DENTAL ALLOYS USED IN PROSTHODONTICS

Basic Information about Metals and Alloys

Metals are normally crystalline solids at room temperature, although there are some exceptions such as hydrogen (a gas) and gallium and mercury (liquids).

Metals are noted for the ease with which they give up their valance electrons; this accounts for certain characteristics such as good electrical and thermal conductivity and the tendency for metals to form cations (positive ions) in solution; metals are also strong, lustrous, and ductile.

Alloy: two or more metals that are mutually soluble in each other in the molten state.

Liquidus: the temperature below which a metal is completely solid (i.e., the temperature at which it begins to melt).

Solidus: the temperature above which a metal is completely melted.

Grain: a single crystal of metal as seen in the metal's microstructure.

Grain refiner: a metal such as iridium that is added to a metal or alloy because of its high melting temperature. Since it remains solid while the rest of the metal is molten, its small particles act as seeds around which grains of the solidifying metal form. This enhances the physical properties of the solid metal.

Sag: deformation of a metal or alloy; for our discussion, this occurs at high temperatures such as during porcelain firing.

Generally, alloys are used in dentistry because alloying strengthens a metal. Pure metals such as gold are not used because their relatively poor physical properties make them a poor choice for intraoral use. For example, pure cast gold is only 1/5th as strong and 1/6th as hard as a typical gold-based casting alloy.

During solidification (i.e., when a metal or alloy goes from liquid to solid), the following process occurs:

random atoms to **embryos** (temporary nuclei) to **nuclei** to **dendrites** to **grains**

As the grains grow, they contact each other. The border between them is called a grain boundary.

Generally, a metal to be used under intraoral conditions should have a fine-grained structure because it tends to be more resistant to permanent deformation.

Smaller grain size can be achieved by rapidly cooling the molten metal and by inclusion of a grain-refiner such as iridium (as noted previously). When iridium is added in a small concentration (0.005% = 50 ppm), the tensile strength and ductility increase. There is little, if any, effect on hardness and yield strength.

Important Properties for Prosthodontic Alloys
Several properties have a bearing on the clinical performance of prosthodontic alloys. Some of the most important are yield strength, hardness, modulus of elasticity, proportional limit, and corrosion.

Yield Strength: is the amount of stress required to produce a pre-established amount of permanent strain (i.e., change in length) of the alloy. Ideally, we want our alloys to have a high yield strength, so that a great deal of stress must be applied before they permanently change dimensions. Generally, alloys with tensile yield strengths above 300 MPa function satisfactorily in the mouth.

Hardness: alloys must be hard enough to resist wear but not too hard, because excessive hardness can cause wear of the opposing dentition or restoration(s).

Modulus of Elasticity (MOE): equates to rigidity or stiffness. When prosthodontic alloys are used for metal-ceramic long-span fixed partial dentures, it is important that the restoration be resistant to flexure. If not, the overlying brittle porcelain will catastrophically fail. MOE is also important for removable partial dentures so that the major connectors have adequate rigidity to prevent flexure during placement and function. Resistance to flexure is also beneficial because clasps can be placed into areas of minimal undercut and still provide adequate retention.

Proportional Limit: the amount of stress required to produce permanent deformation of a material.

Corrosion: surface deterioration of a metal because of its interaction with the surrounding environment. Resistance to corrosion is critically important for a dental alloy because corrosion can lead to roughening of the surface, weakening of the restoration, and liberation of elements from the metal or alloy. Liberation of elements can produce discoloration of adjacent soft tissues and allergic reactions in susceptible patients. Commonly, noble metals are added to an alloy to reduce its tendency to corrode. These include gold, platinum, palladium, ruthenium, rhodium, osmium, and iridium.

Ductility: The degree to which a material can be permanently deformed by a tensile force without undergoing fracture or rupture. Often expressed as *Percentage Elongation*. Gold alloys with a PE greater than 5% are considered ductile; those less than 5% are described as brittle. The most ductile metals are gold and silver.

Malleability: The degree to which a material can be permanently deformed by a compressive force without undergoing fracture or rupture. The most malleable metals are gold and silver.

Older Classification System for Classifying Dental Alloys

Approximately 25 to 30 years ago, alloys were organized into three groups according to their use:

1. Gold-based alloys for full-cast restorations
2. Metal-ceramic alloys for porcelain bonding
3. Alloys for removable partial dentures

Gold-based Alloys for Full-cast Restorations

There were four types of these alloys as seen in the table below. This method of classification was based on one developed in 1927 by the then Bureau of Standards (now the National Institute for Standards and Technology) and was based on their dental function. After the American Dental Association (ADA) revised Specification 5, the alloys were classified according to their properties and not their compositions.

Type	Hardness	Yield Strength (MPa)	Percentage Elongation (%)
I	Soft	<140	18
II	Medium	140-200	18
III	Hard	201-340	12
IV	Extra-Hard	>340	10

These alloys were essentially ternary alloys of gold, silver, and copper with small amounts of zinc, platinum, and palladium; iridium was occasionally added for grain refinement (which helped improve physical properties).

The most commonly used one was Type III which typically had a composition similar to: (in weight %):

Gold	75%
Silver	10%
Copper	10%
Palladium	3%
Zinc	2%

Effects of the Various Constituents

Gold: increases resistance to tarnish and corrosion; increases ductility and malleability

Copper: principal hardener; is necessary for heat treatment (when added in a concentration >12 wt%)

Silver: main purpose is to modify the red color produced by gold and copper; reduces melting temperature; increases ductility and malleability

Platinum: raises melting temperature; increases tensile strength; decreases the coefficient of thermal expansion; reduces tarnish and corrosion
Palladium: raises melting temperature; increases hardness; acts to absorb hydrogen gas which can cause porosity in the casting; prevents tarnish and corrosion; has a very strong whitening effect on gold alloys even when used at a low concentration (i.e., 5 wt%)
Zinc: acts as a scavenger and prevents oxidation of the other metals during the manufacturing process; increases fluidity and decreases surface tension, which improves castability
Iridium: acts as a grain refiner; this increases tensile strength and percentage elongation (i.e., ductility); it also increases, to a much lesser degree (if at all), hardness and yield strength

As these gold-based full-casting alloys go from Type I to Type IV, their composition changes: gold content, melting temperature, and ductility decrease, while copper content, proportional limit, hardness, tensile strength, and yield strength increase. To a great extent, the alloys' physical properties determine where they are best suited for use:

- Type I: inlays for non stress-bearing areas.
- Type II: inlays and onlays in stress-bearing areas
- Type III: full crowns, ¾ crowns, and short-span fixed partial dentures
- Type IV: full crowns, long-span fixed partial dentures, and removable partial dentures

Metal-ceramic Alloys for Porcelain Bonding

These alloys differed from the gold-based alloys used for full-cast restorations in the following ways:

1. they had higher melting temperatures (due to greater palladium content) to accommodate the temperatures required for porcelain application
2. they contained little, if any, silver which could cause the porcelain to turn green
3. they contained little, if any, copper because it could cause the alloy to sag during porcelain firing

There were six types of these alloys: four were gold- or palladium-based, however the most common contained both gold and palladium. The remaining two were nickel- or cobalt-based.

Thirty years ago, the nickel-chromium and cobalt-chromium alloys for metal-ceramic use were much less commonly used than they are today. They differed in composition from their counterparts used for fabricating removable partial denture frameworks in that they contained no carbon.

Alloys for Removable Partial Dentures
These consisted of three types:

1. Type IV gold-based alloys
2. Chromium-based alloys
3. Cobalt-based alloys

The Type IV gold-based alloys were strong enough to function adequately when used to make frameworks.

The Cr- and Co-based alloys differed (as already noted) from their metal-ceramic counterparts in that they contained a small amount of carbon (usually from 0.1 to 0.5 wt%) for hardening.

These alloys had advantages compared to the Type IV gold-based alloys in that they were stronger, 30% harder, less dense (therefore light and cheaper), and had twice as high a higher modulus of elasticity (i.e., rigidity). The greater rigidity made them a good choice for RPD frameworks because the frameworks could be cast in thinner sections and still retain the important property of rigidity. Also, because they flexed less, undercuts used for clasp retention could be less pronounced and still function adequately.

Disadvantages of these alloys (compared to the Type IV golds) were their higher casting temperature and higher hardness (which made fabrication, finishing, and polishing more difficult), and their low ductility. Low ductility meant that clasps could only be permanently deformed (such as during chairside adjustment) a few times before they failed.

Current System for Classifying Dental Alloys
The previous system for classifying alloys used in prosthodontics was based on three mutually-exclusive categories: gold-based alloys for full-cast restorations, metal-ceramic alloys for porcelain bonding, and alloys for removable partial dentures. For economic and technical reasons, there is now considerable overlap of these three. Today's system is based on two separate criteria: physical properties and composition.

Classification Based on Physical Properties

Type	Hardness	Yield Strength (MPa)	Percentage Elongation (%)
I	Soft	<140	18
II	Medium	140-200	18
III	Hard	201-340	12
IV	Extra-Hard	>340	10

Another system, this one based on alloy composition and not physical properties, was proposed by the ADA in 1984 to accommodate new types of alloys that were being introduced at the time.

Classification Based on Composition

Type	Composition
High-Noble	Gold content $\geq$ 40 wt% and Noble metal content $\geq$ 60 wt%
Noble	Noble metal content $\geq$ 25 wt%
Primarily Base-Metal	Noble metal content < 25 wt%

High-Noble Alloys

By definition, these alloys must have a noble metal content of at least 60 wt%, of which at least 40 wt% is gold. They usually contain a small amount of tin, indium, and/or iron which provides for oxide layer formation. This increases the alloy's bond strength to porcelain by a factor of three. The disadvantages of these alloys include their lower rigidity and poor sag resistance during porcelain firing. There are three subclasses of high-noble alloys:

1. Gold-platinum
2. Gold-palladium
3. Gold-copper-silver-palladium

Gold-platinum alloys:

Initially developed as an alternative to palladium alloys, these can be used for full-cast as well as metal-ceramic restorations. Because they are subject to sag, they should be limited to short-span fixed partial dentures. They often contain silver or zinc as a hardener.

A typical composition is:

1. Gold 85%
2. Platinum 12%
3. Zinc 1%
4. Silver (in some brands)

Gold-palladium Alloys

Like gold-platinum alloys, these can be used for full-cast or metal-ceramic restorations. They usually contain indium, tin, or gallium to promote oxide layer formation for better bonding to porcelain.

A typical composition is:

1. Gold 52%
2. Palladium 38%
3. Indium 8.5%
4. Silver (in some brands)

Gold-copper-silver-palladium Alloys

These are used only for full-cast restorations because (1) their melting temperatures are too low for metal-ceramic use, and (2) they contain silver and copper which can green the porcelain and cause the metal casting to sag during porcelain firing.

A typical composition is:

1. Gold 72%
2. Copper 10%
3. Silver 14%
4. Palladium 3%

Noble Alloys

By definition, these alloys must contain at least 25 wt% noble metal. Because the noble alloys can contain a number of different metals, they are a rather diverse group. As a general rule, however, they have relatively high strength, hardness, and ductility. They may be yellow or white in color. When white, it is due to their palladium content. Palladium also gives them their relatively high solidus temperatures. The one exception are the gold-copper-silver-palladium alloys which are only used for full-cast restorations. The degree to which the noble alloys corrode varies because of their diverse compositions.

There are three subclasses of noble alloys:

1. Gold-copper-silver-palladium
2. Palladium-copper-gallium
3. Palladium-silver and Silver-palladium

Gold-copper-silver-palladium Alloys

Introduced in 1970, these alloys are used solely for full-cast restorations. Their relatively low solidus temperatures preclude them from being used as metal-ceramic alloys. These are similar in composition to the high-noble gold-copper-silver-palladium alloys, except they contain less gold. Greater amounts of copper and silver are added in place of the gold.

A typical composition is:

1. Gold 45%
2. Copper 15%
3. Silver 25%
4. Palladium 5%

Palladium-copper-gallium Alloys
Introduced in 1982, these are extremely rigid and are used for full-cast and metal-ceramic restorations.

They contain some copper, so laboratories have to use them carefully to avoid sagging of the casting during porcelain firing.

Gallium is added to reduce the temperature at which the alloy is completely melted; this enhances bonding of porcelain to the metal and increases strength.

Susceptibility to corrosion varies widely depending on the alloy's specific composition.

A typical composition is:

1. Palladium 79%
2. Copper 7%
3. Gallium 6%

Palladium-silver and Silver-palladium
Introduced in the 1970s, these alloys are used for full-cast and metal-ceramic restorations. Their composition varies widely, ranging from those with a majority of silver to those with a majority of palladium. Generally, the higher-silver alloys exhibit more corrosion. Because they contain silver they can also cause greening of porcelain, so if used as metal-ceramic alloys, steps must be taken to compensate for this such as using a "non-greening" porcelain. On the positive side, the Pa-Ag and Ag-Pa alloys generally have low sag tendency, high rigidity, and are easy to solder.

A typical composition for a Palladium-silver alloy is:

1. Palladium 61%
2. Silver 24%
3. Tin (in some formulations)

A typical composition for a Silver-palladium alloy is:

1. Silver 66%
2. Palladium 23%
3. Gold (in some formulations)

Base-Metal Alloys
These alloys, introduced in the early 1970s, contain (by definition) less than 25 wt% noble metal. In actuality, most contain no noble metal. They are used for full-cast and metal-ceramic restorations as well as for removable partial denture frameworks. As a group they are much harder, stronger, and have twice as high an elastic modulus as do the high-noble and noble-metal alloys. This latter property is advantageous because castings can be made thinner and still retain

rigidity. For metal-ceramic purposes, this means that porcelain need not be overbulked for esthetics, and long-span fixed partial dentures will be more resistant to flexure, which can lead to porcelain fracture. For removable partial dentures, greater rigidity is advantageous because major connectors can be made thinner (and therefore less objectionable to the patient) and still be rigid. The base-metal alloys also have excellent sag resistance.

The base-metal alloys are not without their disadvantages. They are more difficult to cast than non base-metal alloys because of their very high liquidus temperatures. They also exhibit a greater casting shrinkage (about 2.3%) that must be compensated for. Because of their lower ductility and greater hardness, they are less burnishable and more difficult to finish and polish than the high-noble and noble-metal alloys. They are also more prone to corrosion under acidic conditions, difficult to solder, and can cause an allergic reaction in susceptible patients. Finally, beryllium and nickel can cause allergic reactions and may have carcinogenic effects. They must be handled according to appropriate safety standards.

There are three subclasses of the base-metal alloys:

1. Nickel-chromium-beryllium
2. Nickel-chromium (with higher chromium content)
3. Nickel-chromium (with lower chromium content)
4. Cobalt-chromium

Nickel-chromium Alloys

These alloys (which include the Ni-Cr-Be subclass and both Ni-Cr subclasses) can be used for full-cast and metal-ceramic restorations as well as for removable partial denture frameworks. They invariably contain at least 60% nickel and may or may not contain a small amount of carbon (about 0.1%) as a hardener. Beyond that, they will contain either: >20% chromium; <20% chromium with no beryllium, or; <20% chromium with 1 to 2% beryllium.

The nickel-chromium-beryllium alloys are very common in the United States. They exhibit excellent sag resistance as well as high strength and rigidity. Small amounts of beryllium reduce the liquidus temperature and, therefore, make casting easier. Beryllium also improves the following physical properties because it acts as a grain refiner: tensile strength, ductility, and possible hardness and yield strength. Unfortunately, beryllium increases corrosion.

Cobalt-chromium Alloys

These can be used for full-cast and metal-ceramic restorations but are most commonly used to fabricate removable partial denture frameworks. When used, they are most frequently chosen as an alternative to the nickel-based alloys for patients allergic to nickel.

They are much less commonly used in the United States than are the nickel-chromium alloys, primarily because they are more difficult to work with due to their high melting temperatures, which necessitate the use of special casting equipment. Also, their high hardness and low ductility make them difficult to finish and polish.

<u>Sources</u>

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