

# Direct and indirect restorative materials

ADA COUNCIL ON SCIENTIFIC AFFAIRS

**P**atients and practitioners have a variety of options when choosing materials and procedures for restoring carious lesions or missing teeth. This report outlines important features of many of the most popular restorative choices and is intended as a communication tool for dentists to use in discussing the options available for a particular restoration with their patients. This is not a comprehensive literature review and, due to space

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limitations, it covers only the most commonly used restorative materials. The choice of material and procedures to restore form, appearance and function to the dentition is an important health care decision that is ultimately made by the patient after careful consultation with his or her dentist. It is imperative that dentists provide this information in a manner that is clear, concise and based on the best available scientific information.

This article is a companion piece to the chart comparing the important features of many frequently used restorative materials that appeared in the March 18, 2002, issue of ADA News<sup>1</sup> (Tables 1 and 2). The chart tabulated physical and clinical characteristics of the two common categories of materials: direct and indirect. Practitioners might wish

**Background.** In recent years, dentistry has benefited from a marked increase in the development of esthetic materials, including ceramic and plastic compounds. But the advent of these new materials has not eliminated the usefulness of more traditional restorative materials such as gold, base metal alloys and dental amalgam.

**Overview.** This report outlines important features of direct and indirect restoratives, with an emphasis on the safety and efficacy of each material.

### Conclusions and Practice

**Implications.** This article was developed to help dentists explain to their patients the relative pros and cons of various materials used in dental restorations, which include fillings, crowns, bridges and inlays. The weight of the scientific evidence indicates that all of these materials are safe and effective for their intended use. Patients, in consultation with their dentists, are free to choose the most appropriate among them for their particular needs.

to explain the differences between the two categories thus: Direct materials are those that can be placed directly in the tooth cavity during a single appointment. Indirect materials are used to fabricate restorations in the dental laboratory that then are placed in or on the teeth; placement of indirect materials generally requires two or more visits to complete the restoration. Table 3 (page 466) lists commonly used direct and indirect materials.

The service life of dental restoratives depends on a number of patient-, material- and procedure-related factors. Patient-related factors include the size and location of the restoration, chewing habits and loads, the level of oral hygiene and maintenance, and systemic

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TABLE 1

COMPARISON OF DIRECT RESTORATIVE DENTAL MATERIALS.				
FACTORS	AMALGAM	RESIN-BASED COMPOSITE (DIRECT AND INDIRECT)	GLASS IONOMER	RESIN-MODIFIED GLASS IONOMER
<b>General Description</b>	A mixture of mercury and silver alloy powder that forms a hard solid metal filling. Self-hardening at mouth temperature.	A mixture of sub-micron glass filler and acrylic that forms a solid tooth-colored restoration. Self- or light-hardening at mouth temperature.	Self-hardening mixture of fluoride containing glass powder and organic acid that forms a solid tooth colored restoration able to release fluoride.	Self- or light-hardening mixture of sub-micron glass filler with fluoride-containing glass powder and acrylic resin that forms a solid tooth-colored restoration able to release fluoride.
<b>Principal Uses</b>	Dental fillings and heavily loaded back tooth restorations.	Esthetic dental fillings and veneers.	Small non-load-bearing fillings, cavity liners and cements for crowns and bridges.	
<b>Leakage and Recurrent Decay</b>	Leakage is moderate, but recurrent decay is no more prevalent than other materials.	Leakage low when properly bonded to underlying tooth; recurrent decay depends on maintenance of the tooth-material bond.	Leakage is generally low; recurrent decay is comparable to other direct materials, fluoride release may be beneficial for patients at high risk for decay.	Leakage is low when properly bonded to the underlying tooth; recurrent decay is comparable to other direct materials; fluoride release may be beneficial for patients at high risk for decay.
<b>Overall Durability</b>	Good to excellent in large load-bearing restorations.	Good in small-to-moderate size restorations.	Moderate to good in non-load-bearing restorations; poor in load-bearing.	
<b>Cavity Preparation Considerations</b>	Requires removal of tooth structure for adequate retention and thickness of the filling.	Adhesive bonding permits removing less tooth structure.		
<b>Clinical Considerations</b>	Tolerant to a wide range of clinical placement conditions, moderately tolerant to the presence of moisture during placement.	Must be placed in a well-controlled field of operation; very little tolerance to presence of moisture during placement.		
<b>Resistance to Wear</b>	Highly resistant to wear.	Moderately resistant, but less so than amalgam.	High wear when placed on chewing surfaces.	
<b>Resistance to Fracture</b>	Brittle, subject to chipping on filling edges, but good bulk strength in larger high-load restorations.	Moderate resistance to fracture in high-load restorations.	Low resistance to fracture.	Low to moderate resistance to fracture.
<b>Biocompatibility</b>	Well-tolerated with rare occurrences of allergenic response.			
<b>Post-Placement Sensitivity</b>	Early sensitivity to hot and cold possible.	Occurrence of sensitivity highly dependent on ability to adequately bond the restoration to the underlying tooth.	Low.	Occurrence of sensitivity highly dependent on ability to adequately bond the restoration to the underlying tooth
<b>Esthetics</b>	Silver or gray metallic color does not mimic tooth color.	Mimics natural tooth color and translucency, but can be subject to staining and discoloration over time.	Mimics natural tooth color, but lacks natural translucency of enamel.	
<b>Relative Cost to Patient</b>	Generally lower; actual cost of fillings depends on their size.	Moderate; actual cost of fillings depends on their size and technique.		
<b>Average Number of Visits To Complete</b>	One.	One for direct fillings; 2+ for indirect inlays, veneers and crowns.	One.	One.

NOTE: The information in this chart is provided to help dentists discuss the attributes of commonly used dental restorative materials with their patients. The chart is a simple overview of the subject based on the current dental literature. It is not intended to be comprehensive. The attributes of a particular restorative material will vary from case to case depending on a number of factors.

TABLE 2

COMPARISON OF INDIRECT RESTORATIVE DENTAL MATERIALS.				
FACTORS	CERAMIC	METAL-CERAMIC	CAST-GOLD (HIGH NOBLE) ALLOYS	BASE METAL ALLOYS (NON-NOBLE)
<b>General Description</b>	Porcelain, ceramic or glass-like fillings and crowns.	Ceramic is fused to an underlying metal structure to provide strength to a filling, crown or bridge.	Alloy of gold, copper and other metals resulting in a strong, effective filling, crown or bridge.	Alloys of non-noble metals with silver appearance resulting in high-strength crowns and bridges.
<b>Principal Uses</b>	Inlays, onlays, crowns and esthetic veneers.	Crowns and fixed bridges.	Inlays, onlays, crowns and fixed bridges.	Crowns, fixed bridges and partial dentures.
<b>Leakage and Recurrent Decay</b>	Sealing ability depends on materials, underlying tooth structure and procedure used for placement.	The commonly used methods used for placement provide a good seal against leakage. The incidence of recurrent decay is similar to other restorative procedures.		
<b>Durability</b>	Brittle material, may fracture under heavy biting loads. Strength depends greatly on quality of bond to underlying tooth structure.	Very strong and durable.	High corrosion resistance prevents tarnishing; high strength and toughness resist fracture and wear.	
<b>Cavity Preparation Considerations</b>	Because strength depends on adequate ceramic thickness, it requires more aggressive tooth reduction during preparation.	Including both ceramic and metal creates a stronger restoration than ceramic alone; moderately aggressive tooth reduction is required.	The relative high strength of metals in thin sections requires the least amount of healthy tooth structure removal.	
<b>Clinical Considerations</b>	These are multiple-step procedures requiring highly accurate clinical and laboratory processing. Most restorations require multiple appointments and laboratory fabrication.			
<b>Resistance to Wear</b>	Highly resistant to wear, but ceramic can rapidly wear opposing teeth if its surface becomes rough.	Highly resistant to wear, but ceramic can rapidly wear opposing teeth if its surface becomes rough.	Resistant to wear and gentle to opposing teeth.	
<b>Resistance to Fracture</b>	Prone to fracture when placed under tension or on impact.	Ceramic is prone to impact fracture; the metal has high strength.	Highly resistant to fracture.	
<b>Biocompatibility</b>	Well-tolerated.	Well tolerated, but some patients may show allergenic sensitivity to base metals.	Well-tolerated.	Well tolerated, but some patients may show allergenic sensitivity to base metals.
<b>Post-Placement Sensitivity</b>	Sensitivity, if present, is usually not material-specific.			
	Low thermal conductivity reduces the likelihood of discomfort from hot and cold.	High thermal conductivity may result in early post-placement discomfort from hot and cold.		
<b>Esthetics</b>	Color and translucency mimic natural tooth appearance.	Ceramic can mimic natural tooth appearance, but metal limits translucency.	Metal colors do not mimic natural teeth.	
<b>Relative Cost to Patient</b>	Higher; requires at least two office visits and laboratory services.	Higher; requires at least two office visits and laboratory services.		
<b>Average Number of Visits To Complete</b>	Minimum of two; matching esthetics of teeth may require more visits.	Minimum of two; matching esthetics of teeth may require more visits.	Minimum of two.	

conditions that can change the amount of saliva and its chemistry. Material-related factors include strength, wear resistance, tolerance to water, dimensional stability and color stability. Added to this are procedural factors generally encountered in making and placing a restoration, such as the size and depth of the cavity, the ability to prevent contaminating the cavity surface with saliva and blood, and the ability to access the tooth and tooth surface needing restoring. Because each restoration has unique circumstances that profoundly affect its lifetime, this article does not attempt to discuss or predict longevity of service for any of these materials. Dentists need to consider all of these factors and discuss them with patients for them to make the best informed decision.

**DIRECT RESTORATIVE MATERIALS**

**Dental amalgam.** A modern amalgam restoration is an alloy composed of mercury, silver, tin and copper along with other metallic elements added to improve physical and mechanical properties. A unique aspect of the amalgam restoration is that it starts out as a pastelike mixture of metals and, within a few minutes after placement, hardens in the mouth by a series of chemical reactions to form a stable metallic alloy. The mercury is transformed from the metallic liquid state into a solid and stable intermetallic compound.

Amalgam is especially suitable for Class I and II restorations in teeth that encounter heavy chewing forces. Class II restorations tend to be large with extensive tooth-material interface areas. These present a potential for leakage of oral fluids around the margins of the tooth-filling interface, increasing the risk for recurrent caries. However, amalgam has been reported to be capable of sealing the tooth-restoration margins with corrosion products that accumulate with time. Since it is metallic in composition, amalgam is unable to mimic the color or translucency of natural teeth, and its silver-gray color limits its use on anterior teeth.

Advantages of amalgam restorations over other direct-placement materials include resistance to wear; tolerance to a wide range of clinical place-

**TABLE 3**

CATEGORIES OF MODERN RESTORATIVE MATERIALS.	
DIRECT	INDIRECT
Amalgam	All-Ceramic (Porcelain)
Resin-based Composites (Direct and Indirect)	Metal-Ceramic
Glass Ionomers	Cast-Gold (High Noble) Alloys
Resin-Modified Ionomers	Base Metal (Non-noble) Alloys

ment conditions, especially wet fields; and excellent load-bearing properties.<sup>2-4</sup> Amalgam’s resistance to wear is superior to that of resin-based composites, especially for areas in direct and heavy contact with opposing teeth. This is due largely to amalgam’s ability to adapt through deformation under load.

Ideally, amalgam should be placed in a clean, dry field. Often, cavity location or patient management considerations make this impossible, and amalgam is the only direct material currently available that can be used to provide a serviceable restoration under these conditions.<sup>5</sup> The inability to keep a clean, dry cavity preparation occurs most frequently in very young patients, in deep cavities under the gingival margin or very far back in the mouth. In these very challenging situations, amalgam can provide a satisfactory and very serviceable restoration.

*Safety of dental amalgam.* Amalgam has been used successfully as a restorative material since the middle of the 19th century.<sup>6-8</sup> Despite its long history of success, the safety of this material has been questioned periodically owing to the presence of mercury in its composition. Nevertheless, virtually every major health organization responsible for protecting public health in the United States (such as the National Institute of Dental and Craniofacial Research, the Centers for Disease Control and Prevention and the U.S. Food and Drug Administration<sup>9</sup>) and abroad (such as the World Health Organization and Federation Dentaire International) have declared dental amalgam as safe and effective.

Very small quantities of elemental mercury vapor (less than one-half of the estimated natural daily exposure) can be released from amalgam restorations during chewing.<sup>10</sup> The possibility of localized allergic reactions to amalgam is recognized.<sup>9</sup> A recent study reported that immediate hypersensitivity to amalgam is relatively infre-

quent.<sup>11</sup> A 1986 review of the literature spanning a time frame of 1905 to 1986 turned up only 41 cases of amalgam allergy.<sup>12</sup> Considering the hundreds of millions of amalgams that were placed over this period, amalgam allergy can be considered very rare.

*Efficacy of dental amalgam.* Until the advent of resin-based composites in the late 1960s, amalgam was the restorative material of choice for all but the most esthetically demanding restorations. For example, the total number of amalgam restorations placed in 1979 in the United States was estimated to be 157 million.<sup>13</sup> That number had declined to about 66 million in 1999. The relative number of amalgam restorations placed was surpassed by resin-based composite restorations in the late 1990s, and the use of amalgam continues to decline at a fairly constant rate. This decline can be attributed to several factors, including the increase in the demand for esthetic restorations, the reduction in dental caries and its severity, improvements in composite technology and improved training and experience of the clinician in the placement of composite restorations.

**Resin-based composites.** Composite restorative materials are complex blends of polymerizable resins mixed with glass powder fillers. To bond the glass filler particles to the plastic resin matrix, the filler particles are coated with silane, an adhesive coupling molecule. Other additives also are included in composite formulations to enhance radiographic opacity for better diagnostic identification, to facilitate curing and to adjust viscosity for better handling. Color and translucency of dental composites are modified to mimic the color and translucency of teeth, making them the most esthetic direct filling material available.

*Safety of resin-based composites.* Like other restorative materials currently approved for use in dentistry, resin-based composites are considered safe. Allergic reactions to resin-based composites have been noted in a very small number of people.<sup>14-16</sup> Postoperative tooth sensitivity after the use of composite materials is not uncommon, but it usually is transient and related to leakage next to the margins of the filling or, occasionally, to mechanical stress placed on the tooth as the filling material cures.<sup>17</sup> Highly effective bonding resins are used to provide adhesion of composite

fillings to the tooth. Shrinkage of the composite on curing can induce stress on the restoration/tooth bond, resulting in strain or bending of the tooth and in rare instances fracture. Failure of the tooth/composite bond also can be a source of early postoperative sensitivity. Recent improvements in composites and the adhesives used to place composites have minimized the occurrence of these adverse events.

Composite restorative materials are rarely placed without the use of an adhesive. The cavity preparation is cleaned, etched with phosphoric acid or similar etchant and impregnated with a bonding resin to adhere mechanically to the

microporosities created by etching the dentin and enamel. Bonding resins typically contain low-molecular-weight resin monomers, and some of these have been implicated in allergic reactions. Sensitization to compounds such as hydroxyethyl methacrylate have been reported, but the problem is actually more common among dentists than it is among patients.<sup>16</sup> Frequent exposure to these resins have been

reported to cause allergic dermatitis on the fingertips of clinicians who have had repeated direct contact with these unreacted monomers.<sup>18</sup>

Another safety concern regarding resin-based composites arose in the mid-1990s, when some researchers claimed to have detected the presence of bisphenol A, which is known to have an estrogenic potential, in the saliva of patients who recently had received pit-and-fissure sealants.<sup>19</sup> The presence of bisphenol A in the dental sealants in this study was thought to have originated from the breakdown of bisphenol A glycidyl dimethacrylate, or Bis-GMA, a monomer commonly used in composite and sealant formulations. Two recent studies disputed this contention. A study published in 2000 demonstrated that a small amount of bisphenol A could be detected in saliva immediately after placement of a particular pit-and-fissure sealant, but this presence was very transient and no detectable level was measured in the blood of these patients.<sup>20</sup> The authors of this study concluded that the suspicions of sealants' potential for estrogenicity was unfounded. A second study, published in 2001, demonstrated that the bisphenol A measured in these clinical trials<sup>19,20</sup> most likely was derived from the enzymatic cleavage of a different

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monomer—bisphenol A dimethacrylate, or Bis-DMA—and not from the suspected breakdown of Bis-GMA.<sup>21</sup> The majority of composites and sealants currently used do not contain Bis-DMA. Therefore, current resin-based composite materials generally are regarded as safe and effective when placed properly.

*Effectiveness of resin-based composites.* These esthetic materials originally were designed and intended for anterior restorations only. As their popularity increased and the materials were further improved, their use expanded into nearly all classes and types of dental restorations. Today, composites are commonly used for anterior restorations and also used extensively for small- to moderate-sized posterior fillings in teeth without severe chewing loads. While they generally are not as strong or durable as metals, resin-based composites have shown promise of improvement in durability and length of service in clinical studies of their performance in Class I and Class II restorations.

An important factor in the placement of resin-based composites is adequate field control. Composite restorations cannot be placed successfully in a cavity that is contaminated by blood or saliva. Cavity contamination results in failure to achieve adhesion between the filling and the tooth and subsequent leakage at this interface.

*Direct versus indirect composites.* Curing shrinkage can be prevented partially by fabricating and curing the bulk of the restoration outside the mouth. Heat and pressure also can help improve the degree of cure in the restoration. For these reasons, indirect composite restorations fabricated in a dental laboratory were developed, attempting to improve the overall durability of the filling. However, indirect composites may require a second appointment for placement. While some improvement in properties could be achieved, clinical evidence indicates that direct composite restorations carefully fabricated from quality materials probably are as serviceable as the indirect laboratory-fabricated equivalents.<sup>22,23</sup>

**Glass ionomers.** Glass ionomers are tooth-colored filling materials that can be used to restore cavities with low load-bearing requirements. They are supplied as a powder-liquid system composed of an acid-soluble glass powder and liquid polyacrylic acid. On mixing, the acid reacts with the surface of the glass powder, forming a hard matrix that surrounds the unreacted portion of the glass powder. The resulting

structure is much like a dental composite in that it has acceptable esthetics, except for the tendency of ionomers to appear opaque when compared with natural tooth enamel.

Variations of this material incorporate metal powders, such as the alloy powder also used in amalgam, or involve the sintering of silver with the glass powder in an attempt to improve strength and wear resistance. The polyacrylic acid also has been freeze-dried and incorporated into the glass powder, requiring only the addition of water to react and set. Residual acid in the mixed material promotes an ionic bond to tooth structure, adhesively bonding the material to the tooth. The glass powder has a natural rich fluoride content that has been credited with providing a cavity-inhibiting environment to protect the tooth from decay.<sup>24</sup> Although widely quoted, this protective effect of fluoride in glass ionomers has come under scrutiny in recent years, as there has been little clinical evidence of its effectiveness.<sup>25</sup>

*Safety of glass ionomers.* Glass-ionomer materials have proven to be safe with little potential for soft-tissue irritation or other adverse responses. Postoperative sensitivity of glass ionomer material is low and most often is attributed to the placement technique rather than to a direct reaction to the material.<sup>26</sup>

*Effectiveness of glass ionomers.* Modern glass-ionomer materials often are used to restore non-carious erosion or abrasion defects that develop in the tooth near the gumline. They also are used for pediatric restorations, for which service longevity requirements are low. Glass ionomers also frequently are used as cavity liners or bases, providing protection to the underlying tooth pulp in deep fillings. The tooth color of the material allows for an esthetic restoration, but natural appearance suffers since the material lacks translucency. In addition, glass ionomers have been used as pit-and-fissure sealants. However, the high viscosity of these materials and their rapid chemical setting restricts their use to wide fissures and patients with a high risk of developing caries.<sup>27</sup> Glass-ionomer materials also have functioned well as cements for crowns and bridges.

The materials are sensitive to both moisture contamination and desiccation during the setting reaction. These factors make glass ionomers a rather technique-sensitive material to place properly and one that requires good control of mois-

ture and contamination within the cavity.

**Resin-modified glass ionomers.** Resin-modified glass ionomers are similar to conventional glass ionomers but have better properties and handling characteristics.<sup>28</sup> Acrylic resins similar to those used in resin-based composites are added to the material to reduce sensitivity to the setting environment and to provide the ability for the material to be rapidly cured (hardened). Resin-modified glass ionomers (sometimes called “hybrid ionomers”) have two curing systems, light-curing and self-curing. The light-curing system enables the material to be cured on demand with a visible light-curing unit. The mechanical properties of resin-modified glass ionomers are similar to those of conventional ionomers, thus preventing them from serving effectively in permanent load-bearing restorations. They are tooth-colored and have a slightly better enamel-mimicking translucency than that of conventional glass ionomers.

*Safety of resin-modified glass ionomers.* Resin-modified glass ionomers are well-tolerated when properly placed.<sup>27</sup> However, the addition of the acrylic monomers slightly increases the potential for irritation or allergic response when compared with conventional glass ionomers without resins. These materials are not indicated for patients who have a demonstrated allergic response to resin-based composites.

*Effectiveness of resin-modified glass ionomers.* The clinical uses of resin-modified glass ionomers are the same as those of conventional glass ionomers. Unlike conventional glass ionomers, which suffer from short working and long setting times, the working and setting times of these materials are under better control by the dentist. This removes some of the technique sensitivity from this material, making it easier to achieve a successful restoration. For this reason, resin-modified glass ionomers have largely replaced conventional glass ionomers for most indications. In addition, the improved translucency results in a better esthetic match to natural tooth enamel.

## INDIRECT RESTORATIVE MATERIALS

All indirect restorations require a cement for the prepared teeth to retain them. The cement can have a large influence on the performance and biocompatibility of the overall restoration. Two broad categories of available cements are water-based cements and resin-based cements. From these two categories, a dentist has a wide variety

of materials with different working characteristics and properties from which to choose. The choice often depends on the type of material selected for the indirect restoration and the clinical requirements, such as setting characteristics, film thickness, setting rates and adhesion to the underlying tooth.

**All-ceramic.** Dental ceramic materials are used to fabricate lifelike restorations. Ceramic’s translucency and toothlike color contribute to highly esthetic restorations. Ceramic is a very hard and strong material capable of sustaining biting forces but, being a brittle glasslike material, can fracture when subjected to extreme forces or sharp impact. Because of the natural hardness of ceramic, these restorations are highly resistant to wear. However, if they are not highly polished and smooth, they rapidly can wear opposing restorations or natural teeth. Over the years, laboratory-fabricated all-ceramic restorations have become very popular owing to their excellent esthetic properties, high strength and excellent biocompatibility.

*Safety of ceramic materials.* These materials are composed largely of fused natural oxides. Their glasslike properties render them very inert, and they tend to be highly biocompatible and well-tolerated.<sup>29,30</sup> However, all-ceramic restorations rely on technique-sensitive resin-based cements and adhesives to hold them in place and to seal the tooth against leakage. Rare allergies or sensitivities to the resin components of the cements and adhesives can occur. There are a few nonresin cements that can be used with all-ceramic restorations, but they may reduce the overall strength of the restoration owing to their lack of adhesion to the ceramic and the tooth.

*Effectiveness of ceramic restorations.* Dental ceramics are indicated for crowns, inlays, onlays and veneers in areas where the highest level of esthetics is desired. Although ceramic is a naturally strong material, crowns on posterior teeth composed entirely of ceramic have lower success rates than those of metallic restorations because of the material’s brittleness.<sup>31</sup> The low fracture resistance of all-ceramic restorations also limits them primarily to single-tooth restorations.

Ceramic veneer restorations replace a very thin layer of enamel on the front of teeth to improve the appearance or color of the teeth. These restorations are only approximately 0.5 millimeter in thickness, but because they are bonded to the underlying tooth with resin-based

cements and adhesives, they have proven to be very durable. All-ceramic crowns, inlays and onlays can be similarly bonded to teeth to improve their strength and performance. A properly constructed and bonded all-ceramic restoration can provide many years of service with very little change in color or appearance.

**Metal-ceramic.** The technology for effectively bonding porcelain to dental metal alloys was developed in 1962 in an attempt to improve the strength and durability of these restorations.<sup>32,33</sup> These restorations are made by thermally bonding dental porcelains to an underlying metal framework that has been cast to fit the tooth or bridge preparation. The high supportive strength of the underlying metal allows metal-ceramic restorations to provide full coverage of posterior teeth and to be used for multiple-tooth bridges. The natural tooth color of ceramic masks the unnatural appearance of the underlying metal to provide excellent toothlike color and appearance.

*Safety of metal-ceramic restorations.* These restorations generally are well-tolerated except for the moderately rare incidence of allergy to the metal portion of the restoration. High-noble alloys are better tolerated than the base alloy metals when used for these restorations. For this reason, the proper choice of metal becomes an important consideration when using this option.

Another clinical consideration when choosing a metal-ceramic restoration is the additional amount of tooth reduction necessary to accommodate the proper thickness of metal and ceramic needed to fabricate the crown. Care also must be taken to achieve a smooth ceramic surface to reduce the potential for excessively wearing opposing teeth. Metal-ceramic restorations generally do not rely on adhesion to the tooth for strength and can be cemented with a wide variety of dental cements. The resin-based cements, in rare occasions, may induce allergies and sensitivities.

*Effectiveness of metal-ceramic restorations.* The longevity of a metal-ceramic crown or bridge is somewhat less than that of an all-metal restoration because of ceramic's potential to fail. The opacity of the underlying metal tends to render the restoration somewhat less lifelike than the all-ceramic restoration. However, a skilled techni-

cian can overcome this drawback to some degree.

The metal-ceramic restoration cannot provide the high level of esthetics achievable with an all-ceramic restoration, but it can provide much better durability for posterior restorations. Very high-strength metal alloys also can be used to fabricate larger multiple-tooth bridges using this option. Metal-ceramic restorations provide a very durable, long-lasting option for the restoration of posterior teeth or teeth with a great deal of structural damage.

**Cast-gold (high noble metal) alloys.** One of the most serviceable dental restorations available is the cast-gold (high noble metal) restoration.

Gold alloys provide a strong, biocompatible, long-lasting option with a long history of outstanding service to dentistry. The relative high strength of cast-gold alloys allows for a minimal reduction of tooth structure to achieve adequate thickness for the restoration. The long survival time and the low wear of both the restoration and opposing natural tooth structure establish cast gold as the standard by which other dental materials are measured.

*Safety of cast-gold alloys.* By their nature, noble metals are chemically nonreactive with little potential for adverse biological response. Allergic reaction to gold is rare, but it can occur in the form of localized inflammation.<sup>34</sup> Non-noble metals are added to improve the strength of cast-gold alloys, and these additions tend to reduce the noble nature of the alloy. However, even at noble metal content below 75 percent, these alloys generally are well-tolerated.

The high strength and toughness exhibited by these metals allows for the fabrication of thinner restorations, thus reducing the amount of tooth reduction required during preparation. Cast-gold alloys also can be cemented with practically any effective cement, providing the dentist a wide variety from which to choose. Cast-gold alloys still are considered the standard against which other restorative materials are compared clinically in terms of fit, biocompatibility and clinical service.<sup>35</sup>

*Effectiveness of cast-gold alloys.* Noble alloys are used to fabricate inlays, onlays, crowns and bridges. Longevity is difficult to measure because of the many human factors that affect an individual restoration, but it generally is agreed that

One of the most serviceable dental restorations available is the cast-gold restoration.

cast-gold alloy restorations have a typical service lifetime of 20 years or more.<sup>35</sup> These restorations owe their longevity to a high resistance to mechanical failure, excellent fit to the tooth preparation and resistance to recurrent decay. The largest disadvantage of cast-gold alloys is the inability to match natural tooth color. However, small restorations often can be conservatively placed in locations in which little or no metal can be seen under normal conditions.

**Base metal casting alloys.** Base metal, or non-noble, alloys were developed to provide a more economical alternative to cast-gold alloys. These alloys generally are composed of nickel, chromium and cobalt. Base metal alloys can be precision-cast into crowns and bridges or into larger frameworks for removable partial dentures.

*Safety of base metal casting alloys.* Nickel is recognized as a common metal contact allergen; as much as 14 percent of the general U.S. population has been reported to be sensitive to the metal.<sup>37</sup> Despite this high level of sensitivity, allergic reactions in the oral cavity generally are not as severe as those manifested on the skin and are not nearly as common.<sup>38,39</sup> Many people who cannot tolerate jewelry containing nickel can tolerate dental restorations containing nickel. Yet, allergies to nickel in the oral cavity are known, and the use of nickel-based alloys is contraindicated for use in patients with a known nickel allergy.<sup>40</sup>

*Effectiveness of base metal casting alloys.* The base metal alloys serve as effective materials for crown-and-bridge restorations. The higher stiffness of these materials results in less flexure than that which occurs in gold alloys. This is especially important when ceramic is fused to the surface or when long spans are required between supporting teeth. Also, base metal alloys are much lighter in weight than comparable gold alloys. This is important for larger castings such as partial denture frameworks. Base metal restorations also can be cemented using a wide variety of cements.

On the negative side, base metal alloys are about three times harder than gold, which makes adjustments for fit or balanced bite more difficult.

## CONCLUSION

Advances in modern dental materials provide patients and practitioners a number of choices from which to create more pleasing and natural-

looking restorations. This article has presented many of these options, along with their indications for use and possible safety concerns. On the basis of current knowledge from laboratory and clinical studies, the choices discussed in this report, when placed properly, can provide the patient, in almost all cases, with a safe and effective treatment in the repair of missing, worn, damaged or decayed teeth. ■

Address reprint requests to the ADA Council on Scientific Affairs, 211 E. Chicago Ave., 4th Floor, Chicago, Ill. 60611.

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