Development of Novel Bioceramic Cements

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Bioceramic cements, composed of calcium and strontium silicates and aluminates, have gained prominence in orthopedics and dentistry due to their bioactive and biocompatible properties. These materials are effective in bone regeneration and root canal sealing, overcoming the limitations of traditional cements such as Mineral Trioxide Aggregate (MTA). The synthesis of bioceramics is performed using the solution combustion synthesis (SCS) method, which enables the production of homogeneous and highly pure powders. This process enhances control over crystalline phases and increases the materials' reactivity. The combination of different compounds and the use of this synthesis method allow for the optimization of properties such as mechanical strength and bioactivity. Thus, these materials offer a promising alternative for developing more effective and safer solutions for regenerating mineralized tissue.

Keywords: Cements. Bioceramics. SCS.

Bioceramic cements have been extensively studied for applications in orthopedics and dentistry due to their superior bioactive, biocompatible, and mechanical properties [1].

These materials have shown excellent performance in bone regeneration and root canal sealing, playing a key role in replacing traditional cements such as Mineral Trioxide Aggregate (MTA), which, despite its clinical success, has disadvantages such as long setting time, difficult handling, and potential cytotoxic effects associated with the presence of bismuth compounds [2].

In this context, new formulations based on calcium and strontium silicates and aluminates have been investigated to optimize properties such as setting time, mechanical strength, and bioactivity [3]. Calcium silicates, widely used in dentistry, exhibit excellent bioactivity and the ability to induce hydroxyapatite formation, promoting tissue regeneration [1]. However, their manipulation and setting time remain challenging. On the other hand, calcium aluminates stand out for their rapid hydration and biocompatibility, while strontium aluminates provide increased radiopacity and osteoinductive potential [4].

Recent studies suggest that combining these compounds may lead to cements with improved characteristics for biomedical applications. To prepare different cement formulations, the following parameters must be varied: the concentration of bioceramics (Calcium Silicate, Calcium Aluminate, and Strontium Aluminate); the liquid-to-solid ratio; and the incorporation of additives in the liquid phase [4]. These variations aim to optimize the physicochemical and mechanical properties of the cement, ensuring better workability, appropriate setting time, and enhanced bioactivity [2].

In this context, this project aims to develop new bioceramic cement formulations for future orthopedic and/or dental applications. It is essential to note that the project is currently in the initial phase of bioceramic synthesis, with characterization as the next step. The synthesis and characterization of these materials will be conducted with a focus on optimizing their physicochemical and biological properties, aiming for performance superior to currently available materials. Thus, the research intends to contribute to the advancement of health-applied biomaterials, offering more effective and safer solutions for mineralized tissue regeneration.

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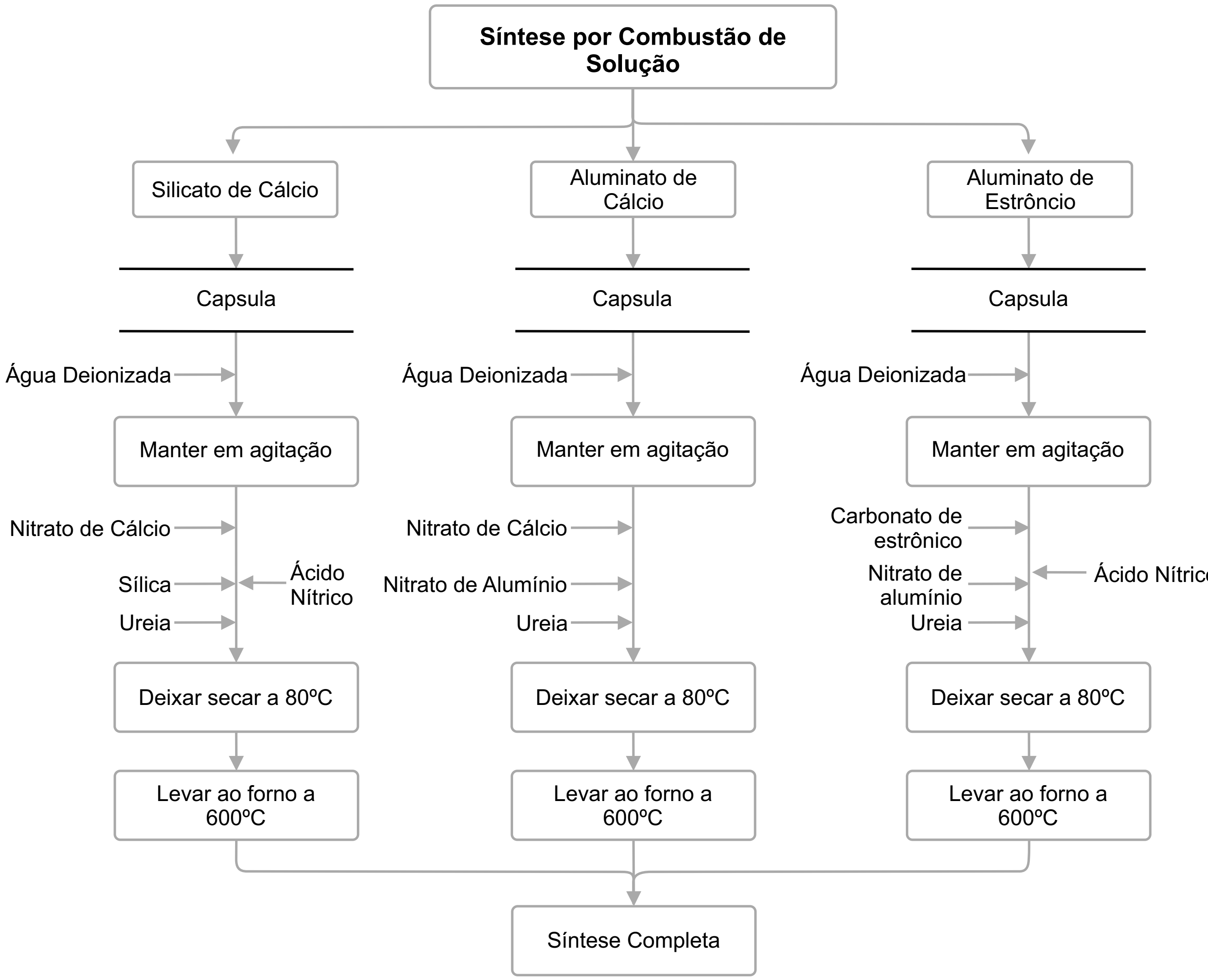
Figure 1. Methodological flowchart of bioceramic synthesis by SCS.



Materials and Methods

The method adopted for developing new bioceramic cement formulations involved two main stages: a literature review and bioceramic synthesis.

First, a search of scientific articles related to the topic was conducted in indexed databases. The keywords used were: "Bioceramics", "Endodontics", and "Synthesis". This approach allowed the identification of relevant studies on bioceramic production and their main challenges.

The literature review provided insights into the most important parameters for bioceramic production, including the influence of the liquid/solid ratio, the type of chemical precursor used, synthesis temperature, and the addition of modifying agents to control final properties.

Additionally, the main characterization techniques required to assess formulation quality were identified, including X-ray diffraction (XRD) for crystalline phase identification, scanning electron microscopy (SEM) for morphological analysis, and evaluation of radiopacity, setting time, bioactivity, biocompatibility, and mechanical strength. Based on this review, the fundamental parameters for bioceramic synthesis were defined.

Following the literature analysis, the most promising bioceramics for cement formulation were selected, consisting of calcium and strontium silicates and aluminates. These bioceramics have already been synthesized using the SCS method. The synthesis method used for each bioceramic is detailed in Figure 1, followed by grinding and sieving.

Theoretical Framework

Bioceramics are widely studied materials in the field of materials engineering due to their applications in dentistry and orthopedics, particularly for bone regeneration and endodontic treatments. Among the most commonly used materials for these purposes are calcium and strontium silicates and aluminates, which exhibit bioactive and biocompatible properties, capable of inducing apatite formation and stimulating tissue regeneration [1].

Mineral Trioxide Aggregate (MTA) has been one of the primary bioceramic cements used in endodontics due to its excellent sealing ability and biological compatibility. However, its formulation based on Portland cement has disadvantages such as prolonged setting time and difficult handling, in addition to potential cytotoxic effects attributed to bismuth in the composition [2]. Consequently, new cements are being developed to overcome these limitations, including those based on calcium and strontium aluminates, which have better radiopacity and superior mechanical properties [3].

Aluminate-based cements offer several advantages over silicates, including more precise control over setting time and greater mechanical strength, while also promoting bioactivity through the release of ions that stimulate bone mineralization [4]. Studies suggest that the component ratios of calcium and strontium aluminates can be adjusted to optimize properties such as workability, setting time, and adhesion to bone tissue [1].

In addition to chemical formulation, the synthesis method used to produce bioceramic cements plays a crucial role in their final properties. The SCS method has been widely adopted due to its ability to produce homogeneous and high-purity powders, ensuring better control over the resulting crystalline phases and improving material reactivity [4]. This technique enables the production of bioceramics with high bioactivity and the ability to form apatite layers when in contact with simulated body fluid (SBF), an indicator of their clinical potential [2].

The theoretical framework highlights the importance of developing new bioceramic cements that overcome the limitations of current materials. The combination of different proportions of calcium and strontium aluminates and silicates, along with advanced synthesis methods, enables the design of biomaterials with tunable properties for dental and orthopedic applications. Therefore, the current research aims to contribute to the advancement of bioceramic materials by providing more effective and safer alternatives for mineralized tissue regeneration.

Conclusion

Bioceramic cements have proven to be a promising alternative for regenerating mineralized tissues, particularly in orthopedic and dental applications. The combination of calcium and strontium silicates and aluminates provides materials with excellent bioactive and biocompatible properties, surpassing the limitations of traditional cements, such as Mineral Trioxide Aggregate (MTA), particularly in terms of setting time and handling. The use of the solution combustion synthesis (SCS) method contributes to the production of homogeneous and high-purity powders, thereby enhancing the reactivity and bioactivity of cement.

The present research highlights the importance of strategically combining these compounds and optimizing synthesis conditions, such as the liquid-to-solid ratio and additive incorporation, to achieve superior mechanical and chemical properties. Furthermore, advances in material characterization—through techniques such as XRD, SEM, radiopacity, setting time, bioactivity, and biocompatibility—are essential for ensuring formulation quality.

The development of new bioceramic cements, based on the knowledge acquired, aims not only to improve existing solutions but also to offer more effective and safer alternatives for mineralized tissue regeneration. As such, bioceramic materials are expected to enable more efficient and high-performance treatments in orthopedics and dentistry, contributing to the advancement of health-applied biomaterials technologies.

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