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# Original Research

## Metals and Metal Alloys Used in Dentistry: Types, Properties, and Clinical Applications – part 1

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***ABSTRACT:***
Metals form an essential material in dentistry, especially prosthetic dentistry. Metals have various properties, which are not only difficult to interpret but also apply to each particular clinical situation. In terms of longevity and biocompatibility, some of the metals cannot be matched by any other material. However, individual metals have no use in dentistry, which is why dental alloys are made. Each component of an alloy has its own specific advantage, disadvantage, and property. The amount of each component varies depending upon the use desired. This two-part review presents an insight and brief review of metals and their alloys with special attention to their types and properties and, more importantly, clinical applications. In the first part the review focusses on metal characteristics like solid solution, eutectic alloys and cold working along with description of noble and base metal alloys.

**Key words**: dental alloys, solid solution, cold working, base metal alloys, eutectic, peritectic

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**INTRODUCTION**

In dentistry, metals are one of the four main types of dental biomaterials, along with polymers, ceramics, and composites.[1] They are used to fix teeth and other oral tissues that have been damaged, decaying, or lost. The process of refining and extracting metals from ores is at the heart of metallurgy as both an art and a science.[2] In the last few years, this area has seen the rise of several subfields, such as those related to chemistry, mechanics, and physics. There are many different types of metals used in dental restorations and dental prostheses, so it's important to know their properties in order to understand their individual quality and the efficiency of such dental treatments. Also, when making dental restorations, it's important to know how to recreate the properties of metals and alloys. This requires knowledge about metallurgy and how metals behave in the field of restorative materials and oral environment. Biocompatibility and toxicology of metal go hand in hand, and both depend on individual cellular responses, which may vary from mild to severe.[3] All metals are also capable of biofilm formation, the deposition and content of which vary according to different restorative materials, different types of metals, and surface structure.[4] Traditionally, metallurgy is split into three parts: chemical, physical, and mechanical.[2] Chemical metallurgy, usually called "process" metallurgy since it focuses on processing ore, is mostly about refining and making metals. Physical metallurgy is a relatively new field that is closely related to metallography, which analyzes the structure and physical properties of metals and uses microscopic examination of metal structures to predict how they will behave. Mechanical metallurgy's focus on production processes, including rolling, casting, and drawing, shows how important it is to combine physical and mechanical metallurgy with metallography in restorative materials. Ferrous metallurgy deals with iron and steel, while non-ferrous metallurgy works with all other metals and alloys, like gold, platinum alloys, and aluminum. Ferrous metallurgy is crucial in dentistry because it makes steel tools and appliances that don't rust.[5]. Some of the ions released have been termed as cardiovascular risk factors, as evidenced in nonferrous metal workers.[6] Givan emphasizes that clinicians and technicians should select alloys by understanding the alloy system, using products from reputable manufacturers, and matching alloy properties to specific clinical requirements (e.g., metal–ceramic vs. full-cast).[7] The review underlines that informed alloy selection remains critical to long-term success, even as alternative base-metal and all-ceramic systems expand available options. Metals are elements that ionize positively in solution and have properties that make them different from nonmetals, like luster, opacity, density, and conductivity.[1] It's vital to remember that pure metals are more ductile and malleable than alloys, which is highly useful in dentistry, especially orthodontic treatments.[8] stainless steel orthodontic brackets bond for a longer time duration than plastic brackets, depending upon the structure (enamel, temporary, or definitive restorations).[9] Alloys are solid combinations of metals or nonmetals. Alloys need metalloids like carbon, silicon, or boron because they can carry heat and electricity. There are two kinds of systems: binary (with two metals) and ternary (with three metals).[7] When metals are heated until they are liquid, they can or can't mix with other metals. When chilled, metals that can mix can form solid solutions, intermetallic compounds, or eutectic forms.[1,3,7] Alloys like copper and lead with zinc don't mix well.

**Solid Solutions**: Alloys that are solid solutions are made when two metals can mix completely in the liquid state and stay combined after they solidify. An example is the combination of copper and gold, where copper atoms are randomly dispersed within the crystalline structure of gold, yielding a single-phase system with solution-like properties.[10] In this case, the solvent is the metal that fills more than half of the locations in the space lattice, and the solute is the metal that fills the rest of the positions. There are three types of solid solutions: substitutional, interstitial, and ordered.[7,10] In a substitutional solid solution, the solute atoms take the place of the solvent atoms in their normal lattice places. In an interstitial solid solution, the solute atoms fit into the spaces between the solvent atoms, like carbon in steel and iron. Also, silver and copper are instances of substitutional solid solutions since the atoms are the same in the lattice structure.[10] Ordered type or superlattice refers to a structure where unit cells combine to form a space lattice, specifically represented by $AuCo_3$, with three times as many copper atoms as gold atoms. In this setup, the gold atoms are in the corners and the copper atoms are on the faces. The solid solubility of two or more metals is mainly affected by four things: the size of the atoms (less than 15% difference favors solubility), the valence (similar valence metals tend to form solutions more easily), the chemical affinity (high affinity leads to intermetallic compound formation), and the type of lattice (only metals that share the same crystal lattice can form complete solid solution series).[11] Intermetallic compounds are metals that are dissolved in a solution and then come together to create solid chemical compounds. In alloys, atoms of one metal occupy specific positions in the space lattice of another, instead of appearing randomly.[12] For example, an alloy of 73.2% silver and 26.8% tin by weight, when heated above 500°C, is a single-phase liquid. When it cools, it turns into the complex $Ag_3Sn$, which has silver and tin in specific lattice locations. People often utilize these alloys in dental amalgam. When two metals can mix together in their liquid state but not in their solid state, they form eutectic mixtures. This means that one metal is on top of the other in thin layers. A case in point is an alloy made up of 72% silver and 28% copper. Metallic dental alloys may induce biological alterations pertinent to oral carcinogenesis; nevertheless, a direct causal relationship between conventional restorative metals and oral cancer in people is yet to be established and remains contentious.[13] Making solid solutions in base-metal dental alloys (Ni-Cr, Co-Cr) is important for improving their mechanical, physical, and corrosion properties, which affects how well they work in prosthodontics.[14] Substitutional solid solutions are what make alloys stronger. They do this by changing the size of the atoms in the lattice, which makes the yield strength and hardness better. This is important for making thin structures in dental frameworks that will last long and are removed and placed repeatedly. Both cast partial and fixed partial dentures require to be thin-sectioned yet have the necessary strength. Certain designs in particular, like partial veneer crowns,[15] resin-bonded prostheses,[16] fixed-movable bridges (pier abutment management),[17,18] and full mouth rehabilitation cases,[19] with extensive posterior fixed restorations, have to be thin yet have the stiffness and strength. The elastic modulus and ductility are also affected by the exact mix of base metals. For example, base metal alloys having higher cobalt content are stiffer, which is an important requirement for different types of partial denture designs. Chromium also makes these alloys more resistant to corrosion by promoting stable oxide layers. This helps biocompatibility and reduces the release of metal ions, and it also avoids problems like phase segregation that can cause corrosion.[3]

Eutectics have a lower temperature than the melting points of silver (Ag) or copper (Cu), which is the lowest temperature at which silver-copper alloys can be completely liquid.[12,20] Solidification happens at a fixed temperature, which means that it doesn't change, which makes it an invariant transition. Peritectic alloys, which have limited solubility of two metals, undergo an invariant reaction that usually happens at a certain temperature and composition.[21] They are not frequent in dentistry, although silver-tin (Ag-Sn) is one example.[12] Crystalline structures are arrangements of atoms that make up crystals. The cubic system used in dentistry is one of the most common of the 14 shapes of a space lattice.[22] Atoms are located at the intersections of three orthogonal crystal planes. Rhombohedral, orthorhombic, monoclinic, triclinic, tetragonal, simple hexagonal, and close-packed hexagonal are all sorts of lattices that are important to dentistry.[20,21] When metals crystallize, they solidify at nucleation sites that are made up of impurities. This makes dendritic patterns. When metals crystallize, they usually form polycrystalline structures containing grains. The size of the grains is affected by the speeds of nucleation and cooling.[22] Smaller grains usually have superior physical qualities. Adding trace elements to improve nucleation is part of the process of grain refinement. [23] Dislocations in the crystal structure can change ductility.[24] When stress goes over the elastic limit, movement between slip planes happens, which causes permanent deformation.[12,21]

**Cold Working:** When dislocations travel along slip planes, cold working happens. This phenomenon is when a lot of force changes materials permanently, usually at room temperature.[25] This process changes the microstructures and grain shapes from equiaxed to fibrous, which makes the material harder and stronger.[26] It also makes the surface less flexible and more resistant to rust. The recrystallization temperature is the temperature below which cold working occurs.[8,25] To remove the effects of cold working, annealing is the process of heating metal. There are three steps to it: Recovery, when the material's cold-work properties start to go away; recrystallization, when new, strain-free grains replace old ones, making the material soft and ductile again; and Growing grains.[25,27] Grain growth is when the average size of the grains changes because the number of nuclei changes. This happens as cold working gets worse. The process's purpose is to minimize barrier energy, which makes bigger grains devour smaller ones. But this doesn't make a single crystal; it makes a rough grain structure instead.[26] Too much annealing, especially in wrought materials, can make grains bigger and stop them from getting bigger.[25]

**Classification of dental alloys**: There are four types of metals based on their composition: noble metals (like gold, platinum, and silver), precious metals (which include all noble metals), semiprecious metals (a term that is often avoided because it is not clear), and base metals (non-noble elements like chromium and nickel that make dental alloys stronger).[2,7,14] The ADA's 1984 classification of dental casting alloys divides them into three groups: high noble, noble, and mostly base metal, according to how much noble metal they include.[7] Crown and bridge alloys and metal ceramic alloys are two types of alloys that use both noble and base metals for different dental purposes, like bonding porcelain and making detachable partial dentures.[28-30]

**Noble metal alloys:** Based on their composition and qualities, metals are divided into basic, noble, precious, and semiprecious metals.[7,25] Noble metals, like gold and platinum, don't rust and don't react with acids. Precious metals, on the other hand, have worth on their own, and noble metals are one of these types of metals.[31] There isn't a definite definition for semiprecious metals, so it's best to avoid using that phrase. Base metals like chromium and nickel are very important in dental casting alloys because they change their physical properties.[32] The Bureau of Standards has divided gold casting alloys into four kinds depending on their yield strength and use.[7,25] In 1984, the ADA suggested classifications for dental casting alloys, separating them into high noble, noble, and mostly base metal alloys and giving details on their noble metal percentage. There are crown and bridge alloys, metal ceramic alloys for bonding, and removable partial denture alloys, among other sorts of alloys.[32] White in color, silver-palladium alloys are mostly silver with a lot of palladium, which makes them less likely to tarnish. They could have copper and very little gold. Non-copper versions had 70–72% Ag and 25% Pd, whereas copper-based versions have 60% Ag and 25% Pd.[25,31] Some of the bad things are that it doesn't cast well and is more likely to tarnish and corrode.

**Base metal alloys:** Nickel-chromium and cobalt-chromium alloys are used in dentistry, especially for partial denture frameworks, porcelain-metal restorations, crowns, and bridges.[14,33] Co-Cr alloys have become more popular over the years for making detachable partial dentures. Chromium makes alloys more resistant to tarnishing and makes them more stainless. However, if the amount of chromium is more than 30%, casting becomes rigid and the brittle sigma phase occurs.[34] Not more than 28–29% chromium should be in dental alloys. Cobalt makes the elastic modulus, strength, and hardness better than nickel does.[14,35] You can change the hardness by changing the amount of carbon in the alloy. For example, increasing the amount of carbon by 0.2% makes it too brittle for dental use, while decreasing it makes it weaker. Nickel alloys with aluminum have higher ultimate tensile and yield strengths.[14,33] The microstructure, which is important for the qualities of materials, shows that changes in physical attributes mean changes in microstructure. When cast, Co-Cr alloys have a uniform microstructure with cobalt and chromium in an austenitic matrix. This matrix has cobalt-rich dendritic areas and an interdendritic quaternary mixture of four phases.[34] Three main problems with using cobalt-chromium (Co-Cr) alloys are: 1) Clasps can break while in use, often in a short amount of time; 2) the alloys are very dense and don't stretch much, which makes it difficult to make changes and takes up time in the dentist's chair; and 3) teeth can wear down easily when they touch the metal because it is so extremely dense.[33,35] Morris (1975) notably reported that Co-Cr alloys possess greater hardness than iron-based alloys and that heat treatment may reduce their strength in comparison to

Au-Pd alloys.[36] Wataha et al. (1992) emphasized that different preparative methods can modify the surfaces of alloys.[25] Adding 13% tantalum to a Co-Cr-Ni alloy makes it stronger in both tensile and yield strength by 12–13% and helps keep the structure stable by lowering dislocations.[35] When choosing extra elements, you should think about how well they resist corrosion, how well they resist oxidation during alloying, how well they work as a nucleating agent, how well they can harden solid solutions, how fine they can precipitate, and how coherent they are.[36] Iron–chromium–nickel stainless steels, such as 316L, and cobalt–chromium–nickel alloys have been used in dental applications like frames and pins; however, modern implants favor materials like titanium and ceramics.[37] These alloys' reliance on chromium for corrosion resistance and nickel for strength presents issues like nickel hypersensitivity and biocorrosion when in contact with other metals.[3] Consequently, current dental implant systems prioritize titanium and related materials over Ni–Cr alloys due to their superior performance and lower biological risk.

## CONCLUSION

To comprehend and forecast how dental alloys will behave in the clinic, you need to know about solid solutions, cold working, and eutectic alloys. Gold- and palladium-based noble metal alloys are the basis for the history of dental casting alloys. They are still the best for corrosion resistance, biocompatibility, and metal–ceramic performance. Base metal alloys like Ni-Cr and Co-Cr have become essential for permanent and removable partial dentures because they are strong, stiff, and cost-effective, as long as their composition, processing, and biological interactions are adequately monitored.

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