Adhesive restorative materials: A review

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Abstract

'Adhesive' restorative dentistry originated with the work of Buonocore in 1955 in bonding resin to etched enamel. Since then, adhesive materials and techniques have developed at a rapid rate. The first chemically adhesive material (zinc polycarboxylate cement) was marketed in the late 1960s, and glass-ionomer cements and dentine bonding agents have since become available.

This review focuses on the latter two products. Glass-ionomer cements have a particular role in adhesive dentistry because of their reliable chemical adhesion to enamel and dentine, and because of their apparent ability to promote the remineralization of 'affected' dentine. Dentine bonding agents have undergone marked changes in presentation over the last 15 years, but all have an essentially similar bonding system, that of hybrid layer formation. However, the most recent systems have limited clinical data supporting their use.

Key words: Dentine, adhesion, bonding, resin, glass-ionomer, review.

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INTRODUCTION

The pioneering work of Michael Buonocore nearly 50 years ago[1] marked the beginning of successful 'adhesive' dentistry. Buonocore[1] was able to demonstrate that the treatment of enamel with phosphoric acid resulted in a porous surface, which could be infiltrated by resin, to produce a strong micromechanical bond. However, the clinical application of acid etching was not realized until 15 years later when resin composites became available as a result of the work of Bowen's group.[2]

In contrast to micromechanical bonding to tooth tissue, chemical bonding was developed by Smith[3] and resulted in the introduction of polycarboxylate cement.

The basic bonding mechanism was an ionic attraction between two carboxyl (COO-) groups in the cement to the calcium (Ca++) in enamel and dentine. Further work by Wilson's team[4] resulted in the introduction of glass-ionomer (glass polyalkenoate) cements, based essentially on the liquid of the polycarboxylate cements. Polycarboxylate cements are now little used, as the glass-ionomers have a wider range of applications and are easier to use.

Glass-ionomer cement is water-based, and therefore compatible with dentine, which is a water-containing tissue as well as commonly having a film of odontoblast tubular fluid on the cut surface. In contrast, resin composite is a hydrophobic material and thus is relatively incompatible with dentine. The problem of bonding hydrophobic resin to dentine was largely resolved by the work of Nakabayashi.[5,6]

This review will focus on the two adhesive systems most relevant for today's dentistry: glass-ionomer cements, and dentine bonding agents (DBAs) for resin composite. Bonding of resin composite to etched enamel will not be discussed further as it is a well-established technique and has changed little for several years. In contrast, there is increasing interest in glass-ionomers, and DBAs are constantly evolving.

Glass-ionomer cements

The original glass-ionomer cements (GICs) were water-based materials which set by an acid-base reaction between a polyalkenoic acid and a fluroaluminosilicate glass.[4] Since these were brittle materials, attempts were made to enhance the physical properties by the addition of either metal particles (silver or gold), by a fusion process resulting in a 'cermet' (ceramic-metal),[7] or amalgam alloy particles by a simple addition ('admix'). The use of 'metal-reinforced' GICs appears to be diminishing following the introduction of high powder:liquid ratio products, which are described below, and will not be discussed further.

Further modification of water-based ('conventional') GICs took place in the early 1990s by the addition of water-soluble resin,[8] to produce the 'resin-modified' GICs. The purpose of adding resin was to enhance the physical properties and to reduce the sensitivity to

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water balance of the conventional GICs. The first of the 'resin-modified' GICs (RM-GICs) was Vitrabond (3M Dental Products, St Paul, Minnesota, USA), now called Vitrebond (3M/Espe Dental). Vitrebond is a liner/base material, and several restorative RM-GICs are now available, including Vitremer (3M/Espe Dental), Fuji II LC (GC International, Tokyo, Japan) and Photac-Fil (3M/Espe, Seefeld, Bavaria, Germany). Other names for RM-GIC which have been used include 'resin-ionomers', 'resinomers', 'hybrid ionomers' and 'light-cured glass ionomers'. The last should not be used as some products are not light-cured (see below); 'resin-modified glass-ionomers' is preferred.[9]

Setting reactions

Conventional GICs set by a complex reaction between the (acidic) liquid and the (basic) powder. (Some products have the polyalkenoic acid freeze dried in the powder, and the liquid is either water or tartaric acid.) A simplified description[10,11] of the setting reaction is adequate for this review.

On mixing powder and liquid, the acid attacks the glass resulting in surface degradation of the glass and release of metal ions (e.g., strontium, calcium, aluminium), fluoride ions and silicic acid. The metal ions react with the carboxyl (COO^-) groups to form a polyacid salt, which becomes the cement matrix, and the surface of the glass becomes a silica hydrogel. The unreacted cores of the glass particles remain as a filler.

Although the clinical set is completed within a few minutes, a continuing 'maturation' phase occurs over subsequent months. This is predominantly due to the slow reaction of the aluminium ions,[11] and is the cause of the set material's sensitivity to water balance. The set material needs to be protected from salivary contamination for several hours, otherwise the surface becomes weak and opaque, and from water loss for several months, otherwise the material shrinks and cracks and may debond.[11]

The RM-GICs also undergo an acid:base reaction (which is a pre-requisite for any material to be described as a glass-ionomer cement). However, there is an additional resin polymerization phase. Depending on the product, the resin polymerization may be self-cure, light-cure or both. On mixing powder and liquid, the acid:base reaction, and if present, the self-cure resin polymerization reaction, begin and setting commences. Restorative RM-GICs (in contrast to luting RM-GICs) undergo photopolymerization on exposure to light, resulting in clinical set. However, the acid:base reaction continues, albeit much more slowly. Although the set material can be contoured and polished under water spray immediately following polymerization, delayed polishing has been recommended.[12] However, dehydration remains a potential problem.[10] All GICs show an increase in translucency at seven days compared to that at placement, resulting in an aesthetic improvement.[11]

Fig 1. Restorations (arrowed) using a high powder:liquid ratio conventional glass-ionomer cement (Fuji IX GP, GC Corporation, Japan) in 74 disto-occlusal and 75 mesio-occlusal surfaces.
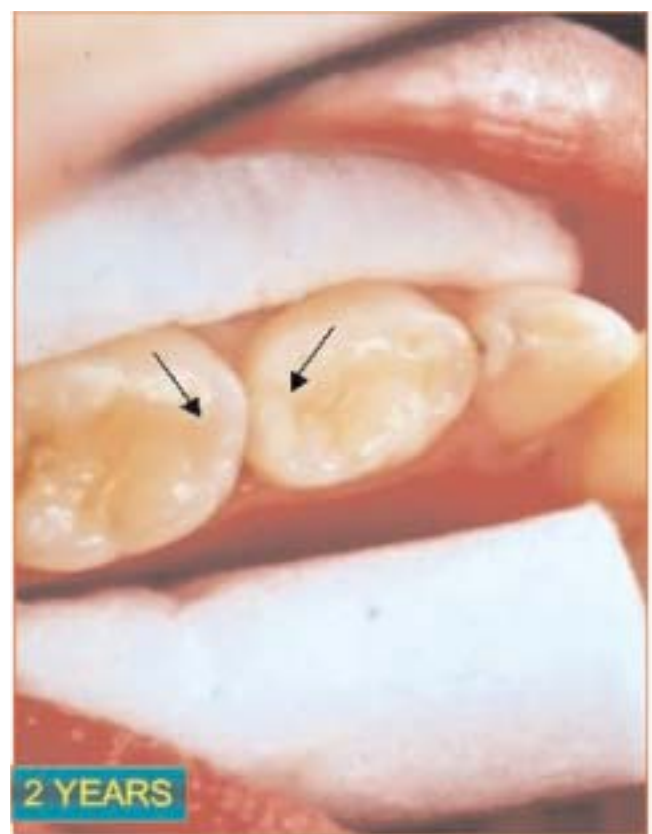

Fig 2. Restorations (arrowed) after two years clinical service.

Classification

The most practical classification of the GICs is on their clinical usage.[11,13] Type I GICs are the luting cements, characterized by low film thickness and rapid set; when available as an RM-GIC, the photopolymerization reaction will be absent. Type II GICs are restorative cements, with sub-types 1 and 2. Type II-1 GICs are aesthetic cements (available in both conventional and resin-modified presentations) and Type II-2 GICs are 'reinforced' (however, despite their description, are not necessarily stronger than Type II-1
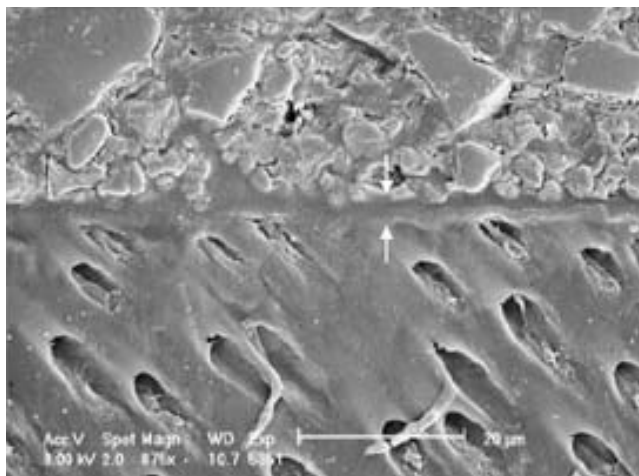
Fig 3. A bonded specimen of a conventional glass ionomer cement to demineralized dentine. The 'acid-base resistant layer' can be observed at the interface (arrows). This has also been referred to as the 'ion-exchange layer'.

products). However, they are more wear-resistant.[7] Type III GICs are the lining cements and fissure sealants, characterized by low viscosity and rapid set.

In the mid- to late-1990s, high powder:liquid ratio conventional GICs were introduced, alternatively termed 'packable' or 'high viscosity' GICs.[10] These products (e.g., Ketac Molar, 3M/Espe, Seefeld, Bavaria, Germany; Chemflex, Dentsply, York, Pennsylvania, USA; Fuji IX and Fuji IX GP, GC International) are promoted principally for small cavities in deciduous teeth (Fig 1, 2),[14] temporary restorations, liner/base applications, and in the 'Atraumatic Restorative Treatment' (ART) technique.[15]

Bonding mechanism

The bonding mechanism of the GICs to the dental hard tissues is very complex, and may be different for RM-GICs compared to conventional GICs. Simplistically, an ionic bond occurs between the carboxyl (COO^-) ions in the cement acid and the calcium (Ca^{++}) ions in enamel and dentine.

When freshly mixed conventional GIC is placed on enamel or dentine, dissolution of any smear layer occurs but demineralization is minimal since the tooth hydroxyapatite buffers the acid, and polyalkenoic is quite weak.[16] Phosphate ions (negatively charged) and calcium ions (positively charged) are displaced from the hydroxyapatite, and are absorbed into the unset cement. This results in an intermediate layer between the 'pure' GIC and the 'pure' hydroxyapatite; the so-called 'ion-exchange' layer.[11] Problems of specimen preparation of a water-based material have hindered investigation of this layer, although better techniques are now becoming available.[17]

The ion-exchange layer appears to consist of calcium and phosphate ions from the GIC, and aluminium, silicic, fluoride and calcium and/or strontium ions (depending on glass composition) from the GIC.[18] The thickness of the ion-exchange layer appears to be in the order of a few micrometres,[17,19] and merges into the GIC on one side and into the enamel/dentine on the other. Unfortunately there is some confusion in the literature regarding the ion-exchange layer. Other terms have been proposed such as 'zone of interaction',[17] 'inter-diffusion zone',[20] 'hybrid layer',[21] 'interphase',[22] and 'intermediate layer'.[19] In particular, the notation 'hybrid layer'[21] causes confusion with the 'hybrid layer' formed between resin composite and dentine (see below). The term 'ion-exchange layer' should be used, since it accurately describes its nature. It has been shown that this layer is resistant to acid and base treatment, and has thus also been referred to as the 'acid-base resistant layer' (Fig 3).

Ionic bonding between the carboxyl ions from the cement acid and the calcium ions from the tooth structure has been confirmed using X-ray photon spectrometry,[23] and ionic bonding to the collagen of dentine has been proposed[24] but not investigated.

Measurement of the bond strength of GIC to enamel and dentine is complicated by the brittle nature of the GIC. Laboratory bond strength tests invariably result in cohesive failure of the GIC, rather than failure within the ion exchange layer.[22] Consequently, the true strength of the ion-exchange layer is not known;[10,16] values in the range 3-10MPa are commonly reported, i.e., approximately the cohesive strength of GIC.

Additional bonding mechanisms have been explored for the RM-GICs, since the presence of resin suggests that bonding analogous to resin composite may occur, i.e., resin tags into enamel and establishment of a hybrid layer into dentine. However, the experimental evidence seems equivocal. Some workers[25-27] have demonstrated resin tags in the dentinal tubules, while others[28-30] did not appear to do so. The 'hybrid layer' of resin-dentine bonding was apparently observed by Pereira *et al.*,[10,27] but could not be identified by Lin *et al.*[25] or by Ramos and Perdigão.[28] Bonding by an ion exchange layer[25] and ionically[28] as for conventional GICs has also been proposed.

Fluoride release

The release of fluoride ions is one of the notable characteristics of GICs. It is present originally as a flux in the manufacture of the glass, and is released from the glass particles on mixing with the polyalkenoic acid. The presence of fluoride also has benefits in increasing translucency and strength and improving handling properties.[31] The mechanism of release is complex and not fully understood. However, it is maximum in the first few days and decreases rapidly to a lower level over weeks, and maintains a low level over months.[31] It has also been shown that GIC can be 'recharged' with fluoride, resulting in a subsequent short-term boost in release.[32,33] Most of the fluoride is released as sodium fluoride, which is not critical to the cement matrix, and thus does not result in weakening or disintegration of the set cement.[34] Resin-modified GICs show similar

dynamics of fluoride release,[35] although for both types of material the dynamics of release and the amounts released depend on the particular material and the experimental design.

The clinical significance of the fluoride release is controversial. Many laboratory studies using, for example bacterial and demineralization-remineralization models, have suggested that GIC will prevent secondary caries.[36-42] Clinical studies have shown an effect of GIC on salivary fluoride levels,[43] acidogenic bacteria[44] and on demineralized dentine restored with GIC and worn in removable appliances.[45] There is anecdotal clinical evidence that secondary caries in association with GIC is at a very low level. This has been supported by one retrospective study,[46] but significantly contradicted by a cross-sectional study,[47] and one five-year prospective study was inconclusive.[48] However, using an evidence-based systematic review of the literature, there was no evidence for or against an anti-cariogenic effect of GIC.[49]

Biological properties

The biocompatibility of the GICs has been extensively reviewed by Sidhu and Schmalz,[50] and the reader is referred to this excellent paper for more detail.

The term 'biocompatibility' is frequently misused, and is assumed to mean 'inert'. However, the accepted definition is more complex: 'the ability of a material to elicit an appropriate biological response in a specific application.'[50] Therefore, in the context of restorative materials it is important to identify the tissues with which the material may come into contact. For GIC, these tissues are dentine (and therefore pulp), gingivae, and oral mucosa.

Sidhu and Schmalz[50] have recommended that the relevant issues regarding biocompatibility of GICs are the release of degradation products, cytoxicity in various situations, antibacterial properties, osteogenic effects, long-term host and tissue response and the effect on dental personnel.

Several metallic ions are released from GIC, as well as fluoride. The highest release occurs from the unset material, and as described above, most research has been done on fluoride. Hydroxethylmethacrylate (HEMA) is released from RM-GICs and can diffuse through dentine in laboratory studies. Since HEMA can induce allergic and toxic responses, the clinical relevance of its release requires more investigation.[50] Nevertheless, to date there is no evidence that HEMA in dental materials is responsible for any local or systematic adverse effects.

The pH of GIC increases as the cement sets.[11] It has been suggested that the initial low pH may be responsible for the early anecdotal reports of sensitivity following crown cementation.[51] However, laboratory studies indicate that the dentine buffers the hydrogen ions released from GIC,[52] and objective reports[53,54] have shown that GIC was not associated with post-operative sensitivity.

There have been numerous cytotoxicity tests of several GICs.[50] The trend has been that GIC is more cytotoxic when freshly mixed, and that cytotoxicity decreases as the material sets. The equivocal nature of the results indicates that direct pulp testing is necessary. However, in pulp and connective tissue studies the results are also equivocal, and appear to depend on the particular brand of GIC being evaluated. A further complication in interpreting human and animal studies is the generally accepted theory that bacterial microleakage is responsible for the majority of pulp damage. The contribution of material damage and bacterial damage to overall damage is difficult to separate.[50]

Glass-ionomer cement has been shown to have an antimicrobial effect in several studies, and greater than that shown by other materials such as amalgam and resin composite. However, again it is difficult to do more than generalize, as the results depend on the experimental method, the bacteria used and the product tested.[50] There are several theories regarding the antibacterial activity. Most workers propose that fluoride is responsible, possibly acting synergistically with pH. However, other released agents have been cited as possible antibacterials, including zinc[55] and polyalkenoic acid,[56] acting alone or synergistically with pH and fluoride.[57]

Additional studies have been carried out on the biological properties of RM-GICs.[50] It might be expected that a different pattern of pulp damage might occur because of the presence of unreacted monomer. However, the results are also equivocal. This issue has been explored in detail elsewhere,[50] and the reader is referred there for more information. One of the principal reasons for the wide variation in results is the lack of standardization among testing protocols, even though standard tests have been available for some time.[50]

Clinical performance

One of the principal benefits of GICs is their adhesion to the dental hard tissues, and this has been confirmed in non-undercut non-carious cervical lesions (NCCLs) where dentine is the main substrate.[46,58-60] However, because of the low fracture toughness of GICs (including RM-GICs), they are recommended principally for non-stress-bearing areas, e.g., carious and non-carious cervical lesions and approximal anterior lesions. Nevertheless, the high powder:liquid ratio materials may be useful in the restoration of small cavities in deciduous teeth[14] (Fig 1, 2). Clinical studies on RM-GICs are less extensive because of their more recent introduction.[61-69] However, the results are mixed with respect to both brand comparisons and comparisons with polyacid-modified resin composites. One presentation of an RM-GIC is in a low powder:liquid ratio form (Fuji Bond LC; GC International), and is used in a similar way to a dentine bonding agent. Excellent five-year results have been obtained for the retention by this material of resin composite in non-carious cervical lesions.[70]

Evidence is accumulating that GIC may have an important role in minimum intervention dentistry.[11,71] Modern concepts of operative dentistry propose that only the 'infected' dentine should be removed, leaving the 'affected' dentine which has the potential to remineralize.[72,73] Recent evidence suggests that such remineralization may be potentiated by GIC,[74,75] and this has special relevance in the ART technique.[73,76]

Types I and II glass-ionomer cements

Although the focus of this review has been on Type II (Restorative) GICs, the important role of Type I (luting) and Type III (liner/base and fissure sealants) should not be ignored. The 'cervical lining' technique (also known as the 'open sandwich', a term not favoured by the first author) was described in 1984,[7] and clinical trials are supporting its usefulness, provided that an appropriate GIC is used.[77-80] Glass-ionomer cements can be effective fissure sealants and are useful when optimum moisture control for resin-based sealants cannot be achieved.[81] Although clinical retention appears less than for resin-based sealants, prevention of fissure caries is comparable.[81,82]

Dentine bonding agents

The concept of bonding a restorative material to the dentine surface is by no means a new idea. Even at the time of Buonocore using phosphoric acid to bond to enamel, the idea of bonding to dentine was considered. However, due to limitations of materials and knowledge of the structure and nature of dentine the dream remained just that until the late '70s. In fact Buonocore did try to introduce a dentine adhesive but was unsuccessful.[83] The earliest bonding agent which showed some success was introduced by Fusayama.[84,85] At the same time Bowen[86] in the USA started investigating new formulations of resins that were more water tolerant as well as methods of treating the dentine with oxalates to gain adhesion. The concern of many clinicians at that time was the potential damage phosphoric acid was going to cause the dental pulp if dentine was etched. This led to the development of the first Scotchbond (3M Dental, St Paul, Minnesota, USA), a phosphate ester of Bis-GMA. This material could almost be considered as the first self-etching priming material for dentine, although it was recognized the enamel needed to be etched.[87,88]

The first material to be truly successful in bonding to dentine was introduced as GLUMA (Bayer Dental, Leverkusen, Nordrhein-Westfeld, Germany). This material used EDTA to etch or condition the dentine which was then primed with a solution of formaldehyde and 2-hydroxyethylmethacrylate followed by a bonding resin of Bis-GMA.[89] The mechanism proposed for this material was to bond to the organic component of the dentine, namely the collagen. The first work to investigate the mechanism of bonding to the dentine was by Nakabayashi.[90] His paper of 1982[90] has now become one of the classic
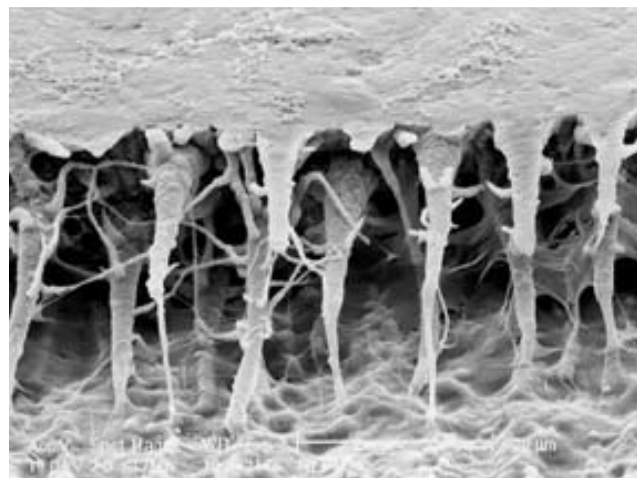
Fig 4. Bonded specimen in which the dentine (mineral and protein) has been removed. The infiltration of resin into the acid-etched dentine can be seen with an associated permeation of resin throughout the dentine tubular network and its lateral branches.

papers to first identify a layer between the resin and dentine substrate referred to as 'hybrid' dentine, in that it was the organic components of the dentine that had been permeated by resin (Fig 4).[90] The term 'hybrid layer' has now become synonymous with bonding of resins to etched dentine. There has been a tremendous amount of research done on the hybrid layer, its structure, formation and how it can be improved. Without a hybrid layer a bond will not be formed to the dentine. Therefore, it is essential for some modification to be made to the dentine surface so a mechanical interlocking of resin around dentinal collagen can occur. This layer has also been referred to as the 'resin-dentine interdiffusion zone'.[91]

Classification

Dentine bonding agents have gone through many changes over the last 10 years. This has led some people to refer to the changes as 'generations' of material, implying that there has been some chronological development. This is a falsehood — for example, the first 'self-etching' type material was introduced by Coltène (Altstätatten, Switzerland) as 'ART Bond'. Therefore, it is more logical to classify materials by the number of steps needed to complete the bonding process.

'Three-step' or 'Conventional' systems

This group represents those materials that have separate etching, priming and adhesive steps. It just so happens that this group of materials is also the oldest. However, they are still widely used and have been shown to provide reliable bonding. The greatest problem with this group would seem to be that three distinct steps are needed, which gives rise to possible problems through contamination of the bonded surface prior to placement of the resin composite filling material; in other words, they are more technique sensitive (Fig 5).
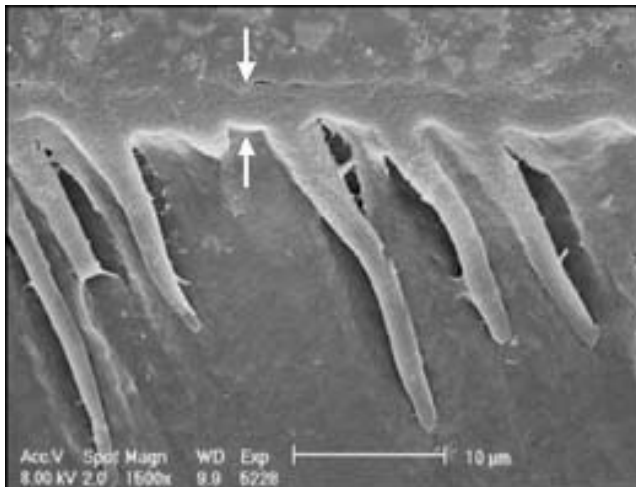
Fig 5. SEM of conventional system showing a hybrid layer of approximately 3µm thick (arrows). The dentine has been partially removed to show tags entering the tubules.

'Two-step' systems

This group has two subgroups; the first includes those systems that have a separate etch and have combined the priming and bonding steps. These systems are often referred to as 'Single-bottle' systems. In general, the problems experienced with the Conventional Systems still exist with the Single-bottle systems. Although one step has been eliminated, the great problem is ensuring good infiltration of the priming-bond into the demineralized dentine. The other subgroup combines the etching and priming steps together and are referred to as 'Self-etching primers'. These systems also have not been without their problems. The major concern has been their ability to etch the enamel to a great enough extent to ensure a good seal. This seems to be overcome now.[92] The problem of technique sensitivity also seems to have been significantly reduced with these systems compared with the Conventional and Single-bottle systems.[93] This is attributed to the fact that the self-etching priming agent does not have to be washed off the dentine, therefore eliminating the need to maintain the dentine in a moist state. The method of demineralization of these materials is by the use of an acidic resin that etches and infiltrates the dentine simultaneously (Fig 6). The dentine is an excellent buffer, so the acidity of the self-etching primer is rapidly reduced and after polymerization is neutralized.[94] A recent study compared the 24-hour bond strengths of an etch and rinse adhesive (Single-bottle) and a self-etching priming adhesive after enamel and dentine had been prepared using different methods.[95] It was shown that treating the enamel or dentine with an Er:Yag laser produced a significant reduction in bond strength compared with preparation using a diamond bur, diamond-sonoabrasion or airbrasion.

'One-bottle' or 'All-in-one' systems

This fourth group is the simplest of all the DBAs. They combine all steps into one process. Their mode of demineralization is identical to that of the self-etching priming materials, but the bonding resin is also incorporated. These systems also have the problem of not etching the enamel as effectively as phosphoric acid. In addition these systems are the newest and have no long-term clinical data to demonstrate their effectiveness, although early studies are showing some variability in the success of these materials.[96,97]

Bonding mechanism

As already mentioned, the mechanism of bonding of resin-based DBAs is via a hybrid layer. This is a micromechanical interlocking of resin around dentinal collagen fibrils that have been exposed by demineralization. The interlocking occurs by the diffusion of the resins in the primer and bonding resin. The formation and structure of the hybrid layer has been extensively studied, and has also been referred to as the resin-impregnated layer, the resin-dentine interdiffusion zone. This came about with the use of argon-ion beam etching introduced by Inokoshi[98] and later Van Meerbeek and his co-workers who provided some of the first detailed descriptions of the hybrid layer.[99-103] The thickness of the hybrid layer ranges from less than 1µm for the all-in-one systems to up to 5µm for the conventional systems. The strength of the bond is not dependent on the thickness of the hybrid layer, as the self-etching priming materials have shown bond strengths greater than many other systems but exhibit a thin hybrid layer. At the same time as Van Meerbeek et al.[99] described the hybrid layer, Sugizaki[104] showed that the etching, washing and drying process caused the dentine to collapse due to the loss of the supporting hydroxyapatite. Further work showed that this collapse of the collagen was an impediment to the successful diffusion of the resin to the base of the region of demineralization. To overcome this problem, Kanca[105] introduced the 'wet bonding technique' which left the demineralized collagen fibres supported by residual water after washing. This allowed the priming solution to diffuse throughout the collagen fibre network more successfully. However, when it comes to clinical practice, it is very difficult to find the correct balance of residual moisture. Sano et al.[106] showed in their work on nanoleakage that most resin-based DBAs allowed the ingress of silver nitrate along the base of the hybrid layer. However, the clinical significance of this is unclear. It may be a pathway for fluid to affect collagen not coated by resin, and the outcome may be degradation of the bond over time. However, the degree of nanoleakage is very much material dependent rather than system dependent,[107] meaning that there are conventional systems and self-etching priming systems that show small amounts of nanoleakage whereas others show more. For the self-etching systems, these are able to solubilize the smear layer and demineralize the underlying dentine, forming a quite thin hybrid layer.[108]
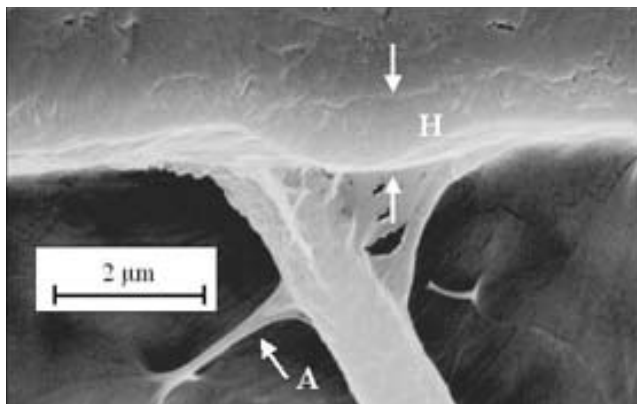
Fig 6. SEM of a self-etching priming system showing a 1µm thick hybrid layer (H) between the arrows. These systems can remove smear plugs allowing resin infiltration into the tubules and lateral branches.

Bonding substrate

Dentine is quite a variable tissue. Within the tooth itself the dentine approaching the dentino-enamel junction is more highly mineralized and the area occupied by the tubules is less than that of dentine adjacent to the pulp.[109] In addition to this, dentine should be considered as a dynamic tissue that changes due to ageing, in response to caries and restoration placement. Most changes relate to occlusion of tubules and also an increase in the mineralization of the dentine. The implication of this is that the dentine becomes slightly more difficult to etch and exposure of collagen fibrils can also be reduced, hence there is a potential for the bond to be somewhat tenuous. This is particularly the case for the highly sclerosed dentine of non-carious cervical lesions. Laboratory studies indicate that the hybrid layer of the dentine surface of NCCLs is thinner than that of normal dentine.[110,111] In addition, it seems that some bonding systems do not adhere as well to this surface and show a slightly decreased bond strength.

A considerable amount of work has also been done looking at the variation of the bond to caries-affected dentine. Some of the early studies used artificial caries-like lesions. However, this does not reproduce the situation that occurs in the oral cavity since caries is a process of demineralization and remineralization associated with the damage of the supporting collagen matrix.[112,113] For those studies that have investigated the bond strength to caries on extracted teeth, the hybrid layer tends to be thicker and the bond less, although this is bonding system dependent.[114,115] The increased thickness of the hybrid layer is mainly because the dentine is already partially demineralized from the caries and the action of the acid etch is therefore somewhat greater. This provides a clear basis for not etching for longer than that recommended by the manufacturer.[116] In addition, the water content of caries-affected dentine is believed to be greater than normal dentine. This too will also have an effect on the ability of the resins to penetrate to the full depth of the demineralized dentine. In the case of caries-affected dentine treated with chemo-mechanical caries removal solutions, there appear to be no adverse effects on the bond with a DBA.[117-121]

However, the bond to radicular and pulp chamber dentine does seem to vary quite a lot depending on the DBA used.[122-126] This perhaps provides a strong case for being careful with the selection of a DBA for these regions of the tooth. It is believed that it maybe necessary to use different DBAs for different regions of the tooth, or a system needs to be selected where it has been shown to provide a reliable bond to all parts of the tooth. Another alternative is the use of GIC restorative materials when then is a deep cavity on the radicular surface of a tooth, as it is known that a reliable bond can be achieved and moisture control is not such a problem.

Clinical studies

There has been a considerable amount of work done to evaluate the success or otherwise of DBAs in clinical studies. However, one of the great problems has been that many of the DBAs have been considerably changed or a new material introduced by the time these studies are completed or published. Many of the studies have also been performed on NCCL, which means the outcomes can not really be applied to restorations in other parts of the mouth because NCCL dentine is usually sclerosed and therefore different from that of an intracoronal cavity. However, these outcomes will provide some indication as to whether the DBA is able to achieve a durable bond under very harsh conditions. Since the early materials were introduced, the retention rates of the DBAs to sclerosed cervical dentine have steadily improved to extent that retention rates are little different from GICs.

With regard to clinical studies on posterior teeth restored with a DBA, there is still little evidence available.[127-131] It would seem though, that clinical studies of resin composite restorations are showing evidence that when placed in the correct manner and the patient has a low caries rate, restoration survival is approaching that of amalgam.[132]

When it comes to the use of DBAs, it is important to follow the manufacturers' directions carefully. Over-etching can create a situation where there will potentially be a region of poorly or uninfiltrated dentine. This zone may be susceptible to acid or enzyme attack from oral bacteria, hence leading to bond failure.[133-135]

In the case of the self-etching priming materials, this is not believed to be a problem. However, the converse problem may occur: as mentioned, the dentine or smear layer may neutralize the etching primer if the primer has a relatively high pH. The anecdotal evidence would seem to indicate that gentle agitation of these solutions may assist with the etching. However, there are no research data to support this.

CONCLUSIONS

The last 35 years has seen major developments in adhesive materials, particularly the glass-ionomer cements and DBAs, and their introduction has facilitated the concepts of 'minimum intervention dentistry'. Further improvements in these materials can be expected, particularly with respect to the toughness of GICs and the reliability and ease of use of DBAs.

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