Casting Alloys: The Materials and "the Clinical Effects"

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It is estimated that 96% of adults in the United States between the ages of 18 and 65 have one or more carious or filled teeth, with an average of almost 10 decayed or filled teeth for each adult (Miller *et al.*, 1987). The best treatment for carious teeth, to prevent loss and restore masticatory function, often involves the use of cast dental restorations. This paper will discuss the chemical compositions of noble and base metal dental alloys and, based on 72-month data from a 10-year clinical study (Morris *et al.*, 1986), will summarize the clinical behavior of alloys with "representative formulations". "Noble" refers to metals with marked resistance to oxidation and chemical reaction. Silver is not considered noble in the context of dental casting alloys. "Precious" refers to an economic value. The American Dental Association has stated that "semi-precious" has no meaning in dentistry because no definition has been agreed on (ADA, 1984). "Base metal" refers to metal elements that are chemically reactive to their environment (Phillips, 1991).

TYPES OF DENTAL ALLOYS

Dental alloys can be categorized as noble alloys (gold- and palladium-based) or base metal alloys (nickel- and cobalt-based). Major (> 10 at%) and minor (< 10 at%) components of these different alloy types are shown in Tables 1-4.

Noble Alloys

Noble/Gold-based Alloys

Noble/gold-based alloys (Table 1) have the longest history of use in dentistry and are "the standard" with which other alloys are usually compared. They are used for fabrication of inlays, crowns, fixed partial dentures, and metal ceramic restorations (PFM). Gold adds high corrosion resistance, good castability, good ductility, and the distinctive yellow gold color. Silver reduces density, slowly whitens the alloy color when added in increasing amounts, and counteracts the redness of copper. In PFM alloys, silver may discolor porcelain veneers. Copper strengthens gold-based alloys ($AuCu_3$). Both palladium and platinum increase casting temperature, strength, and corrosion resistance of the alloy (Tuccillo and Nielson, 1971). Palladium lowers cost and improves rigidity and sag resistance of PFM alloys (Moffa, 1983). Zinc (traces) increases castability (Raub and Ott, 1983) and forms intermetallic (gold) compounds to harden the alloy (Labarage and Treheux, 1979). Iron improves mechanical properties and, in PFM alloys, increases sag resistance (Kojima, 1980) and bond strength with porcelain (Espevik and Øilo, 1979). Tin acts as a bonding element in PFM alloys and a hardening agent in palladium-gold alloys (German, 1979). Iridium acts as a grain refiner in gold-based PFM alloys (Raub and Ott, 1983). Indium serves as a bonding agent in PFM alloys (Espevik and Øilo, 1979).

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TABLE 1
NOBLE/GOLD-BASED ALLOYS: "GENERAL" CHEMICAL COMPOSITIONS

(A)	Crowns and fixed partial dentures	
	(1)	Major: gold, silver, copper
	(2)	Minor: palladium, platinum, zinc, indium, iridium, rhenium, germanium
(B)	Metal ceramic (PFM)	
	(1)	Major: gold, platinum, palladium
	(2)	Minor: rhodium, silver, indium, tin, iron, iridium, rhenium, copper

TABLE 2
NOBLE/PALLADIUM-BASED ALLOYS: "GENERAL" CHEMICAL COMPOSITIONS

(a)	Crowns and fixed partial dentures	
	(1)	Major: palladium, silver, copper, gold
	(2)	Minor: zinc, indium, iridium
(B)	Metal ceramic (PFM)	
	(1)	Major: palladium, silver, gold, copper, cobalt
	(2)	Minor: gold, platinum, indium,tin, gallium, ruthenium, rhenium

TABLE 3
BASE METAL/COBALT-BASED ALLOYS: "GENERAL" CHEMICAL COMPOSITIONS

(A)	Metal ceramic (PFM)	
	(1)	Major: cobalt, chromium, tungsten, molybdenum
	(2)	Minor: copper, silicon, gallium, aluminum, nickel, tantalum, ruthenium
(B)	Removalbe partial dentures	
	(1)	Major: cobalt, chromium, nickel
	(2)	Minor: molybdenum, tantalum, manganese, gallium, silicon, carbon, tungsten

Germanium increases the castability of gold-copper alloys (Townsend and Hamilton, 1983).

Noble/Palladium-based Alloys

Noble/palladium-based alloys (Table 2) with silver have been available since 1974 (Tuccillo, 1977). In the early 1980's, there was an increase in palladium-based formulations with reduced amounts of silver. They are used primarily for the fabrication of PFM restorations. However, a variety of type IV, extra-hard alloys exists that can be used to cast inlays, crowns, fixed partial dentures, and removable partial dentures (RPD). Palladium reduces the cost of the alloy while increasing strength, rigidity, and sag resistance (Moffa, 1983). The coefficient of thermal expansion is increased with the addition of silver (Kollmannsperger and Helfmeier, 1983). Indium and/or tin can be added to improve bonding with the porcelain veneer. Gallium contributes to a homogeneous microstructure. Ruthenium is used primarily as a grain refiner. Palladium-based alloys absorb small amounts of carbon that increase brittleness of the alloy (Eichner, 1983). Gas porosities (CO gas) may occur after the alloy is cooled. The palladium-silver alloys are somewhat more difficult to cast (McLean, 1983).

Base Metal Alloys

Base metal alloys (Tables 3 and 4) were first introduced to dentistry for the fabrication of RPD's in the early 1930's. Subsequently, they have largely replaced the noble-based alloys for RPD's. The most successful RPD alloys are cobalt-chromium-based (Table 3) and nickel-chromium-based (Table 4). There has also been an increase in the use of similar "base metal" alloys for less costly crowns, fixed partial dentures, and PFM restorations due to the dramatic increase in price of gold bullion and gold-containing dental casting alloys in the 1970's.

Base Metal/Cobalt-based Alloys

Base metal/cobalt-based alloys (Table 3) are used primarily in the fabrication of RPD's. Several manufacturers (*e.g.*, J.F. Jelenko, Dentsply) market cobalt-based alloys for PFM restorations. Cobalt provides strength, hardness, and corrosion resistance. Chromium provides hardness and resilience and increases corrosion resistance when present in at least 16 wt%. Nickel increases ductility (Asgar and Peyton, 1961) while lowering melting temperature and hardness (Asgar and Allan, 1968). The carbon content of these alloys is critical. It is only

TABLE 4
BASE METAL/NICKEL-BASED ALLOYS: "GENERAL" CHEMICAL COMPOSITIONS

(A)	Crowns and fixed partial dentures	
	(1)	Major: nickel, chromium, iron
	(2)	Minor: molybdenum, silicon, manganese, boron, copper
(B)	Metal ceramic (PFM)	
	(1)	Major: nickel, chromium
	(2)	Minor: molybdenum, iron, silicon, manganese, beryllium, boron, aluminum, yttrium, tin
(C)	Removable partial dentures	
	(1)	Major: nickel, chromium
	(2)	Minor: molybdenum, iron, silicon, manganese, beryllium, boron, aluminum, carbon, cobalt, gallium, tin

slightly soluble in cobalt-chromium solid solution and is present mainly as dispersed carbides of chromium, cobalt, or molybdenum, increasing the strength and hardness of the alloy (Tesk and Waterstrat, 1985). Manganese is a de-oxidizer. Tungsten helps reduce formation of chromium-depleted zones.

Base Metal/Nickel-based Alloys

Base metal/nickel-based alloys (Table 4) are used primarily for RPD's and PFM restorations. Nickel yields a softer alloy and lowers the melting temperature. Aluminum (Ni_3Al) increases strength and hardness. Carbon may be added to increase strength but increases brittleness as well. Beryllium decreases melting temperature and corrosion resistance (Lee *et al.*, 1985) while improving castability and bonding. Lower melting temperatures also provide a smoother casting surface that requires less finishing. Boron decreases alloy melting temperature (Haudin and Perrin, 1981). Titanium and manganese increase corrosion resistance (Meyer, 1977) and serve as bonding agents (Espevik and Øilo, 1979). Iron increases strength (Meyer *et al.*, 1979). Cobalt increases hardness. Copper increases corrosion resistance (Bui and Dabosi, 1981). Gallium improves castability (Kollmannsperger and Helfmeier, 1983). Yttrium aids in the adherence of oxide layers (Townsend and Hamilton, 1983). Molybdenum increases corrosion resistance (Lee *et al.*, 1985). Tin increases strength and hardness (Ando and Nakayama, 1983).

CLINICAL EFFECTS/RPD ALLOYS

Sufficient clinical experience with RPD alloys would indicate that there are no harmful side-effects; no studies suggest otherwise.

CLINICAL EFFECTS/PFM ALLOYS

In 1980, a comprehensive 10-year clinical study was activated (VA Cooperative Studies #147) to study alloys of "representative chemical compositions" that included Olympia (Au-Pd), W-1 (Pd-Ag), ticon (Ni-Cr-based with Be), Micro-Bond N/P2 (Ni-Cr-based with Ga), and Ceramalloy II (Ni-Cr). The study was conducted at six Veterans Affairs Medical Centers, with 20 clinical/basic researchers and more than 600 patients (2400 restoration units). A paired-comparison design was used. Preliminary (72-month) data (Morris *et al.*, unpublished) suggest the following:

(1) Number of re-makes/castings *per* restoration: Olympia (Oly) = 1.1; W-1 = 1.2; Ticon (Tic) = 1.2; Ceramalloy II (CeramII) = 1.1; and Micro-Bond N/P2 (MicN/P2) = 1.3.
(2) Total cost *per* unit: Oly = $54.91; W-1 = $31.48; and base metals = $20.58 (avg.).
(3) Changes in overall quality: Oly = -0.48; W-1 = -0.75; Tic = -0.41; CeramII = -0.73; and MicN/Ps = -0.66 (change of -1.00 units, on a five-point scale where 5 = best and 1 = worst; considered by the research group to be clinically significant).
(4) Deterioration of porcelain: Oly = -0.16; W-1 = -0.41; Tic = -0.25; MicN/Ps = -0.31; and CeramII = -0.68 (change of -1.00 units, on a five-point scale, was considered clinically significant).
(5) Change in metal surface: Oly = -0.69; W-1 = -0.72; Tic = -0.32; CeramII = -0.27; and MicN/Ps = -0.49 (change of -1.00 units, on a five-point scale, was considered clinically significant; such changes appear to be related to hardness).
(6) Percentage of removals/failures: 6% of all restorations cemented (all restorations removed were considered "failures").
(7) Removals/failures for each alloy: Oly = 4%; W-1 = 7%; Tic = 8%; MicN/Ps = 5%; and CeramII = 13%.
(8) Causes for removals/failures: about 60% were related not to materials but to technical/fabrication errors.
(9) Plaque index: slightly lower for cast restorations than "unrestored" periodontal controls.
(10) Gingival index: slightly higher for "restored teeth" than unrestored periodontal controls.
(11) Pocket depth: slightly higher for restored teeth than unrestored periodontal controls.
(12) Loss of an attachment: slightly greater for restored teeth than unrestored periodontal controls.
(13) Number of patients sensitized to nickel: All patients were patch-tested for nickel, chromium, and cobalt sensitivity each year for five years. No patients were sensitized due to a base metal dental restoration.

FUTURE DIRECTIONS FOR RESEARCH

A comprehensive, cost-effective, scientific clinical research center needs to be established to address the numerous questions that exist in the areas of restorative materials and dental implants. This center would involve the coordinated efforts of both basic and clinical investigators and would focus research on (1) improving the sensitivity of clinical research instrumentation and methodologies, (2) defining the long-term effects of "materials" on "favorable and unfavorable" clinical performance, (3) determining the properties that are needed for clinical success, and (4) identifying the "*in vitro* tests" that accurately predict clinical success. This research will increase the cost-effectiveness and productivity of new materials, and it would ensure the long-term safety of current and new restorative materials.

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