Chapter 1
Synthesis and Characterization of Pure and Co-Substituted ß-TCP Powders:
Case of Substitution of Ca^{2+} by Mg^{2+} and/or Cu^{2+}

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ABSTRACT

According to the similarity of calcium phosphate structure with that of human bone, they are the most used in different medical applications. Among these bioceramics, β-TCP has very important and different properties, which can be modified by several approaches, including changing chemical composition by substitution. This chapter objects to work on cationic substitution using magnesium (Mg) and copper (Cu); this study aims to synthesize pure monophasic β-TCP powders and other β-TCP powders substituted by bivalent ions of Mg and copper, using the aqueous precipitation method with controlled amounts of Mg2+ and/or Cu2+ ions. The results obtained describe the variation of unit cell parameters and the grain size with the nature of substituted ions and the substitution rate.

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INTRODUCTION

Historically, the introduction of foreign objects into the human body has been a remarkable advance. The science of biomaterials focuses on analyzing the properties and composition of materials, also the physiological and biological interactions they engage in with living systems. This multidisciplinary field has evolved significantly, drawing from insights in materials science, biology, and medicine. Since the late 18th century, when the initial foundations were laid through the development of early dental materials and orthopedic implants, the discipline has grown to involve a wide range of applications. Biomaterials have been used in various medical fields, including joint replacement, bone plates, bone cement, artificial ligaments, artificial tendons, dental implants, blood vessel prostheses, heart valves, cardiovascular stents, and artificial skin (Bharadwaj, 2021; Bordbar-Khiabani et al., 2020; Desai et al., 2020). These devices are called "implantable medical devices", and the materials suitable for their production are called "biomaterials". The development of biomaterials is divided into three phases: inert biomaterials, biodegradable biomaterials, and bioactive biomaterials (Touri et al., 2019). A unifying characteristic of biomaterials is called «biocompatibility», which defined by the European Society of Biomaterials in 1986 as "The ability of a material to function with an appropriate host response in a specific application" (Molt et al., 2016). Biomaterials are classified according to their material composition: polymer materials, metallic materials, naturally occurring materials, and ceramic materials (Molt et al., 2016). Calcium phosphate ceramics are particularly valued as bone grafts in hard tissue surgery due to their chemical composition, as the beta-type tricalcium phosphate which is similar to that of human bone that makes them the most commonly used (Chaair et al., 2017; Niu et al., 2024; Yao et al., 2023).

Beta-type tricalcium phosphate (β-TCP: $Ca_3(PO_4)_2$) is a ceramic bone substitute according to its stability, considering that it is the crystalline form of tricalcium phosphate (Ramona-Nicoleta BORŞA, 2008; Rollin-Martinet S, 2011). This compound is characterized by different properties, such as biological and physical properties (Cui et al., 2022; Ftiti et al., 2024) such as biodegradablity and osteoconductivity and high porosity (Bhawal et al., 2016; Hashimoto et al., 2024). But these properties are not sufficient for specific medical uses (Saito et al., 2024). To enhance these properties, researchers have explored various methods, one of which is the substitution method. The incorporation of trace elements into tricalcium phosphates can be done for a number of reasons, such as the modification of mechanical and crystallographic properties, and the optimization of the biological response. The substitution approach allows in particular to regulate the solubility of the material, increase resorption or osteoconduction/osteoinduction, and even to grant antibacterial properties (Sinusaite et al., 2020). β-TCP substitution can be performed either in the anionic lattice or in the cationic lattice. The first type called anionic substitution; which is related to phosphate ions PO_4^{3-}. It can be done by the incorporation of several anions including SiO_4^{4-}, SO_4^{2-} (Khayrutdinova et al., 2023). for the second type, it is a cationic substitution; when replacing calcium ion by other elements such as (Fe, Zn, Cu, and Mg…). In synthetic of calcium phosphate, prior research showed that partial Ca replacement by Fe ions could produce materials with several uses. Superparamagnetic Fe-doped CPs were successfully used as imaging agents for magnetic resonance and nuclear imaging in vivo (Sinusaite et al., 2020). When the zinc as an implant for bone replacement can promote bone growth and limit bone absorption (Pan et al., 2020) according to its anti-inflammatory activity (Ferreira et al., 2018). In addition, Mg^{2+} is a highly effective substituent for β-TCP due to its ability to alter resorption rate, and that was confirmed by Gallo et al., who investigated how Mg^{2+} substitution affects β-TCP resorption behavior (Gallo et al., 2019; Schatkoski et al., 2021). Therefore, the magnesium is an element with exceptional biological qualities that aids in bone growth (Pan et al.,