Composite Resins: A Review of the Types, Properties and Restoration Techniques

Abstract: The history, composition, properties and types of composite resins were reviewed. Clinical restorative techniques using composite resins as the filling material are different from those using amalgam. Specific cavity preparation designs, filling techniques, and finishing and polishing procedures are reviewed and discussed. Composite resins should be used with full awareness of their advantages as well as their short-comings and limitations.

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Introduction

According to McLean, the first attempt to develop plastic restorative materials was revealed in the Allied Field Information Technical Report No. 1185, published in 1947. A cold-cured acrylic resin for use in restortive dentistry was developed in Germany(1). The self-cured, unfilled acrylic materials could be placed directly into the prepared tooth. The polymer and monomer were combined and inserted into the cavity where it polymerized. However, these amine-containing resins were not colour stable and turned dark on exposure to sunlight. They also had problems of excessive working time for initial set (1.5 minutes), poor compressive strength, low abrasive resistance, low modulus of elasticity, high water absorption and a polymerization shrinkage of 7% by volume. Their high coefficient of thermal expansion also predisposed them to microleakage and the problems associated with microleakage(2).

In 1958, the first composite resin material, P-Cadwrit, was made available in Germany. In 1959, Bowen filed his first patent in the U.S.A. on the famous Bis-GMA resin. The advantages of composite resins based on Bis-GMA resin over an acrylic resin include: lower polymerization shrinkage, non-volatile, lower exothermic properties, greater compressive strength and less toxic to the pulp(3).

Knight et al developed the urethane dimethacrylates in 1973. A resin was made for use in composite dental materials subsequently which have advantages of higher molecular weight, lower viscosity and less in vivo staining with use than Bis-GMA(1) resins.

Composition of Resins

According to Lutz et al(4), filled restorative resins consist of three-dimensional combinations of a minimum of two chemically different materials with a surface interfacial phase. The 3 phases are: the matrix phase, the surface interfacial phase, and the dispersed phase. Each resin must also include an accelerator-initiator system to begin and complete polymerization. The chemically cured composites generally use an amine-peroxide system, whereas the light-cured resins use a diketone-amine system which is activated by the intense blue light. In addition, pigments and opaquers are added to control transluency and shade.

The resin matrix is a dimethacrylate oligomer such Bis-GMA or urethane-diacrylate. The surface interfacial phase consists of either a bipolar coupling agent to bind the organic resin matrix to the inorganic fillers, or a copolymeric of homopolymeric bond between the organic matrix and partial organic filler. The degree of interfacial adhesion and chemical stability is critical for successful clinical use of any composite resin(5).

Lutz et al(4) classified the dispersed phase based on the three major classes of filler particles used. Traditional macrofillers consist of quartz, glass, borosilicate, and ground or crushed ceramic. The diameter of macrofillers particles range from 0.1 to 100A.055µm. Microfillers are usually pyrogenic silica which are amorphous, finely dispersed particles of about 0.04A.05.5µm in size. The microfiller-based complexes are usually one of three types : (1) splintered prepolymerized particles of 1 to 200A.05 5µm in size, (2) spherical pripolymerized particles of 20 to 30A.055µm in diameter, and (3) agglomerated microfiller complexes of 1 to 25A.055µm in diameter.

Self-cured resins are advantageous where composite-resins need to be placed in areas of the mouth where light cannot reach adequatly(2). However, the visible light-cured resins have many advantages, including: control over the working time, immediate finishing of a restoration and control over the depth of cure. Since no mixing is required, it means easier handling and minimal porosity, The major benefit is that the restoration will be much more colour stable compared to self cured resins. Therefore, the majority of the composite resins now available are light-cured resins(2,6).

Types and Characteristics of Composite Resins

Traditional (large particle-size) compositics

Traditional compsite resins were widely used in the late 1960's and early 1970's. The best known resins of this type are Adaptic (Johnson & Johnson) and Concise (3M). They were chemically cured and were about 70% filled with particles of glass or quartz. The average diameter of these filler particles was about 15µm. The major weakness of these resins was the bond between the dispersed purely inorganic large particles and the organic matrix(5). Clinically the macrofillers fracture and are dislodged selectively from the faster wearing resin matrix. Hence, with clinical wear, they have a poor wear resistance and develop a rough surface which trapped plaque. Colour stability was also poor which caused staining of the restoration.

Although the traditional large particle sized composite resins had served as an acceptable restorative material for Class III and IV restorations for 2 decades, they are now basically obsolete.

Fine-Particle size Composite Resins

This type of comp osite resins contain glass or other filler particles of 1 to 5µm in diameter(2.6) which comprise 70% to 80% of the material by weight(2) Some products may contain a small amount of silica to improve their condensability(6,7). The increased filler content in volume percentage improves the clinical handling characteristics and wear resistance. Most of these resins are visible light cured. Compared to the large-particle composite resins, they provide a smoother restorative surface with less surface degeneration, better color stability and higher strength(5). However, they are still not ideal for the most aesthetic anterior restorations. The relatively large filler particle size limit the degree of polishability and the most highly lusterous surface cannot be obtained. Also, even if an acceptable smoothness is achieved initially, chemical degeneration at the filler-matrix interface would still cause some degree of surface degeneration(5).

Examples of fine-particle anterior composite resins include Prisma-fil (L.D. Caulk), Visio-fil (ESPE - Premier) and Aurafill (Johnson & Johnson) and examples of posterior composite resins include: Estilux posterior (Kulzer), Fulfil (L.D. Caulk and Marathon (Den-mat).

Fine-particle type of composite resins are indicated for use in Classesl, II or IV cavities, and incisal edge restorations in mandibular incisors(2).

Hybrid (Blended) Composite Resins

These are the most recently developed group of composite resins. They contain a blend of microfill and small particles in the range of 0.04 to 5.0µm(6). In addition to colloidal silica, different particles such as barium silicate and borosilicate glasses may also be added as fillers to the hybride composite resins, so as to improve their working properties(5). Well-controlled particle size distribution allow increased filler loading (70% to 87%) for higher strength. The high filler content also results in lower thermal expansion and less polymerization shrinkage. The increase in smaller particles allows improved polishability so that this group of composite resins can be finished to give surface smoothness approaching that of microfilled composites.

Examples of hybrid anterior composite resins include: Command Ultrafine (Sybron/Kerr) and Valux (3M). Examples of hybrid posterior resins include: Occlusin (ICI) and P-50 (3M).

Some companies have claimed that the hybride composite resins they produce can be used for both anterior and posterior restorations. Examples of these so called 'all-purpose composite resins' include: Herculite XR (Sybron/Kerr); Prisma AP.H (L.D.Caulk) and Briliant (Coltene). One of the characteristics of these composite resins is that they have expanded shade ranges. E.g. the Brilliant (Coltene) resins have 8 dentine shades, 6 enamel shades and a grey/blue incisal shade. Herclute XR (Sybron/Kerr), on the other hand, have 6 dentine shades, 6 enamel shades and 2 incisal shades. Prisma AP.H (L.D. Caulk) have a total of 16 shades, including 8 normal shades and 8 accessory shades.

Hybrid composite resins can be used in a wide range of cavities including Classes I, II, III and IV cavities, except where the restoration involves a large labial surface on the anterior and a highly polished smooth surface is required for aesthetic reasons. In those cases, hybride composite resins may not give the best esthetic results.

Microfilled Composite Resins

Homogeneous microfilled composite resins contain 0.02 to 0.07μm pyrogenic silica particles in an organic matrix to obtain a filler content of 38% to 65%(5). To increase filler loading, the resin containing the colloidal silica may be pre-polymerized, ground into particle and incorporated as fillers(6).

Microfilled composite resins can be finished to a high degree of smoothness, and their surface actually become smoother with time. Microfilled resins are very hard and therefore difficult to finish in areas of poor access. However, their tensile strenght is low, they are brittle and should not be used in Class IV stress bearing areas. They are excellent for use in cases where an aesthetic and smooth finish restoration of moderate strength is required. They can be used as a veneering material over cores built-up using fine-particle size composite resins or hybrid resin in large anterior restoration, so that both strength and aesthetics can be optimised. The thermal expansivity and water absorption of microfilled resins are usually higher than those of hybrid and small-particle composite resins, and they normally cannot be syringed(6).

Examples of anterior microfilled resins include : Durafill VS (Kulzer), Heliosit (Vivadent) and Silux-Plus (3M). One example of posterior microfilled resins is Heliomolar (Vivadent) although the manufacturer claims that this product can be used for anterior restorations as well.

Properties Composite Resins

Polymerization Shrinkage

All composite resins contract during polymerization, such contracti on is termed polymerization shrinkage. Polymerization shrinkage of composite resin is important because of its effect on cavosurface margins. It cause separation between a composite resin mass and the adjacent tooth structure. Marginal adaptation of a composite resin restoration is dependent on several factors including: polymerization shrinkage, hygroscopic properties, bonding between restoration material and the cavity walls. coefficient of thermal expansion of the material, and the finishing methods(8-11). It has been demonstrated that despite acid etching of enamel walls, hygroscopic expansion of composite resin, careful finishing procedures, and use of material with thermal expanxivity similar to that of enamel, marginal gaps will still result from polymerization shrink age. Such shrinkage may cause marginal gap formation, or when the enamel - resin bond remains intact, it may result in damage within the composite resin in the form of microcracks which may in turn will dause premature failure of the restoration(12).

The shrinkage properties of a composite resin are dependent on both the physical components of the materials and how the materials are cured and handled clinically. Various composite materials have been shown to exhibit polymerization shrinkage from about 1.5 - 5.5% by vo lume(8). Recent studies report shrinkage of about 1-2% volume for posterior composite resins compared to about 4-5% volume for early conventional composites(13). Incorporation of a high fraction of filler particles along with an appropriate composition of the monomer matrix theoretically would give a composite resin the lowest possible polymerization shrinkage. The amount of volumetric ch ange in posterior composite resins when cured has been stated as one of the main determinants of the longevity of the composite resin restoration.

Water Absorption

The technical properties of composite resins are affected by absorption of water, which acts as a plasticizer and a stress corrosion agent, weakening the particle matrix interface.

Localized swelling occurs at the filler-matrix interface causing debonding, which may lead to hydrolytic breakdown. Break down on the surface of composite resins may also be facilitated by temperature changes and solvent effects. The higher the temperature, the more rapid the water absorption(14). The amount of water absorption in posterior composite resins used today is about 0.2 - 0.6% by weight. Water absorption will lead to breakdown of the composite resin with use.

Wear

Wear may be defined as the unwanted removal of solid material from surface as a result of mechanical action(15). The traditional large-particle size composite resins contain large filler particles which are considerably harder than the resin matrix. During mastication, stresses are transmitted onto the restoration surface and particularly the particles projecting from the occlusal surface. Since the particles ae harder than the resin matrix in which they are embedded, much of the stress is transmitted through the particle into the resin itself. Stress will concentrate and become excessively high where the submerged portion of the particle is angulated or irregular in shape. Such a condition tends to generate small cracks arround the particle, thereby weakening the matrix locally(16). A new generation of composite resins has therefore been developed which contain filler particles of reduced sizes but increased filler loading. The amount of stress around each particle is reduced which result in a significant reduction in loss of anatomical form.

In some composite resins, softer filler particles have been incorporated in order to decrease the difference in hardness between the filler and the matrix. When softer filler particles are used, the masticatory stresses are partially absorbed by the particle, rather than being totally transmitted into the surrounding matrix(12). The use of softer filler particles therefore reduce the likelihood of generating small cracks around the filler and weakening the matrix locally. Scanning electron microscopic examinations of the stress-bearing area reveals that the softer particles actually become worn and polished with wear.

Restorative Techniques

In the past decade, several alternative preparations to the traditional G.V. Black's cavity preparations have been suggested. These alternative preparations are much smaller than the conventional cavity preparation and are termed 'microconservative'(17). The reasons for modifying the cavity design is because the conventional cavity requires unnecessary extension. Extension for prevention is increasingly questioned and this seems unnecessary since fissure sealants are now available. Extention for retention had also become unnecessary since adhesive restoration materials are available. Extension to remove weakened tooth structure is unnecessary since materials like composite resins can provide reinforcement.

With increasing concern about microleakage, there is a desire to reduce the perimeter of a restoration, because the longer the margin, the greater the potential for marginal breakdown and leakage. Futhermore, the newer restorative materials like glass ionomer cements and composite resins require a different approach from that use for amalgam restorations. It is difficult to manipulate composite resins to produce a successful result in the conventional cavity designed for amalgam restorations. It is therefore logical to design a preparation that best suits the restorative material being used.

Hunt(17) proposed an "internal" preparation technique which involved access to the carious lesion form an occlusal approach just inside the marginal ridge, removal of the carious dentine via this occlusal cavity and finally handling the proximal enamel lesion. There are three methods of handling the enamel lesion: (i) punching or drilling out the weakened or porous enamel; (ii) enamal porosity is left intact to avoid trauma to the enamal wall and to retain a shell of porous enamel, allowing for remineralization; and (iii) cut a minibox to remove the porous enamal, at the same time removing the overlying enamal up to and including a portion of the enamal ridge.

Covey et al(18) measured the resistance to fracture of the marginal ridge in teeth prepared with a modified Class II cavity proparation (the internal tunnel technique) which is considered to be weaker than the 'internal' preparation. It was found that teeth prepared with tunnel cavities were understandably weaker than unprepared teeth. However, once the teeth were restored they became no weaker than the unprepared teeth. Covey et al(18), therefore suggested that the restorative materials are capable of re-establishing most of the fracture resistance of the marginal ridge.

Filling Techniques

To minimise the effect of polymerization shrinkage and contraction stresses, there are specific filling techniques proposed for composite resin restorations. Studies have shown that ligh-cured composite resins shrink in the direction of the polymerization light source(12). Contraction towards the light source causes the resin to shrink from margins of the preparation.

Fisbein et al(19) investigated the effect of an incremental filling technique on microleakage around Class II composite restorations in vitro. They believed that curing an increment of a filling gives rise to a smaller contraction th an curing of an entire filling placed in bulk. Part of the space resulting from contraction of the first increment will be filled by the second increment. In addition, if the first increment is placed on the dentine bonding agent at the cavity floor without being anchored on other surfaces, it may be expected to contract toward dentine and not away from it. Asumssen and Munksgaard(20) described a two-step filling technique involving inclining layers. After curing the first inclining layer, a second layer is added and polymerized. It was found that the width and occurence of the marginal gaps was reduced when this technique was used with a variety of dentine adhesives.

Lutz et al(21) proposed the 'three-sited light curing technique' which was used in conjunciton with light - reflicting wedges (Figure 1). It was found that this tech-

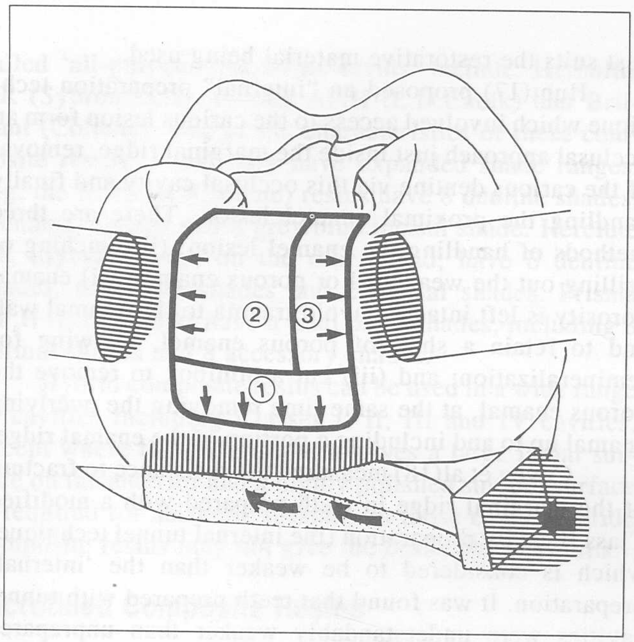

Fig. 1 Three-sited curing technique. The first increment is cured through the light-reflecting wedge; the large second and the smaller third from the buccal and lingual directions in order to ensure that the shrinkage vectors run towards the cavity margins. A fourth increment is added to the occlusal surface. [From Quint Int 1986; 17(2) :778.]

nique, though complex, can minimise the adverse effects of composite resin polymerization shrinkage. Therefore, this was recommended for use in Class II restorations.

It was generally believed that multiple small increments of resins would reduce the polymerization shrinkage stress, minimize post-operative sensitivity or discomfort, and increase the longevity of service of the restoration. However a recent research published by Eakle and Ito(22) showed that although the diagonal insertion technique used in filling mesio-occluso distal cavities produced less microleakage than if fillings were placed in one single increment or in horizontal layer increments, the difference was not satistically significant. They also found that cervical margins that ended on the root surface had extensive microleakage regardless of the filling technique employed. Another study was published by Ciucchi et al(23) which compared the proximal adaptation and the marginal seal of different types of posterior composite resin restorations employing different filling techniques. The three filling techniques they employed included: the three-sited light-curing technique, the multilayer technique and the indirect composite inlay technique. The results did not show statistically significant differences in adaptation or marginal seal among the three composite resin techniques used. They also found that adaptation and seal in composite resin restorations were inferior to those of the amalgam restorations.

Although there are some encouraging research results on the success rates of posterior composite restorations(24), a study using scanning electron micrographic evaluation of the posterior composite revealed that moderate to medium marginal degradation occurred during the first two years of clinical service(25). The later study tested four different light cured posterior composite resins, including: two hybrid composite resins (P - 30, 3M Dental Products Div; Ful-fail, LD Caulk / Dentsply Int.), one microfilled composite resin (Heliomolar, Vivadent Inc.), and a two-component system with a hybride base and a macrofill occlusal material (Estilux-Posterior, Kulzer Co). It was concluded that the use of these products should be limited to selected cases in which esthetics is of primary concern.

Finishing and Polishing

According to Farah et al(26), initial reduction should be done using 25-45μm diamonds (e.g . MF1/MF2, Premier Dental Products Co.; ET fine diamonds, Brasseler USA, Inc.), in a high-speed handpiece running at 1/3 to 1/2 full speed with water/air coolant spray and light sweeping motion. A 10 - 25A.055m diamond bur (e.g. MF3, Premier Dental Products Co.; E T extra fine diamonds, Brasseler USA, Inc.; and T & F Hybrid Points, Shofu Dental Corp.) should then be used again in a high-speed and piece running at 1/3 to 1/2/ full speed with water / air coolant spray and a light sweeping motion. Sof-lex (3M Dental Products) medium, fine and superfine disks should be used where access permits, and finally Quasite Midi-Points (Shoufu Dental Corp.) used to obtain a final luster.

Pratten and Johnson(27) evaluated the various finishing instruments used on a highly-filled posterior composite and a blend anterior composite. They found that the same finishing instruments and techniques revealed no significant differences in the surface roughness of the anterior and posterior composite resins. The smoothest surface was achieved with Mylar matrix strips; and the smoothest instrumented surface was achieved with a series of abrasive disks. Although a fine diamond bur with 25A.055μm particles produced the roughest surface, and estra-fine diamond with 15A.055μm particles produced a surface smoothness superior to that produced with a white stone and similar to the smoothness produced with a carbide bur and rubber points.

It has been speculated that the wear rate of a composite resin restoration may, in part, be attributed to the mechnaical finishing procedures done after insertion and polymerization(28). Specifically, it was postulated that the rapid rotating blades of the finishing instrument gene rated numerous microcracks in the subsurface. Such a condition would weaken the surface superficially, making it less resistant to wear. Ratanapridakul et al[24] investigated clinically the effect of finishing on the wear rate of a posterior composite resin. They found that the elimination of conventional finishing procedures on the occlusal surface resulted in a substantial reduction in wear. Therefore, careful contouring of the composite resin before light-curing, so as to minimise the need of finishing and polishing, would help to reduce wear to the restoration during service.

Conclusions

The types and characteristics of composite resins and their properties, and the modified cavity preparations, filling techniques and finishing and polishing procedures of composite resin restorations have been reviewed and briefly discussed. During the last decade, composite resins have been used more frequently in the posterior region of the mouth. More and more patients are now demanding nonmetallic restorations for esthetic reasons and because of concerns about alleged but unsubstantiated mercury toxicity. At present, they do not completely replace amalgam and other metallic fillings. However, with proper selection of cases and the exercise of due care in their manipulation and placement they should help to provide aesthetic and functional restorations for both the anterior and posterior teeth.

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