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Swelling Behavior of Bovine Amniotic Membrane-Carbonate Hydroxyapatite Biocomposites: Literature Review

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Abstract

Background: Tooth extraction can lead to progressive alveolar bone resorption due to the loss of periodontal ligament support. This reduction in alveolar ridge height and width can interfere with prosthetic rehabilitation and dental implant placement. Socket preservation is therefore needed to maintain bone volume and support proper healing. Biomaterials such as bovine amniotic membrane (BAM) and carbonate hydroxyapatite (CHA) have gained attention due to their biocompatibility and regenerative potential.

Objective: This study aimed to review the biological basis and effectiveness of BAM and CHA, individually and in combination, in supporting alveolar bone regeneration, and to highlight the importance of evaluating swelling capacity in the BAM–CHA biocomposite.

Discussion: BAM provides a collagen-rich biological matrix containing growth factors that promote angiogenesis and tissue repair, while CHA supports structural reinforcement and osteoconduction. When combined, BAM–CHA forms a biocomposite that mimics the natural organic–inorganic composition of bone. The freeze-drying method ensures scaffold porosity and preserves biological activity. Swelling capacity influences cell attachment, nutrient diffusion, and healing efficiency, making it a key parameter for evaluating scaffold performance.

Conclusion: BAM and CHA act synergistically in enhancing alveolar bone regeneration. Their combination as a biocomposite shows strong potential for socket preservation. Assessing swelling capacity is essential to determine the optimal ratio for achieving scaffold stability and effective tissue regeneration.

Keywords: Bovine Amniotic Membrane Carbonate Hydroxyapatite Biocomposite, Alveolar Bone Regeneration, Freeze-Drying, Swelling Capacity, Human and Health

Introduction

Tooth extraction commonly induces progressive resorption of the alveolar bone due to the loss of periodontal ligament support, which plays a central role in maintaining alveolar structural integrity [1]. The resulting dimensional reduction of the alveolar ridge, occurring both horizontally and vertically, can compromise the predictability of prosthetic rehabilitation and dental implant placement [2]. To mitigate these adverse morphological changes, socket preservation techniques are employed by introducing biomaterials designed to promote osteogenesis, maintain structural stability of the extraction site, and optimize the local microenvironment throughout the healing phase [3].

Alveolar bone regeneration involves a complex interplay between osteogenic cells, extracellular matrix components, and regulatory growth factors [4]. Biomaterials used in socket preservation must therefore exhibit high biocompatibility, osteoconductive capacity, and a rate of biodegradation that corresponds to the pace of new tissue formation. In this context, bovine amniotic membrane (BAM) and carbonate hydroxyapatite (CHA) have emerged as relevant biomaterial candidates. BAM provides a biologically active collagen-rich matrix enriched with growth factors, while CHA serves as a mineral phase that reinforces structural integrity and supports osteoconduction. The combination of these two components (BAM–CHA) offers the potential to form a biocomposite that achieves an organic–inorganic balance closely resembling the composition of natural bone [5].

The aim of this literature review is to elucidate the biological and scientific rationale for the use of BAM and CHA in alveolar bone regeneration, as well as to highlight the importance of evaluating the swelling capacity of the BAM–CHA biocomposite as a key parameter influencing scaffold structural stability and the overall effectiveness of the healing process.

Material and Methods

The method employed in this article is a narrative literature review. The literature search was conducted to identify recent and relevant studies addressing the application of bovine amniotic membrane, carbonate hydroxyapatite, and BAM–CHA biocomposites in alveolar bone regeneration, as well as the evaluation of swelling behavior in biomaterial scaffolds. International scientific databases, including PubMed, ScienceDirect, ProQuest, ResearchGate, and Google Scholar, were utilized to obtain secondary data sources. The selection criteria included full-text availability for studies published between 2009-2024.

Discussion

1. Alveolar Bone

The alveolar bone is a specialized portion of the maxilla and mandible that forms and supports the tooth socket. It develops in conjunction with tooth eruption and provides essential structural support to the dentition [6]. The organic component of the alveolar bone consists of approximately 10 percent cellular elements and 90 percent extracellular matrix (ECM). The cellular component is composed primarily of three key cell types: osteoblasts, osteocytes, and osteoclasts. Together with the vascular system and ECM, these cells play a central role in maintaining bone tissue homeostasis through the balanced regulation of bone formation and resorption [7].

The organic matrix of the alveolar bone is predominantly composed of collagen proteins (80–90 percent), which mainly consist of type I collagen (95 percent) and a smaller fraction of type V collagen (5 percent). Additionally, type III and type XII collagen are present in minor quantities. The alveolar bone also contains various non-collagenous proteins such as osteocalcin, osteonectin, osteopontin, sialoproteins, proteoglycans, phosphoproteins, and bone morphogenetic proteins (BMPs), all of which contribute to mineralization, matrix organization, and signaling processes involved in bone remodeling and regeneration [8].

2. Socket Preservation

Tooth extraction triggers alveolar bone resorption due to the loss of functional stimulation provided by the periodontal tissues, a process that progresses over several weeks following extraction. To reduce this resorptive outcome, alveolar ridge preservation (ARP) is performed as an interventional approach [9]. ARP may involve the use of bone graft materials, barrier membranes, or soft-tissue grafts, depending on the clinical objective. The effectiveness of socket preservation has been demonstrated by a significantly reduced loss of alveolar ridge height and width, with approximately *2 mm* less reduction compared to extraction sites without preservation procedures [4].

Key parameters that determine the quality and regenerative capacity of grafting materials include biocompatibility, osteoconductivity, osteoinductivity, and osteogenic potential [10]. These characteristics collectively influence the ability of the material to integrate with host tissues, support cellular activity, and promote stable bone regeneration.

3. Bovine Amniotic Membrane (BAM)

The amniotic membrane is rich in growth factors, cytokines, and structural proteins, which collectively confer its unique biological properties, including antibacterial effects, anti-inflammatory activity, anti-scarring capability, and anti-fibrotic potential. Owing to these characteristics, the amniotic membrane has been widely utilized as a biomaterial in tissue engineering applications [11].

The extracellular matrix of the amniotic membrane is composed of collagens type I, III, IV, V, VI, and XV, along with laminin, nidogen, fibronectin, and proteoglycans [12]. Bovine amniotic membrane (BAM) contains functional chemical groups such as amide I, II, and III, as well as hydroxyl (OH) groups. The amide I group is primarily associated with hydrogen bonding between N-H and C=O linkages, while the amide II group reflects interactions involving N-H and C-N bonds [13].

BAM exhibits osteoinductive properties in bone tissue regeneration, as evidenced by the expression of osteopontin, osteocalcin, and osteonectin during healing and new bone formation [14]. Growth factors and cytokines present within the membrane contribute to wound healing and tissue regeneration by promoting angiogenesis, reducing inflammation, preventing microbial colonization, and limiting excessive scar formation [15].

4. Carbonate hydroxyapatite (CHA)

Carbonate hydroxyapatite (CHA) is a biomaterial known for its ability to stimulate bone tissue regeneration due to its biocompatibility and osteoconductive properties (16). Compared to pure hydroxyapatite, CHA demonstrates enhanced effectiveness, attributed to its superior chemical stability, crystallinity profile, biodegradation rate, and faster osteointegration capability [17].

The use of CHA has been shown to effectively support bone regeneration in both *in vitro* and *in vivo* studies. Its regenerative effectiveness is evidenced by the formation of mineralized tissue throughout the defect area, as well as its ability to modulate macrophage polarization, which facilitates osteoblast differentiation and promotes angiogenesis [18].

5. BAM–CHA Biocomposite

A biocomposite is a hybrid material composed of two distinct structural components and is designed for biomedical applications to achieve properties such as biocompatibility, non-toxicity, non-inflammatory response, and bioactivity, which collectively help prevent infection (19). Bone itself is a natural composite consisting of inorganic and organic phases, where hydroxyapatite crystals are embedded within a collagen matrix. To emulate this biological architecture, biomimetic bone composites have been developed using polymers as the organic phase and mineral compounds as the inorganic phase [20].

The amniotic membrane has demonstrated effectiveness in supporting bone regeneration due to its osteoinductive potential and its content of growth factors, such as Bone Morphogenetic Protein-2 (BMP-2), a member of the Transforming Growth Factor-β (TGF-β) superfamily, which plays a key role in directing precursor cells toward osteogenic differentiation. Additionally, the use of amniotic membrane has been shown to reduce interleukin-6 (IL-6) levels, thereby attenuating inflammatory responses and accelerating tissue repair by enhancing cell proliferation and collagen synthesis [21].

However, the amniotic membrane exhibits certain limitations, particularly its low mechanical strength and relatively rapid degradation rate, which can compromise its structural integrity during bone regeneration [22]. To address these limitations, the membrane can be combined with mineral phases to reinforce scaffold structure and enhance osteogenic performance [23]. The incorporation of carbonate hydroxyapatite into the collagenous matrix is particularly advantageous because its composition closely resembles natural bone and supports osteogenesis through improved mechanical stability and bioactive signaling [24].

6. Freeze-Drying Method

The freeze-drying method is widely utilized in the fabrication of materials for tissue engineering applications. Its primary advantage lies in the absence of heat during processing, which allows thermosensitive biological components to retain their functional activity. In addition, this technique enables the production of materials with improved structural stability and extended shelf life [25].

7. Swelling

The swelling behavior of a biomaterial plays a critical role in supporting cellular proliferation. A higher swelling capacity increases the available surface area for cell attachment, thereby potentially accelerating cell growth (26). In addition, swelling characteristics contribute to enhanced fluid absorption from the biological environment and facilitate the transport of nutrients and the removal of metabolic waste products. A greater degree of swelling is generally associated with higher hydrophilicity, a property that promotes cell adhesion and proliferation and subsequently accelerates tissue regeneration [22].

Conclusion

BAM and CHA play complementary roles in alveolar bone regeneration. BAM provides a biologically active matrix that supports tissue healing, while CHA contributes structural reinforcement and osteoconductive properties. When combined as the BAM–CHA biocomposite, these materials demonstrate strong potential as a socket preservation scaffold. Evaluating swelling capacity is essential to determine the most effective compositional ratio, ensuring an optimal balance between scaffold stability and its ability to facilitate new tissue formation.

Conflict of Interest

The author declares no conflict of interest.

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