

Casting alloys

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Dental casting alloys play a prominent role in the treatment of dental disease. This role has changed significantly in recent years with the improvement of all-ceramic restorations and the development of more durable resin-based composites. However, alloys continue to be used as the principal material for fixed prosthetic restorations and will likely be the principal material for years to come. No other material has the combination of strength, modulus, wear resistance, and biologic compatibility that a material must have to survive long term in the mouth as a fixed prosthesis.

The compositions and types of casting alloys available to the dental practitioner have changed significantly over the past 25 years. Before the deregulation of the price of gold in the United States in the early 1970s, gold-based alloys, with gold comprising over 70 weight percentage (wt %) of the composition, were virtually the only type of alloy used for fixed prostheses, with or without ceramic veneers [1]. Fluctuations in the price of gold in the early 1980s (and more recently palladium) and the need for superior modulus and strength have since spurred the development of alternative alloys. Initially, these newer alloys were primarily gold based with less gold (35–50 wt %). However, today's practitioner may select from alloys based on palladium, silver, nickel, cobalt, and titanium, among others [1]. Furthermore, alloys within each of these groups are diverse, and the practitioner faces a bewildering array of choices. Because of the long-term role these materials play in dental treatment, the selection of an appropriate alloy is critical from technical, ethical, and legal perspectives.

Although uses for pure metals such as gold foil and platinum foil exist in dentistry, the main role for metals in dentistry has been in alloys. Alloys are mixtures of metals and nonmetals. Alloys are used for fixed prostheses rather than pure metals because pure metals do not have the appropriate physical properties to function in these types of restorations. For example, the tensile strength of pure gold is 105 MPa. By adding 10 wt % of copper,

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this strength increases to 395 MPa [1,2]. With the appropriate addition of other elements and proper casting conditions, the strength increases to over 500 MPa. Even more impressive is the increase in hardness: from 28 kg/mm² for pure gold to nearly 200 kg/mm² for a typical gold-based casting alloy. Thus, the use of alloys provides physical and biologic properties that are required for successful, long-term fixed prostheses.

Properties of alloys important to clinical performance

Color

A few properties of dental alloys are important to their clinical performance. Color would seem to be an obvious such property. The color of alloys is often described as being “yellow” or “white.” These limited terms are inadequate because the range of alloy colors is much greater, encompassing reddish, brownish, and even greenish tints. Furthermore, the term “white” is a metallurgical term that does not describe the silver color ascribed to these alloys by most clinicians and patients. In any case, the color of casting alloys has little to do with the physical, chemical, dental, or biologic performance of the alloy [3]. The prevailing bias is that yellow alloys cost more, are more biocompatible, and corrode less; however, these biases are not true. Thus, although the color of an alloy may be an important social or esthetic consideration for the patient, color has little or no bearing on clinical cost or performance and should not be used by the practitioner to judge potential clinical performance.

Phase structure

When metals and nonmetals are mixed to create an alloy, they have varying degrees of solubilities in each other [4]. The ability of elements to dissolve in each other is similar to compounds encountered in everyday life, such as alcohol and water or vinegar and oil. If most of the components of the alloy dissolve in one another, the alloy is described as a single-phase alloy and has a more or less homogeneous composition throughout. If one or more components are not soluble in the other, then two or more phases form in the solid state, each having a different composition. In this case, the alloy is described as a multiple-phase alloy. Single-phase alloys are generally easier to manipulate (ie, easier to cast) and have lower corrosion rates than multiple-phase alloys [3]; however, multiple-phase alloys may be etched for bonding and may be significantly stronger than single-phase alloys [1,2]. Before 1975, the majority of alloys were single phase, being based on gold, which is miscible with silver, copper, and palladium [4]. Today’s alloys often use more complex chemistries based on other elements that are not soluble in each other. A typical nickel-based alloy has 8 to 10 different metals and 3 or 4 distinct phases. The phase structure of an alloy is not discernible by the naked eye, so the clinician must rely on laboratory or manufacturer information to know an alloy’s phase structure.

Grain size

A second important microstructural feature of casting alloys is their grain size. Grains are crystals of the alloy that form upon solidification from small nuclei, much as ice crystals form from water. As an alloy cools from the liquid state, these crystals grow until they meet each other at boundaries called grain boundaries. The size of the grains is influenced by factors such as the cooling rate of the alloy, the presence of special nucleating elements such as iridium, heat treatment after casting, and the composition of the alloy [5]. For gold-based alloys, a small ($<30\text{ }\mu\text{m}$) grain size has been shown to improve tensile strength and elongation [6]. For base-metal alloys, small, dispersed secondary phases (each with a small grain structure) are critical to the strength of the alloys. In other base-metal alloys, the grains are large and may approach 1 mm in diameter [7]. These large grains, which do not have anisotropic properties, may be a clinical liability if they occur in critical areas such as the connectors between units of a multiple-unit fixed restoration. As with phase structure, grain structure is not visible to the naked eye.

Strength and hardness

The compressive strength of all dental casting alloys is sufficiently high that it is not a consideration for clinical performance; however, tensile strength varies considerably among alloys. A tensile strength above 300 MPa is necessary to avoid fracture of alloys in high-risk areas such as between pontics of a multiple-unit fixed restoration [2]. Because tensile strength is difficult to measure in practice, most manufacturers cite yield strength instead. The yield strength in tension is the stress required to permanently deform an alloy by a given amount, expressed as a percentage of the length of the specimen being tested. This percentage “offset” (normally 0.1% or 0.2%) indicates a permanent deformation of the alloy and is relatively reproducible. Information on yield strength is easily obtainable from the manufacturer.

The hardness of an alloy must be sufficient to resist wear from opposing teeth or restorations and not so hard as to wear enamel (which has a Vicker’s hardness of 340 kg/mm^2) [1] and other materials such as porcelain. In practice, a Vicker’s hardness less than 125 kg/mm^2 makes an alloy susceptible to wear, and a hardness greater than enamel may wear existing teeth [2]. However, wear is a complex phenomenon, and predicting clinical wear based on hardness alone is not advisable [8]. Information on hardness is commonly available from manufacturers.

Alloy solidus and fit

The shrinkage properties of alloys force the practitioner to consider this property. When a molten alloy solidifies from the liquid state during casting, a large amount of shrinkage occurs but is compensated for by the addition of molten metal from the reservoir in the casting ring. However, once all of the

metal in the restoration has solidified, the shrinkage as the alloy cools from its solidus to room temperature cannot be compensated for by the addition of liquid. If the dimensions of the hot casting were the right clinical size, then the final cooled casting would be too small because of this shrinkage. The higher the solidus temperature, the more shrinkage occurs; these shrinkage values range from about 0.3% to 0.5% for high-gold alloys with solidi of about 950°C to nearly 2.5% for nickel- and cobalt-based alloys with solidi of 1300°C to 1400°C [9]. The shrinkage must be compensated for by expansion of the die, application of die spacers, the use of special expanding investment mechanisms, or increasing the burnout temperature of the investment. The risk of ill-fitting crowns is much greater for alloys with high solidi, and this factor is a significant consideration in the choice of alloys.

Corrosion

Perhaps no property has captured as much attention in recent years as alloy corrosion. The degree of corrosion, which results when one or more components of the alloys is oxidized, is critical to the long-term success of a fixed prosthesis for several reasons. Corrosion may compromise the strength of the restoration, leading to catastrophic failure [2] or the release of oxidized components may discolor natural teeth, porcelain veneers, or even the soft tissues in severe cases [10]. Corrosion may leave the restoration itself esthetically unacceptable because of the formation of pits or colored patinas. The electrons released during corrosion may be detectable by the patient as a shock (galvanic corrosion) that can be disconcerting and even debilitating. Released metallic components may cause an undesirable metallic taste leading the patient to request that the restoration be removed.

The measurement of corrosion is complex, and although many investigators have tried to predict corrosion of an alloy based on its composition, such predictions are difficult at best. Corrosion may be quantified by measuring the current flow associated with metal oxidation or the concentrations of released metals. These measurements may be made under a variety of conditions in vitro or, in some cases, in vivo. Although corrosion is clearly visible to the naked eye when it is severe (such as rust on iron), most corrosion of dental casting alloys is insidious and invisible to the naked eye. Manufacturers of alloys must measure corrosion by specific (ASTM or ISO) standards to gain ISO or ADA certification of their alloys, and this information is usually available from manufacturers, although it is not commonly reported in brochures. Because corrosion generally results in the release of mass from the alloy into the oral environment, it is related in complex ways to alloy biocompatibility [10].

Biocompatibility

Biocompatibility is best described as how an alloy interacts with and affects biologic systems. Although the interactions between an alloy and

tissues may take many forms, the release of elements from the alloy into the oral cavity is a primary focus of alloy biocompatibility because most adverse biologic effects, such as allergy or inflammation, have been attributed to such release [3,10,11]. In this sense, biocompatibility is related to the corrosion of an alloy. However, care must be taken not to assume poor biocompatibility on the basis of elemental release alone because the ability of tissues to tolerate this element release varies widely [12]. In theory, the biocompatibility of casting alloys could be predicted on the basis of their corrosion properties, but in practice, this strategy has proven almost impossible because of the complex dynamics of release of multiple elements and the interactions among them. Thus, direct assessment of biocompatibility, by *in vitro*, animal, or clinical tests, is necessary.

One common misperception of dental casting alloys is that they may be inert in the oral environment [3]. The placement of a material into the oral cavity creates active interfaces through which the body affects the material and the material affects the body. Regardless of the material placed, these interactions occur. Thus, inertness of dental casting alloys is not possible. Furthermore, the interactions that occur are dynamic and may change as the environment of the interface changes. For example, the development of periodontal inflammation, changes in occlusal loading, or a change in diet may alter the way the alloy and oral tissues interact. Additional research is needed in this area.

The biocompatibility of alloys may have legal implications for dental practitioners. Litigation by patients over issues of biocompatibility is rare but usually involves reactions of taste, inflammation, or infection—purportedly from elemental release from casting alloys [10]. These allegations by patients are difficult to prove conclusively but can be avoided altogether by careful selection and proper manipulation of the alloys by laboratories and the practitioner. Procedures such as casting, soldering, polishing, or porcelain application may alter the nominal corrosion properties of casting alloys and their biologic behavior if these procedures are improperly performed [2,7,10].

Porcelain application

The application of porcelain to casting alloys plays a prominent role in the restoration of teeth with fixed prostheses, and several properties of casting alloys are particularly important to the long-term integrity of the porcelain–alloy restoration. The failure (through debonding or cracking) of porcelain on a porcelain–metal restoration is a significant and often emergent clinical problem that is expensive, time consuming, and inconvenient to repair. Furthermore, the failure of the porcelain may not occur for months or years after the restoration is placed. Avoiding these failures is more desirable than trying to correct them. One property of casting alloys that is critical to the successful long-term integrity of porcelain–metal bonds is the melting range

of the alloy. The alloy solidus (lower temperature of the melting range) must be at least 50°C higher than the temperature needed to apply the porcelain (including degassing) or the alloy substructure will deform as the porcelain is applied [9]. These distortions are commonly referred to as “sagging” and are exacerbated by thin metal substructures or long spans. Certain types of casting alloys, such as Pd-Cu alloys, are prone to sagging and should be avoided in these situations [2].

More insidious is the problem of residual stress in the porcelain of a porcelain–metal restoration as the porcelain and alloy cool after firing [1]. These stresses result from differences in the amount of shrinkage that occurs as the materials cool. The coefficient of thermal expansion is used to quantify such shrinkage, and a higher coefficient of thermal expansion implies that more shrinkage will occur on cooling (and more expansion on heating). To avoid residual stresses in porcelain–metal restorations, a matching of coefficient of thermal expansion (CTE) for the porcelain and metal are necessary [1,2]. In practice it is nearly impossible to get the CTE to match over the wide range of cooling temperatures, so current practice is to design the metal to have a slightly (0.5/°C) greater CTE than the porcelain [1]. Thus, the metal shrinks slightly more, and the porcelain, which is bonded to the metal, will be in compression. Compressive stresses are better tolerated by the porcelain than tensile stresses because of the brittle nature of porcelain, and porcelain–metal restorations using this paradigm are generally more stable long-term. In practice, the manufacturer controls the CTE of the alloy and the porcelain, but the laboratory or practitioner should use only combinations of porcelain casting alloys recommended by the manufacturer.

Porcelain bonds to most casting alloys through a metal oxide formed on the metal surface during the degassing stage of porcelain application. Properties of the oxide layer such as oxide color, thickness, and strength vary widely by alloy type and are critical to the strength and esthetics of the porcelain–metal bond [13]. Almost all oxides are brittle, and therefore the thickness of the oxide layer should be minimized to avoid failure of the porcelain–metal bond within this layer. Alloys based on nickel and cobalt commonly form thick oxides, and it is common laboratory practice to remove some of the oxide before porcelain application [9]. On the other hand, alloys based on gold or palladium form thinner oxide layers because of the nobility of these metals. In general, oxide-forming elements such as tin or gallium must be added to gold- or palladium-based alloys to ensure adequate oxide formation [1,9]. Because some of these oxide formers are lost during casting (which is an oxidizing process), the re-use of gold- and palladium-based alloys may result in inferior porcelain–metal bonds unless sufficient (usually at least half) new metal is added to the casting. Although these issues are beyond the direct control of the practitioner, they exemplify the need of the practitioner to choose a high-quality dental laboratory.

The color of the oxide layer must be properly managed to ensure the correct shade of a porcelain–metal restoration. Although the oxide and metal

are covered by opaquing porcelain, the effectiveness of the opaque in masking the oxide color and the thickness required to do so vary significantly by alloy type. Nickel-, silver-, cobalt-, and palladium-based alloys have grayer oxides that are harder to mask and tend to make teeth have lower color values and grayer hues. Furthermore, the thicker layers of opaque required to mask these gray colors reduces the thickness available for subsequent layers of dentin and enamel porcelain and ultimately reduces the esthetics of the porcelain [1,2]. Gold-based alloys generally have lighter white to yellow oxides that are easier to mask and more congruent with the normal hues of human dentin.

For some casting alloys, release of elemental vapor during application of the porcelain can discolor porcelain. Alloys containing high amounts of silver and copper are most likely to cause this porcelain discoloration (termed “greening”) [1,2]. Laboratories also must be careful to ensure that the muffle of the porcelain oven does not become contaminated with these elements, leading to porcelain discoloration in subsequent uses of the oven.

Soldering

Soldering of alloys is highly dependent on the type of alloy and may be a significant factor in the clinician's choice of alloy. Soldering becomes even more complex if porcelain–metal restorations are involved. Aside from the issues of soldering below the solidus of the alloys (at least 50°C is generally a safe margin) [2], the compatibility of solders and fluxes is not straightforward. If the treatment plan requires soldering wires, clasps, attachments, or pontics, then the ability of the alloy to be reliably soldered must be considered. In general, gold-based alloys are most easily soldered compared with palladium-, nickel-, silver-, or nickel-based alloys. Furthermore, the heating that occurs during soldering is more likely to alter complex phase structures of base–metal alloys than of high-noble alloys.

Classes of alloys currently available

Casting alloys are categorized several ways, but the classification system most used by dental practitioners is the American Dental Association (ADA) compositional classification system. The ADA system divides casting alloys into three groups on the basis of wt % composition [1]. The high-noble alloys are those with a noble metal content (sum of gold, palladium, and platinum) of at least 60 wt % and a gold content of at least 40 wt %. Most gold-based alloys before 1975 fell into this category. The noble alloys must contain at least 25 wt % noble metal but have no specific requirement for gold content. Finally, the predominantly base-metal alloys contain less than 25 wt % noble metal, with no other specification on composition. The ADA has adopted symbols for each of these classes of alloys to aid the practitioner in knowing to which category a given alloy belongs (Fig. 1). This classification system is



Fig. 1. Symbols adopted by the ADA for its three major classifications of alloys based on composition.

more encompassing than the previous classification system it replaced in 1984, which focused primarily on gold-based alloys.

The ADA also classifies alloys on physical properties of yield strength and elongation (Table 1) [1]. Four categories of alloys are defined in this scheme. Soft alloys are defined for use in low-stress conditions under which the restoration bears no significant occlusion. Medium alloys are recommended for conditions of moderate stress and light occlusal stress. Hard alloys are recommended for full occlusal loads with single units or short-span fixed partial dentures, and very hard alloys are recommended for removable partial dentures and longer-span fixed partial dentures. Each casting alloy is therefore defined by two ADA classification systems—one for composition and one for physical strength. The subsequent discussion focuses on compositional classifications, recognizing that within each compositional class a variety of physical properties are available.

High-noble alloys

High-noble dental casting alloys (Table 2) can be divided arbitrarily into those based on gold-platinum (Au-Pt), gold-palladium (Au-Pd), or gold-copper-silver (Au-Cu-Ag). Of these groups, the first two alloy types are appropriate for full-cast or porcelain-metal applications. The latter group is appropriate only for full-cast applications because of its higher silver and copper content and its lower melting range. The Au-Pt alloys are the newest of the high-noble alloys and were designed to avoid the use of palladium, which became expensive and biologically controversial between 1995 and 1999. Both of these issues have since resolved, but this class of alloys is still

Table 1
Classification of casting alloys by physical properties

ADA designation	Yield strength (MPa, in tension)	Elongation (%)
Soft	<140	18
Medium	140–200	18
Hard	201–340	12
Extra-hard	>340	10

available. These alloys are complex metallurgically because gold and platinum are not completely soluble in one another and are generally strengthened by a dispersed zinc phase. Some formulations contain silver to strengthen the alloy through solid solution hardening with gold [2]. These alloys are white (silver) in color and have a moderately high melting range and moderate hardness, modulus, and strength. Because of their high noble-metal content (>97 wt %), they are expensive. Their corrosion is highly variable depending on the phase structure and appropriate manipulation of the alloy by the laboratory. Au-Pt alloys are especially susceptible to overheating, which can disrupt the dispersed zinc phase and increase its corrosion significantly.

The Au-Pd alloys are a common type of high-noble alloy used for porcelain–metal and full-cast restorations, but they are more common in porcelain–metal applications (see Table 2). These alloys have moderate strength, elastic moduli, and hardness and have a moderately high melting range. The Au-Pd composition is sometimes supplemented with silver to increase the physical properties via solid solution hardening with gold and palladium. Au-Pd alloys are nearly always single-phase alloys and are always white in color because the Pd concentrations are greater than 10 wt % [2]. The corrosion of these alloys is low in biologic environments, even at low pH or during toothbrushing [14,15].

The Au-Cu-Ag high-noble alloys (see Table 2) have a long history of use in dentistry for full-cast restorations (they are compositionally equivalent to the old type III casting alloys). These alloys generally are yellow in color and have moderately high yield strengths and hardness but only moderate elastic moduli. Because copper and silver are miscible with gold, these alloys are almost always single phase, which makes them easy to cast and solder. They

Table 2
Selected properties of major types of high-noble alloys

Alloy type	Solidus-liquidus (°C)	Color	Phase structure	Elastic modulus (static, GPa)	Vicker's hardness (kg/mm ²)	Yield strength (tension, 0.2%, MPa)
Au-Pt (Zn) ^a	1060–1140	Yellow	Multiple	65–96	165–210	360–580
Au-Pd (Ag) ^a	1160–1260	White	Single	105	280	385
Au-Cu-Ag	905–960	White	Single	100	210	450

^a In many formations.

also can be head hardened by heating to about 600°C and then letting the alloy cool to room temperature slowly [2]. Their relatively low melting range makes them castable using gypsum-bonded investments and gas-air torches.

Noble alloys

Noble alloys are much more compositionally diverse than high-noble alloys because they include gold-based alloys and those based on other elements such as palladium or silver (Table 3). They are comprised of four groups: Au-Cu-Ag, Pd-Cu-Ga, Pd-Ag, and Ag-Pd. The Au-Cu-Ag noble alloys are similar in composition and metallurgy to the high-noble Au-Cu-Ag alloys. They were developed in the early 1980s when the price of gold dramatically increased, making their high-noble counterparts too expensive. These alloys have decreased gold content and compensate for the reduced gold by increasing copper, silver, or palladium. These alloys have moderate moduli of elasticity but are higher in hardness and yield strength than their high-noble counterparts. Depending on the amount of silver or copper present, Au-Cu-Ag alloys may be used in porcelain–metal applications but are more commonly used for full-cast restorations. The melting range of these alloys is lower than that of their high-noble counterparts if the copper or silver has been supplemented, and the color of these alloys varies from yellow to reddish-yellow to silver depending how the reduced gold is compensated for in the composition. For example, alloys with 10 wt % or more of palladium have a silver color, whereas those with 20 to 30 wt % of copper are more reddish in color [2]. Most often single-phase alloys, the Au-Ag-Cu alloys generally have poorer corrosion properties than their high-noble counterparts if the copper or silver has been increased to more than 15 wt % [12].

The Pd-Cu-Ga alloys are the most metallurgically complex of the noble alloys (see Table 3). They nearly always have multiple phases, but their corrosion is highly variable depending on the specific nature of the phases. The phase microstructure of these alloys is complex and dependent on how the alloy is manipulated [16]. This manipulation dependence makes selection of an experienced laboratory paramount. The Pd-Cu-Ga alloys are among the strongest alloys used in dentistry for cast restorations and are 25% stiffer

Table 3
Selected properties of major types of noble alloys

Alloy type	Solidus-liquidus (°C)	Color	Phase structure	Elastic modulus (static, GPa)	Vicker's hardness (kg/mm ²)	Yield strength (tension, 0.2%, MPa)
Au-Cu-Ag-(Pd) ^a	880–930	Yellow/white	Single	100	250	690
Pd-Cu-Ga	1145–1270	White	Multiple	127	280	580
Pd-Ag	1185–1230	White	Multiple	125	275	620
Ag-Pd	990–1045	White	Multiple	93	230	480

^a In many formations.

than any of the high-noble alloys or the Au-Cu-Ag noble alloys. These alloys have high melting ranges and must be cast using induction-casting and special high-temperature investments [1,2]. They are difficult to finish and polish. Depending on the amount of copper and its high-temperature volatility, the Pd-Cu-Ga alloys are useful for porcelain–metal applications. However, the higher melting range of these alloys makes them more difficult to ensure a good fit of the restoration intraorally. These alloys also are susceptible to sag during porcelain application.

The Pd-Ag and Ag-Pd alloys are essentially a continuum of the same alloy system but are different in terms of their manipulation and clinical performance (see Table 3). Of the two groups, the Pd-Ag alloys are far more common in dentistry and are far superior in strength, corrosion resistance, modulus, and hardness. The Pd-Ag alloys are used for porcelain–metal restorations, but the high silver content of the Ag-Pd systems makes them unusable for anything but full-cast restorations. Because palladium has a very high melting point (over 1400°C), the Pd-Ag alloys (which typically contain over 60 wt % Pd) have high melting ranges, and obtaining good clinical fit of these alloys depends heavily on properly compensating for casting shrinkage. Furthermore, these alloys require the use of induction-casting and high-temperature investments. Of all the noble and high-noble alloys, the Pd-Ag alloys have the highest moduli, making them most suitable for long-span fixed partial dentures; however, even these alloys are not as stiff as the nickel- or cobalt-based alloys. The Ag-Pd alloys are usually only in the noble category by the use of a minimal amount of Pd (25 wt %) or a combination of palladium and gold totaling 25 wt %. The physical and corrosion properties of these alloys are inferior, and they offer few advantages over the base-metal alloys.

Predominantly base-metal alloys

The base-metal alloys can be arbitrarily divided into four groups: Ni-Cr-Be, Ni-Cr, Ni-high-Cr, and Co-Cr (Table 4). The first three groups are closely related in composition and many physical properties but are fundamentally different in their corrosion properties. These alloys may be manufactured with or without trace amounts (0.1 wt %) of carbon. When used for cast restorations, these alloys generally do not contain carbon. However, when used for partial denture frameworks, carbon is generally added and is a potent enhancer of yield strength and hardness (but not modulus) [7]. All alloys in this group may be used for full-cast or porcelain–metal restorations, and all are silver in color. From the standpoint of porcelain application, these alloys all form heavy, dark oxide layers that are more difficult to esthetically manage than those formed by alloys in the noble and high-noble alloy groups. The base-metal alloys share high physical properties, and these alloys have the highest moduli of any alloys used for cast restorations. They are all equally difficult to solder because of their propensity for formation of surface oxides.

Table 4
Selected properties of major types of predominantly base-metal alloys

Alloy type	Solidus-liquidus (°C)	Color	Phase structure	Elastic modulus (static, GPa)	Vicker's hardness (kg/mm ²)	Yield strength (tension, 0.2%, MPa)
Ni-Cr-Be	1160–1270	White	Multiple	192	350	325
Ni-Cr	1330–1390	White	Multiple	159	350	310
Ni-high-Cr	1250–1310	White	Multiple	205	205	180
Co-Cr	1215–1300	White	Multiple	155	155	390

The nickel-based alloys in this group may have chromium contents of approximately 14 wt % with (Ni-Cr-Be) or without (Ni-Cr) beryllium (see Table 4). Beryllium is used primarily to lower the melting range of the alloy to a point where gypsum-bonded investments can be used for casting [9]. In the United States, the beryllium-containing forms of these alloys are most commonly used. Although beryllium is advantageous in terms of casting manipulation of this alloy by the laboratory, the Ni-Cr-Be alloys corrode far more than their non-Be counterparts [12,17]. This corrosion is particularly evident in acidic environments. In some studies, the amount of nickel released from these alloys in an acidic environment in 30 minutes is more than that released in 1 year in a neutral environment [14]. The Ni-high-Cr alloys are the most corrosion resistant of the Ni-based group and have Cr contents of over 20 wt %. These alloys are the most common of the Ni-based alloys used in Europe. The corrosion of these alloys is far better than the Ni-Cr-Be alloys but not as good as many alloys in the noble or high-noble groups. The common hypersensitivity to nickel (10% to 20% by most estimates [18]) makes use of any of the Ni-based alloys a higher biologic risk than many others.

Co-Cr alloys are the most common base-metal alternative for patients known to be allergic to nickel (see Table 4). Unfortunately, cobalt is the second-most common metal allergen, and cobalt allergy should be ruled out before these alloys are substituted for nickel-based alloys. With the exception of titanium-based alloys, the Co-Cr alloys have the highest melting ranges of the casting alloys, and laboratory manipulation (casting, finishing, and polishing) of these alloys is difficult. The surface oxide of Co-Cr alloys is particularly difficult to mask, and the compatibility of coefficients of thermal expansion between these alloys and porcelains may be problematic.

Clinical selection of alloys

The selection of an alloy for a cast restoration is ultimately the legal and ethical responsibility of the practitioner, but this decision often is made by the dental laboratory. Given the complexities of the decision, its abrogation to the dental laboratory is not surprising. However, given the long-term consequences of this decision on the oral health of the patient, selection of casting alloys should be made primarily by the practitioner with consultation

from the dental laboratory. The practitioner often focuses on the cost and color of the alloy as major factors in this decision, but cost and color are the least important factors in selecting a material for a successful prosthesis. Furthermore, the initial cost of the alloy is often a poor indicator of the overall long-term cost of the restoration. If the restoration fails because of poor clinical performance and must be replaced prematurely, the costs of these repairs (in patient discomfort, time, and money) will far exceed the initial savings of using a cheaper but inferior alloy.

The selection of a casting alloy is best customized for a particular clinical situation. The systemic health of the patient should be the first consideration, and the practitioner should avoid alloys that contain elements to which the patient is hypersensitive. These elements are most commonly nickel and cobalt, although allergies to palladium and gold have been reported. The complete composition of the alloys therefore must be considered by the practitioner in this regard because even trace elements can elicit reactions through disproportional corrosion from grain boundaries or secondary phases [12]. The physical requirements of the alloy are also a primary consideration. For example, if the restoration involves long spans, then an alloy with the highest modulus of elasticity is advisable, particularly if the prosthesis is porcelain–metal. The fit of the restoration depends to a large extent on the ability of the laboratory to manage casting shrinkage. This issue is most difficult with high-melting alloys. The tensile strength is important if the restoration involves connectors between multiple units and if these connectors are narrow occlusal-lingually because of short clinical crowns, periodontal considerations, or esthetic requirements. The color of the alloy's oxide may be important in porcelain–metal restorations.

Finally, practitioners should maintain records of the materials that they use for cast restorations and should give patients this information. The Identalloy system is a convenient means to maintain good dental records and inform patients [1]. Most manufacturers supply laboratories with stickers that contain the name and composition of the their alloys, and most good laboratories supply these stickers to the practitioner upon request. Practitioners should use this, or other means, to maintain records of the materials used. These records are important to help diagnose future problems that might occur (biologic reactions or mechanical failures) and are important legal resources to defend the practitioner in the event of litigation.

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