IN VIVO EVALUATION OF CHITOSAN–TRICALCIUM PHOSPHATE BIOACTIVE COATING FOR ENHANCED OSSEOINTEGRATION OF TITANIUM DENTAL IMPLANTS

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Abstract

The increasing prevalence of partial and complete edentulism necessitates the development of advanced implant systems capable of improving osseointegration and long-term clinical outcomes. Surface modification of titanium implants using bioactive materials represents a promising strategy for enhancing biological integration.This study aimed to experimentally evaluate the osteointegrative effectiveness and biocompatibility of a novel bioactive coating based on tricalcium phosphate and chitosan for domestically manufactured dental implants.An in vivo experimental study was conducted using 72 chinchilla rabbits divided into three groups: commercial implants, uncoated domestic titanium implants, and domestic implants coated with a bioactive polymer matrix. Radiological, densitometric, histomorphological, and biochemical analyses were performed at different postoperative periods.The developed coating demonstrated nanoscale morphology and stable adhesion to titanium surfaces. Experimental implants with bioactive coating exhibited accelerated bone regeneration, increased peri-implant bone density, and improved trabecular organization compared with uncoated implants. Positive osteointegration dynamics became evident after the first postoperative month.

Keywords: dental implants, bioactive coating, chitosan, tricalcium phosphate, osseointegration, biomaterials

Introduction

Edentulism remains one of the major global oral health problems and is associated with functional, aesthetic, and psychosocial impairment. According to the World Health Organization, complete tooth loss affects a significant proportion of elderly individuals worldwide and continues to increase with population aging.

Dental implantation is currently considered the most effective method of oral rehabilitation; however, successful treatment depends largely on the biological integration between implant surfaces and surrounding bone tissue. Modern implantology increasingly focuses on improving implant surface properties in order to accelerate osseointegration and reduce postoperative complications.

Bioactive coatings capable of stimulating osteogenesis have attracted considerable scientific interest. Surface roughness, wettability, chemical composition, and nanostructure are among the key factors influencing osteoblast adhesion and bone remodeling. In this context, calcium phosphate compounds and natural biopolymers are widely investigated for implant surface modification.

Literature Review

Titanium implants remain the gold standard in modern implantology because of their excellent mechanical characteristics and corrosion resistance. Nevertheless, conventional titanium surfaces may exhibit limited biological activity, particularly in patients with impaired regenerative capacity. Therefore, numerous studies have focused on enhancing titanium implant surfaces using bioactive coatings.

Tricalcium Phosphate is considered one of the most promising osteoconductive biomaterials due to its similarity to the mineral component of bone tissue. Experimental studies demonstrated that calcium phosphate coatings accelerate osteoblast proliferation and improve bone–implant contact.

Alves S.A. et al. reported that biofunctionalized titanium surfaces exhibit improved tribocorrosion resistance and enhanced biological performance. Similarly, Antonio Scarano and colleagues demonstrated superior histological bone response around implants possessing modified roughened surfaces.

Another biomaterial of growing interest is Chitosan, which possesses antibacterial, biodegradable, and biocompatible properties. According to Sartoretto S.C. et al., chitosan-containing implant coatings promote early osseointegration and improve surface bioactivity.

Recent advances in nanotechnology have enabled the creation of nanoscale coatings that facilitate protein adsorption and cellular adhesion. Zhou R. et al. demonstrated that microporous and nanostructured coatings significantly improve implant stability and bone regeneration.

Despite substantial progress in implant biomaterials, the development of domestic implant systems with advanced bioactive coatings remains limited. Therefore, the creation of cost-effective locally manufactured implants capable of achieving reliable osseointegration represents an important scientific and clinical objective.

Materials and Methods

The study was performed on 72 chinchilla rabbits weighing 4200–4300 g. Animals were maintained under standard vivarium conditions in accordance with ISO 10993-11 and European ethical guidelines for animal experimentation.

The animals were divided into three groups:

- **Group I:** commercial South Korean implants (Dentium®)
- **Group II:** uncoated domestic titanium implants
- **Group III:** domestic implants with bioactive coating

Bioactive Coating Preparation

The coating was synthesized using electrochemical deposition of:

- chitosan dissolved in acetic acid,
- fibroin solution,
- tricalcium phosphate particles.

Electrochemical parameters:

- temperature: 25–55°C
- current intensity: 0.05–100 mA

- deposition duration: 1–20 hours

Evaluation Methods

The following analyses were performed:

- radiographic examination,
- densitometry,
- histomorphological analysis,
- biochemical and hematological studies.

Digital image processing was conducted using ImageJ.

Results

The developed coating demonstrated nanoscale thickness ranging from 10 to 300 nm. Electron microscopy revealed a multilayer structure consisting of:

1. chitosan matrix,
2. intermediate calcium phosphate layer,
3. external tricalcium phosphate layer.

Spectral analysis confirmed stable deposition of calcium and phosphorus components on titanium surfaces.

Radiological and Densitometric Findings

Implants with bioactive coating demonstrated:

- increased peri-implant bone density,
- accelerated osteogenesis,
- reduced marginal bone resorption.

Positive osseointegration dynamics were observed from the first postoperative month, while bone density values approached physiological levels by the second month.

Histomorphological Findings

Histological analysis revealed:

- mature trabecular bone formation,
- increased osteoblastic activity,
- minimal inflammatory infiltration,
- improved structural organization of newly formed bone tissue.

At 3 months postoperatively, newly formed bone demonstrated homogeneous architecture with clearly visible trabecular structures.

Discussion

The findings of the present study confirm that bioactive surface modification significantly enhances the biological performance of titanium implants. The synergistic combination of tricalcium phosphate and chitosan promoted accelerated bone regeneration and improved structural organization of peri-implant tissues.

Tricalcium phosphate likely contributed to osteoconduction and mineral deposition, whereas chitosan enhanced cellular adhesion and provided antibacterial protection. The nanoscale morphology of the coating may additionally facilitate osteoblast attachment and protein adsorption during early healing phases.

The observed radiological and histological improvements are consistent with previous studies demonstrating superior osteointegration of biofunctionalized implant surfaces compared with conventional titanium implants.

Importantly, the proposed coating technology represents a promising domestic alternative to imported implant systems and may contribute to improving accessibility and cost-effectiveness of implant rehabilitation.

Conclusions

1. The developed bioactive coating demonstrated excellent biocompatibility and osteoconductive properties.
2. Surface modification significantly accelerated osseointegration and increased peri-implant bone density.
3. Histological findings confirmed enhanced bone remodeling and mature trabecular organization.
4. The proposed domestic implant system represents a promising approach for improving clinical outcomes in dental implantology.

References (Vancouver Style)

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