventional materials such as amalgam and copper cement. Traditional means of restoring primary teeth should not, however, be forgotten.

A recently published systematic review has found that preformed metal crowns (PMCs) provide a more favourable outcome than amalgam restorations[10] and PMCs have been found to give the most long lasting restorations in primary molar teeth.[1] However, the uptake of stainless steel crowns by dental practitioners working within the NHS Regulations in the UK is low.[11] It also appears that a high proportion of cavities in primary teeth in patients in the UK go unrestored.[12] This may reflect perceived difficulties in patient management, or concerns about remuneration, along with difficulties in moisture control, which may be more difficult in children.

DENTAL AMALGAM

Dental amalgam is formed by reacting mercury and a powdered alloy composed of silver, tin and copper. Mercury has the lowest melting point of all metals and the liquid readily reacts with the silver–tin–copper alloy powder to produce a workable plastic mass that can be condensed into a prepared cavity and sets to form a solid at mouth temperature. Dental amalgams have been employed successfully as a direct posterior restorative filling material for over a century. The popularity of dental amalgam amongst general dental practitioners can be attributed to its strength, durability, wear resistance,[13] cost-effectiveness, ease of manipulation and long-term clinical performance.[14]

The use of mercury has been a major concern amongst practitioners, the scientific community and the general public since it was first employed as a restorative filling material. Within 8 years of the introduction of amalgam to the United States in 1833, the first ‘amalgam war’ was initiated. The early amalgamation techniques employed involved the practitioner mixing filings from silver coins with mercury in the palm of his/her hand. These early amalgamation techniques were considered to be sloppy and unprofessional compared with the technique proficiency employed in gold foil restorations.[15] Dental amalgams have developed and improved since the first commercial silver amalgam and scientists in the late nineteenth century developed a stable amalgam by combining silver, tin and mercury. Whilst the potential toxicity of the stable dental amalgam was highlighted by a series of scientific research papers, no toxic responses to amalgam restorations were identified at the time. However, the stable amalgam suffered from poor corrosion and creep resistance and was susceptible to ditching at its margins attributed to the tin–mercury (γ_2 phase) formed in the set amalgam. The development of high-copper amalgams (where up to 30% of the silver was replaced by copper) resulted in the formation of a copper–tin phase on setting rather than the deleterious γ_2 phase. In recent years, the impact of dental mercury on environmental pollution[16] has been an area of concern. Furthermore, high copper amalgam with its metallic sheen is also far removed from the appearance of sound tooth structure.

The other major disadvantage of dental amalgams is their lack of adhesion to tooth substance. As a result, sound tooth structure is inevitably lost to the bur in an attempt to achieve mechanical interlocking between amalgam and tooth. The lack of adhesion, combined with the removal of sound tooth structure, may contribute to the catastrophic failure of the tooth.

Although amalgam fillings restore the function of tooth structure, they do not reinforce the tooth. As a result, cusp fracture is common with amalgam restorations. Fracture of cusps weakened by the loss of adjacent tooth structure would be markedly reduced if an adhesive amalgam supported the tooth structure by achieving an intimate bond by etching dentine, priming to create a hybrid layer and the application of a liner. Previous investigators have suggested that adhesive amalgams give better clinical performance than their non-adhesive counterparts. As a result, the advent of adhesive dental amalgams has expanded the number of indications for the use of such a versatile material. Cannon *et al.*[17] identified paediatric dentistry as one of these areas because of the cost-effectiveness of dental amalgam compared with technique-sensitive, tooth-coloured restoratives which may be difficult to place successfully in unco-operative patients.

In spite of the encouraging

Country	Recommendations
Iceland	No policy
Greece, Republic of Ireland, Italy, Spain	No policy; amalgam widely used
Israel	No policy; amalgam still used, some parents object
Norway, Netherlands, Belgium, Denmark	No policy; amalgam used but parents asking for alternatives
Sweden*	No policy; parents usually insist on other materials; usually avoid amalgam use in children and pregnant women
Germany, Switzerland	No policy; parents usually insist on other materials
France	No official policy but avoidance for children and pregnant women
Finland⁺	Amalgam only to be used when there is no acceptable alternative

*Original ban on amalgam use for environmental reasons has now been lifted
⁺Do not advise the removal of well functioning existing amalgam restorations

Table 1. *Recommendations on the use of amalgam in a range of countries within the European Union*[18]

Figure 1. The setting reaction in acid–base dental cement: hydrogen ions from the liquid penetrate into the powder particles, liberating metal ions that migrate into the liquid and combine with the anion to form the salt-like gel matrix.

information regarding the use of adhesive amalgams over their non-adhesive counterparts, a fourth ‘amalgam war’, possibly initiated by tabloid journalism, is probably just around the corner. In the advent of such a ‘war’, it is possible that the use of dental amalgam (adhesive or non-adhesive) in young patients could be restricted, thereby bringing the UK into line with some of its European counterparts (Table 1).

COPPER CEMENTS

Copper cements are similar to phosphate cements, except that the powder contains a copper compound in addition to zinc oxide. If copper(I) oxide (cuprous oxide) is used, the cement is red, while copper(II) oxide (cupric oxide) gives a black material. Black copper cements are considered to be bactericidal, and have therefore been used to prolong the life of deciduous teeth from which it has been impossible to remove all the carious tooth substance. These materials were extensively used a quarter of a century ago, but are little used today because of the high acidity of the unset cement, its lack of any bond to tooth substance and the consequent high risk of leakage and pulp death.

GLASS IONOMER (POLYALKENOATE) CEMENTS

Before describing newer variants of material (see article 2 in this series), the properties of ‘conventional’ glass ionomers will first be described, as these are common to all members of the glass ionomer ‘family’. Glass ionomer cements have been available in the UK for almost three decades[19] and have been used in primary teeth since their introduction.[2,20] These cements contain a fluoroaluminosilicate (FAS) ion-leachable glass, and a water-soluble polymer acid, originally poly(acrylic acid), which react to form a cement. The fluoride assists in the manufacture of the glass by lowering fusion temperature but also contributes to the therapeutic value of the cement, although the value of fluoride release from glass ionomer in respect of control of secondary caries has recently been questioned.[21]

Many early glass ionomer materials used poly(acrylic acid), but current materials may contain a copolymer of acrylic acid with itaconic or maleic acid, referred to as a poly(alkenoic acid).[22] Instead of a viscous aqueous solution, the polymer is often supplied as a dry powder blended with the glass. Such products are hand-mixed with water or are supplied in capsules for mechanical mixing. Tartaric acid is added to provide a clinically acceptable setting time.

On mixing the basic glass with the aqueous poly(alkenoic acid), an acid–base reaction ensues (Figure 1). The outer layers of the glass particles decompose, releasing Ca^{2+} and Al^{3+} ions. These ions migrate into the aqueous phase, and cross-link the polyalkenoate chains, causing gelation and setting of the material. The set cement consists of a core of unreacted glass particles surrounded by a salt-like hydrogel, bound by the matrix of reaction products.[21] Water is an essential component in these materials.

Bonding to Tooth Substance

Bonding of glass ionomer cements to tooth substance is thought to occur by ion exchange between the cement and apatite,[23] although the precise mechanism is not fully understood. The polyalkenoic acid penetrates the molecular structure of hydroxyapatite, releasing phosphate ions, which link with a calcium ion from the tooth surface to maintain electrical neutrality. These ions combine with the surface layer of enamel to form a layer of material which is firmly attached to the tooth substance. It has also been suggested that there is adhesion by hydrogen bonding to the collagen of the dentine.[24] The longevity of the adhesion has been well established in clinical practice.[25] The tooth surface should be conditioned with 10% polyacrylic acid for 10 to 20 s,[26] which effectively cleans the tooth surface. This lowers the surface energy and allows the cement to adapt to the surface more readily.[27] Stronger acids should not be used as they may demineralize the tooth and reduce the efficiency of the ion-exchange mechanism.[28]

The bonding of glass ionomer cements to tooth does not fail readily, and failure will normally be cohesive within the cement, with careful observation showing that a thin layer of material is left attached to the tooth.[29] It has also been considered that the greater the strength of the glass ionomer material, the greater will be the strength of adhesion. For this reason, restorations placed under occlusal load should have the highest possible powder content.[28]

Properties of Glass Ionomers

Glass ionomers have been reported to cause some inflammatory response in the pulp but are considered to be biocompatible to within 1 mm of the pulp.[30] A calcium hydroxide base is therefore indicated for restorations greater than this depth. Anticariogenic properties may result from the release of fluoride by these cements, but the effectiveness of this in preventing secondary caries has recently been questioned.[21] In this respect, a systematic review has failed to elucidate a cariostatic effect of glass ionomer restorations in all but one of 73 papers reviewed.[31]

Glass ionomer cements, when fully hardened, are durable. However, as the set cement may take up to 24 hours for

Figure 2. *Cavity in upper second primary molar restored with glass ionomer cement.*

the material properties required to be realized, it is generally recommended that a freshly set cement must be protected from exposure to moisture, ideally by application of a layer of unfilled resin.

Glass ionomers possess reasonable compressive strength but are brittle with low tensile strength, so cannot be used for high stress-bearing tooth restorations.[22]

The aesthetic properties of glass ionomer cements may be considered disappointing in terms of translucency. Other materials offer better aesthetics.

Clinical Applications

Conventional glass ionomer materials have been used to restore primary teeth (Figure 2), or can be combined with resin composite in the laminate or 'sandwich' technique. However, the brittle nature of conventional glass polyalkenoate cements (Table 2) and the introduction of newer variants (high-viscosity glass ionomers) now contraindicate use of the 'traditional' glass ionomer materials for load-bearing restorations in primary teeth. Restorations in conventional glass ionomer cement have been shown to have a mean survival time of 33 months, compared with 41 months for amalgam.[32] However, restorations in glass ionomer cement may require less destruction of tooth substance than restorations in amalgam, and so direct comparison is difficult. Most recently, Welbury *et al*. have shown that compomer restorations have a higher mean survival time than glass ionomer restorations (42 months, compared with 37 months for the glass ionomer restorations[33]). Secondary caries is rarely noted with glass ionomer restorations in primary teeth, but fracture of the restoration or its margins are reported most frequently when glass ionomer is used as the restorative material.[1]

CONCLUSION

Amalgam may provide the necessary physical properties for restoration of primary teeth, but there have been concerns regarding its safety.[34] As a result, the dental profession has focused on the need to develop alternative materials.[34]

Stainless steel crowns have been shown to provide optimum survival rates, with survival rates being, in order, stainless steel crowns, amalgam, resin composite and glass ionomer.[35]

The low tensile strength of traditional glass ionomer materials makes them unsuitable for load-bearing restorations in primary teeth.[22]

The second article in this series will examine the materials that have been developed to improve the qualities of traditional glass ionomers and will consider which of these variants may perform as effective restorative materials for primary teeth.

Material	Clinical characteristics	Name	Manufacturer
Conventional glass ionomer	Powder/liquid	Chemfil	Dentsply, Addlestone, Surrey, UK
		Fuji I	GC Corp, Tokyo, Japan
		Ketac Fil	ESPE, Seefeld, Germany
		Glasionomer II	Shofu/Advanced Healthcare, Kent, UK

Table 2. *Examples of conventional glass ionomers.*

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BOOK REVIEW

Orthodontic Radiographs – Guidelines (Guidelines for the Use of Radiographs in Clinical Orthodontics). 2nd edn. K. G. Isaacson and A. R. Thom, eds. BOS, London, 2001. ISBN 1-899297-05-7. (Available from the British Orthodontic Society, 291 Gray's Inn Road, London WC1X 8QF: UK £7.00; Overseas £10.00 incl. p&p.)

The first edition of this booklet was produced in 1994 by the British Orthodontic Society. It has now been updated to take account of recent statutory changes, particularly Ionizing Radiation (Medical Exposure) Regulations 2000 – IR(ME)2000. This legislation requires that employers establish referral criteria for referrers and for IR(ME)R practitioners to take responsibility for the justification of medical exposures. To this end this booklet is an invaluable aid with respect to orthodontic radiographic selection criteria.

Patient dose levels have shown a reduction in recent years following improvements in radiographic equipment design and the use of fast films. However, there has been a steady increase in the frequency of radiographic examinations taken in dental practice. This is particularly so with orthodontic practice, where data from the Dental Practice Board has shown a 110% increase in the number of lateral cephalograms in the last five years.

There is thus a need for guidelines to assist dental practitioners through expert advice to minimize the number of unnecessary radiographs. This booklet has been produced with this in mind and contains simple, sensible and easily followed flow diagrams to help the clinician decide whether and when radiographs are required for orthodontic treatment planning.

The booklet opens with a succinct account of radiation hazards, risks and aspects of IR(ME)R2000. It discusses the indications for taking radiographs before outlining the types of views used in orthodontic practice. The last few pages of the booklet summarize digital radiography, the medico-legal aspects of orthodontic radiography, quality assurance and concluding with a comprehensive list of supportive references. The booklet is well thought out and easy to follow.

If I had to nit pick, I would argue with the statement that the dental panoramic tomogram (DPT) and the upper standard occlusal together could be used to assess the vertical position of unerupted canines. The upper standard occlusal view, because of its steep vertical angulation, tends to show a palatally located canine higher than it actually lies in relation to the upper incisor tooth root, and is thus not particularly accurate for demonstrating its vertical position. It would have been better to say that, by using these two views and the principles of parallax, the bucco-palatal displacement of an unerupted canine can be determined. In fact, an example of this principle is illustrated. Further, it would have been helpful if the occlusal view had been printed above, rather than below, the DPT to make it simpler to follow the tube shift and perhaps to have chosen a technically more accurate panoramic image cropped to show more of the maxilla and less of the mandible.

Despite these minor criticisms, I can thoroughly recommend this publication, which is informative and well laid out. It is a useful document for employers and the information it contains should be included in their selection criteria information for those requesting and taking orthodontic radiographs.

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Self-Assessment Answers

1. A	**6.** B, C, D
2. A, B, D	**7.** B, D
3. A, C	**8.** A, D
4. A, C, D	**9.** A, D
5. B, C, D	**10.** A, B, C, D