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Ceramic Biomaterials in Dentistry: Review

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Abstract

Recent years have seen significant advancements in the field of materials science, accompanied by progress in analytical techniques and the discovery of new control devices and materials. These advancements have paved the way for the development of innovative approaches for raw material selection, with particular attention to creating advanced materials with specific physical and chemical properties tailored to meet desired criteria. This growing demand is particularly pronounced in environments with complex conditions, such as biological environments like the oral cavity. Consequently, there is a pressing need to identify and design materials that meet rigorous standards capable of withstanding such demanding environments. In the search for materials suitable for these applications, the need for advanced additives or biomaterials arises, which not only possess specific physicochemical attributes but also emulate biological materials, such as teeth, once integrated into biological systems. These biomaterials, spanning a wide range from metals, alloys, and polymers to glasses (bioglass), carbon fiber composites, and biological materials, interface with biological systems such as tissues and human fluids. However, it is essential to emphasize that biomaterials, while in contact with biological entities, differ from pharmaceutical materials. Therefore, they must exhibit biocompatibility, bioabsorbability, or inertness, depending on the intended applications. Unlike traditional inert materials, biomaterials are closely linked to the biological environment. Their surfaces can be customized to mimic organic structures they replace, ensuring optimal adhesion to tissues or skeletal structures. Moreover, they must not only interact harmoniously with organic molecules but also avoid eliciting toxic responses similar to those of xenobiotics. Therefore, interdisciplinary definitions such as biocompatibility, bioabsorbability, and toxicity, along with bioethical considerations, are indispensable for delineating the suitability of various materials in medical contexts.

Keywords:: Biomaterials; Ceramics; Dental materials; Biological environment; Xenobiotics; Polycrystalline; Orthophosphates; Microstructure; Biomaterials science; Pharmaceutical

Introduction

In recent years, the field of biomaterials, particularly ceramic-based biomaterials, has witnessed a significant surge in interest and research activity, driven by their remarkable properties and promising applications across various biomedical domains, prominently including dentistry [1-5]. Ceramic materials, characterized by their exceptional attributes such as high temperature resistance, lightweight nature, impressive hardness, and corrosion resistance, stand out as highly desirable materials for a diverse array of applications within the biomedical field [6-11]. Among the spectrum of ceramic materials, dental ceramics hold a pivotal position, primarily due to their ability to offer not only functional advantages but also aesthetic appeal [12-17]. Dental ceramics are engineered to exhibit improved mechanical properties while maintaining a visually pleasing appearance, making them indispensable in restorative and prosthetic dentistry [18-21]. These materials are meticulously designed to seamlessly integrate with natural dental structures, providing patients with both functional and cosmetic benefits [22-25]. The realm of ceramic biomaterials includes various subtypes such as glass-based ceramics, low-glass ceramics, and polycrystalline ceramics [26-29]. Each subtype offers distinct advantages and applications in the field of dentistry and beyond [30-33]. Glass-based ceramics, renowned for their aesthetic appeal and biocompatibility, find widespread use in dental restorations where both functionality and appearance are paramount [34-37]. Low-glass ceramics, on the other hand, are engineered to possess enhanced mechanical properties, catering to applications that demand superior strength and durability [38-43]. Polycrystalline ceramics, characterized by their formidable mechanical strength and resistance to fracture, are favored in dental prosthetics where longevity and reliability are critical [9,44-46]. Furthermore, the emergence of porous bioceramics has opened new avenues in the fields of tissue engineering and regenerative medicine [43,47-49]. Mimicking the microstructure of natural materials like coral, porous bioceramics facilitate tissue growth and integration, offering promising solutions for repairing and regenerating damaged or lost tissues [50-53]. Various manufacturing techniques, including foaming and impurity-induced porosity, enable the customization of porous bioceramics to meet specific application requirements, further enhancing their utility in biomedical settings [50,54-56]. Despite the myriad advantages offered by ceramic biomaterials, they are not without challenges. Intrinsic fragility poses a significant concern, necessitating meticulous consideration of fracture toughness and brittleness in material design and application [57,53,58,59]. Strategies aimed at mitigating fragility, such as the development of high-strength base materials and optimization of manufacturing processes to minimize defects, are essential for enhancing the reliability and performance of ceramic biomaterials[51,60-63]. By exploring the diverse landscape of ceramic biomaterials and addressing challenges associated with their utilization, this paper aims to contribute to the advancement of biomaterials science and pave the way for innovative solutions in healthcare and beyond [64-68].

Discussion

Research on biomaterials, especially those intended for integration into biological systems such as teeth and tissues, requires the adoption of advanced additives or biomaterials that not only possess specific physicochemical attributes but also emulate biological materials once integrated into biological systems [69-72]. These materials, which range from metals, alloys and polymers to glasses (bioglass), carbon fiber composites and biological materials, must interface with biological systems such as human tissues and fluids [73-75]. Crucially, despite their contact with biological entities, biomaterials differ from pharmaceutical materials and must exhibit biocompatibility, bioabsorbability or be inert, depending on their intended applications [76-79]. Ceramic materials, characterized by properties such as temperature resistance, low weight, hardness, and corrosion, have applications in various fields, including electronics and high-temperature environments [80-83]. Among these, bioceramics, particularly dental ceramics, play a key role, offering aesthetic advantages and improved mechanical properties [19,26,84,85]. Dental ceramics include several categories, such as glass-based ceramics, low-glass ceramics, and polycrystalline ceramics, each with specific characteristics that make them suitable for certain applications [86-89]. Glass-based ceramics, renowned for their aesthetic appeal, are composed mainly of silicon dioxide and are ideal for applications requiring superior aesthetic properties [81,90-94]. Low-glass ceramics, on the other hand, offer improved mechanical properties due to a reinforcing phase based on the SiO_2-Li_2O system [92,95-98]. Finally, polycrystalline ceramics such as zirconium oxide, characterized by exceptional flexural strengths, find applications in dental restorations due to their distinctive mechanical properties [99-102]. In addition to traditional ceramics, porous bioceramics have attracted attention for their potential in tissue engineering and regenerative medicine (Figure1) [103-105].

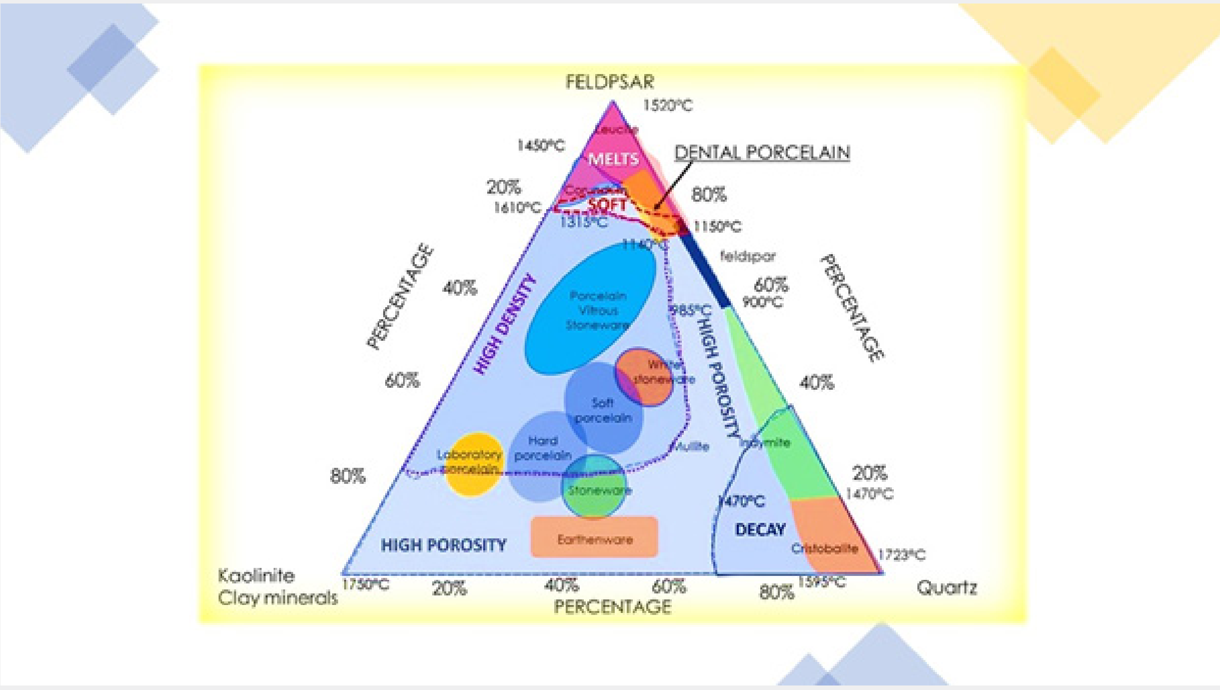

Figure 1: Composition and main characteristics of the ceramic's materials.

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These materials, inspired by the microstructure of natural materials such as coral, facilitate tissue growth and promote biological integration [106-109]. However, the inherent brittleness of ceramics makes them susceptible to brittle fracture under tensile loads, requiring careful consideration of fracture toughness in material design [67,110-112]. Strategies to mitigate brittleness include developing high-strength materials and optimizing manufacturing processes to minimize defects. In the dental context, ceramic materials such as alumina and zirconia are used for dental restorations because of their mechanical properties and biocompatibility [113-117]. The use of bioabsorbable bioceramics such as calcium orthophosphates is aimed at replacing hard tissue with autologous tissue over time, improving biological integration of implants [118-122]. However, research continues to evaluate the risk and prevention of infectious complications in dental materials, with a focus on antimicrobial upgrades to address bacterial and viral resistance [3,68,123-125]. Research on ceramic biomaterials continues to advance, with efforts aimed at improving mechanical properties, biocompatibility, and clinical efficacy [126-130]. Interdisciplinary approaches and innovative fabrication techniques are crucial to unlocking the full potential of ceramics in a wide range of biomedical applications, from dental restoration to tissue engineering [1,131-134].

Conclusion

In conclusion, ceramic biomaterials continue to evolve, driven by ongoing research aimed at improving their mechanical properties, biocompatibility, and clinical efficacy. By leveraging interdisciplinary approaches and innovative manufacturing techniques, researchers seek to unlock the full potential of ceramics in various biomedical applications, ranging from dental restorations to tissue engineering scaffolds. Ceramic-based substitutes for hard tissue repair, bioactive bioceramics, and bioabsorbable ceramics represent promising avenues for future research and development. Moreover, advancements in antimicrobial ceramics offer new possibilities for preventing infectious complications in dental implants and other biomedical devices. Overall, ceramic biomaterials hold immense promise for advancing healthcare and enhancing patient outcomes in the years to come.

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