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Review Article

The use of precious metals in restorative dentistry

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ABSTRACT

This review delves into the historical and contemporary use of precious metals in restorative dentistry, tracing the evolution from ancient practices to modern technological advancements. It underscores the critical role of metallic materials, such as gold, silver, copper, and alloys like cobalt-chromium and titanium, in dental restorations due to their superior mechanical properties, including high elastic modulus, tensile strength, and hardness. These materials are favored for their biocompatibility, corrosion resistance, and adaptability to various manufacturing processes, including casting, mechanical processing, and advanced methods like CAD/CAM, laser sintering, and welding. Despite the advent of alternative materials catering to aesthetic preferences, metals maintain their relevance in dentistry for structural components in prosthetics, demonstrating significant advancements in dental material technology. The review highlights the importance of understanding the properties and behaviors of these materials within the oral cavity to ensure the quality and durability of dental restorations. Through a comprehensive literature search and analysis of metallurgy, manufacturing, and classification, this paper presents a thorough exploration of the indispensable role of precious metals in enhancing dental health and restorative practices.

Keywords: Precious metals, Restorative dentistry, Dental alloys, CAD/CAM technology

INTRODUCTION

Metallic materials are utilized both as internal and external structural components in numerous prosthetic restorations in dentistry. Their extensive application is attributed to their excellent mechanical properties, which enhance the structural strength and their capacity to withstand plastic deformation when subjected to loads. Metals and their alloys are characterized by properties like a high elastic modulus and significant load-bearing capacity, making them preferred materials in dental applications. Moreover, when implanted into the body or in contact with tissue, these materials must possess additional characteristics, including biocompatibility, corrosion resistance, high static and dynamic strength, and toughness. They should also not release metal ions into their surrounding environment. The most critical mechanical properties for clinical practice include elastic modulus, tensile strength, and hardness.[1]

The main objective of restorative dentistry is to preserve or enhance the oral health of patients, encompassing a range of dental materials. Dental casting alloys, in particular, must meet specific requirements that represent a balance of various factors affecting their use. Hence, it is crucial to be familiar with the properties of dental materials to comprehend their behavior within the oral cavity and anticipate the impact on the patient's health.[2]

Despite the decline in the use of dental casting alloys in recent years, driven by patients' growing demands for aesthetic qualities alongside durability, it remains essential to have knowledge and understanding of the structure and properties of cast metals and alloys.

Until now, the primary use of dental casting alloys has been in the production of frameworks for partial dentures, bases for crowns and bridges, and as the most durable aesthetic replacement for natural teeth in metal-ceramic restorations.

The historical development of metallic materials in dentistry has seen significant evolution over the centuries. In the 7th century BC, the Etruscans were known to use ivory and gold-rimmed bone as a core for teeth. By the 1800s, metallic substitutes for dental applications began to be developed, utilizing materials such as aluminium, amalgam, gold, lead, platinum, and silver to fill dental cavities.[2] Despite longstanding use of metals for dentures and other dental restorations, the technology for precision casting did not emerge until 20th century. Advancement in dental material technology continued with development of computer-aided design/ computer-aided manufacturing (CAD/CAM), laser sintering, and laser welding. These technologies have significantly facilitated production of metallic materials for dental use.[3,4]

Despite the availability of various methods for producing dental materials, casting remains the preferred technique, especially for creating crowns. This process involves replicating the impression of the prepared tooth in a refractory mold and creating a wax model of the required shape. The model is then encased in investment material and heated to remove the wax, creating a mold into which molten metal or alloy is cast under pressure, often using centrifugal force.[5]

The evolution of metallic materials in dentistry has been influenced by several key factors, including changes in denture technology, advancements in metallurgy, and fluctuations in the prices of precious metals. A notable recent development in dental metallic materials is the creation of composite materials through powder metallurgy and sintering. These composites are made by sintering a high precious alloy in a sponge form, which is then infiltrated with almost pure gold. Unlike traditional materials, these composite metals are not cast but sintered in a refractory mold, representing a significant innovation in the field.[2]

LITERATURE SEARCH

This study is based on a comprehensive literature search conducted on 12 February 2023, in the Medline and Cochrane databases, utilizing the medical topic headings (MeSH) and a combination of all available related terms, according to the database. To prevent missing any possible research, a manual search for publications was conducted through Google Scholar, using the reference lists of the previously listed papers as a starting point. We looked for valuable information in papers that discussed the use of precious metals in restorative dentistry. There were no restrictions on date, language, participant age, or type of publication.

DISCUSSION

The metallurgy of dental metallic materials involves a complex procedure, where all metals used for dental restorations are mixed in their molten state before being cast into molds to solidify. Some dental materials may be directly cast or molded into shapes very close to the final product, whereas others undergo a series of thermomechanical treatments from an initial ingot to produce the desired outcome.[2] The microstructural differences in these materials significantly affect their wear and corrosion rates, highlighting the importance of understanding the physical metallurgy of the metals used in dentistry to comprehend their behavior *in vivo*.

During the cooling process of molten metal in a mold, solidification typically starts at the surface. The nucleation process is determined by the mold's temperature; a hotter mold produces fewer nucleation sites, whereas a cooler mold permits more extensive nucleus growth. In most metallic systems, the solid phase expands with a dendritic growth pattern that resembles a tree with branches. This solidification process continues until two nuclei meet, forming a border. These areas are known as growths, crystals, or grains, and the interfaces between them are grain boundaries. Microscopically, dendrites, interdendritic areas, and grain boundaries are clearly distinguishable.

To achieve a fine-grained and nondendritic structure in dental castings, various alloying elements are added. Alloys are essentially mixtures of several elements, sometimes including precipitated intermetallic compounds. Elements with similar atomic charges, diameters, and crystal structures can be completely soluble in each other, forming a single-phase solution upon solidification. For instance, copper and nickel are completely soluble in each other, but because nickel has a higher melting point, the first solidified phase will have more nickel, and the later solidified phase will be richer in copper, leading to a dendritic structure with macroscopic chemical composition variations.[2]

Casted products may undergo subsequent heat treatments, such as homogenization or solution annealing, to achieve a uniform chemical composition through atomic diffusion. Differences in atomic diameters within single-phase or two-phase alloys can enhance strength through a mechanism known as solid solution strengthening, where the presence of differently sized atoms causes localized lattice stress, increasing metal strength.

Furthermore, elements with vastly different properties and crystal structures tend to have limited solubility. In many alloy systems, the precipitation of a secondary phase is utilized as a strengthening mechanism, known as precipitation hardening. For example, in cobalt alloys, carbides improve wear resistance and strength, whereas in stainless steel, they can negatively affect corrosion resistance. A deep knowledge of metallurgy is essential for enhancing the performance and durability of metallic materials used in dentistry.

MANUFACTURING OF DENTAL METALLIC MATERIALS

Metallic dental products can be fabricated through casting into shapes that are close to their final form, to be utilized either in their cast state or after heat treatment. Often, these cast products undergo mechanical processing such as rolling or drawing, followed by heating to relieve stress, which leads to the formation of new, dislocated crystals.[2] Through managing the heat treatment's temperature and duration, metals with fine grains suitable for cold working are produced. Additionally, dental metallic items can be created through both cold and hot forging processes, as well as powder metallurgy. In powder metallurgy, fine powder is typically generated by melting the alloy and then atomizing it. This powder is then compacted into a shape near to its final form and subjected to sintering under controlled temperature and pressure to achieve consolidation.

The surface quality of dental materials plays a crucial role in their application within the oral cavity, influencing polishability, scratch resistance, and overall appearance. Thus, surface treatments during manufacturing process significantly impact materials' wear and corrosion resistance. Post-casting, products exhibit a matte surface from mold material, necessitating abrasive/ sandblasting to remove residual casting material. For implants made from steel castings, combination of mechanical and electrolytic polishing processes is employed. Furthermore, surface enhancement techniques such as ion implantation, plasma or ion nitration/ application of hard ceramic coatings can be used to improve wear resistance. Since 1980s, various methods have been developed to modify surfaces to promote biological bone growth from porous metal materials, often concluding with passivation in nitric acid to enhance the passive film thickness and remove surface impurities.[6]

Advancements in production phases

Production phases in dental technology, similar to other sectors, are becoming more automated. With laboratory costs becoming a significant consideration in treatment and therapy planning, automation enables more competitive production and profitability. Technological advancements, particularly in computer technology, have facilitated cost-effective manufacturing of individual pieces. In recent years, there has been an increase in production and processing of dental products, such as titanium and its alloys, and cobalt-chromium alloys, using computer assistance, notably through CAD/ CAM techniques. This approach has led to creation of nearly flawless, industrially processed materials that boast enhanced quality, reproducibility, efficiency and precision. With ongoing advancements in computer technology, further developments in production and processing methods are anticipated aiming to reduce costs further.[7]

CLASSIFICATION OF DENTAL METALLIC MATERIALS

Dental metallic materials, especially alloys, are categorized in various ways, such as by their application, main element/production method. Metals deemed noble include gold, copper, mercury, platinum, and platinum group metal (ruthenium, palladium, osmium, rhodium, and iridium). Precious alloys may incorporate up to 10% non-precious elements, yet the quantity of precious metals should not fall below 75%. Alloys with a lower precious metal content are referred to as reduced precious alloys/ alloys with reduced gold content. Noble alloys are distinguished by their corrosion resistance and stability within oral environment.[2] Currently, the most commonly utilized alloys in dental practice are those produced by casting. These alloys must exhibit properties such as biocompatibility, minimal reactivity with mold materials, ease of melting, casting, joining, and polishing, along with high strength, and resistance to wear, corrosion, tarnishing, and inertness in oral cavity.[2]

Noble alloys, particularly gold alloys, are among the oldest used in dentistry (Figure 1). Copper is added to gold to increase its strength, and silver is added to enhance workability. An alloy containing 18-carat gold (75 wt.%) is highly resistant to corrosion. The addition of palladium and platinum further improves mechanical properties, with zinc aiding in the alloy's casting. Small amounts of ruthenium or iridium (0.0005-1%) are added to foster the development of nucleation centers and form a fine-grained structure. Gold alloys are categorized based on their gold content, with variations in color, castability, and solderability, and adjustments in composition to balance palladium's color alteration effects with increased copper content.[2]

Figure 1: Metallic gold crown.[2]

Palladium alloys, due to the high melting point of pure palladium, are modified with silver, copper, and other elements like gallium, indium, and tin to lower the melting temperature for dental casting. These base metals are essential for forming an oxide layer on the metallic part of crowns or bridges, crucial for the alloy-ceramic binding after heat treatment. Palladium alloys are preferred for their corrosion resistance.

Non-precious alloys are based on non-precious metals like chromium, nickel, iron, tin, lead, magnesium, and titanium. They offer an economical alternative to gold alloys, characterized by high hardness, corrosion resistance, rigidity, low elasticity, thermal conductivity, density, and a platinum color. Nickel-Chromium and Cobalt-Chromium based alloys are commonly utilized in this category.

Cobalt-chromium alloys have become increasingly used in dental medicine for their favorable mechanical properties and corrosion resistance, offering a cost-effective alternative, especially in economically constrained regions. However, their application is challenged by complex technical requirements, high melting temperatures, and hardness.[2]

Titanium and its alloys are celebrated for their biocompatibility, lightweight, and strength, making them ideal for dental implants and crowns (Figure 2). The development of new titanium alloys aims to improve mechanical properties and biocompatibility while maintaining aesthetic appeal.[8-12]

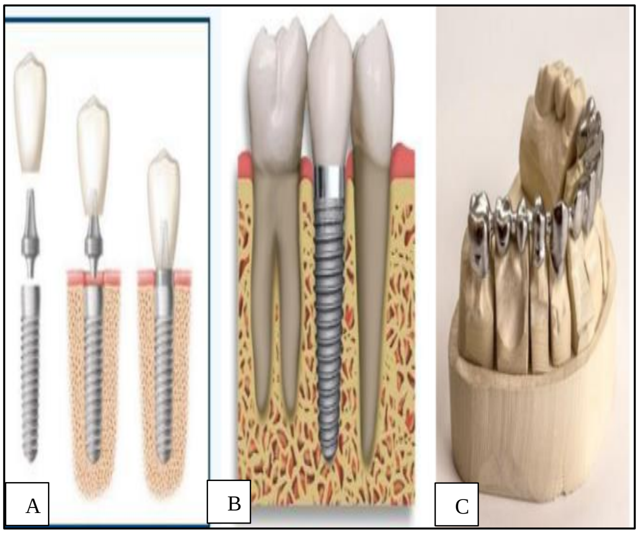

Figure 2 (A-C): Titanium dental implants and crowns.[2]

Stainless steel, utilized for crowns and orthodontics, combines corrosion resistance with mechanical strength, primarily due to the addition of chromium, which forms a passive oxide film. However, its susceptibility to corrosion in the presence of low chromium levels remains a concern.[2]

Amalgam is a blend of mercury and one or more other metals used in dentistry. Dental amalgam is made by mixing liquid mercury with a solid alloy, mainly consisting of silver, tin, and copper, with possible small additions of zinc and palladium. It is crucial to distinguish between dental amalgam, the final product, and amalgam alloy, the pre-mixed filings or particles intended for amalgamation with mercury. When freshly mixed, amalgam possesses a plasticity that allows it to be molded into a tooth cavity, where it then hardens to form a durable restoration. Dental amalgam is suitable for direct, permanent fillings in posterior teeth and for foundational restorations under crowns, offering ease of use, durability, and longevity. However, its silver appearance and potential for brittleness, corrosion, and regulatory concerns regarding wastewater disposal are drawbacks.[13]

The American national standards institute/American dental association (ANSI/ADA) and the international organization for standardization (ISO) set specifications for amalgam alloy composition, primarily silver, tin, and copper, with possible inclusions of indium, palladium, platinum, zinc, or mercury. These standards also address zinc's role in alloy production, emphasizing the need to avoid contamination for restoration integrity.

Amalgam alloys are classified into low-copper and high-copper varieties, with the latter being favored in modern dentistry for its superior properties, as demonstrated by less marginal breakdown in clinical comparisons.

The amalgamation process involves mixing the alloy with mercury to form a workable material that eventually hardens. This reaction results in a strong, durable material, although not all mercury reacts, leaving some unreacted particles that contribute to the amalgam's strength. High-copper amalgams, in particular, show improved performance due to their specific chemical reactions and resultant microstructure, which avoids the formation of weaker phases seen in lower-copper variants.[14-16]

Physical and mechanical properties, such as compressive strength, creep, and dimensional change, are regulated by ANSI/ADA specifications to ensure amalgam quality. These properties are influenced by the alloy's particle size, shape, distribution, and heat treatment. Despite its non-adhesive nature to tooth structures, amalgam remains a widely used, cost-effective, and successful restorative material in dentistry, with ongoing research into bonding techniques to enhance its application and performance.

PROPERTIES OF METALLIC DENTAL MATERIALS

For use of metal in dental medicine it is very important to know its properties, which depend on its crystal structure. Properties are determined by the strength of bond that links the atoms, and in dental metals a strong metal bond is present (Table 1).[2]

Table 1: Summary of essential properties of metallic dental materials necessary for their use in dental restoration.

Property	Description	References
Homogeneous fine-grained structure	Essential for consistent mechanical properties and aesthetic appearance.	6,17
Self-hardening after casting	Ability to harden without additional processes, crucial for durability.	6,17
High strength values	Resistance to deformation and fracture, vital for longevity of dental restorations.	6,17
Possibility of soldering	Enables joining of parts for complex restorations.	6,17
Corrosion resistance	Prevents degradation in the oral environment, ensuring longevity and biocompatibility.	6,17
Technical workability	Includes melting, casting, processing capabilities, and economic viability, ensuring ease of use and cost-effectiveness.	6,17
Clinical suitability	Requires appropriate hardness, strength, ductility, aesthetic color, and biocompatibility for specific clinical indications.	6,17
Hardness (HKN)	Resistance to penetration, critical for wear resistance.	6,18
Strength	Includes tensile, bending strength, and resistance to plastic deformation and fracture, indicating the durability under functional forces.	2
Elongation	Measures ductility, indicating flexibility and resistance to breakage, especially important for clasps in partial dentures.	2
Elastic modulus (Gpa)	Indicates stiffness, matching with dentin or enamel is crucial for therapeutic effectiveness.	19
Biocompatibility	Absence of toxic, irritant, allergic, or carcinogenic effects. Important for safety and comfort in the oral environment.	2
Corrosion	Influenced by alloy composition, oral environment conditions. Important for chemical stability and longevity of restorations.	20

CONCLUSION

Precious metals remain fundamental in restorative dentistry due to their unmatched properties and technological advancements. From ancient gold use to modern alloys and manufacturing techniques, these materials ensure durable, biocompatible restorations. Understanding their properties is crucial for quality dental care, underscoring the enduring significance of metals in enhancing oral health.

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