Part II
National Board Review
Operative Dentistry-Biomaterials
Structures, chemical properties, physical properties

BASIC CONCEPTS ON HOW DENTAL MATERIALS WORK!

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Clinical judgement and choices are based upon knowledge… not luck! Knowledge of the chemical and physical properties of restorative materials help in making judgements in treatment planning and selection of materials.
Ideal restorative material

Why knowing biomaterials is important…
Dentistry is filled with choices… Your choices

• bondable (adhesive to tooth)
• smooth surface
• tooth colored
• wear resistance
• fracture resistant
• excellent marginal adaptation

• biocompatible with pulp and gingival tissues
• caries inhibiting
• easy to place
• easy to repair
• coefficient of thermal change equal to tooth
Chemistry, the basics

- Acid-base reactions result in the formation of a salt compound. Examples in dentistry
  - Inorganic acid-base reaction, e.g., zinc phosphate cement
  - Organic reaction acid-base reaction, e.g., glass ionomer

Mixing a resin modified glass ionomer cement
Chemistry, the basics

- Polymerization reactions
  - polymer is a molecule or group of molecules with repeating single units that are covalently bonded
  - single units are monomers
  - two or more different monomers \(\rightarrow\) copolymer
  - monomers with two carbon double bonds \(\rightarrow\) cross linked polymers

Linear polymer

Linear copolymer
Chemistry, the basics

- Most dental restorative polymers have cross linked components for durability
- Examples of polymers: composite resin, PMMA, addition cured silicone impression materials

Cross-linking of polymer
Specifics for Polymers

- **Degree of conversion**: degree to which monomer becomes polymer

- **Polymerization shrinkage**: polymers shrink when curing (composite resin by 3-5%)
  - depends on amount of filler
    (more filler → less shrinkage)
  - depends on degree of conversion
    (more conversion → less shrinkage)
Chemistry, the basics

• Precipitation reactions
  – liquid becomes a solid due to loss of solvent e.g., cavity varnish (Barrier or Copalite) hardens (sets) as it dries and loses solvent
  – some adhesive primers lose solvents and leave a resin residue impregnating the the dentin tubules.
Chemical setting reaction for silver amalgam

Alloy powder is contacted by mercury liquid to initiate the reaction

$$\text{Ag}_3\text{Sn} + \text{Hg} + \text{Ag}_3\text{Cu}_2 \rightarrow \text{Ag}_2\text{Hg}_3 + \text{Cu}_6\text{Sn}_5 + \text{Ag}_3\text{Sn}$$

(eutectic)

This is a complex reaction between particles and mercury completed by a final crystallization process that takes place over several hours and involves multiple types of solid solutions.

Examples of amalgam alloy powder

Spherical particle alloy

Dispersed phase alloy
Amalgam setting reaction

The complex amalgam setting reaction occurs over an extended period of time. Amalgam is condensed during the first 3-4 minutes of the setting reaction; then carved over the next 5 minutes of the setting reaction; and finally occlusion checked 10 minutes after the start of the mix. The amalgam reaches its near final physical properties 24 hours after placement.

Amalgam restorations are susceptible to fracture within the first 2-3 hours after placement.
Stresses
Applied forces that result in mechanical deformation

- Tensile
  - forces that resists deformation when loaded

- Compressive
  - forces that resist load to compress or shorten

- Shear
  - stress that resists twisting motion or sliding motion
Tensile forces that resist deformation when loaded; tensile forces resist being pulled apart.

Arrows describe vector of force.
Tensile strength

- Amount of force a material can be stretched before breaking. **Difficult to measure.** If materials are not pulled apart at exactly 180 degrees other forces come into play (shear)
- Diametrical tensile strength—usually used in dentistry because it is easier to perform by measuring compressive strength of disc of material

Composite resin fractured due to tensile failure
Compressive:
forces that resist load to compress or shorten; when compressed the material is compacted until it is crushed.

Arrows describe vector of force
Compressive strength

- Amount of force that can be supported before breaking. There has been no direct correlation between clinical performance and compressive strength. This value is used because it is easy to measure.

Compressive strength values are usually high. This can be a misleading number.
Shear
stress that resists twisting motion or sliding motion
Shear strength

- Maximum shear stress that a material can absorb until failure

- Easy test to perform so it is generally used to measure bond strengths with adhesive materials
Peel

• All forces placed at end and the materials joined together are “peeled” apart like a banana.

• Once the material starts to separate (a bond breaks at an end) it continues along the surface breaking the molecules next to it until the bond of the entire piece fails.

• More clinically relevant than tensile
Fatigue: cyclic stressing
How things fail in the mouth

The destructive forces of occlusion

- Fatigue- rigid materials undergo stress and strain. Eventually they break, e.g., amalgam breaks, tooth structure cracks and breaks
- examples of fatigue are small chips of tooth or restorative material; broken denture
- Fatigue is cumulative damage

Fractured porcelain
Fractured incisor
Fatigue within composite resin and porcelain is seen as initial microcracks, crack propagation until catastrophic failure.

Stress concentrations in area of crack.
Stress in areas of crack formation

\[ K = 2 \sqrt{\frac{L}{R}} \]

K = Stress concentration factor by which the mean stress, remote from the crack is multiplied

L = Length of the crack

R = Radius of the crack
Fatigue

- progressive destruction
- cracks form faster in ductile materials, e.g., thermoplastic and metals
- force needed to cause failure decreases over time (explains why restorations do well in function for a long time then break under a small load— the patient was eating white bread or a banana….)

Fractured incisal of porcelain metal crown

Fractured incisal of composite resin
Fatigue failure

- Restorations supported by tooth absorb more stress and strain, e.g., Class I occlusal.
- Restoration areas least supported are more susceptible to fracture, e.g., marginal ridge area of a Class II restoration.

Fracture of distal marginal ridge of silver amalgam.
Fatigue failure can be seen at restoration margins.

In function over time, fatigue will cause restorative materials to develop cracks that develop into fractures. For silver amalgam this is seen when margins develop “ditching.” When the ditching becomes wider it can result in recurrent caries.
What is fracture toughness?

- indication of material’s ability to absorb destructive forces
- stress - amount of force per unit area placed on object
- strain - amount of deformation under stress
- total amount of stress before a material breaks.

Fracture Toughness = area under stress strain curve
Stress-strain relationships are directly affected by the parameters of the tooth preparation and forces placed on the materials in function. Engineering design and material concepts can be used to set limits for specific materials used for clinical restorations.

Fiber reinforced resin bridge
Fracture toughness

Fracture Toughness = area under stress strain curve

METALS > RESINS > PORCELAIN

highest  to  lowest
Elastic limit

• When stressed the material does not return to original shape (length).
• Example is pulling on a metal wire. Let go of the wire it returns to original length. Stretch with more force and it does not return to original shape. Hence the elastic limit.
Stiffness (modulus of elasticity)

• Determines resistance to flexure and deformation.

• Amount of bending when a beam is loaded
Clinical implications of stiffness

The porcelain-metal bridge that has inadequate thin connectors and pontic will flex in function causing the porcelain to fracture and “pop off” the metal framework.
Hardness

• Refers to resistance of a material to being deformed (indented) by a compressive object
• Different tests all use the same concept- Knoop, Brinell, Vickers, and Rockwell hardness test

Resistance to indentation
Wear- how long will the surface last in function?

- Wear is the progressive loss of material due to a relative motion
- related to coefficient of friction
- metals (homogeneous) do better than resins, ceramics and ionomers because they are heterogeneous
- heterogeneous materials develop surface roughness increasing frictional forces
Wear - how long will the surface last in function?

Wear is the progressive loss of material due to a relative motion.

Wear and Abrasion

Frictional motion leads to loss of material on surface.
Types of wear

- adhesive: material lost from shearing points in contact
- abrasive: deformation of softer material removed by harder one (tooth wearing composite resin; ceramic wearing tooth)
- fatigue: removal of material due to cyclical loading
- corrosive: removal due to chemical modification increases wear (acid attack on teeth)
Erosion

- Loss of tooth substance due to chemical attack (no wear)

In truth loss of substance is multifactoral, e.g., acid in lemon attacks and softens dentin on root surface; soft dentin is attacked by abrasive toothpaste
Coefficient of thermal expansion (and contraction)

- relates to marginal leakage to hot and cold foods- tooth expands and contracts at different rates than restorative materials. Also can occur within materials (differences between metal and resin)

- The greater the difference in coefficient of thermal expansion between tooth and restorative material the more leakage. Leakage can lead to sensitivity and recurrent caries.
Coefficient of thermal expansion (and contraction)

- Amount of expansion and contraction in relationship to temperature
- Can contribute to restoration marginal leakage and staining and potentially recurrent caries

Marginal staining at cervical region of Class V composite resin
Water sorption

- The ability of a material to pick up (absorb) water.
- As water is absorbed, material expands.
- Water sorption also degrades a material (usually a polymer); polymer, e.g., composite resin will deteriorate over time.
Fluoride release
vs.
Fluoride containing

A restorative material can contain fluoride but the fluoride is not useful because it is bound up in the restorative material and not available to be released to surrounding tooth structure so that it can be protective to potential future caries. Dental materials that contain fluoride that is available to be released and is useful to caries prevention. An example of a dental material with fluoride release with accompanying protection is a glass ionomer.
Contact angle and wetability

• A measure how a fluid wets a solid; the ability of an adhesive to penetrate enamel and/or dentin.
• The better wetting (contact angle less than 90 degrees the greater the penetration of resin)
Adhesive penetration

• A low contact angle and good wetability contributes to the ability of an adhesive to penetrate and bond to enamel and/or dentin

The undersurface of dentin with resin adhesive penetration that demonstrates good surface wetting
Other physical properties

- Toughness
- Brittleness
- Ductility
- Malleability
- Resilience
- Proportional limit
- Elastic limit
- Yield strength
- Modulus of elasticity
Toughness

Energy required to fracture a material. Can be affected by yield strength, tensile strength, percent elongation and modulus of elasticity

Fracture Toughness = area under stress strain curve
Ductility

- Ability to resist tensile stresses and permanent deformation without rupture
- Percent elongation is a measure of ductility and refers to the ability of gold to be burnished.
- Burnishing is the ability to move metal by thinning it out.

Margins of cast gold restorations are burnishable
Malleability

• Ability of material to withstand permanent deformation without rupture under compression

• example, hammering or rolling metal to thin it out.
Brittleness

- the opposite of toughness
- breakage of a material at its proportional limit.
- material has a high compressive strength but low tensile strength, e.g., amalgam (for this reason one does not bevel stress bearing amalgam preparation margins.

Ditched amalgam margins are due to the brittleness of the restorative material.
Proportional limit

The greatest stress which may be produced in a material so that the stress has a direct ratio to the strain. A biomaterial with a high proportional limit has more resistance to permanent deformation. Similar to elastic limit.
Elastic limit

The greatest stress a material can be subjected to so that it can return to its original dimensions when forces are released. Similar to proportional limit.
Yield strength

A stress slightly higher than the proportional limit.
Modulus of elasticity

Rigidity or stiffness of a material (ratio of stress to the strain below the elastic limit.) Related to fracture toughness.
THE UNDERSTANDING OF DENTAL BIOMATERIALS WILL IMPROVE YOUR PRACTICE OF DENTISTRY AND THE SELECTION OF DENTAL MATERIALS USED WHEN TREATING YOUR PATIENTS