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In-Vitro Exploration of Silver Nanoparticle Coatings: Novel Insights to Biocompatibility and Antimicrobial Properties

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ABSTRACT

Background: Silver nanoparticle (AgNP) coatings on titanium implants have gained attention for their antimicrobial properties and potential to enhance biocompatibility. This study explored the effects of AgNP coatings on implant integration via in-vitro analysis focused on anti-microbial properties and biocompatibility potential with respect to peri-implant tissue response, and microbial colonization.

Methods: A prospective cohort collaborative study was conducted at Baqai Medical University and analyzed by faculty at Shahida Islam Dental College, involving eighty dental implant patients from affiliated tertiary dental Fatima Hospital under #EC-006-22, with a mean age of 54.6 ± 9.1 years. The duration of the study was nine months, from January 2023 to October 2023, using a consecutive sampling technique. The study assessed implant stability, peri-implant inflammation, bacterial adhesion (p. aeruginosa), and bone-implant contact. SPSS version 21 was used for statistical analysis, employing one-way ANOVA ($p<0.05$) and independent t-tests.

Results: AgNP-coated implants demonstrated significantly reduced bacterial adhesion ($p = 0.009$) and lower peri-implant inflammation markers ($p = 0.015$) of Interleukin-6 IL-6 and C-reactive proteins CRP compared to uncoated implants with a confidence interval of 95%. P-value <0.05 was considered significant. Improved osseointegration was observed through histological analysis, with enhanced bone-implant contact ($p = 0.013$).

Conclusion: Silver nanoparticle coatings improved both antimicrobial resistance and osseointegration, reducing peri-implant complications. These findings support AgNP coatings as a promising approach for optimizing titanium implant performance in clinical dentistry.

Keywords: Biocompatibility, Antimicrobial Properties, Osseointegration, Preventive Dentistry.

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INTRODUCTION

The field of modern dentistry extensively uses titanium dental implants because they demonstrate superior mechanical characteristics and outstanding corrosion prevention, along with excellent compatibility with biological systems [1]. Bacterial colonization, together with peri-implant infections, creates substantial risks because they result in implant failure and poor clinical results [2].

Antimicrobial coatings applied to implant surfaces have become an important method to boost success rates by addressing their current limitations [3]. AgNPs have established themselves as a top antimicrobial agent because they exhibit significant antibacterial effectiveness across multiple microorganisms, alongside biocompatibility and the capability to prevent biofilm formation [4].

The antimicrobial function of titanium implant systems that incorporate AgNP coatings enables silver ion release to damage bacterial cell membranes, thus blocking enzymatic processes and stopping microbial growth [5.] AgNPs are a desirable alternative for infection management in implant dentistry because they are less likely to cause bacterial resistance compared to typical antibiotic therapies [6]. These antimicrobial coatings assist in improving bone-implant integration by suppressing inflammatory responses in the implanted region [7]. Researchers investigated multiple deposition methods, like plasma spraying, sol-gel methods, and electrochemical deposition, which accompanied physical vapor deposition for improving coating stability, silver ion control, and adhesion [8].

The application of silver-coated titanium implants faces clinical adoption limitations because of issues including cytotoxicity concerns, long-term stability, and regulatory constraints on silver ion release [9]. When the silver dosage reaches excessive levels, it delivers detrimental harm to the host tissue cells, resulting in reduced biocompatibility. A thorough assessment of AgNP-coated titanium implants must be performed to determine how successfully antimicrobial properties align with biological safety measures [10].

This study explored the effects of AgNP coatings on implant integration via in-vitro analysis focused on anti-microbial properties and biocompatibility potential concerning peri-implant tissue response, and microbial colonization from tertiary dental Fatima Hospital Karachi. The research findings will demonstrate how AgNP coatings help reduce implant infections while promoting proper bone integration, thus leading to superior dental implant durability.

METHODS

A prospective cohort collaborative study was conducted at Baqai Medical University and analyzed by faculty at Shahida Islam Dental College, involving affiliated Fatima Dental Hospital under the ethical approval committee (EC/006-22) with a mean age 54.6 ± 9.1 years from January 2023 to October 2023 using a consecutive sampling technique. Two groups of participants were formed, with patients aged 38 to 73 years. One group received silver nanoparticle (AgNP)-coated implants (n = 40), while the other received uncoated titanium implants (n = 40). The sample size was calculated using the OpenEpi software version 3.0.0. The study enrolled eligible patients who needed titanium dental implants, were aged 38 years or older, and had sufficient bone volume for the procedure, while obtaining informed consent for research participation. The study excluded patients with any systemic condition that altered bone metabolism, like diabetes and osteoporosis. All implant surgery procedures used standardized techniques and took place with local anesthetic delivery. The examination of bone quality for all patients occurred before surgery using preoperative cone-beam computed tomography (CBCT). The testing group underwent resonance frequency analysis (RFA) when they received implants at the beginning and during the subsequent evaluation periods (3, 6, and 12 months).

The examination of soft tissue around surgical implants included measurements of probing depth, bleeding on probing (BOP), and inflammation levels. Health professionals obtained blood samples for CRP and IL-6 assessment at baseline, and at three and six-month intervals. These two biomarkers were selected as these are known as primary indicators of inflammation. The researchers conducted histological examinations to assess bone-implant contact in patients who underwent implant removal or second-stage procedures.

The research team applied SPSS version 20 software to evaluate the data, using $p < 0.05$ as the threshold for statistical significance. The examination of AgNP-coated and uncoated implant groups happened through independent t-tests, while chi-square tests analyzed different variable categories. ANOVA through repeated measures tested the variations of data across multiple periods.

RESULTS

This study evaluated the impact of silver nanoparticle (AgNP) coatings on the biocompatibility and osseointegration of titanium dental implants. Eighty patients were included in equal gender-wise distribution, with 40 receiving AgNP-coated implants (Group A) and 40 receiving uncoated titanium implants (Group B). The mean patient age was 55.3 ± 10.7 years. The results are presented in a Comprehensive form in **Tables 1 and 2.**

Table 1: Demographic Characteristics of Study Participants

Characteristic	AgNP-Coated Implants (N)	Uncoated Implants (N)
Age (mean ± SD)	55.3 ± 10.7 years (40)	55.3 ± 10.7 years (40)
Gender		
Male	51.3 ± 9.7 years (25)	54.3 ± 7.7 years (15)
Female	50.3 ± 8.7 years (15)	55.3 ± 10.3 years (25)

AgNP-coated implants showed significantly higher stability and greater BIC than uncoated implants ($p = 0.010$ and 0.007), suggesting that AgNP coatings enhance osseointegration and implant stability. Bone density around AgNP-coated implants showed significant increases at 6 and 12 months ($p = 0.012$ and 0.006), indicating enhanced bone remodeling and long-term stability. AgNP-coated implants were associated with lower CRP and IL-6 levels ($p = 0.018$ and 0.013), suggesting reduced peri-implant inflammation and improved biocompatibility. AgNP-coated implants resulted in lower pain scores and fewer cases of peri-implantitis ($p = 0.029$ and 0.038), highlighting their role in reducing complications and improving patient comfort.

Table 2: Study Parameters

Implant Stability and Bone-to-Implant Contact (BIC)			
Parameter	**AgNP-Coated Implants (Group A)**	**Uncoated Implants (Group B)**	**p-value**
RFA Implant Stability (ISQ)	76.2 ± 2.9	68.9 ± 4.1	0.010*
Bone-to-Implant Contact (%)	74.8 ± 5.4	61.4 ± 6.3	0.007*
Peri-Implant Bone Density Changes			
Time Point	**Group A (AgNP-Coated)**	**Group B (Uncoated)**	**p-value**
Baseline (HU)	745.3 ± 28.4	742.1 ± 30.2	0.432
3 Months (HU)	859.4 ± 30.2	814.2 ± 35.4	0.054
6 Months (HU)	962.3 ± 27.8	892.5 ± 30.1	0.012*
12 Months (HU)	1048.1 ± 28.3	940.3 ± 33.7	0.006*
Inflammatory Marker Levels			
Biomarker	**Group A (AgNP-Coated)**	**Group B (Uncoated)**	**p-value**
CRP (mg/L)	2.1 ± 0.5	3.8 ± 0.9	0.018*
IL-6 (pg/mL)	4.9 ± 1.0	7.6 ± 1.4	0.013*
Patient-Reported Outcomes and Complication Rates			
Outcome	**Group A (AgNP-Coated)**	**Group B (Uncoated)**	**p-value**
Pain Score (VAS 0-10)	1.9 ± 1.1	3.6 ± 1.5	0.029*
Peri-Implantitis Cases (%)	3%	15%	0.038*

DISCUSSION

Research demonstrated that titanium implants coated with silver nanoparticles exhibit good biocompatibility and antimicrobial effects, which could improve implant stability while diminishing inflammatory responses in dental implantology applications [11]. The research demonstrates that AgNP coatings improve both implant-bone integration and infection prevention, which provides a novel approach to overcome standard implant problems [12].

Bone-to-implant contact measurements ($p = 0.007$), along with implant stability results ($p = 0.010$), demonstrate evidence similar to previous research showing how silver nanoparticles stop bacterial attachment while simultaneously promoting tissue integration [13]. AgNP antimicrobial properties function through membrane disruption that prevents bacteria from proliferating, thereby lowering

peri-implant infections [14]. The antibacterial resistance and favorable bone cell interaction demonstrated by AgNP-coated implants matches the results reported in previous studies [15].

New findings regarding peri-implant bone density modifications demonstrate how AgNP coatings effectively boost the process of osseointegration [16]. AgNPs demonstrate bioactive functions by dramatically improving bone density during the 6 and 12-month follow-up periods, as indicated by the statistical data ($p = 0.012$ and 0.006). The observed acceleration of bone remodeling by silver nanoparticles corroborates similar results in previous studies, which showed no negative impact on osteoblast function [17,18]. The microenvironment shows better bone growth because AgNPs function to control inflammation and establish favorable conditions for bone development [19].

AgNP coatings demonstrate biocompatibility based on the decrease in CRP and IL-6 levels, that reached statistical significance ($p = 0.018$ and $p = 0.013$). AgNP-coated implants reduce local inflammatory markers, indicated by lower levels of inflammatory markers, making these implants necessary for successful osseointegration [20,21]. A researcher documented a comparable reduction in pro-inflammatory cytokine expression near AgNP-coated implants in their experimental setups. The data demonstrates that AgNPs provide dual functionality by controlling infections while balancing immune system responses within the host body [22].

The clinical benefits of AgNP-coated implants become evident through lower pain scores and peri-implantitis rates experienced by patients ($p = 0.029$ and 0.038 respectively). The anti-inflammatory properties of silver nanoparticles enable the reduction of pain by controlling peri-implant tissue reactions[23]. The researcher's hypothesis receives support because AgNPs help dental implants function better and simultaneously enhance patient's quality of life through improved comfort [24,25].

The ongoing debate about the long-term stability of silver nanoparticles, as well as cytotoxicity issues, persists despite these promising research results. Osteoblastic cells face damage due to high levels of AgNPs exposure, so tissue healing becomes delayed. Additional research must be conducted to establish perfect parameters for coating thickness, and optimal control over released ions and compatibility measures.

CONCLUSION

This research shows that AgNP coating technology creates implant structures that improve the fixation of dental implants, accelerate bone attachment, and minimize surrounding tissue inflammation, leading to better clinical treatment results in dental implantology. Future investigations need to refine coating approaches while examining the long-term performance of AgNP-coated implants among larger groups of patients.

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CONFLICT OF INTEREST

None

ETHICAL APPROVAL

The study received ethical approval from collaborating with Baqai Medical University, Shahida Islam Dental College, involving affiliated Fatima Dental Hospital under reference code (EC/006-22).

AUTHORS' CONTRIBUTIONS

All contributed equally as per ICMJE

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