

## **RESIN COMPOSITES**

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A composite is defined as a combination of two or more chemically different materials with a distinct interface between them and having properties better than those of the components acting alone.

Resin composites generally consist of three primary ingredients: an organic resin matrix; inorganic filler particles; and a coupling agent. Other ingredients include color stabilizers, inhibitors, pigments, and an activation system.

#### **Composition**

1. Organic Resin Matrix - The organic resin matrix is a high-molecular-weight monomer such as bisphenol A glycidyl methacrylate (bis-GMA) or urethane dimethacrylate. bis-GMA, which stands for 2,2-bis[4(2-hydroxy-3-methacryloxypropoxy) phenyl]-propane, is an aromatic methacrylate developed by Rafael Bowen of the National Bureau of Standards in the early 1960s; terminal methacrylate groups provide sites for free radical polymerization; it sets to a relatively rigid polymer because it has two benzene rings near its center.

Two disadvantages of bis-GMA are its questionable color stability and high viscosity; high viscosity is the result of its -OH groups which hydrogen bond; to lower the viscosity, manufacturers add low-molecular-weight (low-viscosity) monomers like triethyleneglycol dimethacrylate (TEGDMA) and ethyleneglycol dimethacrylate (EGDMA); these reduce the bis-GMA's viscosity, increase crosslinking, and increase hardness.

Another monomer frequently used as the matrix for resin composites is urethane dimethacrylate. This monomer was introduced in 1974 and is a brittle material with low viscosity.

No study has shown bis-GMA based resins to be superior to UDMA-based ones.

2. Inorganic Fillers - Filler particles vary from material to material but may be colloidal silica, barium silicate, strontium/borosilicate glass, quartz, zinc silicate, or lithium aluminum silicate; each has its own distinctive characteristics: colloidal silica particles have a diameter less than 0.1 micron, are inert, have low coefficients of thermal expansion, and improve condensability and polishability;<sup>1</sup> barium silicate has

medium hardness and is very radiopaque; quartz is very stable but is hard to polish and can wear the opposing dentition.

The most commonly used filler material throughout the 1970s was quartz because of its chemical inertness and high refractive index; its disadvantages included a lack of radiopacity, a high coefficient of thermal expansion, and abrasiveness.

Polishability of a resin composite is affected by the filler particle size. Generally, the smaller the average particle size, the easier it will be to polish the resin.

The physical properties of the resin are affected by the amount of filler in the resin composite. Within practical limits, the greater the percentage filler content, the better the physical properties (because there is less matrix). For example, coefficient of thermal expansion, water sorption, polymerization shrinkage decreases while modulus of elasticity, tensile strength, and fracture toughness increase. The fracture toughness increases because the filler particles divert cracks and more load needs to be applied to get the cracks to move.

Percentage filler content of a resin composite may be expressed in terms of weight or volume; percentage filler by weight is usually greater than percentage by volume; percentage filler content is perhaps best expressed in terms of volume because the mechanical properties of resin composites are mainly dictated by their filler volume fraction.<sup>2</sup>

Various ways exist to classify filler particle sizes. One method is using the terms "macro," "midi," "mini," and "micro."

- Macro fillers -- 10 to 100 microns
- Midi fillers -- 1 to 10 microns
- Mini fillers -- 0.1 to 1 micron
- Micro fillers -- 0.01 to 0.1 micron
- Nano fillers -- 0.005 to 0.01 micron

3. Coupling Agents - The primary purpose of bonding filler particles to the organic resin matrix via the silanating agent is to improve the resin composite's physical properties. The silane agent does this by preventing hydrolytic breakdown along the filler/matrix interface which may result in cracking of the resin and by allowing stress transfer between the filler and matrix. The most common coupling agents or silanating agents used for bonding filler particles to the matrix are the organosilanes; the most common organosilane is gamma-methacryloxypropyltrimethoxy-silane.

This silanating agent is a bifunctional molecule; the silane group on one end bonds to the hydroxyl groups on the filler particles via a condensation reaction that produces a siloxane bond. The methacrylate group on the other end undergoes addition polymerization with the resin composite during light- or chemical-activation of the resin.<sup>3</sup>

The silane agent does not homogeneously cover the filler particles.

#### 4. Other Ingredients -

A. Polymerization Initiators - For chemically-activated resin composites, benzoyl peroxide and tertiary amines serve as the source of free radicals. Tertiary amines such as N,N-dimethyl-p-toluidine and N,N-dihydroxyethyl-p-toluidine are used, the latter more commonly than the former because the former caused discoloration. For light-activated resin composites, a diketone photoactivator is used, such as camphoroquinone, in conjunction with a tertiary aliphatic amine, such as 4-N,N-dimethylaminophenethyl alcohol.<sup>4</sup>

B. Polymerization Inhibitors - Because dimethacrylate monomers can polymerize spontaneously under normal storage conditions, inhibitors are added, such as the monomethyl ether of hydroquinone. Hydroquinone itself had been used, but it was found to cause discoloration.<sup>4</sup> Other inhibitors include monomethyl ether of hydroquinone and butylated hydroxytoluene.

C. Ultraviolet Radiation Absorbers - These are added to improve color stability by absorbing electromagnetic radiation that can cause discoloration. The most commonly used absorber is 2-hydroxy-4-methoxy benzophenone.<sup>4</sup>

### **Types of Direct-Filling Resin Composites**

This classification of resin composites is based on filler particle size. Four types exist:

- Traditional (Conventional)
- Small Particle Macrofilled (Fine Particle)
- Microfilled
- Hybrid (Blend)

#### 1. Traditional Resin Composites (Conventional)

--filled 70% to 80% by weight (60% to 70% by volume)  
with 20- to 50-micron-size filler particles

--disadvantages: roughness, staining, discoloration  
--discoloration occurs because of the presence of tertiary amines which are converted by ultraviolet light into yellowish quinones; usually occurs at the 18- to 24-month point

--surface roughness increases with the lifespan of the material because of the "plucking" effect caused by loss of

filler particles from the matrix

--are very infrequently used today because of their poor polishability and tendency to stain and discolor

--are also known as large particle macrofilled resins

--examples: Adaptic (J&J), Concise (3M ESPE)

## 2. Small Particle Macrofilled Resin Composites (Fine Particle)

--filled 70% to 80% by weight with 1- to 5-micron-size filler particles

--good compressive and tensile strengths, fracture resistant, polish nicely

--examples: PrismaFil (Caulk), Command (SDS/Kerr)

These resin composites are recommended for large (2 mm or larger) diastema closures and for Class IV restorations because of their good strength properties.

## 3. Microfilled Resin Composites

--filled 35% to 50% by weight with prepolymerized 0.02- to 0.04-micron-size silicon dioxide filler particles

--polish to high luster and produce excellent esthetic results

--should not be used in heavy stress-bearing areas because they frequently exhibit marginal chipping and bulk fracture

--because of their low fracture toughness, they should not be used for Class IV lesions

--physical properties in general are inferior to those of the small particle macrofilled (fine particle) resins because of their lower percentage filler content; exceptions are their compressive strength which can be relatively high and two-body wear resistance; compared to other resin composites, the microfilled resins have higher coefficients of thermal expansion, greater water sorption, greater polymerization shrinkage, lower moduli of elasticity, lower tensile strength, and lower fracture toughness; some researchers believe that the lower modulus of elasticity (i.e., greater flexibility) of microfills makes them a good choice for Class V lesions where tooth flexure may occur; failure of microfilled resin composites often occurs at the interface between the prepolymerized filler particles and the matrix because bonding at this interface is frequently poor; they also exhibit a reduced depth of cure compared to small particle macrofills or traditional resin composites.

--examples: Filtek A110 (3M ESPE), Heliomolar RO (Ivoclar Vivadent), Epic-TMPT (Parkell), Durafill VS (Heraeus Kulzer), Renamel Microfill (Cosmedent), Matrixx AM (Discus Dental), and Amelogen Microfill (Ultradent)

Because the filler particles in a microfilled resin are so small,

they have from 1,000 to 10,000 times as much surface area as filler particles in conventional resins; the increased surface area must be wetted by the resin matrix and this results in a significant increase in viscosity; this increase in viscosity limits the percentage filler content of the resin to about 35% to 50%; in an attempt to maximize filler loading while minimizing increase in viscosity, prepolymerized silicon dioxide particles are used. This process involves the addition of 0.04-micron-size silicon dioxide particles to a heat polymerized resin in concentrations of up to 60% by weight. Following polymerization, the monomer is ground into 5- to 50-micron size pieces which, along with more 0.04-micron silicon dioxide particles, are added to the resin matrix. This effectively maximizes percentage filler content and minimizes increase in viscosity. The weak link in microfilled resins is the bond between the prepolymerized filler and the organic matrix.<sup>5</sup> This makes them subject to bulk fracture under high-load conditions.

#### 4. Hybrid Resin Composites (Blend)

- filled 70% to 80% by weight with 0.04-micron and 1- to 5-micron-size filler particles; average particle size is usually about 0.6 microns; note that some researchers make a distinction between hybrids and microhybrids (hybrids having an average filler particle size of 1 micron or greater, and microhybrids having an average filler size of less than 1 micron)

- are usually radiopaque

- physical properties are intermediate to those of conventional resins and small particle macrofilled resins

- fracture resistant

- examples: Herculite XRV, Prodigy (SDS/Kerr), TPH Spectrum (Caulk), Filtek Z250 (3M ESPE), Renew (Bisco), Synergy (Coltene Whaledent), Virtuoso (Den-Mat), Vitaescence (Ultradent), Charisma (Heraeus Kulzer), Palfique Estelite (J. Morita), Glacier (Southern Dental Industries), and Venus (Heraeus Kulzer).

#### **Acid Etching Technique**

The concept of bonding resins to enamel was first conceived in the late 1940s and early 1950s by the Amalgamated Dental Company in London. The first bonding agent was called Sevriton Cavity Seal and was developed in the late 1940s by Dr. Oskar Hagger at Amalgamated Dental. Dr. Michael Buonocore specifically developed the acid etching technique using 85% phosphoric acid ( $H_3PO_4$ ) in 1955, however Silverstone refined the process using a 35% concentration. The basic concept of etching prior to adhesive applications was one that was adapted from industrial situations where paints are applied to metal surfaces.

Purposes:

1. increases surface energy which promotes wetting and adhesion
2. chemically cleans the tooth structure which also promotes wetting and adhesion
3. creates micropores for micromechanical retention

The aim is to cause maximum enamel dissolution with minimum precipitation of calcium phosphate salts.

Work has been done to determine the most effective concentration of phosphoric acid for etching. Some researchers have suggested that concentrations of phosphoric acid >30% are most effective because concentrations <27% result in formation of a dihydrate salt of calcium (calcium phosphate dihydrate) which is difficult to rinse from the enamel surface and may prevent the resin from penetrating into micropores.<sup>6</sup> In fact, maximum calcium dissolution has been shown to occur with 30% to 40% concentrations of phosphoric acid,<sup>7</sup> however other investigators have found that concentrations <30% do not adversely affect bond strength.<sup>8,9</sup>

Other acids including pyruvic<sup>10</sup> and nitric<sup>11</sup> have been tested and found to be effective etchants.

Standard acid etching of enamel involves the application of 37% phosphoric acid for 15 seconds with a 15-second rinse and a 15-second drying; research indicates, however, that a rinse time as short as 1 second may be used without adversely affecting bond strength.<sup>12</sup>

Etching for 15 seconds produces bond strengths equal to those produced by 60-second etching<sup>13</sup> and does not adversely affect the degree of leakage.<sup>14</sup>

If the etched area becomes moisture contaminated, re-etch for 10 seconds to prevent reductions in bond strength which occur with contamination;<sup>15</sup> these reductions can be on the order of 50% to 70%.

The depth of enamel dissolution caused by acid etching is approximately 10 to 15 microns.

Little correlation exists between resin tag length and enamel/resin bond strength.<sup>16</sup>

Although liquid etchants produce a more uniform etch and a greater number of tags than do gel etchants, no difference in

bond strength has been demonstrated between the two.<sup>17,18</sup>

Three different etching patterns may occur when phosphoric acid is applied to the enamel surface (the pattern depends upon the specific location on the tooth that is etched):

- Type I     The cores of the enamel rods are preferentially dissolved
- Type II    The peripheries of the enamel rods are preferentially dissolved
- Type III   Delineation of the enamel rods is not evident

Beveling the enamel margins of anterior resin composite preparations is recommended prior to etching to:

1. reduce microleakage
2. improve esthetics: by gradually blending the resin composite into the enamel
3. increase bond strength: transversely-cut enamel, when etched, provides a stronger bond to resin composite than etched, longitudinally-cut enamel.<sup>19</sup> This occurs because the end of enamel rods are more completely exposed to the etchant and, therefore, more effective etching is accomplished and more retentive tags are produced.<sup>20</sup>

### **Polymerization Methods**

1. Chemically activated: these resins are two-paste systems, with one paste containing the tertiary amine activator and the other containing the benzoyl peroxide initiator; because they are hand spatulated, they contain porosity due to air incorporation.
2. Ultraviolet light activated: these resins contain benzoin methyl ether and tertiary amines which, when activated by ultraviolet light, produce free radicals. The first commercially-available light-activated restorative resin was an ultraviolet light-activated one called Nuva Fil, introduced by Dentsply in 1972. It polymerized by exposing it to the Nuva Light, a handheld ultraviolet light-producing unit. There were some concerns with this light, however, that led to the development of alternative light sources. It was believed that the ultraviolet light might adversely affect the vision of dental staff members and that it might selectively alter the existing oral microflora. Two practical problems also existed. First, the light had a limited depth of cure, because the ultraviolet light did not penetrate the resin very deeply. Secondly, the light could not be used immediately after the base unit was turned on because it needed time to warm up.
3. Visible light activated: these resins contain a camphoroquinone (0.25%) photoinitiator and a tertiary amine in a

single paste. Camphoroquinone has an absorption spectrum of from 450- to 500-nanometer wavelength, with a peak absorption at 470 nm.<sup>21,22</sup> When exposed, the camphoroquinone is converted into an excited triplet state. In this state, it collides with an amine molecule, withdraws electrons from the amine, and converts itself and the amine into free radicals. These then initiate the polymerization process. The tertiary amine is known as a coinitiator, which is a compound that does not absorb light but interacts with an activated photoinitiator to produce the reactive free radicals. Inhibitors are also present to enhance ambient light stability.

Conventional light curing units use halogen bulbs to produce white light that is filtered to allow only blue light (i.e., generally in the wavelength range of from 400- to 540-nanometer) to pass through the tip. Within the last few years, some companies have marketed halogen light units that cure resins by initially emitting a low-intensity light followed by a higher intensity. Often called soft-start polymerization lights, they are purported to enhance the marginal quality of restorations because the resin polymerizes slower at first than it does with standard halogen light units. This permits the resin to flow during polymerization, minimizing stress development at the bonded margins. Three types of soft-start halogen lights are sold: Stepped Cure, Ramped (or Exponential) Cure, and Pulse Delay Cure. Stepped Cure lights employ a period of low-intensity irradiance (usually 100 or 200 mW/cm<sup>2</sup>) followed immediately by a period of high intensity (i.e., 600 to 800 mW/cm<sup>2</sup>). Ramped Cure units start at a low intensity and ramp up to a final high intensity. Pulse Delay Cure lights emit a short period of low-intensity light to which the last increment of the composite is exposed. Then the restoration is allowed to remain undisturbed, usually for three minutes. During this time, finishing and polishing may be done. A final exposure is then performed using the standard higher intensity (i.e., 600 to 800 mW/cm<sup>2</sup>).

High-intensity (i.e., 1000 to 2000 mW/cm<sup>2</sup>) light units have recently been marketed that purportedly are capable of curing resin composites more quickly than traditional halogen lights. Examples include plasma arc curing units and argon lasers. Plasma arc lights use a xenon bulb that contains two tungsten electrodes across which a voltage potential is created. This ionizes a surrounding gas (plasma) which produces a spark and, in turn, white light. The light is filtered to allow only blue light to pass through the unit's liquid tube. Argon laser units emit blue light with a very narrow wavelength. These units use a fiberoptic cord for light transmission. One potential disadvantage of the high-intensity lights is that they may

polymerize resins too quickly, which could lead to greater gaps at the bonded margins.

The latest development in light curing has been the marketing of units that use light-emitting diodes (LEDs). Commercially-available units include the NRG (Dentsply/Caulk), e-Light (GC America), Elipar FreeLight (3M ESPE), and L.E.Demetron I (Kerr/Demetron). These lights have several purported advantages compared to traditional halogen bulb units. First, LEDs emit light of a narrow bandwidth. Blue LEDs (which use gallium nitride as the light-producing semiconductor) produce only visible light in the 450- to 490-nm wavelength range, with a peak of 460 nm.<sup>23</sup> This is ideal for materials using the most common photoactivator, camphoroquinone. Because they emit light of a narrow bandwidth, LED curing units have lower power requirements which means they can run on rechargeable battery power. This enables manufacturers to make some of them cordless, relatively small, and portable. Also, the bulb life of LEDs is at least ten times longer than halogen bulbs (i.e., halogen bulbs last about 100 hours while LEDs last for several thousand hours). Filters, reflectors, and bulbs in halogen units degrade with use, which reduces intensity output. This does not happen with LED units. In fact, LEDs used in dentistry do not require a filter. Finally, LED lights produce less heat. It is important to note that because LEDs produce light of a narrow bandwidth, materials using photoactivators with absorption spectra outside the LED bandwidth will not cure properly.

#### **Advantages of Visible Light-Activated Resin Composites**

1. longer working time
2. shorter chair time
3. greater degree of polymerization
4. reduced porosity
5. greater color stability
6. reduced waste of material

Possible disadvantages of visible light-activated resins compared to chemically-activated ones are nonuniform polymerization secondary to limited depth of penetration by the curing light and difficulty in delivering light to recessed areas of the preparation.

When resin composite polymerizes, it does so so quickly that some polymer molecules have unreacted carbon double bonds at their ends; unreacted monomer is also trapped inside the polymer matrix; degree of conversion (DC) tells you how much reacted versus unreacted material exists.<sup>24</sup> In other words, DC is the percentage of carbon double bonds converted to single bonds as a

result of the polymerization process.

DC of a light-activated resin's double bonds is affected by several factors, including the resin's percentage volume filler content and average filler particle size. As percentage volume filler content increases, DC decreases.<sup>24</sup> As size of the filler particles decreases, DC decreases, probably because the large surface area presented by the many small filler particles causes light scattering that reduces light intensity.

DC is also affected by the duration of exposure of the resin to the curing light. Increased curing time results in increased conversion rates.<sup>25</sup>

Finally, research indicates that the DC of bis-GMA resins is affected by the amount of TEGDMA present. As TEGDMA concentration increases, the DC increases, probably because TEGDMA increases the mobility of molecules (and therefore their reactivity).<sup>26,27</sup>

The DC of the methacrylate's double bonds and the double bonds in diluents such as TEGDMA is important to the resin's physical properties; as conversion rates increase, tensile strength, compressive strength, transverse strength, and hardness increase. Fracture toughness also increases<sup>28</sup> and wear decreases<sup>24</sup> with increased DC. A conversion rate of from 44% to 74% has been reported for several posterior resin composites.<sup>29</sup> Other sources give conversion rates for resins that range from 55% to 75%.<sup>30,31</sup> The minimum degree of conversion necessary for a clinically successful restoration has not yet been determined. A minimum of 55% has been suggested for the occlusal surfaces of resin restorations, however, based on abrasive wear data.<sup>32</sup>

Following light activation, resin composites continue to undergo polymerization for up to 24 hours.<sup>33</sup> Recent research indicates that this dark cure can be quite extensive, with as much as from 19% to 26% of the final conversion occurring from 5 minutes to 24 hours after light activation.<sup>34</sup> TEGDMA is considered by some researchers to be the main factor affecting post-irradiation polymerization of bis-GMA resin composites.<sup>35</sup> Research indicates that the amount of TEGDMA affects the amount of post-irradiation polymerization: as the TEGDMA concentration increases, the amount of post-irradiation polymerization decreases because TEGDMA causes higher initial degrees of conversion by increasing molecular mobility (and reactivity).<sup>25,26</sup>

Storage of a resin composite in dark and under refrigeration prolongs shelf life by slowing decomposition of the peroxide

initiator.

Principles of proper polymerization technique:

1. incremental addition of the resin composite
  - ensures completeness of polymerization which reduces residual monomer and prevents loss of the material due to uncured resin in retentive areas
  - reduces polymerization shrinkage stress which can cause microgap formation and lead to leakage
  - place the occlusal increment first followed by the gingival increment; one study found that this sequence of placement results in significantly less gingival margin leakage<sup>36</sup>
2. resin layer should not exceed 2 mm in depth especially when microfilled resins or resins of a darker shade are being used; 1-mm-thick layers should be the goal
3. wand tip should be within 1 mm of the resin
4. minimum of 40-second exposure time (note, however, that some resin composites have recently been introduced that can be cured in a 2.5-mm thickness using a 20-second light exposure)
5. if polymerizing a resin through tooth structure, use an exposure time that is 2 to 3 times as long as the one you would normally use.

### **Resin Composite Roughness**

Traditional resin composite materials are rough because the matrix is reduced during finishing which exposes large, rough filler particles; this rough surface becomes rougher with time as the matrix continues to wear and the filler particles are lost, producing voids in the matrix.

Microfills, on the other hand, contain filler particles much smaller than the abrasive particles and are finished flush with the matrix; this produces a smooth surface, even as wear occurs and filler particles are lost with time; the resultant voids in the matrix are so small that they are not detected as rough areas.

### **Resin Composite Finishing**

Excess resin at a margin can easily be removed with a scalpel or 12-fluted finishing bur. For hybrids, polish with carbide finishing burs like Brasseler's ET (esthetic trimming) burs. Microfills should be polished with 25- and 45-micron diamond finishing burs like Premier's MFS (Micron Finishing System) burs. Use of carbide burs with microfills can lead to marginal chipping, crazing, and fractures.<sup>37</sup> For both types of resin composites, finish the polishing procedure with an accepted product such as 3M ESPE's Sof-lex discs and strips. Use with water, a water soluble lubricant, or unfilled resin so that if a

void is uncovered the uncontaminated surface can be repaired.

Several manufacturers (in addition to 3M ESPE) market finishing/polishing systems for resin composites; the following is a discussion of products from Shofu and Caulk.

Shofu's Super-Snap Buff Disc and Buff Mini-Disc System: these discs are used with latch-type, slow-speed handpieces. The discs are covered on one side with a velvet jeweler's polishing cloth material while the reverse side is covered with aluminum oxide for polishing lingual surfaces. The discs are used with Shofu's CompoSite polishing paste for polishing resin composites or with Ultra II paste for polishing porcelain. The CompoSite paste contains submicron-size aluminum oxide particles while the Ultra II paste contains 2- to 4-micron-size diamond particles. Shofu also markets the Super-Snap Rainbow Technique Kit which contains discs of four different grits (coarse, medium, fine, superfine). The color-coded discs do not have a metal hub center and the metal shaft of the mandrel is covered by the cup. This helps prevent inadvertent marring of the restoration. The discs come in a multi-compartment plastic tray which also contains polishing stones and interproximal finishing/polishing strips. The product is Shofu's answer to 3M ESPE's Sof-lex system.

Caulk's Enhance Composite Finishing and Polishing System: consists of finishing discs, points, and cups, polishing cups, Prisma-Gloss paste (containing 1-micron aluminum oxide particles) and Prisma-Gloss Extra fine paste (containing 0.03-micron aluminum oxide particles). The system is recommended for polishing both microfilled and hybrid resin composites. Following gross reduction with appropriate burs, the finishing procedure continues with abrasive-impregnated rubber discs, cups, and points. This is followed by use of a foam polishing cup with the Prisma-Gloss paste. The paste is initially used alone and then with a drop or two of water. This completes the polishing procedure for a microfill resin. For hybrids, polish next with the Prisma-Gloss Extra fine paste applied to the cup. Continue polishing and add a few drops of water. The polishing should only take 20 to 30 seconds.

### **Polymerization Shrinkage**

Resin composites undergo volumetric shrinkage of from 1.6% to 5.7% during polymerization due to monomer shrinkage; most values are between 1% and 3%;<sup>38,39</sup> microfills and hybrids shrink by about the same amount (3%).<sup>35</sup> One would expect microfills to shrink more than hybrids because they contain less filler and more matrix, however they do not because of their prepolymerized filler particles.<sup>23</sup> Although it has long been believed that the

light-activated resin closest to the light polymerizes first, recent work indicates that boundary conditions such as shape of the preparation and quality of the bonded resin/tooth interface have more of an effect on shrinkage direction than does location of the light.<sup>40</sup> Similarly, although it has long been taught that chemically-activated resins polymerize primarily toward the center of the restoration, research indicates this may not necessarily be true. Boundary conditions also greatly influence the direction of shrinkage of chemically-activated resins, and these may cause the resin to polymerize toward the bonded margins.<sup>39</sup> Others believe chemically-activated resins polymerize first at the bonded resin/tooth interface because the resin there is accelerated in its polymerization by heat from the tooth and, possibly, by components from the dentin bonding agent.<sup>41</sup>

The most detrimental effect of shrinkage is microgap formation, especially where the resin composite margin is on dentin or cementum. Leakage may occur at this gap resulting in sensitivity, recurrent caries, staining, and even pulpitis and necrosis.

### **Posterior Resin Composites**

#### *Advantages Compared to Amalgam*

1. esthetics
2. low thermal conductivity
3. mechanical adhesion to tooth structure
4. no mercury or galvanism
5. conserves tooth structure
6. may strengthen tooth structure
7. high early strength
8. easily shaped prior to polymerization

#### *Disadvantages Compared to Amalgam*

1. technically demanding
2. time consuming to place
3. microleakage
4. post-treatment sensitivity
5. excessive wear

#### *Requirements for a Successful Posterior Resin Composite*<sup>23</sup>

1. restoration is not in occlusal contact
  2. isthmus is less than 1/3 of bucco-lingual intercuspal dimension
  3. cusps are not involved
  4. margins are in enamel
  5. treatment area must be isolated well
- (As you can see, relatively few posterior restorations meet these criteria)

To a great extent, wear has been eliminated as a problem with posterior resin composites. Research indicates that wear of some current posterior resin composites when used in conservative preparations ranges from 2 to 10 microns per year,<sup>42</sup> values similar to those reported for amalgam.<sup>43</sup> Several studies, in fact, have shown that current-generation posterior resins exhibit wear rates similar to that of amalgam.<sup>44,45</sup>

It is important to know that resins wear differently depending on average filler particle size. For example, supramicron resin composites (i.e., resin composites with an average filler particle size greater than 1 micron) wear more, wear in a decreasing fashion with regard to time (with 75% of their three-year wear occurring in the first year), and they wear uniformly over the entire surface.

Reasons for the decreasing rate of wear with supramicron resin composites:

1. high early forces generated between the opposing tooth and the restoration
2. stresses generated during finishing procedures cause cracks in the matrix which result in initially high wear rates

Submicron resin composites (i.e., resins with an average filler particle size less than 1 micron) wear differently than supramicron resins. Submicron resins wear less, they wear linearly with respect to time, and they wear in a localized pattern (especially in centric holding areas). They are also prone to bulk fracture in areas of high stress, probably because the prepolymerized filler particles are often poorly bonded to the organic matrix.<sup>23</sup>

The lower wear rates exhibited by current posterior resin composites compared to earlier resins are a result of compositional changes made in the resins by their manufacturers and greater awareness by clinicians of the role that case selection plays in the successful use of these resins.

Compositional changes made by the manufacturers have included higher percentage filler loading, a decrease in filler particle size, better silane coupling of the filler particles to the resin matrix, and the use of softer filler particles.

Softer filler particles such as barium glass (KHN 400) are used instead of silicon dioxide (KHN 600); this helps the filler particles to absorb some of the masticatory stresses instead of directing them to the surrounding matrix which can cause cracks

to develop with loss of the filler particles.

While compositional changes helped to reduce wear, proper case selection remains a major factor in further reducing wear of these materials. Posterior teeth to be restored with resin composites should be located as far anteriorly as possible in the posterior quadrant, the preparations should be as narrow buccolingually as possible, and contacts should be kept on tooth structure and off the resin composite.

Hybrid resins are favored over microfills for posterior use because even though current research has shown greater wear rates for hybrids compared to microfills,<sup>46</sup> microfills exhibit greater localized wear, marginal chipping, and are susceptible to bulk fracture in areas of high stress. In short, hybrid resin composites are universal resins; they work equally well in anterior and posterior teeth locations. Microfills are best used in clinical situations where a smooth, esthetic surface is necessary and/or a more flexible restoration would be beneficial (i.e., abfraction lesion).

### **New Classes of Resin Composites**

Within the last few years, several new types of resin composites have been introduced to the market. Whether these products actually constitute a new type of material is debatable, however they are being marketed and classified as such, so it is important to be aware of them. The new classes are: packable (condensable) composites, universal composites, reinforced microfills, and nanofilled composites.

#### *Packable (Condensible) Resin Composites*

A number of problems have been associated with using resin composite for posterior restorations, including staining, marginal ditching, post operative sensitivity, increased wear compared to metallic restorations, and difficulties in obtaining adequate interproximal contacts. In an effort to overcome these problems, manufacturers have developed a subset of posterior resin composites called the "condensible" or "packable" resin composites which they market as amalgam alternatives. The preferred term for these resin composites is "packable" rather than "condensible," because during placement, they are simply being packed rather than condensed. Currently there are several packable resin composites on the market: SureFil (Dentsply/Caulk), ALERT (Jeneric/Pentron), Solitaire 2 (Heraeus Kulzer), Prodigy Condensible (SDS/Kerr), Filtek P60 (3M ESPE), Tetric Ceram HB (Ivoclar Vivadent), and Pyramid (Bisco). First marketed in 1998, they purportedly have several characteristics that make them esthetic alternatives to amalgam. First, their

manufacturers claim they can be placed into a preparation and condensed as if they were amalgam. In fact, they are still resins and handle like resins, but do resist packing to an extent because they are filled with either fibrous (ALERT), porous (Solitaire 2), irregularly-shaped (SureFil) filler particles, or different sizes of particles (Pyramid). In an attempt to make them appear to be similar to amalgam, some of the resins (e.g., ALERT, SureFil) are packaged in blister packs that differ by spill size. SureFil also comes with an amalgam carrier that the clinician uses to place it into the preparation. All the products can be packed with amalgam condensers and are used with traditional metal matrix bands and wooden wedges. Because they are more viscous and stiff than standard resin composites, it is a bit easier to achieve acceptable interproximal contacts with them compared to traditional resin composites. One study found they resisted condensation more than conventional composites but less than amalgam.<sup>47</sup> Wear rates are supposedly similar to that of amalgam (about 3.5 microns/year), however, it should be noted that a study presented at a recent dental research meeting found a much higher wear rate for Solitaire (a previous version of Solitaire 2).<sup>48</sup> Another study of five packable resin composites showed wear rates similar to those of nonpackable composites.<sup>49</sup> Again, Solitaire had poor wear resistance. The manufacturers claims notwithstanding, the packable resin composites exhibit properties that are no better than those of a typical microhybrid.<sup>(50)</sup> For example, they are no harder, shrink about the same amount or slightly more, and must be incrementally placed and light activated. Also, they cost at least as much or more than many current resin composites. Perhaps the most troubling claim made for these products by their manufacturers is that they can be placed in bulk (usually 5-mm thicknesses are cited) and light activated because they shrink less than other resins. It is important to note that none of these products can be adequately polymerized to a 5-mm depth.<sup>51</sup> To their credit, Bisco and 3M ESPE do not recommend bulk placement.

#### *Universal Resin Composites*

These products are purported by their manufacturers to have the physical and mechanical properties of a hybrid, along with the esthetics and polishability of a microfill. As such, their manufacturers claim they obviate a clinician's need for a separate hybrid and microfill. Examples of these products include Esthet-X (Dentsply/Caulk), Point 4 (SDS/Kerr), and Filtek Supreme (3M ESPE). They tend to come in a broad range of shades (from 22 for Point 4 to 31 for Esthet-X) and different degrees of translucency, to emphasize their esthetic capabilities.

### *Reinforced Microfills*

Perhaps in an attempt to compete with the universal resin composites, manufacturers of microfills have introduced the reinforced microfills. These composites generally have a higher percentage filler content than traditional microfills and because of this, it is claimed that they are appropriate for posterior as well as anterior use. Products include Micronew (Bisco) and Heliomolar HB (Ivoclar Vivadent).

### *Nanofilled Resin Composites*

These products are different from other types of composites in that they contain nano-sized fillers. One such product is Filtek Supreme, introduced in early 2003. Supreme purportedly uses unique nanofiller technology; it is formulated with nanomer and nanocluster filler particles. As a result, Supreme is claimed to combine the strength of a hybrid and the polish of a microfill, a claim similar to that made by manufacturers of universal composites and reinforced microfills. Supreme's nanomers are discrete nonagglomerated particles 20 to 75 nm in diameter. Nanoclusters are loosely bound agglomerates of nano-sized particles. The agglomerates act as a single unit, the company claims, enabling high filler loading (79% by weight) and giving the composite high strength. Supreme comes in 30 different shades in 4 opacities (dentin, body, enamel and translucent). Most shades contain a combination of non-agglomerated 20-nm-size nanosilica filler and aggregated zirconia/silica nanocluster (primarily 5- to 20-nm size) filler. The cluster particle size ranges from 0.6 to 1.4 microns. The combination of nanomer-sized particles and the nanocluster formulations reduces the interstitial spacing of the filler particles. This reportedly provides increased filler loading, better physical properties, and longer retention of surface polish compared to composites containing only nanoclusters.

### **General Information**

The best predictor of a resin composite's wear is its fracture toughness.<sup>23</sup>

Translucency of a resin composite depends on two factors:

--the indices of refraction: if the index of refraction for the matrix matches the index of refraction for the filler, the resin composite will appear translucent. If not, light will be scattered and the resin composite will appear opaque.

--particle size: if the filler particle size is close to that of the wavelength of light, the particles will absorb light and the resin composite will appear opaque.

### *Shelf Life*

Shelf life is the length of time (from the date of manufacture) that a material retains the physical and mechanical properties necessary to accomplish its prescribed purpose.<sup>52</sup>

Research has found that when refrigerated, a chemically-polymerized resin composite retained its clinical efficacy past seven years; if stored under uncontrolled conditions, physical properties deteriorated after four years. Specifically, working and setting times increased while hardness, strength, and rigidity decreased.<sup>53</sup>

A visible light-activated resin composite showed no changes in its physical properties after seven years, regardless of storage conditions.<sup>53</sup>

A study using two resin composites (Durafill and Z100) found that their shades poorly matched the Vita shade guide tabs to which they were indexed. The authors concluded that it is better to use the resin composite manufacturer's guide or a custom shade guide when selecting a shade of resin.<sup>54</sup>

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