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Cross-Sectional Evaluation of Hydroxyapatite-Coated Titanium Implants: Insights into Biocompatibility and Osseointegration

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ABSTRACT

Background: The application of hydroxyapatite (HA) coatings represents a powerful method for improving the biorientation of titanium dental implants and their compatibility with human tissue. The research examined the consequences of applying HA coatings on dental implant integration while investigating bone tissue response in the nearby area.

Methods: In this cross-sectional collaborative study conducted mainly at Baqai Medical University, Lahore Medical and Dental College and Muhammad Islam Dental College, eighty patients (BMU-EC/006-22) (average age 55.3 ± 8.7 years) participated in the assessment during the period from August 2022 to December 2023 based on a purposive sampling technique. The evaluation of implant stability, together with peri-implant bone density and inflammatory response markers, constituted the clinical measurement criteria. Professionals used both patient evaluations and imaging data to evaluate the efficiency of osseointegration. The analysis of data occurred through SPSS version 20 using one way ANOVA with p-value<0.05, statistically significant. Research findings for HA-coated versus uncoated implants derived from independent t-tests for continuous variables and chi-square tests for categorical data.

Results: The study outcomes revealed that implants coated with HA exhibited better bone attachment to implant surfaces, enhanced implant stability (p = 0.012), and decreased inflammation markers (p = 0.018). Under histological examination, there was improved contact between bone tissue and the implant surface, which proves that HA contributes to quick osseointegration.

Conclusion: The implant recipients with HA coatings experienced fewer complications and better outcomes in terms of functionality.

Keywords: Hydroxyapatites, Titanium, Implant, Osseointegration, Biocompatibility, Dental Implant Stability.

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INTRODUCTION

The use of titanium implants in dentistry has created substantial gains through their durable and biocompatible approach as tooth replacement options [1]. Wide usage of titanium dental implants exists, but achieving bone-implant integration at its best engineering level continues to be the primary performance obstacle [2]. Titanium implant surface properties directly affect their integration with the bone tissue surrounding the implants. Osseointegration alongside long-term implant stability is now being achieved through hydroxyapatite (HA) coatings [3]. The calcium phosphate compound named hydroxyapatite functions as an excellent material for biocompatibility while exhibiting bioactive properties due to its structural similarity to natural bone mineral components [4]. Titanium implants receive enhanced bone cell binding capabilities and accelerated bone healing when HA coatings are added to their surfaces thus lowering the chance of implant failure [5]. The deposition techniques of plasma spraying and sol-gel coating as well as biomimetic methods help improve both adhesive strength and structural stability of HA coatings [6,7]. Studies indicate that HA-coated dental implants generate greater bone-to-implant contact rates and bring about decreased implant site inflammation for better treatment outcomes [8,9]. Additional barriers including coating delamination and determining long-term stability as well as controlling the optimal thickness challenge clinical adoption of these coatings [10,11]. The complete assessment of how HA coatings affect titanium implants should include examinations of both biocompatibility and osseointegration efficiency and patient treatment results [12]. The research focused on evaluating how HA coatings impact implant performance by reviewing clinical and biological standards. The research investigated HA-coated titanium implant effects on peri-implant bone response together with inflammatory markers to create evidence-based recommendations for enhancing dental implant success rates. Dental practitioners could benefit from adopting HA-coated implants as their implementation appears to boost treatment effectiveness and minimize implant failure statistics within modern dental practices.

METHODS

In this cross-sectional collaborative study conducted mainly at Baqai Medical University, Lahore Medical and Dental College and Muhammad Islam Dental College, 80 patient's ethical approval committee (BMU-EC/006-22) (average age 55.3 ± 8.7 years) participated in the assessment during the period from August 2022 to December 2023 based on a purposive sampling technique. Patients aged from 38 to 73, were divided into two groups: HA-coated implants (n = 40) and uncoated implants (n = 40). The sample size of 80 patients was taken based on power analysis that detected the statistically significant results for implant stability and peri-implant bone response. The calculation considered a power of 80% with a p-value of 0.05 and an estimated effect size derived from studies on dental implants' osseointegration. Patients were included if they required titanium dental implants, were aged 38 years or older, had adequate bone volume for implant placement, and were willing to provide informed consent. Exclusion criteria ensured participants had no systemic conditions affecting bone metabolism (e.g., diabetes, osteoporosis). A clinical and radiographic examination serves to determine the influence of hydroxyapatite (HA) coatings on titanium dental implant biocompatibility and bone integration abilities. Implant Placement and Assessment. Medical staff performed implant surgeries through standardized procedures under local anesthesia. A preoperative cone-beam computed tomography (CBCT) examination assessed implant site bone qualities and measures. The examination of implant stability proceeded via resilience frequency analysis (RFA) both at the beginning and during subsequent checkup appointments. During the follow-up period at months 3, 6, and 12, bone density changes in CBCT images were monitored. Biological and Clinical Evaluations Health examinations of peri-implant soft tissue involved measurements of probing depth alongside bleeding on probing (BOP) assessments, as well as evaluations of peri-implant inflammation. Blood tests were done at three different time points: baseline and the third month, along the sixth month to assess CRP and IL-6 inflammation levels in the patients. Histological evaluation of bone-to-implant contact occurred in patients who underwent second-stage procedures or implant removal.

The analysis of data occurred through SPSS software, while considering p values under 0.05 as statistically significant. Research findings for HA-coated versus uncoated implants derived from independent t-tests for continuous variables and chi-square tests for categorical data. The research used repeated-measures ANOVA to evaluate modifications that occurred over time.

RESULTS

Table 1: Demographic Characteristics of Study Participants

Characteristic	HA-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)

This study assessed the impact of hydroxyapatite (HA) coatings on the biocompatibility and osseointegration of titanium dental implants. A total of 80 patients were included in an equal gender-wise ratio, with 40 receiving HA-coated implants (Group A) and 40 receiving uncoated titanium implants (Group B). The mean age of patients was 55.3 ± 10.7 years, with requirements for titanium implants either alone or in combined instances forming the study group in **Table 1**.

Table 2: Implant Stability and Bone-to-Implant Contact (BIC)

Parameter	HA-Coated Implants (Group A)	Uncoated Implants (Group B)	p-value
RFA Implant Stability (ISQ)	74.5 ± 3.2	68.9 ± 4.1	0.012*
Bone-to-Implant Contact (%)	72.1 ± 5.8	61.4 ± 6.3	0.009*

Table 2 shows that HA-coated implants exhibited significantly higher implant stability values and greater bone-to-implant contact (BIC) compared to uncoated implants (p = 0.012 and 0.009, respectively). These results suggest that HA coatings enhance early osseointegration and improve the overall stability of dental implants.

Table 3: Peri-Implant Bone Density Changes

Time Point	Group A (HA-Coated)	Group B (Uncoated)	p-value
Baseline (HU)	745.3 ± 28.4	742.1 ± 30.2	0.432
3 Months (HU)	852.6 ± 31.7	814.2 ± 35.4	0.061
6 Months (HU)	945.8 ± 26.3	892.5 ± 30.1	0.015*
12 Months (HU)	1024.2 ± 29.6	940.3 ± 33.7	0.008*

Table 3 shows that Bone density around HA-coated implants increased significantly over time, particularly at 6 and 12 months (p = 0.015 and 0.008). This indicates that HA coatings promote better bone remodeling, ensuring long-term implant stability.

Table 4: Inflammatory Marker Levels

Biomarker	Group A (HA-Coated)	Group B (Uncoated)	p-value
CRP (mg/L)	2.4 ± 0.6	3.8 ± 0.9	0.021*
IL-6 (pg/mL)	5.2 ± 1.1	7.6 ± 1.4	0.017*

Table 4 shows that Patients with HA-coated implants exhibited lower levels of inflammatory markers (CRP and IL-6) compared to the uncoated group (p = 0.021 and 0.017). This suggests that HA coatings help reduce peri-implant inflammation, potentially decreasing post-surgical complications.

Table 5: Patient-Reported Outcomes and Complication Rates

Outcome	Group A (HA-Coated)	Group B (Uncoated)	p-value
Pain Score (VAS 0-10)	2.1 ± 1.2	3.6 ± 1.5	0.032*
Peri-Implantitis Cases (%)	5%	15%	0.041*

Table 5 shows that Patients receiving HA-coated implants reported lower pain scores and fewer cases of peri-implantitis ($p = 0.032$ and 0.041). These findings suggest that HA coatings not only improve implant stability but also enhance overall patient comfort and reduce complications.

DISCUSSION

This research shows that hydroxyapatite (HA) coatings deliver substantial enhancements toward biocompatibility and osseointegration properties of titanium dental implants [13]. HA-coated implants demonstrated increased implant stability together with greater bone-to-implant contact percentages than uncoated titanium implants because they also decreased inflammation levels and provided more favorable patient outcomes [14]. The primary result showed that implant stability together with BIC improved when using HA-coated implants. The studies indicate that HA coatings promote faster osseointegration because they produce higher RFA values ($p = 0.012$) and demonstrate greater BIC percentages ($p = 0.009$) which are necessary for successful implant integration [15]. Bone tissue demonstrates better reaction to HA because of its bioactivity that supports both osteoblast cell adhesion and bone mineral growth [16]. Research confirming that HA coatings lead to reduced bone healing time and more durable implant stability system has supported these current findings. Significant improvements appeared in the density of bone tissue surrounding implants when research investigators tracked the outcomes over time [17,18]. The amount of bone density enhancement among HA-coated implants was statistically significant at 6 months ($p = 0.015$) and reached even greater significance at 12 months ($p = 0.008$). This confirms that HA coatings drive prolonged bone integration [19]. Research findings demonstrate that HA coatings provide an optimal biochemical environment for persistent integration between implant and bone tissue thus reducing implant instability and failure chances [20]. Data reveals that patients with implants coated in HA experience reduced inflammatory marker levels (CRP and IL-6) which proves their compatibility with human tissues [21]. The research suggests that HA coatings minimize implant-associated systemic inflammation as confirmed by significant statistical data ($p = 0.021$ and 0.017). Previous research indicates that HA coatings prevent immune activation which helps lower the chance of peri-implantitis development [22]. Pain scores and cases of peri-implantitis decreased statistically ($p = 0.032$ and $p = 0.041$) indicating the positive clinical outcomes of HA coatings [23].

The benefits of HA coatings are supplemented by significant limitations. The long-term stability of these coatings is a problem because aging may weaken the implants and impact their stability. Further research is needed to establish improved HA coating methods through plasma spraying and nano-structured coatings that will extend their service lifespan. Research that extends patient follow-up during HA-coated implant examinations is required to establish long-term success rates of these implants. HA coatings enhance implant stability together with osseointegration and patient comfort and decrease both inflammatory response and post-operative complications. The study confirms how HA-coated dental implants maintain clinical importance in oral reconstruction while revealing possible uses in orthopedic diseases and maxillofacial reconstruction procedures [24,25].

CONCLUSION

Research data shows that titanium dental implants gain better biocompatible properties when they receive hydroxyapatite (HA) coating treatments. Healthier conditions were observed from patients with HA-coated implants because they displayed firmer stability combined with better bone-to-implant contact and greater peri-implant bone density with less inflammation than patients with uncoated implants. The patients who received implants with HA coatings experienced reduced postoperative pain intensity and postoperative complications. HA coatings deliver significant advantages to clinical implant success and patient treatment results according to this research. The durability of HA coatings requires extensive long-term examination, while techniques for their implementation need optimization. Using HA coatings within implantology positions them as an important method for dental rehabilitation and bone integration because they improve treatment effectiveness.

LIST OF ABBREVIATIONS

HA: hydroxyapatite
CBCT: Cone-Beam Computed Tomography
CRP: C-Reactive Protein
IL-6: Interleukin 6

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CONFLICT OF INTEREST

None

ETHICAL APPROVAL

The study received ethical approval from collaborating with Baqai Medical University, Lahore Medical and Dental College, and Muhammad Islam Dental College, with the reference code (#BMU-EC/006-22).

AUTHORS' CONTRIBUTIONS

TR, AAK, AUR conceived the idea and designed the research work, **IA, AMI, KA** did data analysis, **AA, AAK** did the manuscript writing, **TR, AAK** did proofreading and editing, all authors agreed to be accountable for all aspects of the research.

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