OVERVIEW OF BONDING SYSTEMS:

A. Goals of Bonding (and Adhesion):
   1. Sealing
   2. Retention

B. Definitions and Terminology for Adhesion:
   1. Terminology for adhesion:
      a. Adhesive - material forming the layer
      b. Adherend - substrate being bonded
      c. System (EBS, DBS) and agents (EBA, DBA, ABA)
   2. Adhesive systems:
      a. Adhesive layer
         (Adherend/ Adhesive)
      b. Adhesive joint
         (Adherend-1/ Adhesive/ Adherend-2)

<table>
<thead>
<tr>
<th>Bonding system applications</th>
<th>Adherend-1</th>
<th>Adhesive</th>
<th>Adherend-2</th>
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<tbody>
<tr>
<td>Sealant</td>
<td>Enamel</td>
<td>Sealant</td>
<td>-----------</td>
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<tr>
<td>Surface Sealers</td>
<td>Composite</td>
<td>Sealer</td>
<td>-----------</td>
</tr>
<tr>
<td>Enamel bonding system</td>
<td>Enamel</td>
<td>EBA</td>
<td>Composite</td>
</tr>
<tr>
<td>Dentin bonding system</td>
<td>Dentin</td>
<td>Primer-DBA</td>
<td>Composite</td>
</tr>
<tr>
<td>Amalgam bonding system</td>
<td>Enamel/Dentin</td>
<td>DBA</td>
<td>Amalgam</td>
</tr>
<tr>
<td>Composite cement</td>
<td>Enamel/Dentin</td>
<td>BA/Comp/BA Inlays</td>
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<tr>
<td>Crown and Bridge Cement</td>
<td>Enamel/Dentin</td>
<td>BA/Comp/BA Metal/Ceramic</td>
<td>Amalgam</td>
</tr>
<tr>
<td>Orthodontic bonding system</td>
<td>Enamel</td>
<td>Composite</td>
<td>Bracket</td>
</tr>
<tr>
<td>Maryland bridge cement</td>
<td>Enamel</td>
<td>Composite</td>
<td>Metal Alloy</td>
</tr>
<tr>
<td>Porcelain veneers</td>
<td>Enamel</td>
<td>Composite</td>
<td>Porcelain</td>
</tr>
<tr>
<td>PFM repairs</td>
<td>Metal/Porcelain</td>
<td>Composite</td>
<td>-----------</td>
</tr>
</tbody>
</table>

C. Steps in Formation of Good Adhesion (for Retention):

   1. Clean adherend
   2. Good wetting
   3. Intimate adaptation
   4. Bonding
   5. Good curing
D. Bond Strengths (Measure of Destruction of Adhesion): (1 MPa = 145 psi)

1A. Shear Bond Strength (SBS):
- SBS = (1.5-2) x TBS;
- SBS = (1/3-1/4) x μTBS
- Enamel bonding = 18-22 MPa
- Dentin bonding = 10-35 MPa
- Amalgam bonding = 3-22 MPa
- SBS for dentin = 165 MPa

1B. Micro-Shear Bond Strength (μSBS)

2A. Tensile Bond Strength (TBS):

2B. Micro-Tensile Bond Strength (μTBS)

E. Factors determining performance:

1. Operator factors (etching, washing, drying, and bonding techniques)
2. Design (preparation) and Substrate factors (smear layer, moisture content, ...)
3. Materials factors (product, modulus, thickness, ...)
4. Tooth location factors (lesion size and shape, local morphology, flexure, arch)
5. Patient factors (F exposure, diet, age, occlusal stress, ...)

F. Design (functions) of bonding systems (3,2,1-components):

1. Conditioning (clean and/or etch surface for good wetting)
   (a) Phosphoric acid (10%, 35%, 37%)
   (b) Polyacrylic acid, EDTA, Citric acid, Maleic Acid, Pentaerythritol
2. Priming (hydrophilic monomers for interpenetration for micro-mechanical)
3. Bonding (monomers for reaction with other adherend)
REVIEW OF MICROSTRUCTURE OF DENTAL ENAMEL:

Schematic representation of enamel formation during amelogenesis. (A) Ameloblast cell movement away from the DEJ producing enamel prismatic structure in regions behind cells to form enamel prisms. (B) Individual enamel prism with apatite crystals well packed longitudinally within the center of the prism but less-well packed along the peripheries. (Compliments of Scott and Symons) (C) Schematic end-on view of hydroxyapatite crystals packed together in the middle of a prism. (D) Geometry and dimensions of an apatite crystal. (E) TEM of packing arrangement of apatite crystals along tail of one prism (left) and head of another prism (right). (Compliments of Tim Wright, University of North Carolina School of Dentistry) (F) TEM section through tail of enamel rod showing regularity of hydroxyapatite crystal sizes. (G) SEM of enamel prisms at the margin of a cavity preparation.
ENAMEL BONDING:

A. Components:

1. Conditioner (etchant):
   a. 37% phosphoric acid (liquid or gel) -- Buonocore, 1957
   b. (Weaker organic acids such as citric, tartaric, maleic, ...)

2. (Priming Agent and/or) Bonding agent:
   a. Main monomer: BIS-GMA or UDMA
   b. Diluent monomer: TEDGMA
   c. Fillers: None
   (d. Solvents: H₂O, ethanol, acetone)

B. Bonding mechanism:

1. Bonding types:
   a. Physical -- Very weak
   b. Chemical -- None
   c. Mechanical bonding --
      (1) Micro-mechanical between prisms (Macro-tags)
      (2) Micro-mechanical within prisms (Micro-tags)

2. Bond strength notes:
   a. Tag length has no significant effect on bond strength
   b. Moisture interferes with tag formation
   c. Degree of cure affects bond strength
REVIEW OF DENTIN MICROSTRUCTURE:

Schematic representations of dentin formation patterns. (A) Odontoblast cell movement away from the DEJ producing a corresponding tubule pattern in forming dentin. (B) Relative position of original odontoblasts to fully formed dentin. (C) SEM cross-sectional view of primary dentinal tubules in the middle third of human dentin. (Compliments of Stephen C. Bayne, University of North Carolina School of Dentistry) (D) Schematic view of variation in tubule number and size from the DEJ to the edge of the dental pulp. (Compliments of David Pashley, Medical College of Georgia) (E) Freeze-fractured dentin without smear layer (Compliments of Dr. Jorge Perdigao, University of Minnesota)

Smear layer on dentin. (A) SEM view down onto smear layer at bottom of cavity excavation showing dentin smear layer with some loose debris on surface. (Compliments of Stephen C. Bayne, UNC School of Dentistry) (B) High magnification SEM view of smear layer on same surface as 14A showing some cracks within the compacted debris layer. (Compliments of Stephen C. Bayne, UNC School of Dentistry) (C) Cross-sectional view of smear layer (1-to-2 µm in thickness) with smear plugs compacted into dentinal tubule openings. (Compliments of David Pashley, Medical College of Georgia, Augusta, GA)
DENTIN BONDING SYSTEM:

A. Historical development (Generations of DBS = groups with similar designs):

0. Early Generation DBS's (Bonded to Smear Layer):
1. First Generation DBS's (Bonded to Smear Layer):
2. Second Generation DBS's (Modified/Removed Smear Layer):
3. Third Generation DBS's (Modified/Removed SL; Produced HL):
4. Fourth Generation DBS's (Optimized for SL modification + dentin wetting)
5. Fifth Generation DBS's (Reduced-Component Bonding Systems) (Reduced-Component with Self-Etching Primers)
6. Sixth Generation DBS's (True One-Component Bonding Systems)

B. Mechanisms of dentin bonding = micromechanical

C. Hybrid Layer (Interdiffusion Zone, Interpenetration Zone):

1. Schematic of formation of "Hybrid Zone" (Bayne)

2. Pre-impregnation "dehydration effects" on collapse of HZ (Van Meerbeek):

D. Evolution of Components Used for Dentin Bonding System:

1. Shifting to a reduced number of components:

   ![Diagram showing the evolution of components](image)

   **US Companies**
   - 1 = ETCHANT
   - 2 = PRIMER
   - **Bonding Agent**

   **Japanese Companies**
   - 1 = ETCHANT
   - 2 = PRIMER
   - **Bonding Agent**

   

   **ETCHANT**
   **PRIMER**
   **BONDING AGENT**

   **Self-Etching Primer**

   **Total-Etch Systems**
   - **E+nPB + B**
   - **E+nPB**

   **Self-Etch Systems**
   - **nEP+B**
   - **nEPB**

   1. Store in the refrigerator and use quickly.
   2. Use steel or carbide burs (not diamonds) for dentin surfaces to be bonded.
   3. Apply multiple layers and agitate applicator.
   4. SEPs (and SEAs) should be “air dried” >10s, and “not air thinned.”
   5. Consider H$_3$PO$_4$ etch, as well, if significant enamel involved in preparation surfaces.

2. Examples of current dentin bonding system designs:

   **3-COMPONENT SYSTEMS (E + nP + B)**
   - Scotchbond Multipurpose Plus (3M)
   - Permaquick (Ultradent)
   - Bond-It (Jeneric / Pentron)
   - All-Bond 2 (BISCO)
   - Tenure A/B/S (Denmat)
   - ProBond (Dentsply)

   **2-COMPONENT SYSTEMS (E + nPB)**
   - Syntac Single Component (Ivoclar)
   - Ecusit Primer/Mono (DMG Hamburg)
   - One Coat Bond (Collene / Whaledent)
   - Bond-i (Jeneric / Pentron)
   - Tenure Quik with Fluoride (Denmat)
   - Solid Bond (Hereaus-Kulzer)
   - Imperva Bond (Shofu)
   - EG Bond (Sun Chemical)
   - PQ1 (Ultradent)
   - Easy Bond (Parkell)
   - Paama 2 and Stae (SDI)
   - Prime&Bond NT (Dentsply)
   - Single-Bond (3M)
   - Optibond Solo and Solo Plus (Kerr)
   - One-Step (BISCO)
   - Excite (Ivoclar/Vivadent)
   - OSB Bonding System (ESPE)
   - IntegraBond (Premier)

   **2-COMPONENT SYSTEMS (nEP + B)**
   - Clearfil SE Bond & LinerBond 2v (Kuraray)
   - Tyrian SPE (Bisco)
   - Optibond Solo SE Plus (Kerr)
   - Fluoro Bond (Shofu)
   - UniFil Bond (GC)
   - Mac Bond II (Tokuyama)
   - NanoBond (Pentron)

   **1-COMPONENT SYSTEMS (nEPB)**
   - AQBond (Sun Medical)
   - or Touch-and-Bond (Parkell)
   - Adper Prompt or LP3 (3M-ESPE)
   - Solist (One-bottle-bond) (DMG Hamburg)
   - iBond (Hereaus-Kulzer)
   - Xeno III (Dentsply)
AMALGAM BONDING:

A. Components:

1. Enamel/Dentin Bonding System:
   a. Conditioner (or etchant)
   b. Primer
   c. "Thicker" Bonding Agent
2. Amalgam Restorative Filling Material

B. Bonding mechanism:

1. Chemical bonding: None
2. Mechanical bonding:
   a. Enamel and Dentin: Micro-mechanical (macrotags and microtags)
   b. Amalgam: Micro-mechanical (to alloy particles and amalgam irregularities)
COMPOSITE LUTING CEMENT BONDING (Inlays, Onlays, and Crowns):

A. Components:

1. Enamel/Dentin Bonding System
2. Composite Resin Cement
3. Ceramic Bonding System (Etchant and/or Coupling Agent)
4. Ceramic Restorative Filling Material

B. Bonding mechanisms:

1. Bonding types:
   a. Physical (weak and irrelevant)
   b. Chemical (between BA, composite cement, coupling agent, and ceramic)
   c. Mechanical (micro-mechanical also occurs at enamel, dentin, and ceramic)

2. Adhesive Joint Analysis: examine all substrates and interfaces =
   (Enamel or Dentin / Bonding System / Composite Cement / Bonding System / Ceramic or Metal)

C. Composite (Resin Cement) Bonding Systems:

1. Metallic Restorations (Bonding System and Luting Composite)

<table>
<thead>
<tr>
<th>Commercial System</th>
<th>Manufacturer</th>
<th>Bonding System</th>
</tr>
</thead>
<tbody>
<tr>
<td>C&amp;B Metabond</td>
<td>Parkell</td>
<td>None</td>
</tr>
<tr>
<td>CR Inlay Cement</td>
<td>J. Morita</td>
<td>Clearfil Photo-Bond</td>
</tr>
<tr>
<td>Panavia</td>
<td>J. Morita</td>
<td>None</td>
</tr>
<tr>
<td>Panavia 21</td>
<td>J. Morita</td>
<td>ED Primer</td>
</tr>
<tr>
<td>Resinomer</td>
<td>Bisco</td>
<td>All-Bond 2</td>
</tr>
<tr>
<td>Pent-Core Plus (Cement Kit)</td>
<td>Jeneric/Pentron</td>
<td>Pent-Core Plus</td>
</tr>
</tbody>
</table>

(4-META)  (Phosphate)  (Phosphonate)  (MTG-GMA)  (PCDMA, HEMA)

2. Esthetic Restorations (Bonding System, Luting Composite, Coupling System):

<table>
<thead>
<tr>
<th>Adherend</th>
<th>Interface #1</th>
<th>Interface #2</th>
<th>Adherend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel, Dentin, Post and Cement Core, Amalgam/Foundation, Core Post and Core Liner or Base Implants, ZOE, ZOE-EBA, SPC, HEMA, Zinc Phosphate Cement or Polycarboxylate Cement Glass Ionomer Cement Composite (Resin) Cement (with dentin bonding)</td>
<td>Enamel, Dentin, Post and Cement Core, Amalgam/Foundation, Core Post and Core Liner or Base Implants, ZOE, ZOE-EBA, SPC, HEMA, Zinc Phosphate Cement or Polycarboxylate Cement Glass Ionomer Cement Composite (Resin) Cement (with dentin bonding)</td>
<td></td>
<td>Adhesives, Adhesive, Joint</td>
</tr>
</tbody>
</table>
MULTIPLE CHOICE STUDY QUESTIONS: (Answers are bolded)

The principal goal(s) of bonding are:

- a. Sealing and retention
- b. Esthetics and reduction of postoperative sensitivity
- c. Retention and reduction of tooth flexure
- d. Strengthening teeth and esthetics
- e. Sealing and thermal insulation

Which one of the following applications does NOT involve an adhesive joint?

- a. Enamel bonding system
- b. Pit-and-fissure sealant
- c. Dentin bonding system
- d. Amalgam bonding system
- e. Composite cement

Which one of the following applications does NOT involve an adhesive joint?

- a. Surface sealant
- b. Composite resin cement
- c. Dentin bonding system
- d. Amalgam bonding system
- e. Orthodontic bonding system

Which ONE of the following is NOT a major requirement for development of good adhesion?

- a. Clean adherend
- b. Calcium ions present for bonding
- c. Good wetting
- d. Intimate adaptation
- e. Good curing

Dentin bonding systems involve which of the following exclusive joint components?

- a. Adhesive only
- b. Adherend only
- c. Adhesive/adherend
- d. Adhesive/adherend/adhesive
- e. Adherend/adhesive/adhesive

What is 1 MPa equal to in the English system of units?

- a. 145 psi
- b. 195 psi
- c. 225 psi
- d. 445 psi
- e. 999 psi

What is the relationship between standard shear and tensile bond strengths?

- a. Tensile = 2x Shear
- b. Shear = 2x Tensile
- c. Tensile = Shear
- d. Tensile = 4x Shear
- e. Shear = 4x Tensile
What is the relationship between shear strengths and micro-tensile bond strengths?
   a. Micro-Tensile = 4x Shear
   b. Shear = Micro-Tensile
   c. Micro-Tensile = 2x Shear
   d. Micro-Tensile = 10x Shear
   e. Shear = 0.5x Micro-Tensile

What is the typical shear bond strength range for enamel bonding systems?
   a. 2-6 MPa
   b. 6-12 MPa
   c. 12-18 MPa
   d. 10-22 MPa
   e. 22-35 MPa

What is the typical shear bond strength range for newer dentin bonding systems?
   a. 2-6 MPa
   b. 6-12 MPa
   c. 12-18 MPa
   d. 18-22 MPa
   e. 22-35 MPa

Which of the following variables is LEAST important for bonding?
   a. Substrate
   b. Tooth
   c. Material
   d. Patient
   e. Fluoride history

Which category of factors is most important in determining clinical performance?
   a. Operator factors
   b. Tooth factors
   c. Location factors
   d. Materials factors
   e. Patient factors

Which of the following correctly describes the shape of hydroxyapatite crystals?
   a. Cylindrical
   b. Paralleloipipeds
   c. Dodecahedrons
   d. Hexagonal rods
   e. Keyhole shaped tubes

At which location in enamel is the density of enamel crystals the lowest?
   a. Prismless enamel
   b. DEJ
   c. Center of enamel prisms
   d. Edges of enamel prisms
   e. Facial enamel

Which of the following is not a conditioner?
   a. Phosphoric acid
   b. EDTA
   c. Maleic acid
   d. Citric acid
   e. BIS-GMA
What is the principal mechanism for enamel bonding?
   a. Physical bonding
   b. Primary chemical bonding
   c. Hydrogen bonding
   d. Micro-mechanical bonding
   e. Incoherent bonding

In normal dentin, how far does an odontoblastic process extend from the cell?
   a. 10-20 µm
   b. 0.5 mm
   c. 1 mm
   d. Half way to the DEJ
   e. Most of the way to the DEJ

What is the typical volume of dentin occupied by dentinal tubules in the outer third of dentin?
   a. 50%
   b. 40%
   c. 25%
   d. 14%
   e. 5%

What is the principal mechanism for dentin bonding?
   a. Physical bonding
   b. Primary chemical bonding
   c. Hydrogen bonding
   d. Micro-mechanical bonding
   e. Chelation bonding

Which one of the following is most important event for dentin bonding?
   a. Smear layer removal
   b. Smear plug removal
   c. Peritubular dentin decalcification
   d. Intertubular dentin decalcification
   e. Collagen denaturation

What is the hybrid zone?
   a. Decalcified peritubular dentin
   b. Embedded smear layer
   c. Embedded smear plugs
   d. Bonding agent/ composite interface
   e. Embedded smear layer and intertubular dentin

Which of the following terms is not associated with the “hybrid zone”? 
   a. Bonding agent
   b. Interpenetration zone
   c. Resin impregnation zone
   d. Pseudo-chemical bonding
   e. Micromechanical bonding

Which of the following products was the first to represent a 1-component DBS?
   a. Prompt L-Pop
   b. SingleBond
   c. Optibond Solo
   d. One-step
   e. Clearfil Liner Bond
Which one of the following includes a self-etching primer?

a. E+nP+nB  
b. E+nPB  
c. nEP+B or nEPB  
d. E+PB  
e. E+P+B or E+PB

What is the principal monomer in the bonding agent of "amalgam bonding systems" that is responsible for wetting and promoting micro-mechanical bonding?

a. 4-META  
b. HEMA  
c. BIS-GMA  
d. UDM  
e. TEGDMA

What is the most important clinical variable affecting "amalgam bonding" system strength?

a. Conditioning time for enamel  
b. Bonding agent thickness  
c. Type of dental amalgam  
d. Moisture control  
e. Age of the tooth structure

When a ceramic inlay is bonded, which of the following interfaces does NOT involve chemical bonding as part of the joint?

a. Enamel/Bonding Agent  
b. Bonding Agent/Composite Cement  
c. Composite Cement/Coupling agent  
d. Coupling Agent/Ceramic

When a ceramic inlay is bonded, which of the following do NOT involve micro-mechanical bonding in the joint?

a. Enamel/Bonding Agent  
b. Dentin/Bonding Agent  
c. Bonding Agent/Composite Cement  
d. Composite Cement/Ceramic