UDC: 577.112.386:615.46:612.751

THE EFFECT OF CHITOSAN AND WHEY POWDER COMBINATION ON CALCIUM-PHOSPHORUS METABOLISM AND BONE MINERALIZATION

Rakhmonov Farkhod Kholbayevich
Assistant, Zarmed University, Uzbekistan, Samarkand E-mail: farxod1313jon@gmail.com
Turdiyeva Dilshoda Alisher qizi
Student, Zarmed University, Uzbekistan, Samarkand E-mail: turdiyevad4712@gmail.com

Abstract: *This scientific article analyzes the effect of the combination of chitosan and whey powder on calcium-phosphorus metabolism and bone tissue mineralization processes based on modern scientific literature. Chitosan, as a natural biopolymer, possesses high biocompatibility, biodegradability, chelating properties, and the capacity to create an osteoconductive environment, making it a promising scaffold material in bone tissue engineering [4–6]. Whey powder serves as a source of biologically active proteins and mineral components, potentially supporting bone cell metabolism and the formation of the protein-mineral matrix [3,7,8]. The article highlights in vitro approaches concerning mesenchymal stem cell adhesion, osteoblastic differentiation, and mineral deposit formation on chitosan-based modified surfaces, as well as prospects for developing composite scaffolds combined with whey proteins [8–10]. Findings indicate that the combination of chitosan and whey powder has scientific grounds to promote bone mineralization and may serve as an additional prophylactic and biomaterial solution in conditions such as osteoporosis.*

Keywords: *chitosan, whey powder, calcium-phosphorus metabolism, osteogenesis, bone mineralization, composite scaffold, mesenchymal stem cells.*

INTRODUCTION

Bone tissue is the primary structural element of the musculoskeletal system, providing mechanical strength while also acting as a depot for calcium and phosphorus and maintaining their systemic homeostasis. When the balance between osteoblasts and osteoclasts becomes impaired during bone remodeling, or calcium-phosphorus metabolism is disrupted, a decrease in bone mass and deterioration of microarchitecture may occur, increasing the risk of fractures in osteoporosis [1,2].

In clinical practice, bisphosphonates and other pharmacological approaches are commonly used to manage osteoporosis; however, prolonged treatment can result in adverse effects and individual limitations [1,2].

Therefore, developing new prophylactic and regenerative solutions based on biocompatible, safe, multifunctional natural biomaterials is of high relevance.

Chitosan is a linear polysaccharide obtained by the deacetylation of chitin. The presence of amino and hydroxyl functional groups in its structure allows for chemical modification, enhancement of biological activity, and targeted influence on mineralization [4,5]. Since the mineral component of bone tissue consists of hydroxyapatite, chitosan-hydroxyapatite composites are particularly significant from a biomimetic approach [6,10].

Whey powder contains high-value protein fractions, amino acids, and mineral components, making it an important nutritional factor supporting bone metabolism [3,7]. Within composite approaches, chitosan acts as a matrix, while whey proteins may enhance bioactive signaling and support matrix formation during cell adhesion [7,8].

Main part. The osteogenic value of chitosan is associated with its physicochemical and biological properties. Due to positively charged amino groups, chitosan modulates protein adsorption and cell-surface interaction, and its ability to chelate calcium ions allows it to form a “template environment” for mineral precipitation [4,9,10]. Additionally, changes in the degree of deacetylation and molecular weight significantly influence solubility, mechanical properties, and cellular responses [5]. Various derivatives of chitosan (such as carboxymethylated, phosphorylated, or thiolated forms) expand its stability in aqueous environments, enhance bioactivity, and increase its potential as a local drug carrier [11,12].

The whey component may offer dual functional benefits within composite systems. Firstly, whey proteins serve as a bioactive substrate promoting cell adhesion and proliferation; secondly, they support osteoblast differentiation by supplying amino acids and mineral elements essential for bone metabolism [3,7,8]. Over recent years, extensive scientific findings have accumulated on the physicochemical properties and tissue-engineering potential of whey-based biomaterials or chitosan–whey composite scaffolds [7,8].

Methodology. This article combines in vitro and biomaterial-composite approaches to address the research question. In vitro, mesenchymal stem cell adhesion and osteogenic differentiation on chitosan-coated (modified) surfaces are evaluated using cell culture models. Phenotypic characterization is confirmed through immunophenotyping, and osteogenesis is induced in standard osteogenic conditions. Mineralization is assessed by Alizarin Red S and von Kossa staining, while osteogenic marker expression is analyzed using real-time PCR [8,9]. From the composite viewpoint, whey proteins are incorporated into the chitosan matrix, or whey-based systems are reinforced with chitosan to enhance cellular responses and mineral deposition dynamics [7,8].

Analysis. General analysis of scientific literature demonstrates that the chemical nature of chitosan surfaces influences protein adsorption and cell adhesion while forming a microenvironment that directs osteogenic differentiation [4,9]. Chitosan has been described as a “templating agent” in calcium phosphate mineralization, meaning it provides favorable conditions for nucleation and growth of calcium-phosphate precipitates, which is crucial for composite biomaterial design [9,10]. Whey proteins, based on clinical and experimental observations, have shown potential to positively affect bone mass and mineral density [3]. Accordingly, a combination of chitosan and whey powder appears theoretically and practically capable of promoting calcium-phosphorus metabolism and bone mineralization as a composite biomaterial approach [7,8,9,10].

Results. Findings indicate that chitosan-based modified surfaces and chitosan–whey composite concepts may enhance osteogenic differentiation and mineral deposit formation. The synergistic potential of chitosan's chelating and mineralization-directing properties together with the bioactive and nutritional value of whey proteins establishes a scientific rationale for their combined use in promoting bone matrix mineralization [7,8,9,10].

Conclusion. The combination of chitosan and whey powder may positively influence calcium-phosphorus metabolism and bone mineralization processes and is regarded as a promising biomaterial-nutritional approach. The mineralization-modulating abilities of chitosan and the biologically valuable content of whey proteins together provide a scientific foundation for stimulating osteogenesis.

Further studies evaluating mechanical properties, biodegradation profiles, and in vivo efficacy of composite systems will help determine the practical significance of this direction more precisely [6,8,10].

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