Journal of Population Therapeutics & Clinical Pharmacology

ORIGINAL ARTICLE
DOI: 10.53555/yawk2t08

NANO-COATINGS FOR DENTAL IMPLANT SURFACES TO PROMOTE OSSEOINTEGRATION

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Abstract:

Background: This study investigates the efficacy of nano-coatings for enhancing osseointegration on dental implant surfaces, aiming to address gaps in current knowledge regarding implant success rates and patient outcomes. The primary objective is to assess participants' knowledge levels, attitudes, and practices regarding nano-coatings, coupled with quantitative measures such as pain scores post-implantation.

Material & Methods: A prospective cohort study design was employed at Liaquat College of Medicine and Dentistry Karachi over a duration of 12 months. The study population consisted of patients aged between 35-60 years requiring dental implants, with a sample size of 100 participants determined through consecutive sampling. Variables included level of knowledge (on a Likert scale), age, pain scores (visual analog scale), and demographic factors. Descriptive and inferential statistical analyses were planned to summarize data and test hypotheses regarding nano-coatings' impact on osseointegration.

Results: The quantitative analysis revealed positive perceptions among participants regarding nano-coatings' benefits, with the majority agreeing or strongly agreeing with their efficacy. Pain scores post-implantation was predominantly in the moderate range, highlighting the importance of pain

management strategies. Challenges such as cost implications and technical expertise requirements were noted in qualitative responses, emphasizing practical considerations.
Conclusion: In conclusion, this study underscores the potential of nano-coatings to enhance osseointegration on dental implant surfaces, with positive participant perceptions and dental professionals' attitudes. Practical challenges exist, necessitating further research and collaborative efforts to address barriers and facilitate the adoption of nano-coatings in implant dentistry, ultimately improving patient outcomes and treatment success rates.

Introduction:

Dental implants have revolutionized the field of restorative dentistry by offering a durable and aesthetically pleasing solution for tooth replacement. (1) Osseointegration, defined as the direct structural and functional connection between living bone and the surface of an implant, is crucial for the long-term success of dental implants. (2) It ensures stability, functionality, and patient satisfaction over extended periods. (3)

According to global data from the World Health Organization (WHO), dental implant procedures have been steadily increasing, with an estimated 10-15% annual growth rate over the past decade. (4) In 2020 alone, approximately 10 million dental implant procedures were performed worldwide. (5)

The demand for dental implants varies across different demographic groups, influenced by factors such as age, socio-economic status, and geographic location. (6) Higher prevalence rates are observed in older adults and individuals from high-income countries with better access to dental care. (7) Several factors influence the success of osseointegration, including implant surface characteristics, bone quality and quantity, surgical technique, and patient-related factors such as systemic health and smoking habits. (8) Surface modifications, such as nano-coatings, have emerged as a strategy to enhance osseointegration by promoting cellular interactions at the implant-bone interface. (9)

Traditional dental implant surfaces often rely on roughening techniques to enhance osseointegration. (10) However, advancements in nanotechnology have led to the development of Nano-coatings that offer precise control over surface topography, chemistry, and bioactivity. (11) These coatings can mimic the natural composition of bone tissue, promoting faster healing and integration.

Despite the progress in dental implant technology, challenges remain in achieving optimal osseointegration outcomes, especially in compromised bone conditions or patients with systemic diseases. (12) There is a need for innovative approaches, such as Nano-coatings, to address these challenges and improve the predictability and longevity of dental implant treatments. (13)

The primary research question addressed in this study is: Can nano-coatings applied to dental implant surfaces significantly enhance osseointegration compared to traditional surface modifications? The objective is to conduct a quantitative analysis of existing literature to evaluate the effectiveness of various nano-coatings in promoting osseointegration, focusing on outcomes such as bone-to-implant contact (BIC) and implant stability.

Based on preliminary evidence and theoretical frameworks, the hypothesis is that nano-coatings on dental implant surfaces will demonstrate superior osseointegration outcomes compared to uncoated or conventionally coated implants. Specifically, nano-coatings with bioactive components such as hydroxyapatite (HA) will enhance cell adhesion, proliferation, and differentiation, leading to increased BIC percentages and improved implant stability. This study's significance lies in its potential to contribute to advancements in dental implant technology and clinical practice. By systematically analyzing quantitative data on nano-coatings and osseointegration, this research aims to provide evidence-based recommendations for optimizing implant surfaces, improving treatment outcomes, and enhancing patient satisfaction in implant dentistry.

Methodology:

This research adopts a prospective cohort study design to investigate Nano-coatings for dental implant surfaces to promote osseointegration. The study is conducted in collaboration with the

dental department of Liaquat College of Medicine and Dentistry Karachi, located in Pakistan. The duration of the study spans from July 2023 to June 2024, ensuring a comprehensive assessment of maternal and infant nutrition's impact on dental arch morphology.

The study protocol received technical approval from the Institutional Research Board (IRB) at hospitals, ensuring adherence to ethical standards and patient confidentiality. (14) Additionally, informed consent is obtained from all participants, including expectant mothers and guardians of infants involved in the study.

The study population consisted of patients (aged 35-60 years) requiring dental implants for tooth replacement. The sample size was calculated using the formula for estimating proportions in a cohort study, with a confidence level of 95% and a margin of error of 5%. A total of 100 participants were recruited through consecutive sampling from the patient pool at Dental Hospital. Sample size calculation for the cohort study is based on the formula:

$$n = \frac{Z2 \times P \times (1 - P)}{E2}$$

where n is the required sample size, Z is the Z-score corresponding to the desired confidence level (e.g., 95% confidence interval), P is the estimated prevalence or proportion of interest, and E is the desired margin of error.

Inclusion criteria:

- Aged between 35-60 years.
- Patients requiring dental implants for tooth replacement.
- Ability to provide informed consent.

Exclusion criteria:

- Patients with uncontrolled systemic diseases affecting bone metabolism.
- History of radiation therapy to the head and neck region.
- Pregnancy or lactation.

Equipment, Procedure, Intervention, and Follow-up:

Equipment utilized in this study included advanced imaging technology such as cone-beam computed tomography (CBCT) scanners for preoperative assessment and evaluation of osseointegration. Surgical instruments specific to dental implant placement were employed, including implant drills, drivers, and torque wrenches. Additionally, resonance frequency analysis equipment (Osstell ISQ device) was utilized for measuring implant stability quotient (ISQ) values during follow-up visits.

The study procedure began with a comprehensive preoperative assessment of each participant, involving detailed dental and medical histories, radiographic evaluations using CBCT scans, and assessment of systemic health factors that could potentially impact osseointegration outcomes. Participants meeting the inclusion criteria underwent dental implant placement surgery using nano-coated implants, with the type of nano-coating (e.g., hydroxyapatite, titanium dioxide) determined based on the manufacturer's specifications.

Following implant placement, participants were scheduled for regular follow-up visits at 1 week, 1 month, 3 months, and 6 months post-surgery. During these visits, clinical assessments of implant stability were conducted using the Osstell ISQ device, which measures resonance frequency and provides ISQ values indicative of implant stability. Additionally, CBCT scans were taken at specific intervals to assess bone-to-implant contact (BIC) percentages, a key indicator of osseointegration.

The intervention group consisted of participants receiving dental implants with nano-coatings, while the control group comprised participants receiving traditional uncoated dental implants. The follow-up period allowed for longitudinal monitoring of osseointegration progress and comparison between the two groups regarding BIC percentages and ISQ values. Data collected from clinical assessments and imaging studies were entered into a secure electronic database for analysis. Descriptive

statistics, including means, standard deviations, and percentages, were used to summarize demographic characteristics and baseline data. Inferential statistics, such as t-tests and chi-square tests, were employed to compare osseointegration outcomes between the intervention and control groups, with a significance level set at $p < 0.05$.

The study's findings, including comparisons of osseointegration parameters between nano-coated and uncoated implant groups, were reported following the Consolidated Standards of Reporting Trials (CONSORT) guidelines for clinical trials. (15) The results were interpreted within the context of existing literature to determine the effectiveness of nano-coatings in promoting osseointegration and enhancing dental implant success rates.

Data Collection Plan:

The data collection plan for this original research study on nano-coatings for dental implant surfaces encompasses various methods to gather both primary and secondary data. A systematic literature survey will be conducted to review existing studies and collect secondary data regarding the use of nano-coatings in dental implantology, focusing on their impact on osseointegration. This secondary data will provide valuable insights into previous research findings and help frame the study's questionnaire. The primary data collection will be carried out through a structured questionnaire designed based on the literature survey outcomes. The questionnaire will employ a 5-point Likert scale to transform qualitative variables into quantitative measures, specifically assessing participants' knowledge levels, attitudes, and practices regarding nano-coatings for dental implants. Demographic variables such as gender, age, education level, residence, and income will also be included in the questionnaire to capture a comprehensive profile of the study participants.

To complement the quantitative data gathered through the questionnaire, semi-structured interviews will be conducted with dental professionals. These interviews will provide qualitative insights and perspectives on the practical application of nano-coatings in dental implant procedures, offering a deeper understanding of the topic from experts' viewpoints.

In addition to surveys and interviews, observational data will be collected through clinical examinations, laboratory tests, and imaging evaluations. Preoperative assessments will include detailed examinations of patients' oral health status, while postoperative follow-ups will focus on assessing outcomes such as bone-to-implant contact, implant stability, and any observed morbidities or complications. The questionnaire design will adhere to best practices, ensuring clarity and relevance of questions while avoiding common pitfalls such as double-barrel items, leading questions, and emotionally loaded queries. The questionnaire will undergo reliability testing through a pilot study, assessing its internal consistency using Cronbach's alpha coefficient.

All data collected, both quantitative and qualitative, will be entered into a secure electronic database for analysis. Statistical analysis will be performed using SPSS software, allowing for rigorous data examination and interpretation to address the research objectives effectively. The data collection process will adhere to ethical standards, including obtaining informed consent from participants and ensuring confidentiality and privacy throughout the study.

Analysis:

Quantitative Analysis

Variable	Mean (SD)	Median	Range	Frequency (n)
Level of Knowledge (Likert Scale)				
- Strongly Disagree (1)	N/A	N/A	N/A	10
- Disagree (2)	N/A	N/A	N/A	15
- Neutral (3)	N/A	N/A	N/A	20
- Agree (4)	N/A	N/A	N/A	30
- Strongly Agree (5)	N/A	N/A	N/A	25
Age (years)	45.6 (7.2)	46	35-60	N/A
Pain Score (Visual Analog Scale)	4.3 (1.2)	4.5	2-7	N/A

Qualitative Analysis

Theme	Description	Frequency (n)
Benefits of Nano-Coatings	Improved osseointegration, enhanced durability, reduced implant failures	45
Challenges	Cost implications, limited availability of specialized coatings, technical expertise required	20
Dentists' Attitudes	Generally positive towards nano-coatings, perceive them as a valuable advancement in implantology	50

Results:

Interpreting the results from the quantitative and qualitative analyses provides valuable insights into the study's findings regarding nano-coatings for dental implant surfaces.

The quantitative analysis revealed several key findings. Firstly, in terms of participants' level of knowledge regarding nano-coatings for dental implants, the majority agreed (4) or strongly agreed (5) with their efficacy, as indicated by the higher frequencies in those response categories. This suggests a positive perception and awareness among participants regarding the benefits of nano-coatings in enhancing osseointegration.

Additionally, the age distribution among participants ranged from 35 to 60 years, with a mean age of 45.6 years and a standard deviation of 7.2 years. This indicates a relatively homogeneous age group, which may be relevant for understanding age-related factors influencing dental implant outcomes.

Furthermore, the pain scores reported on the visual analog scale ranged from 2 to 7, with a mean score of 4.3 and a standard deviation of 1.2. This provides insights into the pain experiences of participants post-implantation, with the majority falling within the moderate pain range, highlighting the importance of pain management strategies in dental implant procedures.

The qualitative analysis identified key themes related to nano-coatings for dental implants. Firstly, participants highlighted the benefits of nano-coatings, including improved osseointegration, enhanced durability of implants, and reduced instances of implant failures. This positive perception aligns with the quantitative findings of high agreement levels regarding nano-coatings' efficacy.

However, challenges were also noted, such as cost implications, limited availability of specialized coatings, and the need for technical expertise during application. These challenges underscore the importance of addressing practical barriers to widespread adoption and implementation of nano-coatings in dental implantology.

Moreover, dentists' attitudes towards nano-coatings were generally positive, with many considering them a valuable advancement in implantology. This positive attitude among dental professionals is crucial for driving innovation and adoption of new technologies in the field, ultimately benefiting patients through improved treatment outcomes.

In summary, the combined quantitative and qualitative analyses provide a comprehensive understanding of participants' perspectives, experiences, and perceptions regarding nano-coatings for dental implant surfaces. These insights can inform future research, clinical practice, and policy decisions aimed at optimizing dental implant treatments and enhancing patient outcomes.

Discussion:

The discussion section delves into a detailed analysis and interpretation of the study's findings regarding nano-coatings for dental implant surfaces, integrating both quantitative and qualitative results while addressing the research objectives, implications, limitations, and future directions.

The quantitative analysis revealed positive perceptions among participants regarding nano-coatings' efficacy in enhancing osseointegration, as evidenced by the majority agreeing or strongly agreeing with their benefits. This aligns with previous research highlighting the role of nano-coatings in improving implant stability and success rates. (16) The mean age of participants falling within the

mid-40s suggests a target demographic commonly seeking dental implant treatments, emphasizing the relevance of studying nano-coating outcomes in this age group. (17)

The pain scores reported post-implantation, predominantly in the moderate range, underscore the importance of pain management strategies in dental procedures. While nano-coatings may contribute to improved implant outcomes, addressing postoperative discomfort remains crucial for patient satisfaction and adherence to treatment plans.

The qualitative analysis revealed nuanced insights into participants' perspectives on nano-coatings. Benefits such as improved osseointegration and enhanced implant durability were acknowledged, aligning with quantitative findings. However, challenges such as cost implications and technical expertise requirements were also noted, highlighting practical barriers that need addressing for widespread adoption. (2)

Dentists' positive attitudes towards nano-coatings reflect a growing acceptance of advanced technologies in implant dentistry. Their endorsement and understanding of nano-coatings' benefits are instrumental in driving innovation and promoting evidence-based practices within the dental community. (18)

Integration of Findings:

The integration of quantitative and qualitative findings enriches the study's overall understanding. While quantitative data quantify perceptions and experiences, qualitative insights provide depth and context, elucidating factors influencing attitudes, behaviors, and decision-making processes. (16)

The congruence between participant perceptions, dental professionals' attitudes, and existing literature supports the potential of nano-coatings to enhance osseointegration and implant outcomes. However, practical considerations such as cost-effectiveness, accessibility, and training requirements necessitate further investigation and implementation strategies. (17)

Implications and Limitations:

The study's findings have several implications for clinical practice and research. Implementing nano-coatings in dental implant procedures may lead to improved patient outcomes, reduced implant failures, and enhanced long-term success rates. However, cost constraints and technical complexities may limit widespread adoption, highlighting the need for cost-effective solutions and training programs.

Limitations of the study include a relatively small sample size and a single-center focus, which may affect the generalizability of findings. Additionally, the study's cross-sectional design limits causal inferences, necessitating longitudinal studies to assess long-term outcomes and trends over time.

Future Directions:

Future research avenues could explore cost-effective nano-coating alternatives, comparative effectiveness studies with traditional coatings, and long-term follow-ups to assess implant survival rates and patient satisfaction. Collaboration with industry partners and multidisciplinary teams can facilitate translational research and innovation in implant dentistry, ultimately benefiting patients and advancing the field.

Conclusion:

In conclusion, this study has shed light on the potential of nano-coatings for dental implant surfaces, revealing positive perceptions among participants and dental professionals regarding their efficacy in enhancing osseointegration and improving implant outcomes. The integration of quantitative data, such as participant knowledge levels and pain scores, with qualitative insights into attitudes and challenges, has provided a comprehensive understanding of the topic. While nano-coatings offer promising benefits, including improved durability and reduced implant failures, practical considerations such as cost implications and technical expertise requirements remain key challenges. Moving forward, collaborative efforts are needed to address these barriers, conduct further research on cost-effective alternatives, and facilitate the translation of findings into clinical

practice. By harnessing the potential of nano-coatings and advancing evidence-based practices, the field of implant dentistry can continue to evolve, ultimately benefiting patients and improving their quality of life.

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