After reading this chapter, the student should be able to:

1. Describe the types of silver alloy used for amalgam in terms of copper content and particle shape, and explain the clinical consequences of using these different alloy types.

2. Define precapsulated amalgam and its advantages.

3. Describe the amalgamation reaction in terms of the compounds formed and metallurgical symbols.

4. Explain why $\gamma_2$ is important to the clinical performance of amalgam. Explain how $\gamma_2$ has been eliminated in modern amalgam.

5. Describe how manipulation of amalgam affects its strength, dimensional change, creep, and corrosion.

6. List the goals of proper condensation of amalgam into a cavity preparation and why these goals are important clinically.

7. List steps the dental team can take to limit the exposure of the patient and dental personnel to mercury and mercury vapor.

8. Understand the rationale for limiting the patient’s and dental personnel’s exposure to mercury and cite the maximum vapor allowed by the Occupational Safety and Health Administration (OSHA).

9. Describe the clinical advantages of bonding amalgams to tooth structure.
An amalgam is a solution of any metallic element in mercury. Dental amalgam is a mixture of a silver alloy with mercury. When the silver alloy, which is a powder comprised of silver, copper, and tin, is mixed with mercury, which is a liquid, a chemical reaction ensues that forms dental amalgam. A freshly mixed mass of amalgam has a puttylike consistency for 4 to 5 minutes. During this time, the amalgam is packed into a cavity preparation in a tooth and carved to the desired shape (Figure 5-1). In the following minutes to hours, the amalgam reaction proceeds, reaching maturity in about 24 hours.

On a global scale, amalgam restorations still account for a significant portion of all dental restorations. However, because of their gray color, these restorations are limited to the posterior teeth where esthetics is not a clinical concern. Currently, more esthetic ceramics or direct resin composites are increasingly substituted for dental amalgam, even in posterior teeth. However, these alternative materials have clinical problems such as expense, shorter longevity, and technique sensitivity in placement.

**Key Terms**

- Admixed alloy
- Amalgam
- Amalgamation
- Condensation
- Creep
- Dental amalgam
- Dimensional change
- Trituration
- Gamma-2 ($\gamma_2$)
- Precapsulated
- Silver alloy
- Trituration

**FIGURE 5-1** Overview of placement of amalgam restorations. A silver alloy is mixed in a capsule with mercury for approximately 10 seconds. The mixed amalgam has a puttylike consistency that permits it to be condensed into a cavity preparation and then carved back to appropriate contours within 4 to 5 minutes. The strength of the amalgam increases rapidly but does not reach full strength for at least 24 hours.
Amalgam remains a viable clinical choice where longevity, ease of placement, and clinical performance are paramount, especially when clinical conditions are challenging.

Silver Alloys for Dental Amalgams

Historically, the silver alloy used in dental amalgams had low (2 to 4 wt. %) amounts of copper. However, the development of silver alloy with higher (13% to 30%) copper has replaced low-copper alloys because high-copper alloys produce amalgams with higher strength, less corrosion, and better longevity at the margins (edges of the cavity preparation). The range of compositions of high-copper silver alloys is shown in Table 5-1. Today’s high-copper amalgams are also essentially free of zinc because zinc causes a significant, long-term, and clinically unacceptable expansion of the amalgam when it is contaminated with moisture on placement.

The particles of the silver alloy powder can be either irregularly shaped or spherical or a mixture of the two (Figure 5-2). The shape of these particles will significantly influence the setting reaction of amalgam. If a mixture of particles is used, the alloy is referred to as an admixed alloy. Admixed alloys produce amalgams that require greater packing or condensation forces during placement than amalgams with spherical particles alone. However, many practitioners feel that admixed amalgams produce better proximal contacts and are easier to carve. Spherical amalgams require less mercury and set somewhat faster. Many practitioners select either a spherical or admixed amalgam, depending on the clinical situation. The importance of proper manipulation of each type cannot be overemphasized. For example, if a condensation force that is appropriate for a spherical amalgam is applied to an admixed amalgam, the restoration will likely contain voids and lack appropriate proximal contacts.

Mercury

Mercury is a dense metal that is liquid at room temperature (density = 13.5 g/ml). Mercury is the only metallic element in the periodic table that is a liquid at room temperature (density = 13.5 g/ml). However, mercury is a toxic substance and should be handled with care. Admixed amalgams produce amalgams with higher strength, less corrosion, and better longevity at the margins (edges of the cavity preparation). The range of compositions of high-copper silver alloys is shown in Table 5-1. Today’s high-copper amalgams are also essentially free of zinc because zinc causes a significant, long-term, and clinically unacceptable expansion of the amalgam when it is contaminated with moisture on placement.

The particles of the silver alloy powder can be either irregularly shaped or spherical or a mixture of the two (Figure 5-2). The shape of these particles will significantly influence the setting reaction of amalgam. If a mixture of particles is used, the alloy is referred to as an admixed alloy. Admixed alloys produce amalgams that require greater packing or condensation forces during placement than amalgams with spherical particles alone. However, many practitioners feel that admixed amalgams produce better proximal contacts and are easier to carve. Spherical amalgams require less mercury and set somewhat faster. Many practitioners select either a spherical or admixed amalgam, depending on the clinical situation. The importance of proper manipulation of each type cannot be overemphasized. For example, if a condensation force that is appropriate for a spherical amalgam is applied to an admixed amalgam, the restoration will likely contain voids and lack appropriate proximal contacts.

Silver Alloys for Dental Amalgams

Historically, the silver alloy used in dental amalgams had low (2 to 4 wt. %) amounts of copper. However, the development of silver alloy with higher (13% to 30%) copper has replaced low-copper alloys because high-copper alloys produce amalgams with higher strength, less corrosion, and better longevity at the margins (edges of the cavity preparation). The range of compositions of high-copper silver alloys is shown in Table 5-1. Today’s high-copper amalgams are also essentially free of zinc because zinc causes a significant, long-term, and clinically unacceptable expansion of the amalgam when it is contaminated with moisture on placement.

The particles of the silver alloy powder can be either irregularly shaped or spherical or a mixture of the two (Figure 5-2). The shape of these particles will significantly influence the setting reaction of amalgam. If a mixture of particles is used, the alloy is referred to as an admixed alloy. Admixed alloys produce amalgams that require greater packing or condensation forces during placement than amalgams with spherical particles alone. However, many practitioners feel that admixed amalgams produce better proximal contacts and are easier to carve. Spherical amalgams require less mercury and set somewhat faster. Many practitioners select either a spherical or admixed amalgam, depending on the clinical situation. The importance of proper manipulation of each type cannot be overemphasized. For example, if a condensation force that is appropriate for a spherical amalgam is applied to an admixed amalgam, the restoration will likely contain voids and lack appropriate proximal contacts.

Mercury

Mercury is a dense metal that is liquid at room temperature (density = 13.5 g/ml). Mercury is the only metallic element in the periodic table that is a liquid at room temperature (density = 13.5 g/ml). However, mercury is a toxic substance and should be handled with care. Admixed amalgams produce amalgams that require greater packing or condensation forces during placement than amalgams with spherical particles alone. However, many practitioners feel that admixed amalgams produce better proximal contacts and are easier to carve. Spherical amalgams require less mercury and set somewhat faster. Many practitioners select either a spherical or admixed amalgam, depending on the clinical situation. The importance of proper manipulation of each type cannot be overemphasized. For example, if a condensation force that is appropriate for a spherical amalgam is applied to an admixed amalgam, the restoration will likely contain voids and lack appropriate proximal contacts.

Silver Alloys for Dental Amalgams

Historically, the silver alloy used in dental amalgams had low (2 to 4 wt. %) amounts of copper. However, the development of silver alloy with higher (13% to 30%) copper has replaced low-copper alloys because high-copper alloys produce amalgams with higher strength, less corrosion, and better longevity at the margins (edges of the cavity preparation). The range of compositions of high-copper silver alloys is shown in Table 5-1. Today’s high-copper amalgams are also essentially free of zinc because zinc causes a significant, long-term, and clinically unacceptable expansion of the amalgam when it is contaminated with moisture on placement.

The particles of the silver alloy powder can be either irregularly shaped or spherical or a mixture of the two (Figure 5-2). The shape of these particles will significantly influence the setting reaction of amalgam. If a mixture of particles is used, the alloy is referred to as an admixed alloy. Admixed alloys produce amalgams that require greater packing or condensation forces during placement than amalgams with spherical particles alone. However, many practitioners feel that admixed amalgams produce better proximal contacts and are easier to carve. Spherical amalgams require less mercury and set somewhat faster. Many practitioners select either a spherical or admixed amalgam, depending on the clinical situation. The importance of proper manipulation of each type cannot be overemphasized. For example, if a condensation force that is appropriate for a spherical amalgam is applied to an admixed amalgam, the restoration will likely contain voids and lack appropriate proximal contacts.

Table 5-1

<table>
<thead>
<tr>
<th>Element</th>
<th>Range of Percentage of Composition by Weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver (Ag)</td>
<td>40-60</td>
</tr>
<tr>
<td>Tin (Sn)</td>
<td>27-30</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>13-30</td>
</tr>
</tbody>
</table>

*Ranges in percentages indicate variability seen among products. Other minor elements, such as indium or palladium, also may be present.
Historically, excess mercury was added to the alloy particles and mixed with a mortar and pestle until the proper consistency was achieved. Then the excess mercury was removed by “wringing it out” with a cheese cloth. This practice was abandoned because of concerns about mercury toxicity and inconsistencies in the amalgam mix. Later, the powder was compressed into tablets of specific mass, and the proper amount of mercury was added with a dispersing device into a reusable mixing capsule. This new method of trituration gave more consistently strong amalgams and reduced the exposure of the dental staff to mercury.

Today, the silver alloy powder and mercury are sealed into a disposable hard plastic capsule (Figure 5-3). The mercury is sequestered by a plastic membrane that is easily ruptured during mixing. Sometimes, a small inert cylinder called a pestle also is added to facilitate mixing. This precapsulated method provides the proper ratio of alloy powder to mercury, limits handling of pure mercury by the dental staff, and keeps the mercury clean. Previous methods of mixing that exposed the mercury to air risked contamination of the mercury with dirt and dust and worsened the physical properties of the amalgam. Precapsulation reduces the risk that mercury vapor will contaminate the dental operatory because the mercury to air.

Precapsulation is purchased sealed in the capsules. The physical and chemical properties of the mixed amalgams also are better and more consistent using this strategy. Today, almost all practitioners use precapsulated mercury and alloy powder.

**Reaction of Silver Alloy with Mercury**

The reaction of the silver alloy with mercury is called amalgamation. Early amalgams were low in copper (2 to 4 wt. %). In these amalgams, the chemical reaction produced a tin-mercury product called gamma-2 (γ2). The current high-copper amalgams have eliminated the γ2 product, which has increased the resistance of these amalgams to corrosion and marginal breakdown of the amalgam in the mouth.

When high-copper alloy particles contact the mercury, they begin to dissolve in the mercury much as sugar would dissolve in water (Figure 5-4). However, the absence of γ2 product is responsible for the longer clinical longevity of high-copper amalgam restorations.

**Figure 5.2** Micrographs of silver alloy particles used in dental amalgam, taken with a scanning electron microscope. Particles may have irregular (A) or spherical (C) shapes or may be mixed together to form “admixed” amalgam (B). Irregular and spherical particles are formed by different manufacturing processes and do not have a uniform size. Each micrograph has a horizontal field of view of approximately 500 μm.

**Figure 5.3** A composite micrograph of silver alloy particles used in dental amalgam. The micrograph has a horizontal field of view of approximately 500 μm. (A) Randomly oriented particles may have irregular or spherical shapes or may be mixed together to form “admixed” amalgam. (B) Spherical and irregular particles may have irregular or spherical shapes. (C) Scanning electron microscope micrographs of silver alloy particles used in dental amalgam, taken with a scanning electron microscope. The particle shapes may have irregular or spherical shapes or may be mixed together to form “admixed” amalgam. (D) Scanning electron microscope micrograph has a horizontal field of view of approximately 500 μm.
from the manufacturer, a strategy referred to as “precapsulated” amalgam.

Today, all capsules come sealed and ready for use. Historically, dentists added silver alloy and mercury to a reusable capsule. Capsule used for triturating (mixing) of amalgam. The capsule is shown assembled as received from the manufacturer and disassembled for purposes of illustration only (bottom). In some capsules, a pestle (middle) is used to mix the alloy powder and liquid mercury together. To separate the liquid mercury before triturating, a small plastic membrane is used in one end of the capsule (not visible).

Once some of the alloy particle has dissolved, new solid products begin to crystallize from the dissolved elements. As this crystallization continues, the amalgam becomes stiffer and eventually hardens completely. The hardening of the amalgam occurs before all of the original alloy particles are dissolved. Thus, the set amalgam contains much of the original silver alloy particles surrounded by several new products (Figure 5-5). The reaction products are collectively called the matrix of the amalgam. In the set mass, the original particles comprise more than 50% of the volume and are important to the

Once some of the alloy particle has dissolved, new solid products begin to crystallize from the dissolved elements. As this crystallization continues, the amalgam becomes stiffer and eventually hardens completely. The hardening of the amalgam occurs before all of the original alloy particles are dissolved. Thus, the set amalgam contains much of the original silver alloy particles surrounded by several new products (Figure 5-5). The reaction products are collectively called the matrix of the amalgam. In the set mass, the original particles comprise more than 50% of the volume and are important to the
strength and corrosion resistance of the amalgam. In the amalgamation reaction shown in Figures 5-4 and 5-5, each of the components of the reaction has a special name. The silver alloy is called gamma (γ), the silver-mercury is gamma-1 (γ₁), and the copper-tin is eta (η). In high-copper amalgams, the products contain no γ₂. The absence of γ₂ is responsible for the superior properties of the high-copper amalgam over low-copper amalgam.

Once the amalgamation reaction is complete, little or no mercury remains unreacted. In its reacted state, mercury is unable to be released from the amalgam. Therefore, little free mercury is available to be released from the set amalgam. This fact is important because free mercury can pose a health risk if it occurs in sufficient concentrations. In practice, minute amounts of mercury vapor (approximately 1 to 2 \( \mu \text{g} \) per day) are released from dental amalgams as a result of chewing. Higher release may occur during the setting reaction, during removal of old amalgams, or if the amalgam is heated above 80°C (Figure 5-6).

To limit mercury release during the setting reaction, new mercury-indium liquid alloys have been substituted for pure mercury. Other “amalgams” have substituted gallium for mercury and are therefore mercury free. However, clinical evidence indicates that these “gallium-amalgams” have far more corrosion in the mouth and are therefore inferior to high-copper mercury-based amalgam.

**Properties of Amalgam**

The properties of amalgam with most clinical relevance include strength, dimensional change, creep, tarnish, and corrosion. These properties are listed for various types of high-copper amalgams in Table 5-2. Several examples of commercial products are listed in Table 5-3.

**FIGURE 5-5 Scanning electron microscopic view of set lathe-cut high-copper admixed amalgam through a scanning electron microscope.** Unreacted silver alloy (γ) particles are visible at A and B. C Denotes areas in the matrix in which new reaction products have formed from the reaction of mercury with silver (to form γ₁) or copper (to form η). The original particles are thus embedded in a “matrix” of the reaction products. The horizontal field of view is approximately 50μm.
Although this treatment of amalgam is not clinically relevant, it illustrates that the mercury normally chemically bound within the amalgam may be released if sufficient heat is applied. For this reason, heat generation should be minimized during the polishing of amalgam.

(Courtesy K. Frazier, Medical College of Georgia, Augusta, GA.)
**Strength**

The strength of an amalgam must resist forces placed on the amalgam restoration in the mouth. Insufficient strength may lead to the bulk fracture or marginal fracture of the restoration. When these types of fracture occur, the amalgam must be replaced. Table 5-2 lists the strength of amalgam at 30 minutes, 1 hour, and 1 day after mixing. Two types of strength are shown: compressive and tensile. Both types of forces occur in the mouth. Tensile strengths for amalgam are about 12.5% of compressive strengths at 1 day and are therefore an important clinical parameter to consider, because they are the weakest attribute of amalgam strength.

The rate at which an amalgam develops compressive strength is an important clinical characteristic. If an amalgam restoration is subjected to chewing or other oral forces before sufficient strength develops, it is at risk for fracture. As Figure 5-7 shows, different types of amalgam develop compressive strength at different rates. In general, spherical high-copper amalgams develop compressive strength the fastest. Because of its clinical importance, the early (1 hour) compressive strength of amalgam is regulated by the American Dental Association/American National Standards Institute (ADA/ANSI) and must be at least 80 MPa.

The manipulation of amalgam affects its strength. Inadequate condensation results in voids, which weaken the set mass. Mixing the amalgam for too long or too short a time also weakens the final strength by changing the ratio of unreacted \( \gamma \) particles to the \( \gamma_1 \) and \( \eta \) reaction products. In general, the manufacturer’s instructions for mixing should be followed precisely to ensure maximum strength.

**Dimensional Change**

When a freshly mixed amalgam is condensed into the cavity preparation, ideally it would neither expand nor contract as it sets. Expansion may result in detrimental effects, such as fracture or marginal leakage. However, even with proper condensation, dimensional change can occur. The linear coefficient of thermal expansion of amalgam is positive, meaning that the amalgam expands as it sets. This expansion can cause marginal gaps or cracks, which can lead to the failure of the restoration.

**Amalgam Compressive Strength**

![Graph illustrating the increase in compressive strength of amalgam with time.](image)

**Figure 5-7** Graph illustrating the increase in compressive strength of amalgam with time. Both spherical and admix high-copper amalgams increase rapidly in strength after triturature, but spherical amalgam strengths more rapidly because the mercury is able to wet spherically shaped particles better than irregularly shaped particles. For both types of amalgam, the compressive strength reaches its final strength after about 7 days.

**Strength**

Using an amalgam requires dissolving the amalgam in the mouth. The strength of the amalgam is then measured. Table 5-2 lists the strength of amalgam at 30 minutes, 1 hour, and 1 day after mixing. Two types of strength are shown: compressive and tensile. Both types of forces occur in the mouth. Tensile strengths for amalgam are about 12.5% of compressive strengths at 1 day and are therefore an important clinical parameter to consider, because they are the weakest attribute of amalgam strength.

The rate at which an amalgam develops compressive strength is an important clinical characteristic. If an amalgam restoration is subjected to chewing or other oral forces before sufficient strength develops, it is at risk for fracture. As Figure 5-7 shows, different types of amalgam develop compressive strength at different rates. In general, spherical high-copper amalgams develop compressive strength the fastest. Because of its clinical importance, the early (1 hour) compressive strength of amalgam is regulated by the American Dental Association/American National Standards Institute (ADA/ANSI) and must be at least 80 MPa.

The manipulation of amalgam affects its strength. Inadequate condensation results in voids, which weaken the set mass. Mixing the amalgam for too long or too short a time also weakens the final strength by changing the ratio of unreacted \( \gamma \) particles to the \( \gamma_1 \) and \( \eta \) reaction products. In general, the manufacturer’s instructions for mixing should be followed precisely to ensure maximum strength.

**Dimensional Change**

When a freshly mixed amalgam is condensed into the cavity preparation, ideally it would neither expand nor contract as it sets. Expansion may result in detrimental effects, such as fracture or marginal leakage. However, even with proper condensation, dimensional change can occur. The linear coefficient of thermal expansion of amalgam is positive, meaning that the amalgam expands as it sets. This expansion can cause marginal gaps or cracks, which can lead to the failure of the restoration.

**Amalgam Compressive Strength**

![Graph illustrating the increase in compressive strength of amalgam with time.](image)

**Figure 5-7** Graph illustrating the increase in compressive strength of amalgam with time. Both spherical and admix high-copper amalgams increase rapidly in strength after triturature, but spherical amalgam strengths more rapidly because the mercury is able to wet spherically shaped particles better than irregularly shaped particles. For both types of amalgam, the compressive strength reaches its final strength after about 7 days.
For amalgam restorations, the repeated chewing forces applied cause creep (Figure 5-9). Clinically, creep is associated with a breakdown of the marginal integrity of the restoration, which ultimately leads to failure. High-copper amalgams generally have values of creep far below the old low-copper amalgams. As Table 5-2 shows, the creep of high-copper amalgams ranges from 0.15% to 0.44%. By comparison, the creep of low-copper amalgams is on the order of 6.3%. The ANSI/ADA requires that creep be less than 3%. Figure 5-10 shows the clinical effect of creep. The low-copper amalgam has far more breakdown at the margins than the high-copper amalgam. More than any other property, the clinical effect of creep.

Creep is a gradual dimensional change that occurs under cyclical loads such as chewing.

The net contraction or expansion of an amalgam during setting is defined as dimensional change. Dimensional change is negative if the amalgam contracts and positive if it expands during setting. Table 5-2 lists the 24-hour dimensional change for several types of amalgam. In general, most amalgams expand or contract only slightly during setting, but the ANSI/ADA requires that the dimensional change be no more than 20 μm/cm. Because the formation of γ1 causes expansion, whereas the formation of γ2 causes contraction, the overall dimensional change is therefore the sum of these two processes. Thus, improper manipulation that alters the ratio of γ1 to γ2 and γ2 in the set amalgam also will alter its dimensional change. For this reason, amalgam mixing should follow the manufacturer’s recommendations closely.

The net contraction or expansion of an amalgam during setting is defined as dimensional change. For this reason, amalgam mixing should follow the manufacturer’s recommendations closely. Creep is a gradual dimensional change that occurs under cyclical loads such as chewing.
Tarnish and Corrosion

As noted in Chapter 2, tarnish is a surface phenomenon that can result in a discolored restoration. With tarnish, the chemical reaction between the amalgam and the oral cavity is restricted to the amalgam surface. Corrosion results from chemical reactions that penetrate into the body of the amalgam. Although tarnish may be undesirable esthetically, it will not often cause the restoration to fail. Corrosion, on the other hand, eventually leads to failure of the restoration.

Reduced creep of high-copper amalgams has led to their predominance in dental amalgam restorations.

Figure 5-9 Creep in amalgam results from the cyclical application of nondestructive occlusal forces over a period of months to years (symbolized by vertical arrows). As the force application continues over time, the sample responds by gradually changing shape, ultimately leading to fracture (right). Creep-mediated fracture results in loss of marginal integrity and failure of the restoration. The creep of high-copper amalgams is generally very low, ranging from 0.05% to 0.15%.

Figure 5-10 Three-year postoperative placement photograph of restorations using high-copper (A) or low copper (B, C) amalgam. The margins of the high-copper amalgam retain integrity, whereas significant corrosion, creep, and fracture at the margins of the low-copper restorations have occurred. The poor performance of low-copper amalgam has been linked to the presence of the $\gamma_2$ phase, which is not present in high-copper amalgam. (Courtesy Doug Smith, Medical College of Georgia, Augusta, GA.)

Reduced creep of high-copper amalgams has led to their predominance in dental amalgam restorations.

Amalgam fracture

Figure 5-9

Figure 5-10

The $\gamma_2$ phase is a characteristic of high-copper amalgams, which results in reduced creep and improved marginal integrity. Low-copper amalgams, on the other hand, have a higher risk of corrosion, creep, and fracture, leading to failure of the restoration. The presence of the $\gamma_2$ phase in high-copper amalgams is responsible for their superior performance in clinical settings.

Amalgam fracture
Tarnish and corrosion occur more on amalgams with rough surfaces. Thus, a well-polished amalgam limits these problems.

**Manipulation of Amalgam**

The clinical success of an amalgam restoration is highly dependent on the proper manipulation of the amalgam. In general, amalgam manipulation can be divided into four steps: mixing (or *trituration*), condensation, carving, and finishing.

Many brands of dental amalgam are available, and the selection of an amalgam depends on the clinical situation and the desired handling and properties. Precapsulated amalgam is available with capsules containing different amounts of silver alloy powder and mercury. These different amounts are generally delineated by color-coded capsules. A “single mix” (also called “single-spill,” a term used before precapsulated packaging) contains about 600 mg of silver alloy and is sufficient for a small restoration. A “double mix” contains 800 mg of silver alloy and is sufficient for most moderately sized restorations. If larger amounts of amalgam are needed for a single restoration, several capsules should be mixed in succession rather than trying to mix more in one capsule simultaneously.

**Mixing the Amalgam (Trituration)**

The process of mixing the silver alloy together with the mercury is called *trituration*. *Trituration* is accomplished with a mechanical device called an amalgamator (Figure 5-11; Table 5-4). Amalgamators move the capsule containing the silver alloy and mercury back and forth at a high speed and mix the amalgam in less than 20 seconds. Amalgamators generally have a timer and may have a speed control. The speed and time must be selected carefully, based on the manufacturer’s directions (for both the amalgam and the amalgamator) and the expected handling and properties.
clinical judgment of the practitioner. Because trituration has a significant effect on the properties and clinical success of amalgam, proper trituration is essential. The speed, time, and force of trituration have important effects on the amalgam setting reaction. Of these factors, the clinician has control only over speed and time. In general, these factors should be set as recommended by the manufacturer because a deviation of only 2 to 3 seconds may affect adversely the handling and properties of the amalgam. In addition, as an amalgam ages, adjustment to the speed or time may be necessary to ensure a proper mix. Undertrituration or overtrituration generally causes an amalgam to have significantly inferior physical properties that may lead to the failure of the restoration. Undertriturated amalgam has a dull, crumbly appearance (Figure 5-12). Undertriturated amalgam has poor compressive and tensile strengths because an insufficient matrix is formed to hold the mass together and because condensation is unproductive and results in voids. Overtriturated amalgam has poor compressive and tensile strengths because an insufficient matrix is formed to hold the mass together and because condensation is unproductive and results in voids.

<table>
<thead>
<tr>
<th>Table 5-4</th>
<th>Examples of Amalgamators</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product</strong></td>
<td><strong>Manufacturer</strong></td>
</tr>
<tr>
<td>Wig-L-Bug</td>
<td>Dentsply Caulk (Milford, DE)</td>
</tr>
<tr>
<td>Silamat S5</td>
<td>Ivoclar Vivadent (Amherst, NY)</td>
</tr>
<tr>
<td>Valiant</td>
<td>Ivoclar Vivadent</td>
</tr>
<tr>
<td>Promix</td>
<td>Dentsply Caulk</td>
</tr>
<tr>
<td>HS-1 (high speed)</td>
<td>Henry Schein, Inc. (Melville, NY)</td>
</tr>
</tbody>
</table>

**Figure 5-12** The effect of trituration time of amalgam. Undertrituration (right) results in a crumbly, dull mass that cannot be effectively condensed into the cavity preparation. The undertriturated amalgam also is weak because of over production of matrix phases, which are weaker than the original alloy particles. Properly triturated amalgam (center) is somewhat shiny and has a puttylike consistency but offers firm resistance to condensation. (Courtesy Doug Smith, Medical College of Georgia, Augusta, GA.)
amalgam is soupy and may adhere to the inside of the capsule. It will have poorer strength and creep and may have poorer corrosion properties, all caused by overformation of the matrix products. A properly triturated amalgam is shiny but offers some resistance to condensation. With experience, the practitioner and auxiliaries generally develop a sense about the propriety of a properly triturated amalgam.

**Condensation**

After trituration, the amalgam must be condensed into the cavity preparation in the tooth before its puttylike consistency disappears. The goals of condensation are to produce a mass without voids, adapt the mass closely to the cavity walls and margins, and minimize excess mercury in the set mass. Removal of excess mercury is generally more feasible for irregularly or admixed amalgams, which contain a slight excess of mercury. The spherical amalgams contain less (42-46 wt. %) mercury, and removal of excess mercury is generally not possible. The use of precapsulated amalgam greatly reduces the need to try to remove excess mercury from the setting mass. If excess mercury is not removed, an amalgam will generally be weaker and have greater creep as a result of the overformation of matrix products.

The triturated amalgam is transferred from the mixing capsule to a mixing well, then to the cavity preparation via an amalgam carrier (Figure 5-13). Once delivered to the preparation, condensing may be accomplished by hand or mechanical condensers. Hand condensation is far more common and probably better than mechanical condensation. Hand condensers come in a variety of shapes and sizes and are selected on the basis of the type of amalgam, the shape and size of the cavity, and the stage of condensation. In general, smaller condensers (2-3 mm in diameter) are more effective in achieving the goals of condensation.

**After trituration, the amalgam must be condensed into the cavity preparation in the tooth before its puttylike consistency disappears. The goals of condensation are to produce a mass without voids, adapt the mass closely to the cavity walls and margins, and minimize excess mercury in the set mass. Removal of excess mercury is generally more feasible for irregularly or admixed amalgams, which contain a slight excess of mercury. The spherical amalgams contain less (42-46 wt. %) mercury, and removal of excess mercury is generally not possible. The use of precapsulated amalgam greatly reduces the need to try to remove excess mercury from the setting mass. If excess mercury is not removed, an amalgam will generally be weaker and have greater creep as a result of the overformation of matrix products.**
The cavity preparation is generally overpacked with amalgam and carved back to final shape (Figure 5-14). Overpacking gives the practitioner the chance to control the final shape and occlusion more closely than would be possible otherwise. Carving of an amalgam restoration is done with a variety of hand instruments. Depending on the type of amalgam, carving may start 2 to 3 minutes after mixing and should cease when the amalgam mass becomes hard.
Dental Amalgam (5–10 minutes). Carving after the amalgam is set may cause fracture of the amalgam, particularly at its margins.

The finishing and polishing of the amalgam generally are performed at least 24 hours after placement. However, if a spherical high-copper amalgam is used, polishing may be done at the time of placement because these amalgams set much faster than irregular or admixed amalgams. Clinical studies have shown that a well-finished and polished amalgam is easier to keep clean and undergoes less corrosion. Polishing is achieved through a series of steps. Generally, the amalgam surface is contoured with use of green stones, finishing burs, or abrasive disks. The margins of the amalgam are checked and contoured until they are smooth and congruous with the tooth. The next step is to smooth the alloy surface. This step is accomplished using a polishing agent such as fine pumice or silix, or rubber abrasive points. The final step is to put a luster (high shine) on the surface using a very fine abrasive paste or rubber abrasive point. Polishing always should be done wet (with water) because dry polishing may overheat the amalgam and tooth. Overheating may damage the pulp of the tooth and certainly damages the amalgam surface by driving mercury from the amalgam (see Figure 5-6).

The figure shows:

- Amalgam being carved into its final form before it sets.
- Various instruments are used to burnish and carve the amalgam to appropriate contours.
- Excess amalgam is removed by water and vacuum from the patient's mouth.
- After carving is completed, the amalgam will have appropriate contours, proximal contacts, occlusal contacts, and occlusal function.

(Courtesy Kevin Frazier, Medical College of Georgia, Augusta, GA.)

Figure 5-14: Carving the amalgam. Once the amalgam is condensed into the cavity preparation, it is burnished and carved into its final form before it sets. Various instruments are used to burnish and carve the amalgam to appropriate contours. Excess amalgam is removed by water and vacuum from the patient's mouth. After carving is completed, the amalgam will have appropriate contours, proximal contacts, occlusal contacts, and occlusal function.
Limiting Exposure to Mercury

Mercury is toxic, and proper precautions should be taken to limit exposure of the patient and dental team to mercury or its vapor. The toxicity of mercury is especially problematic because it is distributed to lipid-rich tissues such as nerves and fat and is eliminated slowly from the body. Thus, even small daily exposures can build up to toxic levels in the body. Mercury may gain access to the body through the skin on contact, through ingestion, or through the lungs as a vapor. The most likely route of exposure for the patient and dental personnel is by inhalation of vapor. However, good hygiene limits exposure from all of these routes. Finally, although the exposure of the patient is always a primary concern, the occupational exposure of dental personnel is more critical because of daily mercury-metabolizing periods during mixing, placement, and removal.

Good mercury hygiene involves simple, common-sense strategies. Clinical technique should ensure that mercury is never touched, even with gloved hands. A mask should be worn to decrease inhalation of particulate amalgam. The use of precapsulated amalgam limits the possibility of a spill of liquid mercury in the office. The use of high-volume evacuation during placement and removal of amalgam restorations reduces the exposure of the patient and the dental team to mercury vapor. Ultrasonic amalgam condensers should not be used. The dental operator should not be carpeted so that spills of particulate amalgam may be cleaned effectively. All amalgam scrap should be stored in containers containing x-ray fixer or other reducing agent and should be capped tightly and kept cool.

Despite the toxicity of mercury, amalgams are safe restorations. Although a small amount of mercury is released during placement, removal, and mixing, the amount is not sufficient to cause health problems. These people will look to the dental team for reliable information.

Thus, the dental health team should pay close attention to quality of sources of information (the ADA, Food and Drug Administration [FDA], or peer-reviewed literature) when they consider whether to use amalgam and how they respond

Mercury hygiene is the practice of handling amalgam and mercury to minimize exposure of the dental staff and the patient to mercury.
Amalgam bonding does not significantly increase long-term retention of amalgam restorations.

Dental amalgam does not bond to tooth structure, and amalgam restorations have been retained traditionally by undercuts in the cavity design. Without bonding to tooth structure, small gaps remain between the tooth and amalgam, and microleakage of salivary products and bacteria into the tooth can occur. As time progresses, corrosion products from the amalgam fill these gaps, and the amalgam–tooth interface is weakened. In spite of this seal, the lack of a bond between amalgam and the tooth leaves the tooth weaker than it was before the cavity was prepared.

Various bonding agents have been used to “bond” amalgam to tooth structure. Ample evidence exists that bonding agents reduce microleakage, particularly in the weeks immediately postplacement. On the other hand, studies do not support the use of bonding agents to improve long-term clinical retention of amalgam. In large posterior restorations, bonded amalgams are not better retained than those retained with pins or other mechanically designed retention. Furthermore, little clinical evidence exists that these procedures reduce the fracture of cusps, although some improvement might be expected theoretically in this regard. Currently, the reduction of early microleakage appears to be the best reason to use this technique.

### QUICK REVIEW

Dentistry amalgam restorations, although their use continues to decline. The introduction of high-copper amalgams more than 30 years ago improved dramatically the clinical longevity of amalgam restorations by eliminating the corrosion-prone γ phase from the metallurgical structure of the amalgam. These high-copper formulations are still excellent choices for long-term, posterior restorations where esthetics are not a primary concern. The use of precapsulated amalgam has significantly reduced the risk of exposure of dental personnel to mercury and has improved the predictability of the mechanical properties of amalgam. Nevertheless, a successful amalgam restoration depends on the proper trituration (mixing), condensation, carving, and finishing of the amalgam. Each of these manipulation steps significantly affects the physical properties and clinical performance of the amalgam. Although minute amounts of mercury are released from amalgam restorations in service (approximately 1 to 2 µg/day), all evidence currently indicates that amalgams do not cause safety restorations. Amalgam-tooth bonding does not appear to significantly improve long-term retention of these restorations.
SELF-TEST QUESTIONS

Test your knowledge by answering the following questions. For multiple-choice questions, one or more responses may be correct.

1. Which of the following office conditions minimize(s) the health hazard from spilled mercury?
   a. Baseboard heating
   b. Floor carpeting
   c. Tile flooring without seams
   d. Amalgam scrap stored in a closed container

2. By statute, which of the following represents the maximum safe concentration of mercury vapor in the breathing zone for a 40-hour workweek?
   a. 0.05 ng Hg/m³ of air
   b. 30 ng Hg/m³ of air
   c. 100 ng Hg/m³ of air
   d. 0.05 mg Hg/m³ of air

3. For each of the following types of alloys, list which of the phases are present in the set amalgam.
   a. Spherical low-copper
   b. Spherical high-copper
   c. Admixed low-copper
   d. Admixed high-copper

4. Once amalgamation has occurred, which of the following is/are true of mercury?
   a. It is combined primarily with silver.
   b. It has the toxic properties of unreacted mercury.
   c. It can form at the surface of amalgam restorations if heated to 60°C.
   d. It can never be released from the amalgam.
   e. It can be released in vapor or ionic forms.

5. For each of the following properties, list which of the phases has the lowest value for the following properties.
   a. Corrosion resistance
   b. Strength
   c. Marginal fracture
   d. Creep

6. For each property, list the amalgam type (irregular low-copper, admixed high-copper, and spherical high copper) that has the highest value.
   a. 1-hour compressive strength
   b. Tensile strength
   c. Creep

7. Which of the following factors is/are important in obtaining a properly triturated dental amalgam?
   a. Speed of the amalgamator
   b. Time of amalgamation
   c. Size of the mix
   d. Manufacturer of the amalgam
   e. Manufacturer of the amalgamator
8. Which of these statements is/are correct in describing a triturated mass of amalgam?
   a. An undertriturated mass is crumbly and dull.
   b. A correctly triturated mass is smooth, homogeneous, and dull.
   c. An overmixed mass is removed readily from the capsule but is soupy in appearance.

9. The objectives during condensation of amalgam are which of the following?
   a. Good adaptation to cavity walls, margins, and matrix
   b. Development of a mass free from voids
   c. No change in mercury concentration from that used in the mix
   d. Packing to final contour

10. Which of the following statements apply to condensation of amalgam?
    a. Amalgam should be condensed in small increments with uniform force applied.
    b. A condenser is selected on the basis of its ability to apply pressure needed for adaptation.
    c. Too large a condenser tip results in low condensation pressure and poor adaptation.
    d. A force of 30 to 40 N on a condenser is satisfactory for adequate condensation of admixed and spherical alloys.
    e. Condensation force should be applied laterally as well as vertically.

11. In the finishing of an amalgam restoration, which of the following is/are true?
    a. Final polishing and finishing are done just after the amalgam hardens, regardless of the type of alloy.
    b. Burnishing over margins should not be done because thin areas of amalgam susceptible to fracture can be formed.
    c. Polishing should be done in the presence of water.
    d. A correct finishing and polishing sequence would include finishing burs, green stone, ilex, and tin oxide.
    e. Elevated temperatures during polishing help achieve a high luster on the amalgam surface.

12. Which statement(s) is/are true for bonding of amalgam to tooth structure?
    a. The most effective bonding agents contain copalite.
    b. Shear bond strength using amalgam bonding to teeth is clinically proven to be as high as that for bonding composites to teeth.
    c. The use of amalgam bonding restores the strength of the clinical crown to its original condition.
    d. The use of amalgam bonding reduces marginal leakage of amalgam restorations.

In the following questions, a short statement or statements are necessary to answer the questions.

13. Which type of amalgam (spherical vs. irregular) would you choose for a restoration that had to survive higher occlusal forces shortly after placement, and why?

14. Zinc originally was included in the amalgam alloy to facilitate cutting the amalgam into clean, irregular pieces. Why do most contemporary amalgams not include zinc?

15. Summarize the advantages of precapsulated amalgam.
16. You examine set amalgam under an electron microscope and observe that all the original γ-particles have reacted. What will you predict about the physical properties of this amalgam? Why?

17. You see an old amalgam in a patient’s mouth. It is dark and needs polishing. How can you determine if the amalgam has corroded or is just tarnished? If the amalgam has corroded, what is the remedy for this restoration?

18. You are triturating an amalgam in a precapsulated form. The timer on the amalgamator breaks, and you do not know if the amalgam was overtriturated or undertriturated. How will you tell? How do you explain what you see in terms of the amalgamation reaction? Which condition would you rather use clinically?

19. Give the definition of creep, and explain why creep is an important clinical property.

20. A patient arrives at your office and expresses concern about mercury in dental amalgam causing her harm. What will you tell this patient to reassure her about the safety of amalgam?

21. What precautions should be taken to limit the exposure of the dental team and the patient to mercury during the removal of an amalgam?

In the following multiple choice questions, one or more responses may be correct.

22. Which one of the following phases in dental amalgam restoration is most prone to electrochemical corrosion?
   a. Ag-Sn
   b. Cu-Sn
   c. Sn-Hg
   d. Ag-Hg

23. Which one of the following phases in dental amalgam restoration has the best mechanical properties?
   a. Ag-Sn
   b. Cu-Sn
   c. Sn-Hg
   d. Ag-Hg

24. Which one of the following mixing methods permits the escape of dental amalgam mercury vapor?
   a. mixing in a mortar and pestle
   b. proportioning mercury and alloy into a friction-fit capsule
   c. triturating precapsulated alloy and mercury
   d. a cover over the mixing arms on a triturator

25. Which one of the following is/are not true about high-copper dental amalgam restorations?
   a. they have better corrosion resistance than low-copper dental amalgams.
   b. they contain both Sn and Ag in the composition as well.
   c. they produce excessive creep.
   d. restorations are more brittle than low-copper versions.
26. Dental personnel can do which one of the following to limit their exposure to mercury?
   a. Sterilize amalgam scrap
   b. Vacuum up a spill immediately
   c. Avoid touching freshly mixed amalgam
   d. Avoid polishing amalgams

27. The primary difference in the silver alloy between low- and high-copper amalgams is which of the following?
   a. The amount of copper
   b. The amount of copper and zinc
   c. The amount of copper and tin
   d. The amount of copper and silver

28. The primary difference in the reaction products of low- and high-copper amalgam is which of the following?
   a. Low-copper amalgam has $\gamma_2$; high-copper amalgam has no $\gamma_2$.
   b. Low-copper amalgam has higher $\gamma_1$.
   c. High-copper amalgam has a copper-tin phase; low-copper amalgam does not.
   d. Only a and c are true.

29. Ideally, the set amalgam should do which of the following?
   a. Expand greatly to provide marginal seal against the tooth
   b. Shrink significantly to provide space for corrosion products to seal the margins
   c. Have little dimensional change

30. The physical properties most desirable in set amalgam are which of the following?
   a. High strength, low creep, low corrosion
   b. Low strength, low creep, low corrosion
   c. High strength, high creep, low corrosion
   d. High strength, high creep, high corrosion

31. Higher mercury in an amalgam leads to which of the following?
   a. Higher creep
   b. Higher strength
   c. Lower corrosion
   d. Less matrix formation

32. Which of the following occur(s) when dental amalgam is overtriturated?
   a. Compressive strength decreases.
   b. Corrosion decreases.
   c. Tensile strength increases.
   d. Only a and b
   e. Only a and c

Suggested Supplementary Readings
Irregular and spherical particles are formed by different manufacturing processes and do not have a uniform size. Each micrograph has a horizontal field of view of approximately 500μm.


Summitt JB, et al: Six-year clinical evaluation of bonded and pin-retained complex amalgam restorations, *Oper Dent* 29:261, 2004.Figure 5-2 Micrographs of silver alloy particles used in dental amalgam, taken with a scanning electron microscope. Particles may have irregular (A) or spherical (C) shapes or may be mixed together to form “admixed” amalgam (B). Irregular and spherical particles are formed by different manufacturing processes and do not have a uniform size. Each micrograph has a horizontal field of view of approximately 500μm.