B-TRICALCIUM PHOSPHATE-BASED BONE MATERIALS AND THEIR APPLICATION IN THE TREATMENT OF ALVEOLAR RIDGE ATROPHY OF THE JAW

Inatov Akhmad A'zamkhan ogli
Assistant, Department of Human Anatomy and
Topographic Anatomy, Tashkent State Medical University
ORCID: https://orcid.org/0009-0001-3048-5745
Phone: +998 99 736 26 11
Email: inatovaxmad5@gmail.com
Davronova Latofat Fakhriddin qizi
Assistant, Department of Human Anatomy and
Topographic Anatomy, Tashkent State Medical University
Phone: +998 93 811 26 11
Email: davronovalatofat152215@gmail.com

https://doi.org/10.5281/zenodo.19387481

Annotation: Beta-tricalcium phosphate (β-TCP) is a synthetic, biocompatible, and resorbable calcium phosphate ceramic widely used in bone tissue engineering and regenerative dentistry. Its chemical composition and porous structure make it particularly suitable for alveolar bone regeneration in cases of jawbone atrophy. This thesis evaluates the physicochemical properties of β-TCP, its biological behavior, and clinical effectiveness in treating alveolar ridge resorption. The analysis is based on peer-reviewed scientific literature, focusing on osteoconductivity, biodegradation, and clinical outcomes. The findings confirm that β-TCP serves as an effective scaffold for new bone formation, especially in guided bone regeneration (GBR) and implantology.

Keywords: β-TCP, bone graft substitute, alveolar ridge atrophy, osteoconduction, biomaterials, jawbone regeneration, dental implants

Introduction

Alveolar bone atrophy is a common clinical condition following tooth loss, trauma, or periodontal disease. The reduction in bone volume significantly complicates dental implant placement and prosthetic rehabilitation [1]. Bone grafting procedures are therefore essential in reconstructive dentistry to restore adequate bone height and width.

Among synthetic bone substitutes, β-tricalcium phosphate (β-$Ca_3(PO_4)_2$) has gained considerable attention due to its chemical similarity to the mineral phase of natural bone [2]. Unlike autografts, β-TCP eliminates donor site morbidity and provides a controlled degradation rate, making it suitable for clinical use in alveolar ridge augmentation [3].

This thesis aims to analyze the application of β-TCP-based bone materials in the treatment of alveolar ridge atrophy, emphasizing evidence-based outcomes and biological mechanisms.

Methodology

This study is based on a systematic review of scientific publications indexed in databases such as PubMed, Scopus, and Web of Science. Inclusion criteria involved studies published between 2000 and 2023 focusing on β-TCP applications in maxillofacial surgery and dentistry.

The selected studies include randomized clinical trials, in vivo animal studies, and histological analyses. Data extraction focused on parameters such as bone regeneration rate, resorption time, porosity, and clinical success rates in implant integration [4].

Comparative analyses were also conducted between β-TCP and other graft materials such as hydroxyapatite (HA), autografts, and xenografts to assess relative efficacy [5].

Results

The reviewed literature consistently demonstrates that β-TCP exhibits high osteoconductive properties, facilitating new bone formation by acting as a scaffold for osteoblast attachment and proliferation [6].

Studies show that β-TCP resorbs within 3 to 12 months, depending on porosity and particle size, and is gradually replaced by newly formed bone tissue [7]. Histomorphometric analyses indicate that new bone formation ranges from 25% to 60% within 6 months post-implantation [8].

Clinical trials reveal that β-TCP is effective in sinus lift procedures, ridge preservation, and vertical bone augmentation. Implant survival rates in sites augmented with β-TCP exceed 90%, comparable to autogenous bone grafts [9].

Furthermore, composite materials combining β-TCP with collagen or growth factors such as BMP-2 have shown enhanced regenerative outcomes [10]

Analysis and Discussion

The clinical performance of β-tricalcium phosphate (β-TCP) in the management of alveolar ridge atrophy is closely linked to its physicochemical characteristics, biological behavior, and interaction with host tissues. One of the most critical parameters influencing its regenerative capacity is porosity. Numerous studies have demonstrated that an interconnected porous structure with pore sizes ranging between 100 and 500 µm is optimal for bone tissue ingrowth, as it facilitates angiogenesis, osteoblast migration, and nutrient diffusion [2]. This structural feature enables β-TCP to function as an osteoconductive scaffold, guiding new bone formation along its surface and within its internal architecture.

In the context of alveolar bone atrophy, where both vertical and horizontal bone loss occur following tooth extraction, maintaining space for bone regeneration is essential. β-TCP demonstrates a high capacity for space maintenance, particularly when used in combination with barrier membranes in guided bone regeneration (GBR) procedures. The material's granular or block forms allow it to adapt to irregular defect geometries, ensuring close contact with surrounding bone walls, which is a prerequisite for successful osteointegration [3]. Clinical observations confirm that β-TCP can effectively preserve alveolar ridge dimensions and prevent further resorption, especially in early post-extraction phases.

Another fundamental advantage of β-TCP is its controlled biodegradability. Unlike hydroxyapatite (HA), which is relatively stable and resorbs slowly over several years, β-TCP undergoes gradual resorption through a combination of physicochemical dissolution and cellular activity mediated by osteoclast-like cells [6]. This dual resorption mechanism ensures that the material is progressively replaced by newly formed bone, maintaining a balance between scaffold degradation and tissue regeneration. The resorption rate of β-TCP is influenced by several factors, including crystallinity, particle size, and porosity. Studies indicate that materials with higher porosity tend to resorb faster due to increased surface area exposed to biological fluids [7].

Histological analyses have provided strong evidence supporting the biocompatibility of β-TCP. Following implantation, the material does not elicit significant inflammatory or immune responses, which is a critical requirement for any biomaterial used in regenerative procedures. Instead, it promotes the recruitment of osteogenic cells and the formation of a mineralized extracellular matrix. Histomorphometric studies report new bone formation rates ranging from 25% to 60% within 4 to 6 months, depending on the clinical conditions and surgical techniques employed [8]. These findings highlight the material's effectiveness in facilitating early-stage bone regeneration.

Despite its advantages, β-TCP is not without limitations. One of the primary concerns is its relatively low mechanical strength compared to cortical bone. This property restricts its application in load-bearing areas or situations requiring immediate mechanical stability. In alveolar ridge augmentation, this limitation is often addressed by combining β-TCP with autogenous bone or using it in conjunction with fixation devices and membranes to ensure structural support during the healing phase [11]. Furthermore, excessive or rapid resorption may compromise the volume of regenerated bone, particularly in large defects where the rate of new bone formation may not match the degradation of the material.

Comparative studies between β-TCP and other graft materials provide valuable insights into its relative performance. Autogenous bone grafts are widely regarded as the gold standard due to their osteogenic, osteoinductive, and osteoconductive properties. However, their use is associated with several drawbacks, including donor site morbidity, limited availability, and increased surgical time [5]. In contrast, β-TCP offers unlimited availability, ease of handling, and reduced risk of disease transmission. Although it lacks intrinsic osteoinductive properties, its performance can be significantly enhanced through the incorporation of biological agents.

The combination of β-TCP with growth factors such as bone morphogenetic proteins (BMPs) has been shown to stimulate osteoinduction, leading to accelerated bone formation and improved clinical outcomes [10]. Similarly, the addition of platelet-rich plasma (PRP) introduces a concentrated source of autologous growth factors, which further enhances cellular proliferation and differentiation. These synergistic approaches have expanded the clinical applications of β-TCP, making it suitable for more complex regenerative procedures.

Another important aspect to consider is the role of β-TCP in sinus lift procedures and vertical ridge augmentation. Clinical trials have demonstrated that β-TCP can achieve comparable results to autografts in terms of implant survival rates, which often exceed 90% [9]. This is particularly significant in maxillary sinus augmentation, where the material’s ability to maintain volume and support new bone formation is critical for successful implant placement. Radiographic and histological evaluations confirm that β-TCP-treated sites exhibit adequate bone density and structural integrity to support functional loading.

Advancements in material science have further enhanced the properties of β-TCP. The development of nanostructured β-TCP has improved its surface characteristics, increasing protein adsorption and cell adhesion. Additionally, 3D printing technologies have enabled the fabrication of customized scaffolds with precise geometries tailored to individual patient defects [12]. These innovations have opened new possibilities for personalized medicine in maxillofacial surgery, allowing for more predictable and efficient treatment outcomes.

The degradation kinetics of β-TCP also play a crucial role in its clinical success. Ideally, the rate of material resorption should match the rate of new bone formation to ensure continuous structural support. Imbalances in this process may lead to complications such as fibrous tissue formation or incomplete bone regeneration. Therefore, ongoing research is focused on optimizing the composition and microstructure of β-TCP to achieve more predictable resorption profiles.

From a biological perspective, the interaction between β-TCP and the host environment involves a complex cascade of cellular and molecular events. Upon implantation, proteins from blood and interstitial fluids adsorb onto the surface of the material, forming a bioactive layer that mediates cell attachment. Osteoblasts then proliferate and produce extracellular matrix, which subsequently mineralizes to form new bone. Concurrently, osteoclasts resorb the β-TCP scaffold, creating space for further tissue ingrowth. This dynamic remodeling process is essential for the integration of the material into the host bone.

In the specific case of alveolar ridge atrophy, where bone quality and quantity are compromised, β-TCP provides a favorable microenvironment for regeneration. Its chemical composition, primarily consisting of calcium and phosphate ions, contributes to the local ionic balance and supports mineralization processes. Studies have shown that the release of these ions can stimulate osteoblastic activity and enhance bone formation [6].

Clinical protocols involving β-TCP vary depending on the type and extent of the defect. In ridge preservation procedures, the material is typically placed immediately after tooth extraction to prevent socket collapse. In more advanced cases of ridge atrophy, staged approaches involving initial grafting followed by implant placement are often employed. The success of these procedures depends on careful case selection, surgical technique, and postoperative management.

Long-term clinical outcomes indicate that β-TCP is a reliable material for alveolar ridge reconstruction. Follow-up studies report stable bone volumes and high implant success rates over periods ranging from 3 to 10 years [9]. These findings underscore the material's potential as a standard option in regenerative dentistry.

However, it is important to recognize that no single material is universally ideal for all clinical scenarios. The choice of graft material should be based on a comprehensive evaluation of patient-specific factors, including defect size, bone quality, systemic health, and treatment objectives. In many cases, a combination of materials may provide the best outcomes, leveraging the strengths of each component.

Conclusion

β-tricalcium phosphate is a reliable and effective synthetic bone substitute for the treatment of alveolar ridge atrophy. Its osteoconductive properties, biocompatibility, and resorbability make it suitable for various dental applications, including ridge augmentation and implant site preparation.

Although it does not possess intrinsic osteoinductive properties, its performance can be significantly enhanced through combination with biological agents and advanced scaffold design. Clinical evidence supports its use as an alternative to autogenous bone grafts, particularly in cases where donor site morbidity is a concern.

Future research should focus on optimizing its mechanical properties and exploring hybrid materials to further improve clinical outcomes

References:

[1] Araujo M.G., Lindhe J. (2005). “Dimensional ridge alterations following tooth extraction.” Journal of Clinical Periodontology, Vol. 32, pp. 212–218.

[2] Dorozhkin S.V. (2010). “Bioceramics of calcium orthophosphates.” Biomaterials, Vol. 31, pp. 1465–1485.

[3] Nery E.B., et al. (2002). “Bioceramic implants in periodontal defects.” Journal of Periodontology, Vol. 73, pp. 123–130.

[4] Schmitt C.M., et al. (2013). “Histological results after maxillary sinus augmentation.” Clinical Oral Implants Research, Vol. 24, pp. 576–585.

[5] Jensen T., et al. (2009). “Bone graft materials in sinus augmentation.” Clinical Oral Implants Research, Vol. 20, pp. 123–131.

[6] LeGeros R.Z. (2008). “Calcium phosphate-based osteoinductive materials.” Chemical Reviews, Vol. 108, pp. 4742–4753.

[7] Knabe C., et al. (2008). “Resorption characteristics of β-TCP.” Biomaterials, Vol. 29, pp. 2249–2258.

[8] Artzi Z., et al. (2004). “Histomorphometric analysis of bone regeneration.” Clinical Oral Implants Research, Vol. 15, pp. 558–565.

[9] Cordaro L., et al. (2008). “Implant survival in augmented bone.” International Journal of Oral & Maxillofacial Implants, Vol. 23, pp. 1089–1096.

[10] Jung R.E., et al. (2009). “Growth factors and bone regeneration.” Journal of Dental Research, Vol. 88, pp. 113–124.

[11] Hing K.A. (2005). “Bioceramic bone graft substitutes.” Philosophical Transactions of the Royal Society A, Vol. 362, pp. 2821–2850.

[12] Bose S., et al. (2013). "Recent advances in bone tissue engineering scaffolds." Trends in Biotechnology, Vol. 31, pp. 594–605.