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Liners and bases in general dentistry

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ABSTRACT

One of the most controversial areas of restorative dentistry is the subject of liners and bases. Currently, there is no single protocol, with respect to the use of liners and bases, for clinicians to follow. This article is an in-depth literature review that discusses the use of liners and bases and the types of materials that are available to the restorative dentist. The new emerging concept of minimally invasive dentistry will require new restorative techniques. These changes will require the clinician to reevaluate their use of liners and bases. Other clinical considerations and findings from recent research are discussed.

Keywords: Liners, bases, infected dentine, affected dentine, minimally invasive dentistry, review.

Abbreviations and acronyms: BPA = bisphenol-A; CaOH = calcium hydroxide; CHX = chlorhexidine gluconate; GIC = glass-ionomer cement; LED = light-emitting diode; ZOE = zinc oxide eugenol; ZOP = zinc oxyphosphate; ZPC = zinc polycarboxylate.

INTRODUCTION

Restorative dentists have many decisions to make in their general practice, one of which is which material to use for any given procedure. To make matters more difficult for the clinician is the vast number of available choices. Published papers and lectures which conclude that different materials are ideal add to this confusion. Dental manufacturers do not make the decision making any easier, as they constantly introduce 'new and improved' versions of existing products.

The subject of liners and bases is not immune to this confusion. In 1991, Christensen wrote that the use of bases and liners is confusing: the state-of-the-art use varies enormously; many different procedures are successful; and unanimity of opinion is not likely to be achieved soon.[1] Surveys of North American dental schools both five and 15 years later came to the same conclusion.[2,3] In order to lessen this confusion, Cox and Suzuki suggested that clinicians re-evaluate the liners and bases they use.[4] Should clinicians decide to make a change, they should do as Asa recommends, and do so to obtain a better outcome, as opposed to making a change for its own sake.[5] He goes on to say that the selection process necessitates that dentists confer with colleagues and review current literature.

Another aspect of the confusion surrounding liners and bases involves the terminology used, and this can be seen in current dental materials textbooks. In the textbook, *Restorative Dental Materials*, the authors define a 'cavity liner' as a suspension of calcium hydroxide in an organic liquid. Upon evaporation of the solvent, the remaining film on the tooth is the liner.[6] Contrast this to Ferracane, who defines a liner as a material that is applied as a thin layer to seal the dentine floor and walls of the cavity from the influx of bacteria and irritants from restorative procedures.[7] Additional confusion with nomenclature is seen in *Phillip's Science of Dental Materials* which defines a liner as a thin layer of 'cement' used for the protection of the pulp.[8]

This same perplexity is seen with bases. Anusavice defines a base as a layer of insulating, sometimes medicated, cement placed in the deep portion of the cavity preparation to protect the pulp from thermal and chemical injury.[8] This is similar to Ferracane but he adds that bases are placed in thick layers and must be strong enough to support a restorative material during its placement and function.[7] Additionally, it should provide thermal and electrical protection (from galvanic activity). Craig and Powers separate bases into two categories. The first is for low-strength bases of calcium hydroxide (CaOH) and zinc oxide eugenol (ZOE) cements which are referred to as liners.[6] The second category covers high strength bases, which has the same description as Ferracane.[7]

Two types of materials, polycarboxylates and glass-ionomers, are commonly referred to as 'cements'. This can also lead to nomenclature confusion. Craig and Powers note that cements have two primary purposes: as a restorative filling material used either alone or with other materials (essentially a base) and to retain restorations or appliances in a fixed position in the mouth.[6] However, Ferracane wrote that the most obvious use for a cement is for permanently retaining castings to tooth structure.[7] To alleviate the confusion, the present author does not use the word 'cement' when discussing these materials as a liner or as a base, but will use instead the words 'material' or 'product'. This is because under this subject we are not concerned with retaining indirect restorations or appliances.

The range of materials used for liners and bases is illustrated in Fig 1. Many of these materials belong to the family of so-called water-based 'cements', and their basic relationship and time of introduction are shown in Fig 2. The silicate 'cements' are now little used.

This paper will discuss liners and bases, review what they are, why we use these materials, the physical properties needed, the types of the materials available, touch upon the concept of sealing in caries and discuss clinical considerations with respect to their use.

Rationale for use

What is the purpose of these products? It has been generally accepted that the materials that were used to restore teeth posed a danger to the tooth and allowed for the occurrence of postoperative sensitivity. If this were true, then a barrier or protective layer needed to be placed on the tooth before the final restoration. This buffer would, in part, act to reduce or even eliminate postoperative sensitivity.

Over time we have come to learn that it is not the restorative material that causes problems, but bacteria and the by-products of bacteria. These bacteria, present in the oral cavity, enter the tooth at the margin of the restoration through capillary action of oral fluids. This is referred to as microleakage.[6] Others have defined microleakage as 'the marginal permeability of bacterial, chemical, and molecular invasion at the interface between the teeth and restorative material'.[9]

The margin of the restoration is affected by the difference in thermal expansion between the restorative material and the tooth, polymerization shrinkage, effects of finishing and polishing, orientation of enamel prisms, application methods and cavity configuration. This influx of bacteria can cause problems including postoperative sensitivity, marginal discolouration, secondary caries, pulpal inflammation, pulpal necrosis, periodontal disease and the possible eventual need for endodontic therapy.[10]

Other theories on the cause of postoperative sensitivity have been presented and published. Brännström has suggested that postoperative sensitivity is actually caused by the movement of fluid in the space or gap between the tooth and the restoration,[11] resulting in a change in osmotic pressure. This theory is referred to as the 'hydrodynamic theory'. Brännström goes on to explain that dentinal fluid moves in a coronal or outward direction from the pulp (which is under pressure), and any opening in the dentine allows the fluid out of the tubule. These openings also allow

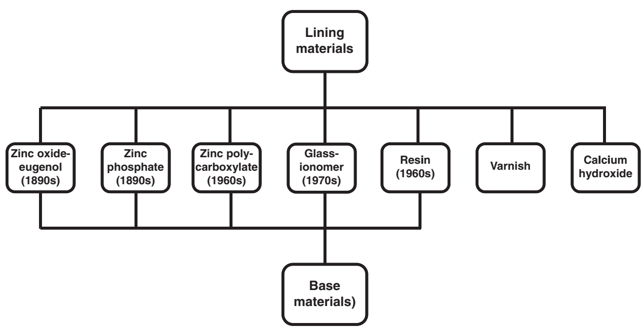

Fig 1. Materials which can be used as liners and bases, with approximate date of introduction.

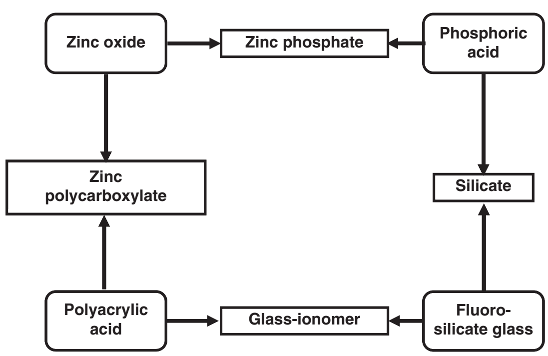

Fig 2. Relationship of water-based 'cements'.

bacteria and other substrates to enter the tooth where they can move along the tubule into the pulp.

Camps *et al.* concluded that bacteria within the tooth structure are the main factor influencing the pulpal reaction.[12] Confirming the need for a 'buffer' layer, Yoshima *et al.* showed that sealing the dentinal tubules completely renders the dentine insensitive, therefore eliminating postoperative sensitivity.[13] In contrast, one paper concluded that there is an increase in microleakage with the use of a liner and/or base.[14]

Contact of dissimilar metals, desiccation of the cavity preparation and thermal conductivity are further possible causes of postoperative sensitivity. Therefore, having a material between the restoration and the dentine will prevent this.

With respect to microleakage, the placement of a liner and/or a base is reactive response. Prevention or using preventive techniques when placing a restoration is an active measure. It has been suggested that scrubbing the cavity preparation with 4% chlorhexidine gluconate (CHX) (Tubulicid Red; Global Dental Products, North Bellmore, NY, USA) and sodium hypochlorite will kill any remaining bacteria and remove any debris found on the dentine surface.[15]

As a protease inhibitor, CHX has been shown by Carrilho *et al.* to stabilize the resin-dentine bond. They showed that bond strength was significantly reduced on untreated teeth compared to CHX-treated teeth after 14 months in the mouth.[16] As a cavity disinfectant, CHX did not interfere with the microtensile bond strength of glass-ionomer or resin composite.[17]

Other methods to reduce or eliminate microleakage include isolation with rubber dam and having the margins both as sealed and as smooth as possible. A rough margin increases the difficulty of keeping it clean, thus allowing the accumulation of plaque.

When using a liner and/or a base, it is important to make sure that it will not be harmful to either the tooth or the patient, i.e. it must be biocompatible. 'Biocompatibility' has been defined as a material's ability to elicit an appropriate biological response when in contact with the body.[6] Anusavice writes that the interface between the material and the body is, in fact, dynamic and not static.[8] The interaction between the two will determine how the body will react to the foreign material and how the material will resist degradation by the body. Possible reactions can be classified as toxic, inflammatory, allergic or mutagenic.

The current view is that the pulp has the ability to lay down more dentine ('reparative' or 'tertiary' dentine) when irritated by caries, cavity preparation or as a result of the interaction between the tooth and the restorative material. There are materials that promote reparative dentine formation and others that can cause pulpal damage. Hebling *et al.* write (when discussing adhesive systems) that the response of the pulpal-dentine complex depends on the remaining dentine thickness.[18]

Currently, one substance that is being researched for biocompatibility is bisphenol-A (BPA), a material that is used to manufacture some plastics and may be found in dental sealants, dentine-enamel bonding agents and resin composites. BPA may affect the reproduction and development by mimicking the effects of female hormones. The position of the American Dental Association (November 2008) is that based on current research. The Association agrees with the authoritative United States government agencies that the low level of BPA exposure that may result from dental restorative materials poses no known threat to general health.[19]

Some liners and bases merely occupy space in the cavity preparation, while others adhere to the tooth structure. Adhesion is defined as 'the force of attraction between the molecules or atoms on two different surfaces as they are brought in to contact'.[7] With respect to resin composite materials, the basic mechanism is the same for all adhesive systems: an acid is used to demineralize both the dentine and enamel, followed by the placement of the resin-based material onto the tooth, thus sealing the cavity preparation and reducing microleakage. The microporosities formed by the demineralization aid in this sealing and also in retention of the material to the tooth.[20]

Failure of adhesion can occur by the formation of cracks between the tooth and the material. Because the tooth is subjected to stress, these cracks can grow, allow moisture and bacteria to penetrate and thus result in secondary caries, stained margins and loss of retention of the material from the tooth. Dentists can reduce the chance of a bond failure by confirming that the tooth structure is clean, the material properly contacts or adapts to the tooth, and that the material is fully set or cured prior to the placement of the next material. In the case of a liner, this would be before the base or the final restoration.

Some of the liners and bases in use can release fluoride ions. In glass-ionomers, fluoride can be found in quantities of about 5 ppm. In the laboratory, it is well known that fluoride has anticariogenic properties and also inhibits secondary caries formation.[8] Fluoride inhibits bacterial metabolism by the formation of hydrofluoric acid, which enters the bacteria and inhibits enzyme activity, thus reducing the rate of acid production.[21] However, the clinical benefit of fluoride-releasing materials is still unclear.[22,23]

Unfortunately, the supply of fluoride does not last forever. If the material is exposed at the margin ('external lining' or 'open sandwich' technique), the fluoride can be replenished. This can be accomplished via the use of fluoride-containing toothpastes, topical gels and mouthrinses, the most effective being topical gels.[24,25] Clinicians should be aware that there is no general consensus on how much fluoride is released nor how much is needed to inhibit caries formation.

Liners and bases can be grouped into varnishes, calcium hydroxide (CaOH), zinc oxide eugenol (ZOE), zinc phosphate (ZOP), zinc polycarboxylate (ZPC), glass-ionomer (GI) and resin (Figs 1 and 2).

Varnish

A varnish consists of one or more resins (from natural gum, synthetic resins or rosin) in an organic solvent (acetone, chloroform or ether). Varnishes are applied in a thin layer to the cavity preparation and on evaporation of the solvent, the remaining solute is the liner which seals the tubules. Therefore, varnishes can be considered a liner. They also fit the definition of a liner in that they seal the dentine, but are contraindicated when a resin composite is going to be placed.[8]

A cavity varnish provides a protective barrier against irritants (from restorative materials) and from the oral fluids penetrating into the dentine. Varnishes also protect the tooth from the newly placed amalgam. A fresh amalgam shrinks on setting, allowing microleakage to occur, and a varnish will seal the cavity-amalgam interface until the amalgam starts to corrode. Varnish also keeps the corrosive by-products from leaching into the enamel and staining the tooth.[6]

Even when varnishes are applied in multiple layers, it is possible that microscopic openings may form in the varnish and this might allow bacteria to penetrate into the dentine. Royce *et al.* have concluded that varnishes are not as effective as other materials at reducing microleakage.[26] This contradicts a 1998 study which concludes that, at least in the short term, varnishes are as effective as adhesive liners.[27] Cavity varnishes do not possess any mechanical strength and they have minimal film thickness, which is not adequate for thermal protection, thus making them unsuitable for use as a cavity base.

According to an October 2005 survey of North American dental schools, only 20% of responding schools teach the use of varnish in shallow preparations, versus 3% in deep cavity preparations.[3] This is down from 56% in 1991 for shallow preparations and 6% for deep preparations when an amalgam was to be used as the final restorative material.[2,3]

There are several factors that clinicians need to remember about varnishes. First, due to the ready evaporation of the solvent, the lid should be kept on the bottle when the varnish is not in use. Eventually, due to evaporation, the liquid will become thick, and manufacturers have thinners available to restore the appropriate viscosity. Second, there are several types of varnish on the market, and care must be taken when choosing a product. For example, Fuji Varnish (GC Corp, Alsip, IL, USA) is used for sealing glass-ionomer restorations, not as a cavity sealer. Varnishes that are intended to be used as a cavity liner include Copalite (Cooley & Cooley, Houston, TX, USA) and Copaliner (Bosworth, Skokie, IL, USA).

Calcium hydroxide

Calcium hydroxide (CaOH) has two components: a base and a 'catalyst'. The base is composed of calcium tungstate, tribasic calcium phosphate and zinc oxide. The catalyst is composed of calcium hydroxide, zinc oxide and zinc stearate. Radiopacity is provided by calcium tungstate, or in some cases by barium sulphate fillers. Craig and Powers consider calcium hydroxide to be a low-strength base.[6] This is ironic, since they suggest that calcium hydroxide should not be applied in a thickness greater than 0.5 mm, which would make it a liner.

Calcium hydroxide is considered to be bactericidal due to its high pH, approximately 12, which is provided by the catalyst. This alkaline property can cause cytotoxic effects to both the pulp and any bacteria in the preparation. Additionally, the acidic by-products of the bacteria are counteracted by the high pH.[28] This high pH continues even after the material has set due, according to Ferracane, to hydroxyl ions that continue to leach out of the material when it comes in contact with the dentinal fluid.[7]

Calcium hydroxide can also irritate the pulp due to its high alkaline nature. This results in the formation of reparative dentine (a dentine bridge). This new dentine forms because CaOH can stimulate growth factors in the dentine matrix, and this process may occur more quickly when a resin-based calcium hydroxide formulation is used.[29] Additionally, Torneck *et al.* write that calcium as well as hydroxyl ions play an important role on the pulpal healing by modifying the environmental pH in the zone of inflammation to levels favourable for pulp matrix mineralization.[30] There are light-cured resin-based versions of calcium hydroxide and such formulations are not harmful to the pulp but do not show any antibacterial characteristics. They have a demand set and are less soluble than the self-cured products. The high solubility of conventional CaOH materials requires that clinicians ensure that restoration margins are sealed.

Operators will find that CaOH is easy to manipulate, hardens rapidly when applied in thin layers, provides a relatively good seal and has positive effects on both carious dentine and exposed pulp. Unfortunately, it is low in strength, undergoes plastic deformation and is highly soluble in water, and resins-based restorative materials will not bond to conventional CaOH.

Calcium hydroxide products are available in either a paste-paste version or a liquid formulation. Examples of calcium hydroxide paste-paste products are Dycal (Caulk Dentsply, Milford, DE, USA) and Life (Kerr, Orange, CA, USA). Liquid versions of CaOH are the resin-based products Hydroxyline (George Taub Products, Jersey City, NJ, USA) and Timeline (Caulk Dentsply, Milford, DE, USA).

Zinc oxide eugenol

The powder is composed of zinc oxide (70% by weight) with rosin added to reduce the brittleness of the set material. The eugenol is in the liquid portion, derived from oil of cloves (one of the 'essential oils'). The eugenol is bactericidal on its own, but is more potent when combined with zinc oxide.[31] The requirements for ZOE as a base are given in ISO 3107-2004 (Dentistry – Zinc oxide/eugenol and zinc oxide/non-eugenol cements), under the category of Type 3.

Said to be the least irritating of all dental materials, zinc oxide eugenol (ZOE) has been available for over 100 years. Despite having a pH of about 7 and having a sedative effect on the pulp, the eugenol can be toxic to the pulp, especially when present in high concentrations.[6] It is for this reason that ZOE should not be placed in direct contact with the pulp.

Eugenol is released from the mixture by hydrolysis. The wet dentine causes enough eugenol to be released to form a concentration gradient that kills bacteria, but does not damage the pulp. Hume showed that the dentine protects the pulp from chemical irritation and as the remaining dentine thickness increases, so does the protection.[32]

Even though ZOE does not bond to the tooth, it does afford an excellent marginal seal,[7] which is better when a lower powder:liquid ratio is used.[33] The advantage of this seal is the prevention of diet-derived substrate from reaching the micro-organisms found below the restoration. This results in the reduction of both acid production and of the formation of secondary caries. Essentially, ZOE inhibits bacterial cell metabolism, the end result being a low incidence of postoperative sensitivity.

Hydrolysis of zinc oxide precedes a reaction between the resulting zinc hydroxide and eugenol, and this allows the ZOE mixture to set. The reaction occurs in the presence of water acting as a catalyst, which is why the reaction occurs faster when wet than when no moisture is present.[8]

The preferred technique for mixing ZOE is adding the powder to the liquid a little at a time using vigorous spatulation. The resulting material is not exothermic, but clinicians should be aware of ambient conditions, as a humid environment could cause the reaction to speed up. As the powder:liquid ratio is increased, the mix becomes drier and less tacky. The resultant mixture is easier to work with and contains less free eugenol (as it is combined in the material) to irritate the pulp.

ZOE is not marketed as a cavity liner, but as a base (as well as other uses not relevant to this paper). Some products contain polymethylmethacrylate, which is incorporated in order to strengthen the material, making it more appropriate for use as a cavity base. Considered a low strength base by Craig and Powers,[6] ZOE has thermal insulating properties that are similar to dentine.

There are no ZOE products that are marketed for use as a liner. An example of ZOE as a base is IRM (Intermediate Restorative Material; Caulk Dentsply, York, PA, USA), available both in powder-liquid and encapsulated versions.

Zinc phosphate

Of all the materials discussed in this paper, zinc phosphate (also known as zinc oxyphosphate, ZOP) has been in use the longest. As with ZOE, it has two components, a powder and a liquid. The powder contains zinc oxide (90%) and magnesium oxide (10%), and some products may have other chemicals added such as tannin fluoride (Shofu Corp, Osaka, Japan). The liquid is composed of phosphoric acid, aluminum phosphate (which acts as a buffering agent) and water. The water influences the rate of the acid-base reaction, and increasing the amount of water results in a reduction in both the compressive and tensile strengths[8] and a longer setting time.

The setting time, according to ISO 9917.1-2007 (Dentistry – Water-based cements – Part 1: Powder/liquid acid-base cements), is required to be between 2.5 and 8 minutes. Varying the setting time can be accomplished first, by reducing the powder:liquid ratio, which will increase the setting time and also lower the pH); second, by adding the powder to the liquid a little at a time (which will extend the setting time); third, by delaying mixing the last amount of the powder, as this will destroy the matrix and lengthen the setting time; and fourth, by mixing on a cold glass slab, which will cool the exothermic reaction and lengthen the setting time. The exotherm is derived from the surface of the alkaline powder dissolving in the acid liquid. The fourth method is the most effective method and allows more powder to be included in the final mix, which improves the physical properties.[8] Operators need to remember that water affects the mix, and therefore the glass slab needs to be dry and thus not cooled below the dew point.[7]

Unlike ZOE, the pH of ZOP is much lower, starting at around 2. However, 24 hours after the mix is complete, the pH is about 5.[3,7,26] From a clinical point of view, this is important since premature dispensing or leaving the cap off the bottle of liquid will allow some water to evaporate. This results in a more acidic liquid and a thicker mix. To account for this evaporation, ISO 9917.1 requires that there be 20% more liquid in the bottle than is needed to mix with the powder in the package.

There are several advantages of ZOP. These include a long history of clinical success, it is easily mixed and is to an extent strong. Unfortunately, it is brittle, lacks adhesion, is soluble in the mouth, is thought to be an irritant to the pulp and lacks any antibacterial properties (except for the copper-based products).

When ZOP was first introduced to dentistry, some contained copper and these were thought to possess antibacterial characteristics. Unpublished studies (Montana State University Center for Biofilm Engineering) have shown that copper-based ZOP does exhibit such antibacterial properties. Zinc phosphate is not usually thought to be used as liner, however, one product (not yet available in Australia) is advocated as a liner when mixed with copal varnish to achieve a thin mix.[34]

When ZOP is to be used as a base, it should be mixed to a thick, dry, putty-like consistency. Doing so will result in a strong, hard base and a short setting time. A ZOP base will provide a thermal and chemical barrier, allowing the final restoration to be placed at the same visit. An additional result of a thick mix will be less free liquid available to act as an irritant.

Many years ago it was thought that ZOP, due to its acidic nature, was a cause of postoperative sensitivity, but this has since been shown not be true.[35] For those who wish to prevent any affect that ZOP has on the tooth, a layer of copal varnish can be placed on the cavity preparation to seal the dentine, prior to the zinc phosphate.

Examples of zinc phosphate are marketed by Henry Schein Halas, Dentavision P/L and Ivoclar Vivadent P/L.

Zinc polycarboxylate

A material that is similar to ZOP is zinc polycarboxylate (ZPC), also known as zinc polyacrylate. As with ZOP, the powder is composed of zinc oxide and magnesium oxide. The liquid contains a 35–40% aqueous solution of polyacrylic acid. Because the liquid is more viscous than that of ZOP, the mix will appear to be thicker (pseudoplastic). The correct consistency is a mix that, when pulled up, will flow back under its own weight. It resembles ZOP in strength and ZOE in biocompatibility. The pH of the liquid is about 1.7, and upon mixing, the free acid is quickly neutralized. Available in powder-liquid formulations, ZPC bonds ionically to tooth structure via the negatively charged carboxyl ions from the liquid and the positively charged calcium ions from the tooth structure. The bond to enamel is stronger than that to dentine.

Freshly mixed ZPC is not as stiff as ZOP and its working time is about half. Unlike ZOP, the liquid of ZPC should not be refrigerated as this will cause it to gel. However, the ZPC powder can be refrigerated in order to extend the working time.

As with zinc phosphate, the ZPC liquid must be protected against water loss from evaporation. When mixing ZPC, the powder should be added all at once. When the mixing is complete, a glossy surface will be apparent, indicating that there are enough free carboxyl groups available to bond to the tooth.

Both ZOP and ZPC have close adaptation to the cavity preparation because both are acidic and help remove the smear layer. Hodash has shown that when potassium nitrate is added, ZPC becomes an effective liner and does not have an adverse effect on the vitality of the pulp.[37] Zinc polycarboxylate is also similar to ZOP when used as a base and mixed to a thick dry consistency, thus allowing a final restoration to be immediately placed over it.

Good biocompatibility exists because the polyacrylic molecules are large and cannot diffuse into the dentine, the pH rises rapidly after mixing and minimal dentinal fluid movement occurs in response to the ZPC.[36] In a study comparing both ZOP and ZPC in deep cavity preparation, it was shown that there was no significant irritating effect on the pulp.[35] It was concluded that any irritation was due to the bacteria that remained in the preparation.

In the 2005 survey study by the present author, none of the responding dental schools claimed to be using ZPC as a liner or base, despite the fact that ZPC has many advantages which include its biocompatibility, adhesion to tooth structure, easy manipulation and strength. The negative aspects of ZPC are the need for accurate measuring when dispensing, high viscosity, short working time, and the need for a clean cavity surface to obtain better bonding.[34]

Hybond Polycarboxylate Cement (Shofu) and Durelon (3M ESPE, St Paul, MN, USA) are examples of polycarboxylate materials.

Glass-ionomer

Composed of acid soluble calcium or strontium fluoroaluminosilcate glass and an aqueous solution of polyacrylic acid, conventional glass-ionomers (GI), which are governed by ISO 9917.1-2007 (Dentistry – Water-based cements – Part 1: Powder/liquid acid-base cements) have been available for about 40 years. To make these products radiopaque, some contain zinc oxide or barium glass.[8] After mixing powder and liquid, the acid etches the glass which results in a release of calcium, aluminium, sodium and fluoride ions into solution. This is an acid-base reaction where the water serves as the medium for the reaction. Set GI has a compressive strength similar to that of ZOP, a tensile strength higher than ZOP and a modulus of elasticity of about half of ZOP.[8]

Glass-ionomer comes in several different versions or systems, each of which has advantages and disadvantages. These include powder-liquid, paste-paste and encapsulated versions. The powder-liquid products are usually less costly, whereas the paste-paste versions allow for a more constant ratio of the active components (acid and base) and are easy to clean up.

An important characteristic of glass-ionomer is its ability to bond to tooth structure, one mechanism being that of a hydrogen bond between the carboxyl group of the polyacid and the calcium in the tooth structure. It has also been shown that there is a micromechanical penetration of the GI into the tooth.[38] Glass-ionomer has a coefficient of thermal expansion similar to the tooth, which may help reduce microleakage and therefore postoperative sensitivity.[39]

The fluoride released during the acid-base reaction is high initially then declines over time. Those clinicians that use the 'cervical lining' or 'open sandwich' technique (bringing the GI to the margin) will find that the released fluoride can be replaced by the methods described earlier. The fluoride released does not inhibit caries but rather causes the formation of fluorohydroxyapatite in the adjacent tooth structure which makes it more resistant to demineralization.[40] Another advantage of the cervical lining technique is that the GI expands slightly when in contact with moisture, and this may compensate for the polymerization shrinkage of the resin composite[41] and may therefore reduce microleakage.[42]

Glass-ionomer has more of an antibacterial effect than does CaOH,[43] and Alex writes that the use of a resin-modified GI is the easiest and most predictable method to manage microleakage.[44] To encourage adhesion of the GI to the tooth, it is necessary to have a clean surface. This can be accomplished using pumice, phosphoric acid or polyacrylic acid followed by a water rinse. However, it is important that clinicians follow the manufacturer's instructions for the particular product they are using. Clinicians should also be aware that once the surface of the mix loses its glossy appearance, it should not be used, as this is an indication that there is no unreacted polyacid available for bonding.

When a resin is added to the glass-ionomer, it is referred to as a 'resin-reinforced', 'hybrid' or, preferably, a 'resin-modified' glass-ionomer. Dentists will find that these usually have a longer working time and are less moisture-sensitive.[8] However, it must be remembered that most resin-modified glass-ionomer restoratives set by the acid-base reaction as well as the resin photo- and self-cure polymerization reactions, thus working time is not unlimited.

Examples of conventional and resin-modified glass-ionomers include those marketed in Australia by 3M ESPE, GC Corp, Shofu, SDI Ltd (Bayswater, Australia), Oradec P/L, Dentsply P/L, Gunz Dental P/L, Henry Schein Halas, Dentavision P/L, Voco P/L and Go Dental P/L.

Resin-based materials

The final materials that can be used as either a liner or a base are those that are resin-based. These can be categorized in two different ways: either by filler content (unfilled or filled), or by how they are cured (either self-, light- or dual-cured). For the purposes of this paper, only those that can be used as a liner or as a base will be discussed, keeping in mind the definitions used in the Introduction.

When resin-based products are used, manufacturers either include the bonding system in the package or recommend a separate purchase of one of their own. The bonding systems are usually composed of a primer (wetting agent) and/or a bonding agent (unfilled resin). From the perspective of a liner, the material that is first placed in the cavity preparation is most important to the clinician, as it is this material that will act as the liner.

The acidic nature of the primer dissolves the smear layer and the surface hydroxyapatite, which allows for the adhesive component of the primer to infiltrate the exposed dentinal collagen. This results in the formation of the so-called 'hybrid layer' and a zone of occluded dentinal tubules, and the solvent (either acetone, alcohol or water) then evaporates. The adhesive (bond) is then placed, which is a low viscosity, hydrophilic material that promotes the bond of the filled resin to the tooth.[8] Complete penetration of the primer monomers into the collagen is essential to create strong adhesion as well as an optimum seal. The occluded tubules reduce the amount of microleakage.

A comparison study of acetone systems and water systems was conducted to evaluate the effect on the hybrid layer. It concluded that the acetone-based systems resulted in a thick hybrid layer that included well formed resin tags that were well adapted to the tubular wall. In contrast, the water-based systems produced a thinner hybrid layer that was less well sealed, thus allowing more microleakage.[45]

Bonding systems can be divided into 'etch-and-rinse' systems and 'self-etching primer' systems (available in one- or two-bottle versions). With respect to microleakage, a study published in 2006 concluded that the etch-and-rinse products were associated with less microleakage than self-etching systems.[46] The self-etching systems are more acidic because of carboxylic acid. Originally developed to be easier for the clinician to use (due to less steps), self-etching systems were shown not to produce improved results when compared to total etch products.[47]

Clinicians should also be aware that prior to placement of a bonding material, the tooth needs to be clean and free from all water, saliva and blood. Contamination can interfere with adhesion and can result in the dentine tubules being left open, leading to postoperative sensitivity.

The deeper the cavity preparation into dentine, the more dentinal fluid that will be encountered, which reduces the bond strength. To account for this, Tay and Pashley have written that it is best to over-dry the dentine.[48] Additionally, blocking or occluding the dentine tubules will reduce dentine permeability and prevent fluid contamination, which will improve bond strength.[49] Dentinal fluid can become trapped within the bonding agent in the cavity. This fluid will eventually form bubbles that evaporate, making the hybrid layer permeable. The over-drying will help prevent this. Water or any moisture that is in the bonding agent can: (1) inhibit polymerization of the bonding agent; (2) produce these so-called 'water channels' that increase the porosity; and (3) soften the resin. All these will cause the adhesive to weaken over time and also reduce the bond strength.[50]

Moisture contamination can also be from the patient's breath, which is an additional reason for using rubber dam. From an examination of the influence of humidity and temperature on bond strength, it was concluded that bond strength decreased when humidity was increased.[51]

There are times when the operator will be replacing an existing restoration, and quite likely bond to sclerotic dentine. The tubules in such dentine are occluded with mineral salts which reduce resin tag formation.[52] Additionally, dentine with a hypermineralized surface has been shown by some to resist acid etching, which results in lower bond strengths, although others have not confirmed this. Kusunoki and others suggest that sclerotic dentine allows the resin to adapt to the cavity preparation better than with normal dentine, and conclude that sclerotic dentine should be preserved and not etched.[53]

Similar to the materials discussed earlier, self-etching bonding agents can also have handling disadvantages. The acetone-based materials particularly will evaporate when exposed to the air, and therefore they should not be dispensed until they are to be used.[54]

From a clinical point of view, placing primers and unfilled resins needs to be done with care. Primers have a very low film thickness compared to unfilled resins, and placement of unfilled resins in the cavity preparation can result in 'pooling' if not done with care. On follow-up or recall bitewing radiographs, this may look like secondary caries. Another reason that thick layers are not ideal is because the coefficient of thermal expansion does not match that of filled resin.[55] There are numerous dentine bonding systems on the market, and most are now used as combined enamel and dentine bonding systems. An extensive review of such systems is to be found elsewhere in this special issue.

Resins as liners or bases are not only confined to primers and bonding agents. Manufacturers also market filled resins, in the form of flowable composites, for lining/base purposes, even though a primer and bonding agent is placed in the cavity preparation first. With respect to a liner, conventional composites are not applicable as they do not meet the definition given earlier. On the other hand, flowable composite resins do.

Flowable composites can reduce microleakage as they have the ability to adapt to the restoration and flex with the tooth, which it is claimed allows for a better seal. However, Christensen stated that these materials are not intended to be used as a liner, and recommended instead the placement of a fluoride-releasing product. Some flowable resins do contain fluoride, but the amount is very low and decreases after the first three weeks.[56] A clinician who is going to place a flowable composite in the preparation will need to evaluate that product. Special attention should be paid to the radiopacity of the material as the clinician will need to distinguish it from the surrounding tooth structure on a radiograph; a radiolucent flowable could be misdiagnosed as secondary caries. Flowable composites are available from most filled resin composite manufacturers and distributors.

Resins as a base are usually marketed as core build-up materials, but like flowable composites, a primer and bonding agent are placed first. As a base, the resin can be shaped and contoured, and will act as a temperature buffer. These products are available in either tooth-coloured or non-tooth-coloured versions. The advantage of a non-tooth-coloured product is that when used under a metallic restoration (direct or indirect), it can be distinguished from the dentine if the tooth needs to be retreated. Several core build-up products are available.

Clinical considerations

Clinical considerations should always be part of the decision making process when purchasing dental products because dental materials cannot be completely separated from clinical technique. With respect to liners and bases, important aspects of the clinical technique are the cavity preparation and the curing light.

Cavity preparation can be accomplished with high and low speed handpieces, hand instruments, laser and air abrasion. Setien *et al.* showed that microleakage did not occur for any preparation method where the enamel was etched prior to placement of the composite,[57] and numerous others support this finding. This indicates that a better seal is obtained when acid etching of enamel has taken place.

Now that liners and bases have been discussed in detail, it should be noted that according to a 2003 presentation, the interactions of the tooth, cavity preparation and the restorative material on pulp injury appeared to have minimal influence on the pulp. The important factor was the remaining dentine thickness between the cavity floor and the pulp, not the restorative material itself. By maximizing the remaining dentine, less pulp injury occurred.[58]

There are numerous manufacturers of liners and bases, and they provide their products in a variety of delivery systems. These include powder-liquid, paste-paste, capsules, conventional syringe and automix syringe. Also, products can be found in self-, light- and dual-cured formulations. Not all products are available in every version, so clinicians need to determine which material and which system is best for them. When choosing a product, dentists must also be comfortable with the packaging, labelling and instructions for use. If a dentist is going to purchase a new product, that decision should be founded on scientific information. Additionally, the operator must understand the manufacturer's instructions for use, as there may be procedures that are new to the office. Peutzfeldt and Vigild performed a study on dentine bonding agents, and reported that the extent to which dentists followed the manufacturer's instruction depended on the degree that the dentists were satisfied with the instructions.[59]

Since many of the products marketed as a liner or a base are light sensitive, a look at light curing units is in order. The wavelength of the light sensitive photoinitiator should be known by the dentist, so that there is an assurance that the curing light being used is compatible. There are many different types of lights on the dental market: halogen, light-emitting diode (LED), fast halogen plasma arc and laser. No one type of curing unit is ideal and it is incumbent on the clinician to determine which light is best for that office.

Many dentists use the same material in deep and shallow preparations, and doing so involves a difference in the distance between the light tip and the floor of the cavity. A greater distance results in a decrease in the light intensity, and a 1 mm space between the light tip and the resin could cause a reduction in power intensity ranging from 8 to 16%. Increasing the cure time may counter this.[60] It is also important to remember that darker resins need longer light activation; the clinician should know the depth of cure that is recommended by the manufacturer for each shade of material.

Light tips need to be examined on a regular basis to check for build-up of deposits on the exit tip, as this build-up can reduce the effectiveness of the light.[61] Single-use barriers are available for infection control, and they do result in a loss of light intensity from the curing tip. However, this loss is minimal and not likely to affect the cure. Clear plastics 'kitchen wrap' was shown to have no significant effect.[62]

A study published in 2007 evaluated curing lights in offices from two United States metropolitan locations. The authors concluded that: (1) nearly 10% of the units tested had an output of <250 mW/cm; (2) the radiometer in many offices did not provide adequate readings; and (3) there was a high number of units (77%) that had debris build-up on the tip surface. The authors also suggested replacing the bulbs on a regular basis.[63] Dentists need to keep in mind that if adequate conversion is not accomplished during polymerization, then the mechanical properties of the material are reduced. Incomplete curing can result in leachable monomers and initiators that pose greater biocompatibility issues.[64]

Over the past few years there has been a new restorative philosophy and concept referred to or frequently called 'minimum intervention' or 'minimally invasive' dentistry. Changes in restorative techniques and the development of adhesive restorative materials have allowed the use of more conservative cavity preparations. Traditionally, dental schools have taught that when treating a caries lesion, all the caries should be removed prior to placing the restoration. More specifically, all the soft dentine should be removed because the teaching was that this was 'caries'. Such soft dentine can be divided into outer 'infected' dentine and inner 'affected' dentine. However, the boundary between the superficial infected dentine that requires excavation, and the deeper, affected but remineralizable dentine, is not always obvious. The inherent subjectivity in detecting this excavation boundary can result in clinically significant differences in the quality and quantity of dentine removed by different operators.[65] Affected dentine can be remineralized, and therefore does not need to be removed during the cavity preparation phase.[66]

Kidd writes that there is little evidence that even infected dentine must be removed prior to sealing the tooth, and that leaving infected dentine does not seem to result in caries progression, pulpitis or pulp death.[67] Two papers, both literature reviews, summarized that there is substantial evidence that removing all caries (complete caries removal) from the carious lesion in a symptomless and vital tooth is not required, especially if attempting to avoid a pulpal exposure.[68,69] The paper by Van Thompson *et al.* goes on to write that once isolated from their source of nutrition by a restoration of sufficient integrity, bacteria either die or remain dormant and therefore pose no risk to the dentition. Ricketts *et al.* suggest that there is insufficient evidence to know whether it is necessary to re-enter after a period of time and excavate further, but studies that have not re-entered do not report adverse consequences. It has also been shown that the presence of affected dentine did not increase the susceptibility to secondary caries.[70]

The concept of affected dentine is relevant to liners and bases as it is this layer which will be in contact with the liner. A review of the literature shows that the materials involved in studies with affected dentine have been limited to glass-ionomers and resins. The other materials, discussed above, have not been studied. Glass-ionomers have the potential to remineralize affected dentine to varying extents. However, the extent to which a glass-ionomer can augment normal physiological remineralization remains to be determined.[71] Palma-Dibb and others have shown that conventional glass-ionomers had lower mean bond strengths to caries-affected dentine than did resin-modified glass-ionomers.[72]

The relationship between resins and affected dentine seems to be dependent on a number of factors. First, the method of cavity preparation has an influence, as it has been shown that one-step products have a lower bond strength to inner dentine than do total-etch systems, when a bur was used to prepare the cavity. When a laser was used, there was no significant difference between the two adhesives.[73] Second, resin infiltration into dentinal tubules of caries-affected dentine is hampered by the presence of mineral deposits,[74] and this is especially true with self-etching materials compared to total-etch products.[75] In an attempt to increase infiltration, etching of the dentine is necessary, and increasing the etching time significantly increases the tensile bond strength to caries-affected dentine. However, this is still less than that to sound dentine.[76] This is different from a 2004 study, where the authors concluded that extra etching of caries-affected dentine resulted in no difference in bond strengths.[77] The lower bond strength may be because caries-affected dentine contains more water than normal dentine.[78] Clinically, this may not be a problem, since such lesions are normally surrounded by normal dentine or enamel. Hybrid layers in caries-affected dentine have been shown to be thicker than in sound dentine, and caries-affected dentine is also more porous which may be because it is partially demineralized.[79,80] As mentioned earlier, it is the hybrid layer which is essential to maximize the strength of the bond of the resin to the tooth and optimize the seal of the cavity preparation. With respect to affected dentine, it has been shown that cleaning the prepared surface with 2% chlorhexidine digluconate prior to the placement of the restoration does not effect the immediate bond strength. However, this was not the case after six months.[81] Lastly, a recent study concluded that during photopolymerization, there was a greater increase in temperature at the resin-dentine interface when bonding to caries-affected dentine compared to normal dentine.[82]

CONCLUSIONS

As can be seen from the above review, the materials science of liners and bases is a not a finite area of study. It is an evolving situation that requires the clinician to stay abreast of the constantly changing research.

DISCLAIMER

The lists of examples of proprietary products may not be exhaustive, and do not imply endorsement by the author or by the Australian Dental Association Inc.

REFERENCES

1. Christensen GJ. To base or not to base. J Am Dent Assoc 1991;122:61–61.
2. Weiner R, Kugel G, Weiner L. Teaching the use of liners and bases: a survey of North American dental schools. J Am Dent Assoc 1996;127:1640–1645.
3. Weiner R. Teaching the use of liners, bases, and cements: a 10-year follow-up survey of North American dental schools. Dent Today 2006;25:74–79.
4. Cox CF, Suzuki S. Reevaluating pulp protection: calcium hydroxide liners vs. cohesive hybridization. J Am Dent Assoc 1994;125:823–831.
5. Asa R. Dental materials aren't what they used to be. AGD Impact 2004;32:10–13.
6. Craig RG, Powers JM. Restorative dental materials. 11th edn. St Louis, MO: Mosby, 2002.
7. Ferracane JL. Materials in dentistry: principles and applications. 2nd edn. Philadelphia: Lippincott Williams and Wilkins, 2001.
8. Anusavice K. Phillip's Science of Dental Materials. 11th edn. Philadelphia: WB Saunders, 2003.
9. Gordan VV, Vargas MA, Cobb DS, Denehy GE. Evaluation of acidic primers in microleakage of Class V composite restorations. Oper Dent 1998;23:244–249.
10. Murray PE, About I, Franquin JC, Remusat M, Smith AJ. Restorative pulpal and repair responses. J Am Dent Assoc 2001;132:482–491. Erratum in: J Am Dent Assoc 2001;132:1095.
11. Brännström M. Etiology of dentin hypersensitivity. Proc Finn Dent Soc 1992;88 Suppl 1:7–13.
12. Camps J, Dejou J, Remusat M, About I. Factors pulpal response to cavity restorations. Dent Mater 2000;16:432–440.
13. Yoshiyama M, Masada J, Uchida A, Ishida H. Scanning electronic microscopic characterization of sensitive vs. insensitive human radicular dentin. J Dent Res 1989;68:1498–1502.
14. von Fraunhofer JA, Marshall KR, Holman BG. The effect of base/liner use on restoration leakage. Gen Dent 2006;54:106–109.
15. Strupp W. Critical factors for clinical success with all ceramic restorations. Crown and Bridge Update 2004;7:25–32.
16. Carrilho MR, Geraldell S, Tay F, *et al.* In vivo preservation of the hybrid layer by chlorhexidine. J Dent Res 2007;86:529–533.

17. Ersin NK, Candan U, Aykut A, Eronat C, Belli S. No adverse effect to bonding following caries disinfection with chlorhexidine. J Dent Child (Chic) 2009;76:20–27.

18. Hebling J, Giro EM, Costa CA. Human pulp response after an adhesive system application in deep cavities. J Dent 1999;27:557–564.

19. American Dental Association. Positions and Statements: Bisphenol A and Dental Materials. URL: 'http://www.ada.org/prof/resources/positions/statements/bisphenola.asp'. Accessed 23 September 2009.

20. Latta MA. Six principles of adhesion. Dent Econ 2007;97:52.

21. de Jong HP, van Pelt AW, Busscher HJ, Arends J. The effect of topical fluoride applications on the surface free energy of human enamel: an in vitro study. J Dent Res 1984;63:635–641.

22. Randall RC, Wilson NHF. Glass-ionomer restoratives: a systematic review of a secondary caries treatment effect. J Dent Res 1999;78:628–637.

23. Wiegand A, Buchalla W, Attin T. Review on fluoride-releasing restorative materials–fluoride release and uptake characteristics, antibacterial activity and influence on caries formation. Dent Mater 2007;23:343–362.

24. Ugarte J, Lagravere MO, Revoredo JA, *et al.* Fluoride agent's uptake effect over two glass ionomer cements and a resin modified glass ionomer cement. J Dent Res 2003;82 (Spec issue):Abstract 938.

25. Gao W, Smales RJ. Fluoride release/uptake of conventional and resin modified glass ionomers and compomers. J Dent 2001;29:301–306.

26. Royse MC, Ott NW, Mathieu GP. Dentin adhesive superior to copal varnish in preventing microleakage in primary teeth. Pediatric Dent 1996;18:440–443.

27. Kennington LB, Davis RD, Murchison DF, Langenderfer WR. Short-term clinical evaluation of post-operative sensitivity with bonded amalgams. Am J Dent 1998;11:177–180.

28. Prati C, Fava F, Di Gioia D, Selighini M, Pashley DH. Antibacterial effectiveness of dentin bonding systems. Dent Mater 1993;9:338–343.

29. Smith AJ, Garde C, Cassidy N, *et al.* Solubilization of dentine extracellular matrix by calcium hydroxide (Abstract). J Dent Res 1995;75:829.

30. Torneck CD, Moe H, Howley TP. The effect of calcium hydroxide on porcine pulp fibroblast in vitro. J Endod 1983;9:131–136.

31. Meeker HG, Najafi MM, Linke HA. Germicidal properties of dental cavity liners, bases, and cements. Gen Dent 1986;34:474–478.

32. Hume WR. Are restorative materials and procedures harmful to the pulp? A focus on in vitro investigations. Transactions of the Academy of Dental Materials 1998;12:105–119.

33. Anderson RW, Powell BJ, Pashley DH. Microleakage of IRM used to restore endodontic access preparations. Endod Dent Trauma 1990;6:137–141.

34. Weiner R. Liners, bases, and cements: an in-depth review. Part 2. Dent Today 2008;27:48–54.

35. Brannstrom M, Nyborg N. Pulpal reaction to polycarboxylate and zinc phosphate cements used with inlays in deep cavity preparations. J Am Dent Assoc 1977;94:308–310.

36. O'Brien WJ. Dental materials and their selection. 3rd edn. Chicago: Quintessence, 2002.

37. Hodash M, Hodash SH, Hodash AJ. Capping carious exposed pulps with potassium nitrate, dimethyl isosorbide, polycarboxylate cement. Dent Today 2003;22:46–51.

38. Lin A, McIntyre NS, Davidson RD. Studies on the adhesion of glass ionomer cements to dentin. J Dent Res 1992;71:1836–1841.

39. Leinfelder K. Characteristics of a new glass ionomer material. Inside Dent 2006;1:42–44.

40. Mount GJ. Minimal intervention dentistry: rational of cavity design. Oper Dent 2003;28:92–99.

41. Trushkowsky R. The role of glass ionomers in minimally invasive restorative dentin. Dent Today 2005;24:72–77.

42. Aboushala A, Kugel G, Hurley E. Class II composite restorations using glass ionomer liners: microleakage studies. J Clin Pediatr Dent 1996;21:67–72.

43. Eli I, Cooper Y, Ben-Amar A, Weiss E. Antibacterial activity of three dental liners. J Prosthodont 1995;4:178–182.

44. Alex G. The use of resin modified glass ionomer liners under composite resins: should they be used to help control microleakage? Inside Dent 2005;1:30–33.

45. Georgoire GL, Akon BA, Millas A. Interfacial micromorphological differences in hybrid layer formation in water and acetone solvent based dentin bonding systems. J Prosthet Dent 2002;87:633–641.

46. Gueders AM, Charpentier JF, Albert AI, Geerts SO. Microleakage after thermocycling 4 etch and rinse and 3 self-etch adhesives with and without a flowable composite lining. Oper Dent 2006;31:450–455.

47. Soderholm KJ, Guelmann M, Bimstein E. Shear bond strength of one 4th and two 7th bonding agents when used by operators with different bonding experience. J Adhes Dent 2005;5:57–64.

48. Tay FR, Pashley DH. Have dentin adhesives become too hydrophilic? J Can Dent Assoc 2003;69:726–731.

49. Sadek FT, Pashley DH, Ferrari M, Tay FR. Tubular occlusion optimizes bonding of hydrophobic resins to dentin. J Dent Res 2007;86:524–528.

50. Weiner R. Liners, bases, and cements: an in-depth review. Part 3. Dent Today 2008;27:65–70.

51. Miyazaki M, Rikuta A, Tsubota K, Yunoki I, Onose H. Influence of environmental conditions on dentin bond strengths of recently developed dentin bonding systems. J Oral Sci 2001;43:35–40.

52. Nakajima M, Sano H, Burrow MF, *et al.* Tensile bond strength and SEM evaluation of caries affected dentin using dentin adhesives. J Dent Res 1995;74:1679–1688.

53. Kusunoki M, Itoh K, Hisamitsu H, Wakumoto S. The efficacy of dentin adhesive to sclerotic dentine. J Dent 2002;30:91–97.

54. Fujita K, Nishiyama N. Degradation of single bottle type self etching primer effectuated by the primer's storage period. Am J Dent 2006;19:111–114.

55. Overton JD, Gureckis K. Preparation designs for minimally invasive dentistry. Contemp Esthet Rest Pract 2007;11–26.

56. Christensen GJ. Direct restorative materials. What goes where? J Am Dent Assoc 2003;134:1395–1397.

57. Setien VJ, Cobb DS, Denehy GE, Vargas MA. Cavity preparation devices: effect on microleakage of Class V resin-based composite restorations. Am J Dent 2001;14:157–162.

58. Asawang K, Windsor LJ, About I, *et al.* Cavity preparation and restoration events and their effects on pulp cellular injury. Presented at 81st General Session of the IADR, 25–28 June 2003, Gothenberg, Sweden. Abstract 1404.

59. Peutzfeldt A, Vigild M. A survey of the use of dentin bonding systems in Denmark. Dent Mater 2001;17:211–216.

60. Chang Tl, Sim A, Hammer L, *et al.* Effect of curing source, distance on composite depth of cure. Presented at IADR/AADR/CADR 82nd General Session, 10–13 March 2004, Honolulu, Hawaii, USA. Abstract 2678.

61. Sarrett DC, ed. LED curing lights. ADA Professional Product Review. 2006;1:1–5.

62. Scott BA, Felix CA, Price RB. Effect of disposable infection control barriers on light output from dental curing lights. J Can Dent Assoc 2004;70:105–110.

63. Barghi N, Fischer DE, Pham T. Revisiting the intensity output of curing lights in private dental offices. Compend Contin Educ Dent 2007;28:380–384.

64. Cakir D, Sergent R, Burgess J. Polymerization shrinkage: a clinical review. Inside Dent 2007;3:84–87.

65. Banerjee A, Watson TF, Kidd EA. Dentine caries: take it or leave it? SADJ 2001;56:186–192.

66. Restorative and Endo Data Online. URL: 'http://www.onlinedentallearning.com/index.php?option=com_content &task=view&id=37'. Accessed 3 November 2009. URL: 'http://www.eclipse.co.uk/moordent/glossa'. Accessed 3 November 2009.

67. Kidd EA. How clean must a cavity be before restoration? Caries Res 2004;38:305–313.

68. Thompson V, Craig RG, Curro FA, Green WS, Ship JA. Treatment of deep carious lesions by complete excavation or partial removal: a critical review. J Am Dent Assoc 2008;139:705–712.

69. Ricketts DNJ, Kidd EA, Innes N, Clarkson J. Complete or ultraconservative removal of decayed tissue in unfilled teeth. Aust Dent J 2008;52:252–253.

70. Borczyk D, Piatowska D, Krzemiski Z. An in vitro study of affected dentin as a risk factor for the development of secondary caries. Caries Res 2006;40:47–51.

71. Smales RJ, Ngo HC, Yip KH, Yu C. Clinical effects of glass ionomer restorations on residual carious dentin in primary molars. Am J Dent 2005;18:188–193. Erratum in: Am J Dent 2005;18:295.

72. Palma-Dibb RG, de Castro CG, Ramos RP, Chimello DT, Chinelatti MA. Bond strength of glass ionomer cements to caries affected dentin. J Adhes Dent 2003;5:57–62.

73. Sattabanasuk V, Burrow MF, Shimada Y, Tagami J. Resin adhesion to caries affected dentine after different removal methods. Aust Dent J 2006;51:162–169.

74. Say EC, Nakajima M, Senawongse P, Soyman M, Ozer F, Tagami J. Bonding to sound vs. caries affected dentin using photo- and dual-cured adhesives. Oper Dent 2005;30:90–98.

75. Strydom C. Self etching adhesives: review of adhesion to tooth structure. Part 1. SADJ 2004;59:415–419.

76. Arrais C, Giannini M, Nakajima M, Tagami J. Effects of additional and extended acid etching on bonding to caries-affected dentine. Eur J Oral Sci 2004;112:458–464.

77. Yazici A, Akca T, Ozgunaltay G, Dayangac B. Bond strength of a self-etching adhesive system to caries-affected dentin. Oper Dent 2004;29:176–181.

78. Ito S, Saito T, Tay FR, Carvalho RM, Yoshiyama M, Pashley DH. Water content and apparent stiffness of non-caries versus caries-affected human dentin. J Biomed Mater Res B Appl Biomater 2005;72:109–116.

79. Sakoolnamarka R, Burrow MF, Kubo S, Tyas MJ. Morphological study of demineralized dentin after caries removal using two different methods. Aust Dent J 2002;47:116–122.

80. Yoshiyama M, Tay FR, Doi J, *et al*. Bonding of self-etch and total-etch adhesives to carious dentin. J Dent Res 2002;81:556–560.

81. Komori P, Pashley D, Tjaderhane L, *et al*. Effect of 2% chlorhexidine digluconate on the bond strength to normal versus caries-affected dentin. Oper Dent 2009;34:157–165.

82. Tosun G, Usumez A, Yondem I, Sener Y. Temperature rise under normal and caries affected primary tooth dentin disks during polymerization of adhesives and resin containing dental materials. Dent Mater J 2008;27:466–470.

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