Direct Esthetic
Restorative Materials
Direct Esthetic Restorative Materials

For a filling material to be used as a direct esthetic restorative material, it should have the following Requirements:

1. Matching the tooth in color, translucency and refractive index.
2. Should not stain or discolor by time.
3. Should not be irritant to the pulp or gingiva.
4. Should have adequate mechanical properties. (Strength, E and abrasion resistance).
5. Should not dissolve or erode in saliva or oral fluids.
6. Matching $\alpha$ to enamel and dentin.
7. Should undergo minimal dimensional changes on setting.
8. Should attain and maintain smooth surface finish.
9. Should be radio-opaque.
10. Should have good adhesion to enamel and dentin.

However, there is no single material that satisfies all these requirements.

Four types of materials have been developed for use as direct esthetic restorative materials:

I. Silicates. *(Historical)*
II. Unfilled acrylic resins. *(Historical)*
III. Resin-based Composites.
IV. Glass ionomer cement.
I. Silicate Cements

Silicates were introduced as filling material for anterior teeth since 1903.

**Properties:**

1. Biological effect:
   a. **Pulpal reactions** may occur due to:
      - The lower initial pH.
      - The heat evolved during setting.
      - The arsenic present content as impurity.
   b. **The main advantage** of silicate as direct restorative materials was the *fluoride release* from the mix, which provided an *anticariogenic effect*. Fluoride uptake by the enamel adjacent the restoration reduces the enamel solubility.

2. Solubility:
   One of the chief *disadvantages* of silicate cements is that they *erode* in oral fluids as it is highly soluble.

3. Esthetics:
   Initially, silicate restorations have *excellent aesthetic properties* and can match the tooth color well. However, after a period of time, silicates become stained, particularly if the surface has been roughened by erosion.

4. Bonding:
   No true adhesive bond is formed between a silicate cement and enamel and dentin.

II. Unfilled Acrylic resins

Acrylic restorative resins were unfilled low molecular weight polymers, less susceptible to fracture, less soluble in oral fluid and more color stable than silicate materials.

**Composition:**

*Powder:* Polymethylmethacrylate together with initiator (benzoyl peroxide) and pigments.

*Liquid:* Methyl methacrylate together with the chemical activator (dimethyl para toluidine) and an inhibitor (hydroquinone) to prevent polymerization on storage.

**Disadvantages:**

1. The monomer can penetrate the dentinal tubules and cause *pulpal irritation*.
2. **Mechanical properties** are poor so they were only used for classes III and V
3. **Esthetics:** Initially excellent esthetics can be achieved; however, over a period of time, *staining* is evident at the *cavity margins* due to their thermal properties.
4. **Thermal properties:** The coefficient of thermal expansion is different from that of the tooth structure, at least *seven to eight times more than enamel and dentin*. This lead to a process termed *percolation*. This will cause staining at the cavity margins and recurrent caries.

**N.B.** Early clinical failure of this material was related directly to dimensional instability (high polymerization shrinkage and thermal dimensional changes).
III. Dental Composites

**Definition:**
A composite is a combination of two or more chemically different materials with a distinct interface separating the components and having properties, which could not be achieved by any of the components alone.

**Indications and uses:**
2. Core build ups.
3. Pits & fissures sealants.
4. Resin cements
5. Direct veneer material.

**Composition:**
1. Organic matrix phase.
2. Inorganic filler phase.
3. Coupling agent.
4. Initiator activator systems.
5. Inhibitors.
6. Ultraviolet stabilizers.
7. Pigments.

### 1. Organic matrix phase:

*a. Principal high molecular weight viscous monomer (oligomer):*

The majority of the materials are based on either Bisphenol A-glycidyl methacrylate (Bis-GMA), which is called Bowen's resin, or urethane dimethacrylates (UDMA). In some products mixture of the two oligomers is present.

These oligomer products are superior to methyl methacrylate monomers by:
1. Lower polymerization shrinkage (due to higher molecular size and less double bond available).
2. Lower volatility (due to its chemical structure).
3. More rapid hardening.
4. Production of stiffer and stronger resin due to higher molecular weight and more cross-linkage.

The UDMA are superior to Bis-GMA by:
1. Lower viscosity.
2. Lower water sorption.
4. Greater susceptibility to visible light curing.

*b. Diluent (lower molecular weight monomers):*

These monomers are included in composite formulations to reduce the viscosity of the material to enable proper blending with the inorganic constituents, and to facilitate clinical manipulation. The monomer of choice may be diethylene glycol dimethacrylate (DEGDMA) or triethylene glycol dimethacrylate (TEGDMA).
2. Inorganic fillers (reinforcing fillers):

The dispersed inorganic phase may consist of several inorganic materials such as quartz, borosilicate glass, lithium aluminum silicate, barium aluminum silicate, strontium or zinc glass, or colloidal silica. The heavy elements contribute to radiopacity. Recently calcium fluoride has also been used as filler.

**Role of inorganic fillers:**

- Improvement in **mechanical properties** such as compressive strength, modulus of elasticity and hardness. The filler in a composite must be in high concentration to achieve good mechanical properties.
- Reduction in **coefficient of thermal expansion**.
- Improved **workability** by increasing viscosity.
- Glass is able to reflect the color of the surrounding tooth material so the filler contributes to the **esthetics**. The refractive index should match that of the organic matrix to secure translucency.
- Reduction in the **polymerization shrinkage**.
- **Less heat** evolved in polymerization.
- The composite is **radiopaque** if barium or strontium glasses are used.

**Filler particle size and shape:**

The filler particle size, shape and distribution have an important effect on the properties.

1. **Conventional macrofilled composites:**

   Historically, early composite (conventional) contained large (20-30μm) spherical particles then products containing large irregular particles come out. Irregular particles have better mechanical retention to the resin. The disadvantage of conventional composites with large filler particles are:

   a. Discoloration and staining tendencies as wear of the organic matrix occurred and particles were dislodged leaving a rough surface.
   b. There was difficulty in finishing and polishing such composites.

   Due to the drawbacks of the early conventional macrofilled composites, current composites are:

2. **Fine composites:** with smaller filler particles (0.5-3μm). They have good mechanical properties and can be finished and polished to a smooth surface.

3. **Microfine composites:** (0.04-0.2μm). They have a perfect surface quality but they have poor mechanical properties.

   The microfine particles may be smaller than the wavelength of light and thus give lustrous surfaces on finishing.

4. **Blend (hybrid) composites:** Containing mixture of fine and microfine fillers. They have high mechanical properties as fine composites and perfect surface finish as microfine composites.

   Attempts to combine the advantage of **fine-microfine particles (high mechanical properties with good surface finish)** led to the development of **hybrid composite** containing significant amounts of microfine fillers and major amount of fine silica or glasses with fine particles (1-5μm). Filler loading up to 70% by volume (88% by weight) was achieved.
3. Coupling agents:
For reinforcement of the polymer by the inorganic filler to occur, it is important that the two constituents should be bonded together. To achieve this, the filler is usually treated with a vinyl silane compound. This compound has two functional groups, an inorganic group that react with the filler and an organic group that react with the organic matrix; thus the filler and matrix are coupled.

Role of a coupling agent:
- **Binds** the inorganic filler with the organic matrix phases
- **Improves** the mechanical properties of composite by transferring the stresses from the weak resin to the stronger filler.
- **Reduces early loss of the filler particles** caused by penetration of water between the resin and filler.

4. Initiator activator systems:
Polymerization of composites is achieved by chemical or light activation, with the latter being more common.

a. **Chemical activation (two pastes system):**
   One paste contain the initiator usually benzoyl peroxide. The other paste contains the activator usually a tertiary amine, which leads to better color stability than dimethyl- P-toluidine.

b. **Light activation (light curing or photo-initiated composites):**
   By the use of visible light radiations (blue light wave of about 470 nm)
   The visible-light cured materials are supplied as one paste system. They usually contain a diketone such as benzyl or camphorquinone and an aliphatic amine activator.

Advantages of light cured materials over chemically cured resin:
1. The light activated materials are single component pastes that required no mixing, thus
   - eliminating human variables.
   - Eliminate air bubble formation (affect strength and esthetics).
2. Control working and setting time.

However the depth of cure is dependent on several variables such as:
1. The characteristics of the light source e.g. a new bulb would give the highest intensity.
2. The distance between source and composite resin surface (note that light intensity varies as the inverse square of the distance).
3. The time of exposure.

N.B. Care should be taken to avoid unpolymerized material in the base of cavities or undercuts. Therefore, directing the light from both sides of an anterior restoration or building up by layers (increments of 2 mm) may be advisable. Composite resin, which is not fully polymerized, will show reduced mechanical properties, poorer color stability and greater susceptibility to stain.
5. **Polymerization inhibitors:**
Since dimethacrylate monomers will polymerize on storage, an inhibitor is necessary to prevent hardening on storage. **Hydroquinone** had been widely used. Few parts per million of this product is required.

6. **Ultraviolet stabilizers:**
Ultraviolet stabilizers are incorporated to absorb electromagnetic radiation to prevent yellowing of the set composite filling and improve color stability.

7. **Pigments:**
Inorganic pigments are added in small amounts so that the color of the composite matches the natural tooth structure.

**Classification of composites:**
Composites may be classified according to particle size, shape and distribution or according to the methods of activation.

1. **Classification according to particle size, shape and distribution:**
   a. Macro filled composite
   b. Fine composite.
   c. Microfine composite.
   c. Hybrid composite products.

<table>
<thead>
<tr>
<th>Type</th>
<th>Range of particle size (µm)</th>
<th>% of filler (by weight)</th>
<th>General comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large particle</strong></td>
<td>20-35</td>
<td>78</td>
<td>Difficult to polish, surface roughness on abrasion of resin matrix may attract plaque, good mechanical properties.</td>
</tr>
<tr>
<td><strong>Fine particle</strong></td>
<td>0.5-3</td>
<td>70-86</td>
<td>Good mechanical properties with superior finishing and polishing characteristics than the above.</td>
</tr>
<tr>
<td><strong>Microfilled</strong></td>
<td>0.04-0.2</td>
<td>25-63</td>
<td>Easy to obtain and maintain smooth surface finish, which does not attract plaque. However mechanical properties are poorer; wear resistance may be poor; also greater shrinkage on setting and more absorption of water owing to lower filler content.</td>
</tr>
<tr>
<td><strong>Hybrid</strong></td>
<td>0.04 and 1-5</td>
<td>77-88</td>
<td>Developed in an attempt to obtain the benefits of both types of filler.</td>
</tr>
</tbody>
</table>

**N.B.**
- The conventional early types, which are not manufactured nowadays, are mentioned only for comparative reasons.
- Recently, **Nano-filled** composites (2-75 nm) have been developed with superior esthetics and mechanical properties.
2. **Classification according to the method of activation:**
   - b. Light cured materials.
   - c. Some types of composite resin polymerize by both mechanisms and are termed *dual cure* resin.

**Properties:**

1. **Biological considerations:**
   Composites are superior to silicate cements and unfilled acrylics in terms of pulpal irritation. However, plaque can accumulate on a rough composite surface.

2. **Solubility:**
   Composites have a very low solubility. It is markedly lower than the solubility of unfilled acrylic due to loss of residual monomer from acrylics. In composites, polymerization leads to a more cross-linked structure with less residual monomer.

3. **Water sorption:**
   Is less than that of unfilled acrylics due to the higher molecular weight and more cross linkage of the BIS-GMA, or UDMA and good adhesion between the polymer matrix and the inorganic filler. Water sorption of the fine and hybrid composite is less than microfine types.

4. **Thermal properties:**
   - a. **Thermal conductivity:** The thermal conductivity values are lower than those for metallic restorations and closely match those of enamel and dentin. Therefore, composites provide good thermal insulation for the dental pulp.
   - b. **Coefficient of thermal expansion:** The higher the amount of organic matrix, the higher the linear coefficient of thermal expansion since the polymer has a higher value than the filler. As a result, the microfilled composites have the highest values for thermal expansion (55-68 X 10^-6). Consequently, restorations from these composites will have a greater change in dimensions with changes in oral temperatures and probably will have more marginal leakage than fine and hybrid (25-38 X 10^-6) composites. Also, *thermal stresses*, which are cyclic in nature, are more in microfilled because of the higher coefficient of thermal expansion. These stresses may cause fatigue of the material and early bond failure.

5. **Polymerization shrinkage:**
   Composite materials undergo shrinkage during polymerization. Shrinkage is a direct function of the amount of organic matrix therefore the polymerization shrinkage of fine particles composite is lower than that of microfine types. This shrinkage creates polymerization stresses between the composite and the cavity of the tooth.

   These stresses, may reach 130 Kg/cm², can lead to failure of the interfacial bond between the composite and the tooth leading to very small gap that can allow marginal leakage of saliva.
The net effect of setting contraction (due to polymerization) can be reduced by:

a. **Incremental addition** (2 mm) of light cure material and polymerization of each increment independently, which allows for some contraction within each increment before successive additions.
b. Directing the light from **both sides** of the prepared cavity (through tooth structure).
c. Obtaining **strong bond** between the composite filling and the enamel and dentin of the cavity.
d. **Composite inlay**: Composite inlay systems are polymerized outside or inside the patient mouth and then removed from the prepared cavity by the help of separating medium. The inlay is then subjected to post-curing by additional light (6 minutes) or heat (about 100°C for 7 minutes), after which the preparation is etched, the inlay is then cemented to the prepared cavity. By this technique the polymerization shrinkage does not occur in the tooth, so the induced stresses and the bond failure are reduced.

6. **Mechanical properties**:
   a. **Compressive strength**: Ranged from 200-340 MPa. Compressive strength of the microfine composite is lower than that of fine and hybrid types.
   b. **Tensile strength**: Of microfine composite 26-33 MPa is only about half those of fine composites (34-62 MPa).
   c. **Modulus of elasticity**: fine composite (from 9000-10,000 MPa), which is two to three times the value for microfine composites.
   d. **Hardness**: Of the fine and hybrid composites (KHN 55-88 kg/mm²) is higher than that of the microfine types indicating more resistance for penetration or indentation under functional stress. This difference in hardness is not an indication of resisting functional wear.
   e. **Wear**: Wear of composite is a complex phenomenon involving abrasion, attrition, and erosion. As a result, no single mechanical property has been predictive of clinical wear.

7. **Esthetic and optical properties**:
   a. Composite materials are **translucent** materials, which can match the color of teeth and have good esthetics.
   b. The materials can be **radiopaque** by the addition of glasses having high atomic numbers such as barium, strontium and zirconium. Radiopacity helps in diagnosis.
   c. Abrasive wear may lead to surface roughness of the material, because the polymer phase wears more rapidly than harder ceramic fillers. This may lead to **discoloration** with time. However, microfine and hybrid types can take and retain smooth surface finish for long periods in the mouth.
   d. **Stress cracks** within the polymer matrix and partial debonding of the fillers as a result of hydrolysis tend to **change the color**.
8. Bonding and retention to tooth structure:
   a. Bonding to enamel:
      - Bonding is obtained by micromechanical retention to acid-etched enamel.
      - After acid etching and washing of enamel, bonding agent is applied to penetrate sufficiently into the etched areas, to produce a good bond.

   Effect of acid etching on enamel surface:
   1. Removal of surface debris.
   2. Producing pores (micropores) for micro-mechanical interlocking.
   3. Increase surface energy of enamel.
   4. Increase surface area exposed to the bonding resin.

   b. Bonding to dentine:

Smear Layer:
Thin tenacious adherent layer develops during cutting or grinding of tooth structure after cavity preparation. It’s formed of:
- Dentin chips.
- Saliva.
- Bacteria.
- Collagen.
- Blood.

Conditioning → primer → bonding agent

The aim of bonding to dentin is to obtain what’s called “HYBRID LAYER” which is “Resin-reinforced dentin layer”.

Resin dentin bonding agents are now available; they are used like enamel bonding agents to provide micromechanical retention resulting from good wetting and penetration of the bonding agent into dentin. Bonding agents usually consist of a bi-functional monomer with hydrophilic groups to improve wetting to dentin, and hydrophobic groups to polymerize with the composite.