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SYSTEMATIC REVIEW

Evaluation of the Implant Success Rate of Titanium-based Implant Materials: A Systematic Review and Meta-Analysis

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ABSTRACT
Objective: To investigate the success of implants, the increase of bone integration, and the effect of nanostructure/nanoparticles as Titanium-based implant materials on the success of implants. The present study evaluated the implant success rate of Titanium-based implant materials. **Material and Methods:** PICO: Population (dental implant), intervention (coated titanium implant surface), comparison (uncoated titanium implant surface), and outcome (bone-implant contact) were considered as a search strategy tool and study inclusion criteria. Searches for systematic literature were conducted on databases from Scopus, Science Direct, PubMed, ISI, Web of Knowledge, and Embase until 12 December 2022. Modified CONSORT Criteria (Reporting guidelines for preclinical in vitro studies on dental materials) were used to evaluate the quality of studies. The fixed effect model and inverse-variance method were used to calculate the 95% confidence interval for mean differences. Stata/MP V.17 software was used to conduct the meta-analysis. **Results:** After reviewing the abstracts of 97 articles, studies not related to the inclusion criteria were excluded, and ten studies were selected from the remaining 39 studies after reviewing the full text. The mean difference in bone-implant contact between coated and uncoated dental implants was 0.25 (MD, 0.25 95% CI 0.01, 0.49; p=0.04). **Conclusion:** The titanium implant surface with nano coating can increase bone-implant contact and cause bone integration.

Keywords: Dental Implants; Nanoparticles; Titanium.

Introduction

Establishing direct contact between the implant's surface and the surrounding bone is one of the parameters that can lead to successful osseointegration [1]. Rough titanium implants are currently the standard dental treatment [2]. Implant surface roughness can affect bone integration. This roughness is divided into three categories (Macro, Micro, and Nano) [3]. Increasing or decreasing methods are used to correct the surface roughness of dental implants [4]. Studies have shown that a nano-rough surface is usually more favorable for osteoblast growth [5,6].

It has also been found that proteins play an essential role in the better adhesion of osteoblasts on the uneven nano areas of titanium substrates [7]. 90% of the organic material in bone is type I collagen, with the remaining 10% being hydroxyapatite [8]. Type I collagen is a triple helical molecule consisting of three polypeptide chains, each consisting of approximately 1000 amino acids, and is synthesized by osteoblasts [9]. When it comes to how surfaces interact with proteins and cells, the thickness and roughness of the implant surface are crucial factors [10].

In the present study, an attempt has been made to investigate the success of implants and the increase of bone integration and to investigate the effect of nanostructure/nanoparticles as Titanium-based implant materials on the success of implants. Therefore, the present study evaluated the implant success rate of Titanium-based implant materials.

Material and Methods

Search Strategy

A systematic review and meta-analysis based on the PRISMA 2020 Checklist are presented in this study [11]. All international databases, including Scopus, Science Direct, PubMed, ISI, Web of Knowledge, and Embase, were searched for keywords related to the study's objectives until 12 December 2022. Relevant papers were also found using Google Scholar. MeSH keywords:

("Dental Implants"[Mesh]) AND "Titanium"[Mesh])) AND "Nanostructures"[Mesh]) OR ("Nanostructures/administration and dosage"[Mesh] OR "Nanostructures/adverse effects"[Mesh] OR "Nanostructures/standards"[Mesh] OR "Nanostructures/statistics and numerical data"[Mesh])) AND "Nanoparticles"[Mesh]) AND "Osseointegration"[Mesh]) AND "osteoblast-specific factor 3" [Supplementary Concept]) AND "Bone-Implant Interface"[Mesh].

Keywords Used in Databases and Google Scholar Search Engine

Dental implants, implants, implant materials, titanium, titanium-based implant, nanostructures, nanoparticles, osseointegration, osteoblast-specific factor 3, bone-implant interface, titanium implant surface, bone-implant contact, Success rate.

Data Items, Data Collection, and Selection Procedures

The group surface was extracted and presented in Table 2 using a checklist that included the author's name, year of publication, sample size, study design, control, and tests. Additionally, data needed for meta-analysis and bone-implant contact was included from the studies. Following the inclusion criteria-based selection of all articles, two reviewers reviewed each record independently, and each report was collected.

Eligibility Criteria

Inclusion Criteria

According to Table 1, inclusion criteria responded to PICO. Articles published in English, in-vitro studies, and studies that assessed osseointegration rate on the nanostructured implant surface.

Table 1. PICO strategy.

PICO Strategy	Description
P	Population: Dental Implant
I	Intervention: Coated Titanium Implant Surface
C	Comparison: Uncoated Titanium Implant Surface
O	Outcome: Bone-Implant Contact

Exclusion Criteria

Review articles, case reports, and case studies. The full text of the studies is not available.

Study Risk of Bias Assessment

Modified CONSORT Criteria (Reporting guidelines for preclinical in vitro studies on dental materials) were used to evaluate the quality of studies [12]. Each study was reviewed with 14 items, and the parameters were reported as yes or no. These items were:

There is a structured summary including the trial's design, methods, results, and conclusions; a scientific context and explanation; specific goals and hypotheses; as well as the intervention of each group, including when and how it was carried out, in sufficient detail to permit replication of the study. Primary and secondary outcome measures that are clearly defined and pre-specified, along with the methods and timing of their evaluation; how the sample size was selected, how the random allocation sequence was generated, where to find the full trial protocol, statistical methods used to compare groups, results for each group, the estimated size of the effect and its precision, trial limitations, the technique used to implement the random allocation sequence, who generated the random allocation, who was blinded after intervention assignment are all outlined, sources of bias and imprecision, and the mechanism used to implement the random allocation sequence, if appropriate, as well as sources of funding and other support. The risk of bias tool (adapted and modified from the Cochrane risk of bias tool) was used. In this tool, each item was given a score of 2, 1, or 0; the sum of scores from 0 to 3 indicates a low risk of bias, 4 to 7 indicates a moderate risk of bias, and scores of 8 to 10 indicate a high risk of bias. This tool's lowest score was 0, and the highest score was 10 [13].

Data Analysis

The data were analyzed with STATA/MP V.17 software. The fixed effect model and inverse-variance method determined the 95% confidence interval for mean differences. I^2 demonstrated heterogeneity, and random effects were employed to address potential heterogeneity. I^2 values indicate low heterogeneity under 50%, and I^2 values over 50% indicate moderate to high heterogeneity.

Results

Study Selection

The initial search found one hundred nineteen articles related to the keywords. Of these, 11 articles were records removed for other reasons. Five articles had been marked as ineligible by automation tools, and six studies had been marked as duplicates. After reviewing the abstracts of 97 articles, the final 58 articles were finally excluded from the study in accordance with the exclusion criteria. After reviewing the full texts of 39 articles, 29 studies were excluded based on the inclusion criteria, and 10 studies were selected (Figure 1).

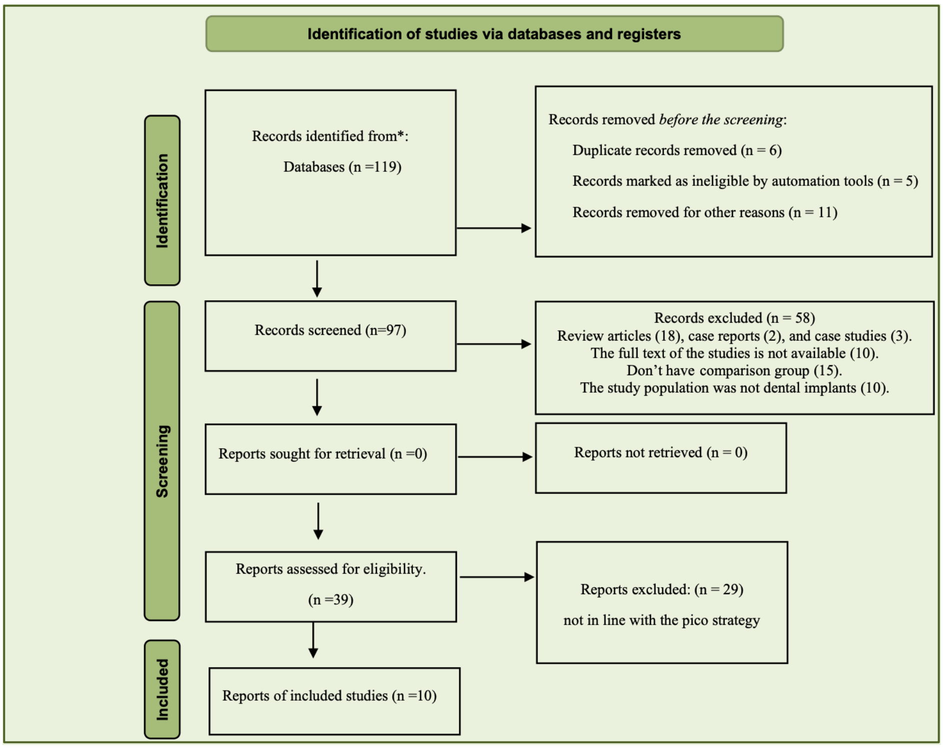

Figure 1. PRISMA 2020 Checklist.

Study Characteristics

There were 209 sample sizes analyzed, and the data collected from the studies is shown in Table 2.

Table 2. Summary of data.

No.	Study. Years	Study Design	Sample Size		Test Surface Means or %	Control Surface
			Test	Control		
1	Mathew et al., 2022 [14]	In-vivo	3	3	90%	10%
2	Bjursten et al., 2010 [15]	In-vivo	7	6	21	21
3	Metzler et al., 2013 [16]	In-vivo	25	25	18	18
4	Jimbo et al., 2012 [17]	In-vivo	10	10	35%	32%
5	Ballo et al., 2011 [18]	In-vitro	20	20	76	42
6	Meirelles et al., 2008 [19]	In-vitro	10	10	9	14
7	Lachmann et al., 2006 [20]	In-vitro	12	12	75	62
8	Ellingsen et al., 2004 [21]	In-vivo	15	15	31	39
9	Salou et al., 2015 [22]	In-vivo	3	3	65.1	45.1

The Risk of Bias in Studies

The bias assessment tool identified moderate bias risks in all studies.

Bone-implant Contact

The mean difference of bone-implant contact between coating dental implants and un-coating dental implants was 0.25 (MD, 0.25 95% CI 0.01, 0.49; p=0.04) with low heterogeneity (I^2=0%; p=0.84). The meta-analysis showed a statistically significant difference between groups (Figure 2). Figure 3 demonstrates the detection of publication bias.

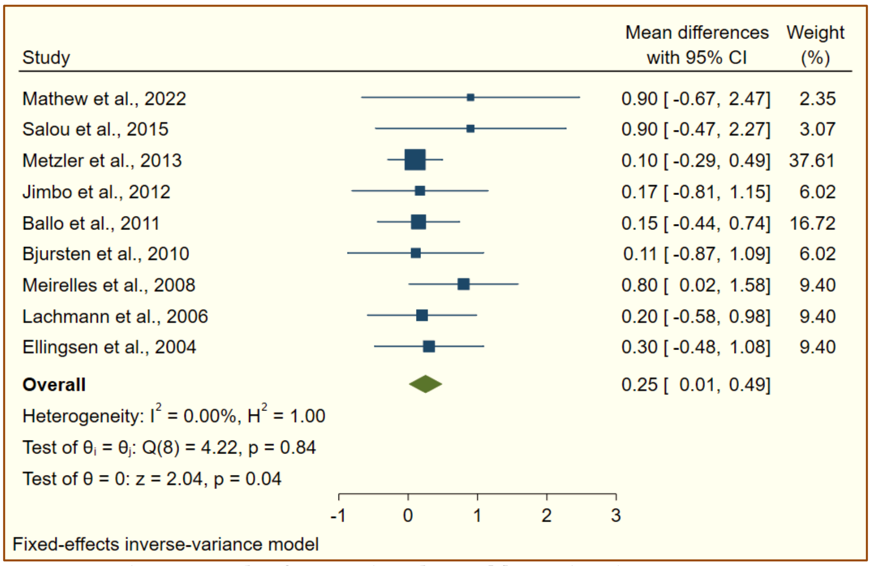

Figure 2. The forest plot showed bone-implant contact.

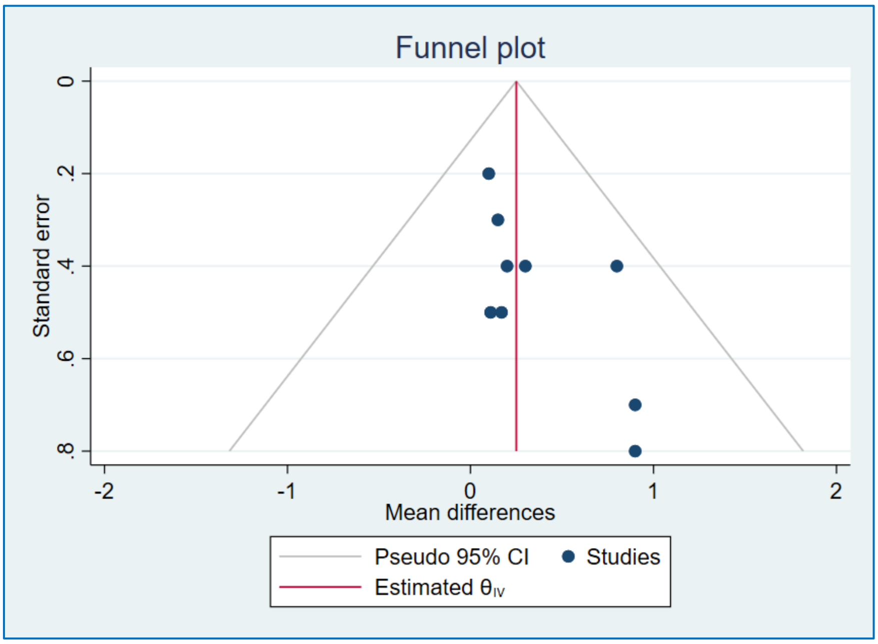

Figure 3. Funnel plot for graphical diagnostics of small-study effects.

Discussion

The performance of dental implants has recently been improved by various methods based on nanotechnology concepts, including surface modification with nanometers, nanocomposite materials for bone regeneration, and surface functionalization to improve topography [23]. Based on the findings of the studies, sandblasted titanium particles can provide desirable qualities as dental composites [24].

In the present study, the rate of bony integration of the dental surface of titanium implants coated with nano and their success rates were investigated. The characteristics of nanoparticles have caused their use to increase significantly. In recent years, studies have shown the superiority of nanoparticle-modified dental implants [25]; however, some studies have also demonstrated contradictory findings [26]. Therefore, a comprehensive review of the study findings is essential. The present study investigated in vivo and in vitro studies with a control group (without coating). The present meta-analysis showed a statistically significant difference between the implant surfaces coated with nano and those without coating. Also, bone integration was higher in the titanium dental implant surface group coated with nano than in the uncoated implant surface. Several surface engineering techniques have been developed to create implant surfaces that can improve the clinical performance of implants.

Additionally, it is necessary to check the surface properties of dental implants to increase the success rate and reduce the recovery time [27]. Based on the available evidence, bone integration's biological mechanisms and function at the nano level are different from the micro level. Nanotopography can affect surface/protein interactions and surface energy. Studies have shown that surface energy can spread fibrin fibers and matrix proteins on the surface and improve cell connection [28]. Based on the findings of a study, the creation of bone nanostructure effectively reduces inflammation and infection and can cause bone integration [29]. Old studies have shown that nanoscale topography affects cell adhesion and osteoblastic differentiation [30]. According to the available evidence, atomic nanotechnology can change the implant's surface [31]. Scientists have reported surface modification by specific biological materials. Another surface treatment method for improving bone integration and accelerating osteoblast attachment in biological environments is sandblasting [32]. It is observed in vitro and in vivo studies that the implant surface characteristics are very important, and surface morphology, surface chemistry, and surface energy can significantly affect the response of primary bone cells to the implant in the bone-implant interphase phase [33].

Nanotechnology in dental implants should be more researched, and nanotechnology methods should help make more efficient materials, materials with bone healing properties, and materials with antibacterial effects. Titanium is widely used in dental implants. Modifying titanium with nano can increase the lifespan of implants. Due to its potential to produce better implantable materials, nanotechnology is a promising field of study [34,35]. A fast healing process, high stability, and durability of the dental implant are all signs of excellent osseointegration. A dental implant made of titanium requires several months to integrate using modern implant materials and procedures. Therefore, there is a potential to improve the titanium dental implant's surface quality while also accelerating its osseointegration. For better performance, it is crucial to understand how titanium implants interact with the host bone. The bone-implant interface is where these interactions primarily occur. The current study had limitations such as the small sample size, the fact that the samples were selected from various groups, and the cognitive methodology of the studies and their evaluation method differed.

Conclusion

Based on the present meta-analysis, bone-implant contact was better in titanium implants coated with nano than in uncoated titanium implant surfaces. The titanium implant surface with nano coating can increase bone-implant contact and cause bone integration. The future performance of titanium-based dental implants using the size of nanocomposites can help expand dental knowledge and improve performance.

Authors' Contributions

AA	https://orcid.org/0000-0001-7280-5500	Methodology, Writing - Original Draft and Writing - Review and Editing.
SHM	https://orcid.org/0000-0002-8333-8511	Methodology, Writing - Original Draft and Writing - Review and Editing.
ET	https://orcid.org/0000-0002-5911-813X	Methodology, Writing - Original Draft and Writing - Review and Editing.
ZMG	https://orcid.org/0000-0003-4881-0865	Validation and Writing - Review and Editing.
SJ	https://orcid.org/0000-0003-3803-1235	Conceptualization, Methodology, Formal Analysis, Investigation, Writing - Original Draft, Writing - Review and Editing and Visualization.

All authors declare that they contributed to a critical review of intellectual content and approval of the final version to be published.

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None.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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