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Selection of restorative materials for the atraumatic restorative treatment (ART) approach: a review

ABSTRACT

The atraumatic restorative treatment (ART) technique or approach for the restoration of primary and permanent teeth has been widely adopted in, but not limited to, developing countries. However, the requirement for the placement of the restorative materials under often less-than-ideal conditions imposes significant restrictions on their selection; and there have been very few randomized clinical trials or reports comparing different types of restorative materials and treatments. Although conventional glass-ionomer cements (GICs) have relatively poor mechanical and adhesive strengths, their satisfactory biological features, ease of use, and low costs are distinct advantages. Most of the published reports of the clinical performance of the newer, high-strength esthetic conventional GICs specifically marketed for the ART approach have been from short-term studies. Satisfactory clinical performance has been demonstrated for single-surface posterior restorations only, over three years. Findings indicate that further improvements in restorative materials are still required for their use with the ART approach, together with further clinical investigations of the remineralization of shallow open caries lesions, as an alternative to placing definitive restorations.

KEY WORDS: Atraumatic restorative treatment, dental materials, dental caries.

INTRODUCTION

The atraumatic restorative treatment (ART) technique or approach has achieved considerable interest worldwide, especially for its application in developing countries where skilled human and other resources are not readily available or affordable for the treatment of dental caries by more conventional means. Basically, the minimally invasive ART approach involves the use of hand instruments only to provide access to remove carious tooth substance, and then restoring the cavity and sealing any adjacent enamel fissures with, usually, a conventional self-hardening glass polyalkenoate (ionomer) restorative cement (GIC).[1,2] The procedure is largely pain-free and readily accepted by children.[3,4] Therefore, the ART approach has also been found useful for caries management in other apprehensive, elderly, institutionalized, and disadvantaged patients in more industrialized countries.[2]

One of the main requirements for the successful application of the ART approach is the selection of suitable preventive and restorative materials. The materials may be placed under less-than-ideal conditions by operators with limited training, and in patients at high risk for caries and tooth wear. Therefore, the biological and physical properties of the materials are important, as are other features such as their availability and costs, ease of use and tolerance to operator variability, storage conditions and shelf-life, and the operative equipment required.

Most of the ART studies[5,6] reported, usually field trials, have involved conventional GICs. However, there have been very few randomized clinical trials published of the modes and rates of deterioration and failure of the GICs used, or of any comparisons with other materials and treatments, either under field or conventional operatory conditions.[5,6] These observations apply to GICs used not only as restorations in primary and permanent teeth, but also as pit and fissure sealants. Alternative materials to conventional GICs could include bonded and non-bonded amalgam alloys, adhesive resin composites, and hybrid resin-ionomers. Alternative treatments could include making caries lesions self-cleansing, the application of topical fluorides after gross caries removal from shallow and open multisurface lesions,[5,7] and the preventive and therapeutic use of fluoride toothpastes.[8] This review paper evaluates the suitability of newer high-strength esthetic conventional GICs for use with the ART approach in the management of dental caries. The literature was searched electronically and by hand by means of key words and author names.

BIOLOGICAL PROPERTIES

Despite their low initial-setting pH, GIC restorations are generally considered to be biocompatible with the dental pulp, provided that they are not in direct proximity to the pulp.[9] Depending on their composition, different GICs can have variable effects on pulp and cell culture tissues.[10] The maintenance of a good cavity seal with the prevention of microleakage for any restorative material is essential to reduce deleterious pulpal changes. The inability of most esthetic restorative materials to form an effective and durable seal without the need for costly and technique-sensitive dentin bonding systems is a distinct disadvantage.

ANTIMICROBIAL PROPERTIES

In situ and *in vivo* studies[11-13] of aged GIC and other restorative materials have failed to demonstrate significant inhibitions of plaque growth on their surfaces, although a reduction in the relative proportion of mutans streptococci has been reported for aged GIC restorations.[14] The same study also showed that fluoride recharging of GICs had no beneficial effects on the levels of fluoride in the adjacent plaque. Another study[15] showed no antimicrobial activity for a high-strength GIC, Fuji IX (GC Intl. Corp., Tokyo, Japan). It has been suggested that the release of metallic ions and the low initial pH of setting GICs are more significant than fluoride ion release for any antimicrobial properties that may be present.[16]

GICs release various ions, of which fluoride has been the most studied. The newer high-strength GICs specifically marketed for the ART approach release amounts of fluoride ions similar to those released by Ketac-Silver (3M ESPE AG, Seefeld, Germany), the amounts being much less than those from earlier esthetic restorative GICs.[17,18] Attempting to recharge conventional GICs with acidic fluoride gels leads to severe surface damage, with only transitory anticariogenic benefits; and the eroded surfaces may enhance plaque growth and retention, and occlusal wear.[19] The effects of the short- and long-term release of other elements from GICs—such as aluminum, strontium, calcium, silicon, and phosphorus[20,21]—on *in vivo* plaque growth and composition remain to be determined.

Although the hand excavation of carious dentin with ART instruments was effective *in vitro*,[22] both infected and affected dentin may remain after *in vivo* cavity preparation. However, high microbial counts in carious dentin can be reduced substantially beneath sealed restorations *in vivo*.[23] Assuming that it is clinically possible to insert a GIC restorative to adapt closely to carious tissue and to seal the cavity margins, then the cement may also assist with some superficial remineralization, similar to that shown *in situ* with artificial caries lesions of dentin exposed to GIC and saliva.[24] Diffusion of various elements from both GIC and dentin to form an acid-resistant interface has also been shown *in vitro*.[25]

REMINERALIZATION

In contrast to resin-based sealants, the long-term clinical effectiveness of GIC sealants[26,27] and restorations[28] to prevent or arrest recurrent caries is still controversial, in spite of many *in vitro* studies that support this belief. Despite their relatively low fluoride ion release, the high-strength GIC restorative materials have been shown *in vitro*[29] to offer some protection against demineralization of adjacent enamel. A review of the newer high-strength GICs used with the ART approach has reported recurrent caries of approximately 2% for single-surface restorations, and approximately 0-4% for fissure sealants, after 2-3 years' use in permanent teeth in relatively low-risk populations.[5]

ADHESIVE AND MECHANICAL STRENGTHS

There is evidence that the low initial-setting pH of GIC plays an important part in the establishment of ionic bonds to tooth structure, with the formation of a narrow intermediate layer,[30] acid-resistant layer,[31] interaction zone,[32] interdiffusion zone,[33] or interface.[25] The interface between the GIC and dentin was found to consist principally of fluoridated carbonato-apatite, detected 2 to 4 hours after the placement of the GIC.[30] Hydrogen ions released from the polyacrylic acid conditioning and the GIC appear to dissolve components of the GIC as well as carbonato-apatite crystals of the adjacent dentin surface. Fluoridated carbonato-apatite crystals then precipitate to form an interface, and fluoride ions from the GIC may also diffuse some distance into the adjacent dentin.[34] A reciprocal diffusion of various ions from GIC and dentin has been demonstrated.[25]

Adhesion of materials to tooth structure minimizes the need for macromechanical retention and the extent of cavity preparations. Importantly, adequate adhesion also prevents or substantially reduces marginal microleakage and subsequent adverse pulp effects. An *in vivo* study showed that a GIC specifically marketed for the ART approach was found to have little marginal leakage.[35]

The reported bond strengths of conventional GICs to enamel and dentin are relatively low when compared with those of other esthetic adhesive restoratives (Table 1). However, the microtensile bond strengths to sound dentin of three GICs marketed for the ART approach were approximately 11-15 MPa, and adhesive failures were usually mixed or cohesive within the GICs.[36] These results may reflect improvements in the mechanical strengths of newer products (Table 2). However, despite these improvements, the high-strength GICs had high early clinical failure rates. These failures were due to loss of retention and fracture of ART restorations placed in shallow and multisurface preparations, especially in primary teeth, and for sealants placed in occlusal pits and fissures in permanent teeth.[5,6,37,38] Incomplete caries removal with ART hand instruments may result in reduced dentin bonding, and may be a possible cause for loss of retention,[2] as may salivary contamination of the bonding surfaces. The provision of adequate material bulk and macromechanical retention may be less effective with hand instrumants, even when treatment is provided under conventional conditions, than with rotary instruments, especially for shallow and multisurface preparations.[39] This assumption is supported by a cumulative survival of 93% found at two years for a high-strength GIC placed under conventional conditions in proximal slot design cavities that were prepared in primary molars by means of rotary instrumentation.[40] The placement of void-free GIC restorations with optimal adaptation to the cavity walls may also be difficult in some clinical situations.

Materials other than conventional GICs have also been reported with the ART approach. The physical properties of an auto-cured resin-modified GIC (RMGIC) were much improved when the powder:liquid ratio was increased to 3.6:1.0[41] (Table 2). The resulting Fuji Plus (GC Intl. Corp., Tokyo, Japan) ART restorations showed a much-improved retention rate of 93% at six months, compared with 30% for Fuji IX, in Class II preparations in primary molars.[42] These preliminary findings may reflect better fracture resistance and better adhesion to tooth structure for RMGICs than for

Table 1. Bond Strengths to Enamel and Dentin of GICs and Other Materials (MPa).*

Material	Enamel	Dentin
Ketac-Fil	4.0	3.1
ChemFil Superior		3.8
Fuji IX	2.6	4.5
Ketac-Molar	3.6	4.5
Glassionomer Cement FX	5.9	5.8
ChemFlex		6.0
Ketac-Silver	2.5	3.1
Fuji II LC	12	6.8
Photac-Fil		5.0
Fuji Plus (self-cure) (P:L, 3.6:1)	11	8.9
Dyract	19	24
Compoglass	18	16
Z100	20	18
Amalgam	0	0 (5.15 with adhesive)

* Based on data from Peutzfeldt, 1996[55]; Ewoldsen *et al.*, 1997[41]; ~~Yoshikawa *et al.*, 1997[56]; and manufacturers.~~

Table 2. Mechanical Strengths of GICs and Other Materials (MPa, 24 hrs).*

Material	Diam. Tensile Str.	Compressive Str.	Flexural Str.
Ketac-Fil	15	140-170	14
ChemFil Superior		160	20
Fuji IX	14-19	130-230	20-35
Ketac-Molar	12	150-240	30-34
Glassionomer Cement FX		210	
ChemFlex		235	39
Ketac-Silver	14	170	27
Fuji II LC	35	200	60
Photac-Fil		125	25
Fuji Plus (self-cure) (P:L, 3.6:1)	31	157	
Dyract	36	230	120
Compoglass	41	260	100
Z100	55	280	130
Dispersalloy (7d)	43	390	

* Based on data from Powers and Burgess, 1996[57]; Ewoldsen *et al.*, 1997[41]; and manufacturers.

conventional GICs. However, the relatively higher occlusal wear rates found for restorative RMGICs[43] may also lead subsequently to lower long-term success rates, especially in permanent teeth. The use of RMGICs may be appropriate for restoring anterior teeth, where conventional GICs have had low success rates in primary teeth with the ART approach.[38]

There is one published study that included amalgam for restoring single-surface occlusal restorations in permanent molars when hand instruments were used with a modified-ART approach for cavity preparations.[44] Under field conditions, success rates were 89% for amalgam and 93% for GIC restorations after two years. Although excellent long-term survival rates for non-bonded amalgam restorations placed in occlusal cavities prepared with conventional rotary instruments can be achieved,[45] the use of hand instruments alone may not provide adequate material bulk and macromechanical retention. Costly resin-based esthetic restorative materials requiring special equipment and technique-sensitive dentin bonding systems are not appropriate for field use in developing countries. There have been no published results of their use with the ART approach in dental practices.

Table 3. Wear Simulation Studies of ART and Other Materials.*

Material	3-body ACTA	3-body ACTA	2-body Artificial Mouth	2-body Enamel
Ketac-Fil	30-50 µm	3.5-5.5 mm³		
ChemFil Superior	40-70 µm	4.8-6.8 mm³		
~~Fuji IX~~	~~20-50 µm~~	~~2.5-3.3 mm³~~	~~0.47 ± 0.22 mm³~~	~~40 mg/1000 cy~~
Ketac-Molar	40-45 µm	2.1-2.9 mm³	0.29 ± 0.09 mm³	
Ketac-Silver	30-70 µm	5.2-7.6 mm³		48 mg/1000 cy
Fuji II LC	65-220 µm			
Photac-Fil	140-360 µm	10.3-13.6 mm³		
Dyract	50-60 µm	5.7-5.8 mm³		
Compoglass	30-45 µm			
Heliomolar		1.4-2.6 mm³	0.05 ± 0.01 mm³	
Amalgam	10-15 µm	1.0 mm³		

* Based on data from de Gee *et al.*, 1996[58]; Kunzelmann, 1996[59]; Graf *et al.*, 1997[60]; Schneider *et al.*, 1997[61].

OCCLUSAL WEAR

Resistance to occlusal wear is an important long-term consideration for any sealant or restorative material placed in the permanent teeth. Despite good *in vitro* fissure penetration when the finger-press technique is used with high-strength GICs as sealants,[46] much of the cement bulk is lost very soon after its clinical placement.[37] However, in one study, the remaining cement was very effective in reducing fissure caries over three years in selected teeth, when compared with unsealed fissures in the same mouths.[47] Over the longer term, resin-based sealants may be more effective than GIC materials,[26,27] but less practical for field use and for the treatment of disadvantaged patients under conventional conditions. Surface losses of GIC material are probably from a combination of brittle fatigue fracture, exposure of porosities, inadequate adhesion, and acid erosion. The results from several *in vitro* wear simulation studies show improved resistance to wear for the high-strength GICs compared with earlier conventional restorative GICs (Table 3). The wear rates, although lower than for RMGICs, are still considerably higher than for resin composite and amalgam alloy materials.

The occlusal wear of GICs marketed for the ART approach has also been measured semi-quantitatively in several short-term clinical studies. After 12 months, a recent study reported cumulative net mean occlusal wear rates for ChemFlex (Dentsply DeTrey, Konstanz, Germany) restorations of 70.3 ± 48.2 μm in primary molars and 53.2 ± 20.5 μm in permanent molars in the same subjects. The corresponding wear rates for Fuji IX GP (GC Intl. Corp., Tokyo, Japan) were 66.5 ± 40.4 μm and 56.3 ± 17.5 μm, respectively.[48,49] One other study found cumulative net mean wear rates after 12 months for Fuji IX GP of 73.0 ± 77.0 μm in adult permanent molars.[50] In another study, after 12 months the cumulative net mean wear for Fuji IX GP was 77.4 ± 47.0 μm, and for Ketac-Molar (ESPE Dental Medizin GmbH, Seefeld, Germany) 82.8 ± 50.9 μm in the permanent teeth of adults.[51] After 2 years, the cumulative net mean wear for Fuji IX was 83.1 ± 67.3 μm in the permanent teeth of adults.[37] These occlusal wear rates are higher than those recommended by the ADA for the unrestricted acceptance of posterior resin composites.[52] The wear rates of individual restorations also showed wide variations, even within the same subjects. However, the long-term consequences of occlusal wear of high-strength GICs in permanent teeth have yet to be determined.

CONCLUSIONS

Current restorative materials are not ideal for use with the ART approach. However, apart from conventional GICs, very little information is available regarding the use of alternative materials. The requirement for the placement of the materials under field conditions imposes additional problems. These problems include such factors as cost, storage and shelf-life, and ease of dispensing and use by minimally trained operators under challenging operative conditions. Although simple in concept, the optimal application of the ART approach requires careful attention to preventive and restorative details.[1] Although GIC restoration survivals over three years in single-surface cavity preparations have improved with the introduction of newer high-strength GICs and better operator training,[53,54] the cements still lack adequate fracture toughness, wear resistance, and adhesion for the long-term survival of multisurface restorations and fissure sealants.

However, further developments in the minimally invasive ART approach will result in esthetic materials with improved handling, adhesive, mechanical, and therapeutic properties for the management of dental caries. More than one type of material and treatment approach may be required for different clinical situations and environments. Further developments should also evaluate the appropriateness of non-restorative treatments for selected dentin lesions. More evidence-based research is required to determine the most cost-effective, minimally invasive management of dental caries in different caries-risk populations, including those persons who are disadvantaged in industrialized countries.

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