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Clinical Applications of β-TCP in Bone Regeneration: A Comprehensive Review of Orthopedic and Dental Use

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Abstract

Beta- Tricalcium phosphate (β-TCP) a synthetic chemical, which has the molecular formula of $Ca_3(PO_4)_2$. It is a crystalline substance which is stable at lower temperatures and is a member of bioceramic class. The rhombohedral crystal system of the β-TCP is very similar to the natural bone components. Even though being insoluble in water, it is slightly soluble in acidic conditions. The chemical composition and structural similarity with the bone makes it highly compatible for the biological system. β-TCP is extensively used bioceramic material in the sector of orthopedics and dentistry due to its high excellent osteoconductivity, biocompatibility, and ability to stimulate the bone regeneration. This review provides the detailed analysis of β-TCP, which focuses on its physicochemical properties, synthesis techniques, and clinical applications in orthopedic and dental regenerative medicine.

In orthopedics, β-TCP is most commonly used in bone grafting, spinal fusion, and fracture healing, proving with the structural support and improving bone formation in critical bone defects. In dental applications, β-TCP is implemented for alveolar bone regeneration, periodontal defect repair, and dental implantology, facilitating bone healing around the implants and improving the long-term implant achievement. The materials resorbability and steady replacement by natural bone make it an ideal choice for both clinical and regenerative implementations. Although it's promising benefits, challenges such as mechanical strength and the requirement for additional biomolecules to strengthen its performance are also discussed. The survey explores the future prospective of β-TCP in combination with advanced technologies such as 3D printing and stem cell therapy, which holds the potential to further prove its clinical efficacy in both orthopedic and dental area.

Keywords: *Beta-Tricalcium phosphate (β-TCP), Rhombohedral Crystal, Osteoconductivity, Osseointegration, hydroxyapatite (HA) and Morphogenetic Proteins (BMP_S)*

Introduction

β-TCP is a synthetic chemical compound which has achieved the significant amount of attention in biomedical research due to its close chemical structural similarity to the mineral elements of natural bone structure(Carrodeguas et al., 2011), (Raúl et al., 2011), and (Salvador et al., 2011). It has a rhombohedral crystal structure and belongs to the class of bioceramic (Frasnelli et al.,2016), (Matteo et al.,2016), (Vincenzo et al.,2016). It has the exceptional qualities such as it can remain stable at lower temperatures, insoluble in water, and slightly soluble in under acidic conditions, this showcased its bioresorbability in vivo (Zhang et al.,2022) (Zhehao et al.,2022)(Debao et al.,2022),(Zuoyu et al.,2022),(Xianghui et al.,2022),(Xuehui et al., 2022), (Xiaohao et al.,2022). These properties, along with its excellent biocompatibility and osteoconductivity, have located β-TCP as a promising material for the application in the bone tissue engineering, particularly in orthopedics and dentistry.

In clinical perspective, β-TCP has indicates the substantial potential in promoting the bone regeneration and healing. In orthopedic surgery, it is constantly implemented in bone grafting procedures, spinal fusion, and the treatment of complex fractures, where it provides the temporary structural support as it is serving as a scaffold for new bone formation (Whang et al., 2003), (Peter et al., 2003) (Jeffrey et al., 2003). It is also particularly beneficial in the management of critical

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sized bone defects, enabling osteoblasts attachment, proliferation, and differentiation. Likewise, in the dental applications, β-TCP facilitates alveolar bone regeneration, periodontal defect repair, and osseointegration in the dental implantology (Guillaume, and Bernard, 2017). The ability to gradually resorb and also be able to replace by natural bone contributes significantly to long term clinical outcomes in implant stabilization process and bone defect reconstruction process.

Despite all of these advantages, several limitations restrict the optimal performance of β-TCP in clinical care. During the procedure some key challenges hinders the procedure such as low mechanical strength, uncontrolled or variable reoperation rates, and the limited biological activity of the material when it is used in isolation. Moreover, while β-TCP is efficient in supporting the bone regeneration, it is often requires combination with the growth factors, stem cells, or other bioactive agents to achieve the enhanced outcomes, by highlighting the gap between material properties and clinical demands (Jiang et al., 2021), (Sijing et al., 2021), (Mohan et al., 2021) (Jiacai et al., 2021).

Current advancement in material science and biomedical engineering have led to the development of the novel strategies directed at the overcoming these limitations. Which includes the fabrication of the β-TCP based composite materials, the incorporation of bioactive molecules, and the adoption of enhanced manufacturing technologies such as 3D printing and scaffold fictionalization. These types of innovations aim to enhance the mechanical properties, bioactivity, and patient specific adaptability of β-TCP scaffolds. Additionally, tissue engineering approaches involving mesenchymal stem cells and controlled drug delivery system are being analyzed to improve the osteoinductivity and speed up the integration process (Porter et al., 2009), (Joshua et al., 2009), (Timothy et al., 2009), (Ketul et al., 2009).

Despite the numerous studies have shown that examination of properties and clinical applications of β-TCP, it still lack of comprehensive reviews, which critically examine the comparative effectiveness of different β-TCP formulations, synthetic procedures and merged therapeutic strategies. Currently, the need for emerging technologies such as additive manufacturing and biomolecular engineering can be integrated with β-TCP based system to expand their regenerative potential.

Method

A structured multidisciplinary methodological framework was developed by the β-TCP bone regeneration process (Garcia et al., 2022), (Daniel et al., 2022), (Larissa et al., 2022), (Marcelo et al., 2022).Because of the exceptional physiochemical and biological properties of β-TCP, including osteoconductivity, biocompatibility, resorbability, and mechanical properties that supports its prominent role in clinical applications. The method focused on evaluating β-TCP from the three kinds of perspectives, its material properties, structure, its biological performance in clinical application, and examining its role in evolving technologies for personalized medicine.

Properties of β-TCP:

β-TCP is a bioceramic material which is widely used in bone regeneration because of its exceptional osteoconductivity and biocompatibility (Lu et al., 2021), (Haiping et al., 2021), (Yinghong et al., 2021), (Yaping et al., 2021), (Lan et al., 2021), (Wenjun et al., 2021), (Yi et al., 2021), (Xin et al., 2021). The β-TCP has the trigonal crystal structure and which also has one of the key phases of Tricalcium phosphate. It showcased a permeable microstructure conductive to cell infiltration and vascularization (growth of a tissue or an organ), which supports the new bone formation. β-TCP is bioresorbable, because of such property it underwent the gradual degradation process through the ionic dissolution and cellular mediated resorption, which arranged with the natural bone regeneration process. However, it has low mechanical strength, which limits its ability to regenerate, and load bearing applications. The materials mineral phase has so much similarity with the natural bone structure, which a very favorable composition for the regeneration procedure. Recent advancements and current study shows if it combined with some other particular material the biocompability increase rapidly, and it also helps in bone regeneration process.

Conceptual Framework:

This study was conducted by three primary field of the analysis:

- **Material Functionality**: The main functionality of β-TCP is to perform as scaffold in supporting the bone cell activity and regeneration (Weinand et al., 2006), (Christian et al., 2006), (Irina et al., 2006), (Craig et al., 2006), (Rajiv et al., 2006), (Eli et al., 2006), (Ijad et al., 2006), (Frederic et al., 2006), (Harutsugi et al., 2006), (Maria et al., 2006), (Joseph et al., 2006).
- **Clinical integration**: In the clinical application the main focus of the β-TCP is its application in orthopedic and dental fields, particularly its function in osseointegration and healing outcomes.
- **Innovation potential**: It helps in enhancing the material modification and personalized design technologies.

Each of this field was assessed independently and in interrelation to provide a well rounded comprehensive of β-TCP's capability and also its shortcomings in the clinical environment.

Analysis of Scaffold Functionality:

The first stage focused on the intrinsic material characteristics of β-TCP which determines the suitability of it as a scaffold. The following parameters were assessed:

Osteoconductivity:

The easement was performed based on β-TCP's ability to assist the adhesion, migration, and proliferation of osteoblasts and other progenitor cells. Moreover, porosity, surface roughness, and micro-structural characteristics were analyzed

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to determine their influence on cellular activity. β-TCP is a high osteoconductive, which means that it promotes the attachment, migration, and proliferation of osteoblasts, the cells which are responsible for bone formation. This particular quality makes it the excellent material for supporting the healing of bone defects and fractures (Garcia et al., 2022), (Daniel et al., 2022), (Larissa et al., 2006), (Marcelo et al., 2022).

Biocompatibility:

Biocompatibility's evaluation is usually based on the observation of the inflammatory response, tissue compatibility, and long term tolerance across various implantation sites. β-TCP is clinically acceptable by the body, with minimal risk of immune rejection. This biocompatibility makes sure that the materials merge well with the natural bone tissue, which enhanced the effect of the bone regeneration process.

Resorbability:

The examination focused on the material degradation rate and its alignment with the new bone formation, with the controlled resorption, regarded essential to avoid the premature scaffold caved in or delayed healing process. One of the core advantages of β-TCP, is its resorbable nature. By the time pass, the material is gradually broken down and replaced by the natural bone element (Kazuz, and Abdul, 2022). This gradual resorption reduced the need for the removal surgeries and allows the fully integration of the material into the bone structure.

Mechanical Strength:

β-TCP was studied for its capacity to bear weight, especially in orthopedic uses. The mechanical strength is relatively low compared to the natural bone (Liang et al., 2010), (Lei et al., 2010), (Paul et al., 2010), (W.Y et al., 2010). In load bearing implementation, this can be limiting the effectiveness. IN order to solve this problem, β-TCP is regularly mixed with the other substances, including the polymers or hydroxyapatite (HA), to improve its mechanical qualities. When these qualities gets combined with the characteristics, which makes the β-TCP a very effective and adaptable biomaterial for bone regeneration. The ability to support new bone growth, while progressively resorbing and combining with tissue, combined with its excellent biocompatibility, established β-TCP as a preferred choice in a wide range of clinical applications.

Evolution of β-TCP in orthopedic Application

Throughout the past years the clinical use of β-TCP in orthopedic procedures greatly increased, where bone regeneration process is essential. The key aspects of the assessment are given below:

- **Application Bone grafting:**

β-TCP is widely used in orthopedic field, as a bone grafting material. It works as a scaffold for bone cells to proliferate and forms the new bone tissue. β-TCP is significantly effective for the treatment of non-union fractures, large bone defects, and in spinal fusion surgeries (Leppilahti et al., 2025), (Juhana et al., 2025), (Mari et al., 2025), (Timo et al., 2025), (Lukasz et al., 2025), (Katri et al., 2025), (Mikko et al., 2025), (Jaakko et al., 2025), (Pekka et al., 2025). When it gets fused with autografts or allograft, β-TCP enhance the bone healing by providing a structure which supports the growth of new bone tissue. The effectiveness of β-TCP as the material which fills the gaps and supports the new bone regeneration was studied. The performance of β-TCP was evaluated in both weight-bearing and non weight bearing conditions.

- **Spinal Fusion:**

The Spinal fusion surgery's object is to stabilize the spine by fusing two or more vertebrae together. β-TCP used as the bone graft alternative to promote bone formation between the vertebrae, enhancing the healing procedure and reducing the risk of graft failure (Damron, and Timothy, 2007). The resorbability of β-TCP allows flawless integration into the vertebrae, making it an ideal material for the spinal surgeries.

- **Repair of Osteoporotic bone:**

Some patients suffer from the osteoporosis or large bone defects, for such cases β-TCP is used for repair the damaged or weakened bone structures. β-TCP has the potential to restore the bone volume and mineral density in damaged skeletal structure was evaluated. The role of the preserving structural integrity, faciliting bone remodeling, and preventing further degeneration gets investigated (Jolic, and Martina, 2025). It helps to restore the bone density and strength, which also helps in the overall improvement in bone health.

Evaluation of β-TCP in Dental Applications:

In the dental area, β-TCP was examined for its ability to boost osseointegration, maintain alveolar ridge integrity, and support the periodentical regeneration. This analysis covered the following process:

- **Peri-implant bone regeneration:**

β-TCP plays a very essential role in the success of dental implants by enhancing bone regeneration around the implant site. When an implant is placed, the surrounding bone has to integrate and support the implant. Here, β-TCP serves as a scaffold for osteoblasts, which helps in promoting the bone formation around the implant and ensured the long term stability and success (Gao et al., 2016), (Peng et al., 2016), (Haoqiang et al., 2016), (Yun et al., 2016), (Liu et al., 2016), (Bo et al.,2016), (Xiaokang et al., 2016), (Xin et al., 2016), (Pingheng et al., 2016). β-TCP has the capacity to support rapid and stable integration between implant surfaces and native bone tissue was evaluated. During the procedure the whole attention is given to scaffold position, vascularization, and the load distribution.

- **Preservation of Alveolar ridge:**

A bone structure which helps in holding the teeth in their proper position is called alveolar bone. Due to disease or some other issues teeth can be compromised. For such cases β-TCP is used to regenerate the alveolar bone, who also helps to preserve the natural bone structure of jaw and improves the outcomes of subsequent dental implant or in restoring procedures (Ni et al., 2025), (Xuewen et al., 2025), (Jing et al., 2016), (Mengxue et al., 2025), (Fangzheng et al., 2025), (Yuanjie et al., 2025), (Zijie et al., 2025), (Dong et al., 2025),

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(Qingyu et al., 2025), (Zehao et al., 2025), (Feifei et al., 2025), (Ping et al., 2025).

- **Treatment of periodontal defects:**

The treatment of periodontal defect was guided by the tissue regeneration. The process gets precede by the interaction of the β-TCP and periodontal ligament cells, which removes intrabony and fraction defects. It is used for the regeneration of the lost bone around the teeth, which helps to restore the structural integrity of jawbone and improving tooth stability.

- **Cyst and lesion defect filing:**

β-TCP is also used to fill void in cases like cysts, benign tumors, or other bone defects in jaw. Because of its resorbable nature it confirms that it does not interfere with natural bone healing process, and over the time, it is replaced by patients own bone tissue.

Result and Discussion

Material Characterization and Scaffold Functionality:

β-TCP shows a rhombohedral crystal structure which is very similar to the natural bone, which ensures the excellent osteoconductivity and biocompatibility. It enhance the osteoblasts adhesion, proliferation, and bone regeneration, making it efficient in orthopedic applications like bone grafting, spinal fusion and critical defect repair. In dental use, β-TCP supports alveolar border preservation, periodontal repair, and implant osseointegration. The gradual resorption allows for flawless replacement by natural bone with minimal immune response. But, β-TCP has low mechanical strength which restricts the load-bearing use, often requiring the combination with other materials like HA or polymers. Inclusion of bioactive agents and advanced fabrication methods such as 3D printing shows promising results for β-TCP's regenerative potential and clinical outcomes.

Orthopedic Applications:

Bone Grafting and Defect Repair

Records of clinical and preclinical evolution revealed that β-TCP scaffolds, when it is being used alone or in the combination with other material, the bone formation process gets enhanced. New bone formation observed in non-union fractures and segment defects. The formation of lamellar bone at defect site gets observed within the 6-12 weeks post implantation.

Spinal Fusion:

β-TCP when gets combined with the BMP_S or other Stem cells the fusion rate gets comparably gets quite high. In controlled studies, spinal fusion process shows higher intervertebral bone bridging and reduced graft collapse, which affirms its role as the structural and biological support material.

Osteoporotic Bone Restoration:

In the Osteoporotic models, β-TCP materials application makes the increase in the bone mineral density (BMD) and also the structural integrity. By the process effective bone remodeling and enhanced implantation gets observed, particularly when the β-TCP was functionalized with the bisphosponates or growth factors.

Dental Application

Peri Implant Bone Regeneration

β-TCP's osseointegration enhanced the peri-implant bone regeneration process. The data indicates a significant amount of increase in bone implant. The treated area shows the results in about after 8-10 weeks post surgery.

Alveolar Preservation

In the tooth extraction process, β-TCP granules were applied to preserve the alveolar ridge formation. The clinical trials demonstrated preservation of bone regeneration. This helps in improving the bone regeneration process and allowed the natural bone to regrow on its own and helps to avoid surgical removal.

Periodontal Defect Treatment

In tissue regeneration process, β-TCP efficiently filled the gaps or the defects within bone. Clinical parameters like probing depth reduction, clinical attachment level gain, and radiographic bone fill improved significantly compared to control groups, highlighting its predictable performance in periodontal procedure.

Table 1: Biomaterial factors and their clinical importance of β-TCP in bone tissue engineering of dental & orthopedic applications

Parameter	Orthopedic Observation	Orthopedic Clinical Relevance	Dental Observation	Dental Clinical Relevance
Osteoconductivity	High(if proper biocompatible material used)	Promotes new bone growth in large skeletal defects	High(if proper biocompatible material used)	Facilitates alveolar ridge augmentation and socket healing
Biocompatibility	Excellent	Reduces immune response and graft rejection	Excellent	Minimizes inflammation in oral tissues
Resorbability	Gradual, site-dependent	Enables remodeling without need for surgical removal	Gradual, site-dependent	Matches natural bone healing rate, avoids persistent graft material

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Mechanical Strength	Low	Requires reinforcement for load-bearing bones	Moderate	Sufficient for non-load bearing areas like jaw ridges
Clinical Performance	Proven efficacy in grafting	Used in spinal fusion, fracture repair, long bone defects	Proven efficacy in grafting	Effective in periodontal regeneration, sinus lifts, and implants
Innovations	3D printing, stem cell seeding, nanotech	Enhances mechanical and biological integration	3D printing, Nano-structuring, growth factor incorporation	Enables patient-specific grafts, faster healing with bioactive cues

As per the data shown in the table1 it is clearly showcased that, the critical properties and emerging technologies mainly effects the clinical application of the biomaterials in the bone regeneration.

Challenges in β-TCP Usage:

While β-TCP has received recognition for its osteoconductive and biocompatibility properties, where its clinical application does not shows any kind of limitations. Throughout the process still there are some challenges, material related and procedural, continue to affect the performance and predictability in biomedical settings. Comprehending the challenges is also essential for optimizing its use in regenerative medicine and implantology.

1. **Mechanical Strength:**

One of the limitations of the β-TCP is about the mechanical strength. Because it relatively has the low mechanical strength compared to the natural bone structure. It is very effective as the scaffold for the bone regeneration, but the lack of the mechanical strength can be problematic in high stress, and low bearing areas. To solve this issue, β-TCP gets combined with other materials such as hydroxyapatite (HA) or reinforced with the synthetic polymers which improve the mechanical properties.

2. **Resorption Rate:**

The rate of resorption β-TCP can be differ depending on the factors like, patients age, the specific site of the application, and the existence of other materials. In certain cases, β-TCP resorbs too quickly, which can results in incomplete bone regeneration. However, if the material absorb too slowly, it can interfere with the natural bone healing process. Currently researches are going through for, optimization of the resorption rate of β-TCP to balance its effectiveness in different clinical circumstances.

3. **Inflammatory Response:**

When the large quantities are used or materials implanted in an area with poor blood supply, there is chance of potential mild inflammatory response. For minimize the risk careful surgical techniques and patient monitoring are required.

4. **Integration with Other Biomaterials:**

β-TCP is usually combined with other biomaterials like the growth factors, stem cells, or the other bioceramic to enhance its properties. These combinations have shown promising results, like their long term effectiveness and safety still requires some further research in that area.

Future Directions

Combination with Growth Factors:

The combination of β-TCP and morphogenetic proteins (BMP_S) and other growth factors used to enhance the osteogenesis. For more effective and faster bone regeneration β-TCP gets incorporated by the growth factors.

3D Printing and Customization:

The arriving of the 3D printing technology has allowed the customization of β-TCP scaffold to be of specific size and shape, which can gets matched with the bone defects. This helps to make the approach more personalized, which ensures the better fit and integration with the surrounding bone defect areas.

Stem Cell Therapy:

The combination of the stem cell therapy and β-TCP holds a massive power for enhancing the bone regeneration process. Stem cell gets seeded with the β-TCP scaffolds, which promotes healing process faster and more efficiently bone regeneration process faster. Currently pursuing studies are focused on the optimizing this combination for further clinical use.

Nanotechnology:

To explore the properties of β-TCP nanotechnology is being used. Nano particle used in nanotechnology increase the surface area of the cellular attachment ant helps to improve the interaction between the β-TCP and its surrounding tissues. This gives the more effective result in the bone regeneration, especially in the critical sized bone defects.

Conclusion

β-TCP has acclaimed itself as a highly aspiring bioceramic material in the field of bone tissue engineering, particularly in orthopedic and dental applications. The unique combination of osteoconductivity, biocompatibility, and resorbability, accompanied with its close structural resemblance to the bone mineral, which allows it to serve effectively as a scaffold for new bone formation. The clinical use of β-TCP covers a wide range of applications from the bone grafting and spinal fusion to the dental implants stabilization and periodontal regeneration, which makes it valuable equipment in the regenerative medicine. However, despite all of these advantages, β-TCP has several limitations. It is observed through the literature survey that it required some biomolecules to enhance the biological activity, which has different resorption rates, and relatively has poor mechanical

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strength, all of which highlight the urgency for the future improvement. All of these given challenges underline the importance of ongoing innovations, particularly immerging β-TCP with the other materials like hydroxyapatite, stem cells, growth factors, and synthetic polymers to improve the performance of it. Further development of the β-TCP include the integration of 3D printing technologies, nanotechnology, and stem cell therapy, which collectively offers the capacity for the patient's specific scaffold design, which improved its bioactivity, and faster, more effective bone regeneration. These improvements not only solve the current limitations but also make the way for more personalized, efficient, and clinically impactful treatment in both orthopedic and dental applications area.β-TCP has demonstrated that the substantial potential in bone regeneration, the full clinical efficacy of β-TCP will be realized through the continued research and interdisciplinary collaboration, which aims to optimize its properties and expanding its therapeutic applications in the ever evolving field of regenerative medicine. As this innovation continues to develop, β-TCP is composed to play a most important role in bone regeneration process across the various medical fields.

Reference

1. Carrodeguas, Raúl G., and Salvador De Aza. "α-Tricalcium phosphate: Synthesis, properties and biomedical applications." Acta biomaterialia 7, no. 10 (2011): 3536-3546.
2. Frasnelli, Matteo, and Vincenzo M. Sglavo. "Effect of Mg2+ doping on beta–alpha phase transition in tricalcium phosphate (TCP) bioceramics." Acta biomaterialia 33 (2016): 283-289.
3. Zhang, Zhehao, Debao Liu, Zuoyu Chen, Xianghui He, Xuehui Li, and Xiaohao Sun. "Fabrication, in vitro and in vivo properties of β-TCP/Zn composites." *Journal of Alloys and Compounds* 913 (2022): 165223.
4. Whang, Peter G., and Jeffrey C. Wang. "Bone graft substitutes for spinal fusion." The Spine Journal 3, no. 2 (2003): 155-165.
5. Guillaume, Bernard. "Filling bone defects with β-TCP in maxillofacial surgery: A review." *Morphologie* 101, no. 334 (2017): 113-119.
6. Jiang, Sijing, Mohan Wang, and Jiacai He. "A review of biomimetic scaffolds for bone regeneration: toward a cell-free strategy." Bioengineering & Translational Medicine 6, no. 2 (2021): e10206.
7. Porter, Joshua R., Timothy T. Ruckh, and Ketul C. Popat. "Bone tissue engineering: a review in bone biomimetics and drug delivery strategies." *Biotechnology progress* 25, no. 6 (2009): 1539-1560.
8. Garcia, Daniel Cardoso, Larissa Eckmann Mingrone, and Marcelo Jorge Cavalcanti de Sá. "Evaluation of osseointegration and bone healing using pure-phase β-TCP ceramic implant in bone critical defects. A systematic review." Frontiers in Veterinary Science 9 (2022): 859920.
9. Lu, Haiping, Yinghong Zhou, Yaping Ma, Lan Xiao, Wenjun Ji, Yi Zhang, and Xin Wang. "Current application of beta-tricalcium phosphate in bone repair and its mechanism to regulate osteogenesis." *Frontiers in Materials* 8 (2021): 698915.
10. Weinand, Christian, Irina Pomerantseva, Craig M. Neville, Rajiv Gupta, Eli Weinberg, Ijad Madisch, Frederic Shapiro, Harutsugi Abukawa, Maria J. Troulis, and Joseph P. Vacanti. "Hydrogel-β-TCP scaffolds and stem cells for tissue engineering bone." *Bone* 38, no. 4 (2006): 555-563.
11. Garcia, Daniel Cardoso, Larissa Eckmann Mingrone, and Marcelo Jorge Cavalcanti de Sá. "Evaluation of osseointegration and bone healing using pure-phase β-TCP ceramic implant in bone critical defects. A systematic review." Frontiers in Veterinary Science 9 (2022): 859920.
12. Kazuz, Abdul. "Bioactive materials based on α-tricalcium phosphate cement and fluoroapatite." Универзитет у Београду (2022).
13. Liang, Lei, Paul Rulis, and W. Y. Ching. "Mechanical properties, electronic structure and bonding of α-and β-tricalcium phosphates with surface characterization." Acta biomaterialia 6, no. 9 (2010): 3763-3771.
14. Leppilahti, Juhana, Mari Kuoppala, Timo Sirola, Lukasz Kolodziej, Katri Ahonen, Mikko Aulamo, Jaakko Niinimäki, and Pekka Jalovaara. "Beta-tricalcium phosphate combined with native bone proteins (β-TCP-NBP): a novel bone graft substitute for ankle and hindfoot arthrodesis." *International Orthopaedics* 49, no. 3 (2025): 721-728.
15. Damron, Timothy A. "Use of 3D β-tricalcium phosphate (Vitoss®) scaffolds in repairing bone defects." Nanomedicine 2, no. 6 (2007): 763-775.
16. Jolic, Martina. From extra-skeletal bone growth to re-osseointegration: Osteoinduction and mechanical disruption in bone repair. 2025.
17. Gao, Peng, Haoqiang Zhang, Yun Liu, Bo Fan, Xiaokang Li, Xin Xiao, Pingheng Lan et al. "Beta-tricalcium phosphate granules improve osteogenesis in vitro and establish innovative osteo-regenerators for bone tissue engineering in vivo." Scientific reports 6, no. 1 (2016): 23367.
18. Ni, Xuewen, Jing Feng, Mengxue Liang, Fangzheng Zhou, Yuanjie Xia, Zijie Dong, Qingyu Xue, Zehao Li, Feifei Pu, and Ping Xia. "Enhancing Bone Repair with β-TCP-Based Composite Scaffolds: A Review of Design Strategies and Biological Mechanisms." Orthopedic Research and Reviews (2025): 313-340.

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