Identification of research gaps and systematization of trends on surface treatment in dental implants based on indexed data in the Scopus database

Talita Rodrigues de Almeida[1] & Rubens Guimarães Filho[1]

[1] Taubaté University, Taubaté, São Paulo State, Brazil

Correspondence: Talita Rodrigues de Almeida, Taubaté University, Taubaté, São Paulo State, Brazil. E-mail: taa.rodrigues@hotmail.com

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Abstract

The installation of dental implants brings significant improvements in patient's quality of life, causing the demand for these procedures to increase. This growth results from the increasing use of innovative technologies in oral care. Since the 1970s, dental implants have continuously evolved, both in terms of shape and surface treatments. This evolution aims to improve osseointegration, an essential process for implant success, and prevent complications such as peri-implantitis. A necessary part of this evolutionary process is surface treatment on dental implants. This treatment improves implant surfaces' physical and chemical properties, promoting a more efficient interaction between the implant and surrounding tissues. To achieve this goal, modifications are made to the texture, composition, and characteristics of the implant surface. In this context, this study aims to identify the research gaps related to surface treatment on dental implants. To this end, a literature review was performed in the Scopus database using specific search terms related to this topic. The 20 most cited articles from 2017 to 2023, which address the main research trends in this area, were selected for analysis. The theoretical contribution of this study is to systematize the current research trends on the surface treatment of dental implants. This provides a better understanding of existing treatments and their limitations and presents ongoing studies that aim to overcome them. Furthermore, the research highlights studies under development, both in vitro and in vivo, that seek to apply scientific advances in clinical practice to improve implant outcomes. This applied contribution is relevant, as it can positively impact clinical practice and benefit patients.

Keywords: dental implant surface treatment, osseointegration of dental implants, implant surfaces.

Identificação de lacunas de pesquisa e sistematização de tendências no tratamento de superfície em implantes dentários, com base em dados indexados na base de dados Scopus

Resumo

A instalação de implantes dentários traz melhorias significativas na qualidade de vida dos pacientes, fazendo com que a procura por esses procedimentos aumente. Este crescimento resulta do uso crescente de tecnologias inovadoras em cuidados bucais. Desde a década de 1970, os implantes dentários evoluíram continuamente, tanto em termos de forma quanto de tratamentos de superfície. Essa evolução visa melhorar a osseointegração, processo essencial para o sucesso do implante, e prevenir complicações como a peri-implantite. Uma parte necessária desse processo evolutivo é o tratamento de superfície em implantes dentários. Este tratamento melhora as propriedades físicas e químicas das superfícies dos implantes, promovendo uma interação mais eficiente entre o implante e os tecidos circundantes. Para atingir esse objetivo, são feitas modificações na textura, composição e características da superfície do implante. Nesse contexto, este estudo tem como objetivo identificar as lacunas de pesquisa relacionadas ao tratamento de superfície em implantes dentários. Para tanto, foi realizada uma revisão de literatura na base de dados Scopus utilizando termos de busca específicos relacionados a este tema. Foram selecionados para análise os 20 artigos mais citados de 2017 a 2023, que abordam as principais tendências de pesquisa nessa área. A contribuição teórica deste estudo é sistematizar as tendências

atuais de pesquisa sobre o tratamento de superfície de implantes dentários. Isso proporciona uma melhor compreensão dos tratamentos existentes e suas limitações e apresenta estudos em andamento que visam superá-los. Além disso, a pesquisa destaca estudos em desenvolvimento, tanto in vitro quanto in vivo, que buscam aplicar os avanços científicos na prática clínica para melhorar os resultados dos implantes. Essa contribuição aplicada é relevante, pois pode impactar positivamente a prática clínica e beneficiar os pacientes.

Palavras-chave: tratamento de superfícies de implantes dentários, osseointegração de implantes dentários, superfícies de implantes.

1. Introduction

Dental implant installation has significantly improved people's quality of life. Patients have reported after implant surgery benefits related to eating, speaking, cleaning teeth or dentures, performing light physical activities with more performance, smiling, laughing, showing teeth without discomfort and embarrassment, emotional conditions such as getting upset faster than usual, enjoying communication with other people, and work-related activities (Sargolzaie et al., 2017). Due to the benefits perceived by patients, the demand for implants has grown significantly, and according to Arizton Advisory & Intelligence (2020), the dental implant market will reach $5 billion by 2025, with a compound annual growth rate (CAGR) of over 5% during this period.

Since the 1970s, dental implants have started to evolve, both in shape and surface treatments. Several methods are described chronologically on implant surface modification, contemplating standard techniques such as abrasive blasting and corrosion, advanced physicochemical approaches such as 3D laser textured modifications, and biomimetic modifications (Souza et al., 2019). Researchers and dentists expect implant surfaces to deliver results from the first moments of installation by altering the physical and chemical properties of the surfaces (Yeo, 2020) to enhance both the osseointegration process and the anti-biofilm effect. Increasing use of innovative oral care technology is one of the significant factors significantly driving the growth of the global dental implant market (Gaviria et al., 2014).

To support the technological development applied to the improvement of implants, scientific studies are needed to align market demands with the theory of dental implants. In this sense, some works were carried out to analyze the issues such as implant procedures, biomaterials, osseointegration issues, and biocompatibility. Saghiri et al. (2021) identified the main methods used in dental implants from 2000 to 2020; it evaluated in this period factors that influence the survival rates of dental implants and, by extension. Elani et al. (2018) observed a significant increase in the prevalence of dental implants, from 0.7% in 1999-2000 to 5.7% in 2015-2016. Kittur et al. (2020) analyzed the impact of primary stability and the relationship with osseointegration for long-term implant success.

Iftikhar et al. (2021) compared, contrasted, and quantified innovations in dental biomaterials in a literature review from 2007 to 2019, verifying the significant increase in publications related to dental implants since 2007. Although these studies contribute to mapping implant-related trends, none of them set out to analyze the most influential review articles in the literature, as per the scientific gap to be filled, highlighted by Huang et al. (2021).

Thus, the guiding question of this research is: What are the main research trends for the scientific development of surface treatments on dental implants? To answer it, this research aims to identify the research gaps in surface treatment on dental implants by analyzing articles indexed in the Scopus database. This paper is organized, besides this introduction, into the following sections: theoretical framework, research method, results, conclusion, and references.

2. Theoretical framework

A dental implant artificially replaces the part equivalent to the tooth root inside the bone and gums; specialized dental surgeons usually perform this procedure. This surgery consists of installing the implant in the jawbone to replace and support a tooth or a replacement prosthesis (Pachauri et al., 2014). This procedure was discovered by Dr. Per-Ingvar Brånemark in 1965 using an implant from a threaded structure with the titanium material used in patients, thus appearing as the first dental implant with effectiveness and documented (Adell, 1985).

From that moment on, implants began an evolution in shape, size, and surface to continuously improve the efficiency and effectiveness of implants, becoming the main procedure for dealing with tooth loss (Kligman et al.,

2021). Dental implantation brings significant benefits to people's lives. However, dental surgeons have two concerns: implant-related infection, biocompatibility, implant/bone interaction, and osseointegration (Rasouli et al., 2018). Biocompatibility is understood as "the ability of an implant to perform an appropriate host response in a specific application." (Nair; Laurencin, 2007; Wu et al., 2022), meaning it is the interaction between the implant and surrounding tissues causing the least possible adversity. We can describe "osseointegration" as the direct contact between implant and bone, which can be revealed using the light microscope (Branemark et al., 1977).

Changes to the implant surface are modified to enhance properties, overcome commonly encountered complications, and increase the success rate and indications (Kligman et al., 2021). According to Albrektsson and Wennerberg (2019) "Oral implant surfaces can be characterized by micro- and nanoroughness, surface chemical composition, and physical and mechanical parameters." Several methods are described chronologically on surface modification, contemplating standard procedures such as abrasive blasting and corrosion, advanced physicochemical approaches such as 3D laser textured, and biomimetic modifications (Souza et al., 2019).

Due to the success of the high demand for dental implants, research has increased to improve construction techniques, materials, design, and characterization of implants (Rasouli et al., 2018). Dental implants in nanotechnology have overcome conventional dental implants' main limitations by improving and decreasing the osseointegration time and approximating mechanical properties resembling bone tissue (Rasouli et al., 2018).

3. Materials and Methods

The research classification can be of fundamental, exploratory, and qualitative. A literature review was selected as the technical procedure. Experimental research aims to obtain more proximity to a particular phenomenon or broaden new points of view on the researched topic (Kothari; Garg, 2019; Reis et al., 2020). The selection was performed in the Scopus database in February 2023.

The search sought only articles in English and publications in journals in the format of indexed review articles. The following terms were used in the titles and keywords, all in English, in the search: "Dental implant surface treatment," osseointegration of dental implants," or "implant surface."

In the search, 65 studies were found and identified according to the search parameters. To analyze the scientific gaps related to the research, the 20 most cited articles in the database were used; considering the period from 2017 to 2023, 6 articles about implant surface treatment in areas other than dentistry were disregarded. The delimitation of 20 pieces was performed using non-statistical sampling since it determines a significant impact on the conduct of research (Nest et al., 2015; Espuny et al., 2021). Data were processed using Microsoft Excel software.

4. Results and Discussion

4.1 Data survey

In this section, a data survey of the 20 most cited articles about surface treatment on dental implants was performed, as shown in (Table 1).

Table 1. Top 20 most cited articles and their research gaps.

#	Title	Author	Journal	Year	Scientific Gap
1	Nano-scale modification of titanium implant surfaces to enhance osseointegration	Julio C.M. Souza, Mariane B. Sordi, Miya Kanazawa, Sriram Ravindran, Bruno Henriques, Filipe S. Silva, Conrado Aparicio, Lyndon F. Cooper	Acta Biomaterialia 94 (2019) 112–131	2019	Use the combination of current methods considering the micro- and nanoscale to enhance the osseointegration process and the anti-biofilm effect.
2	On osseointegration in relation to implant	Tomas Albrektsson, Ann Wennerberg	Wiley, Clin Implant Dent Relat Res.	2019	Search for the optimal implant surface from a

	surfaces		2019;21:4–7.		clinical point of view in terms of mechanical properties.
3	A Review of Nanostructured Surface and Materials for Dental Implants: Surface Coating, Pattering and Functionalization for Improved	Rahimeh Rasouli, Ahmed Barhoum, Hasan Uludag	*Biomater. Sci., 2018,*	2018	Research the influence of different chemical compositions and nanopatterns on the interaction of biological molecules and cells with the implant surface to stimulate osseointegration and bone formation.
4	Modifications of Dental Implant Surfaces at the Micro- and Nano-Level for Enhanced Osseointegration	In-Sung Luke Yeo	*Materials 2020, 13, 89*	2020	To conduct long-term clinical trials to evaluate the surface treatment of grade 4 cp-Ti implants.
5	Methods to Improve Osseointegration of Dental Implants in Low Quality (Type-IV) Bone:An Overview	Hamdan S. Alghamdi	*J. Funct. Biomater. 2018, 9, 7;*	2018	To deepen the knowledge about bone regeneration-biomaterial in cases of osteoporotic bone.
6	The Impact of Dental Implant Surface Modifications on Osseointegration and Biofilm Formation	Stefanie Kligman, Zhi Ren, Chun-Hsi Chung, Michael Angelo Perillo, Yu-Cheng Chang, Hyun Koo, Zhong Zheng and Chenshuang Li	*J. Clin. Med. 2021, 10, 1641*.	2021	Seek a more evolved implant surface that achieves the precise combination of rapid, enhanced osseointegration and limitation of biofilm formation.
7	Sandblasted and Acid Etched Titanium Dental Implant Surfaces Systematic Review and Confocal Microscopy Evaluation	Gabriele Cervino, Luca Fiorillo, Gaetano Iannello, Dario Santonocito, Giacomo Risitano and Marco Cicciù	*Materials 2019, 12, 1763;*	2019	Pursue immediate rehabilitation protocols by improving dental implant geometries and surfaces.
8	Nanointeraction: The profound influence of nanostructured and nano-drug delivery biomedical implant surfaces on cell behavior	Marcel F. Kunrath, Fernando M. Diz , Ricardo Magini , María E. Galárraga-Vinueza	Advances in Colloid and Interface Science 284 (2020) 102265	2020	Investigate the early molecular interactions and advantages of nanostructured biomedical implants in clinical settings.
9	Fitting pieces into the puzzle: The impact of titanium-based dental implant surface modifications on bacterial accumulation and	Raphael C. Costa, Bruna E. Nagay, Martinna Bertolini, Bárbara E. Costa-Oliveira, Aline A. Sampaio, Beĺen	*Advances in Colloid and Interface Science 298 (2021) 102551*	2021	Analyze the methodological evaluation of automated and intelligent surfaces activated by biological stimuli to consider primary results for

	polymicrobial infections	Retamal-Valdes, Jamil A. Shibli, Magda Feres, Valentim A. R. Bara˜o, Jōao Gabriel S. Souza			application in clinical studies.
10	Metallic-nanoparticle release systems for biomedical implant surfaces: effectiveness and safety	Marcel F. Kunrath & Maria M. Campos	NANOTOXICOLOGY 2021, VOL. 15, NO. 6, 721–739	2021	Record the positive and negative long-term effects of using implants that release metallic particles.
11	What is the influence of implant surface characteristics and/ or implant material on the incidence and progression of peri-implantitis? A systematic literature review	Andreas Stavropoulos, Kristina Bertl, Lewis Winning, Ioannis Polyzois	*Clin Oral Impl Res. 2021;32(Suppl. 21):203–229*	2021	Analyze the incidence of peri-implantitis, including clinical signs of inflammation and specific reference values of pocket depth and bone loss.
12	Does incorporating collagen and chondroitin sulfate matrix in implant surfaces enhance osseointegration? A systematic review and meta-analysis	S. V. Kellesarian, V. R. Malignaggi, T. V. Kellesarian, H. Bashir Ahmed, F. Javed	Int. J. Oral Maxillofac. Surg. 2017;	2017	Conduct long-term, randomized, controlled clinical trials, with sample sizes determined by power analysis, to evaluate the incorporation of the collagen-CS matrix into implant surfaces.
13	Antimicrobial efficacy of photodynamic therapy on dental implant surfaces: T A systematic review of in vitro studies	Mohammed N. Alasqah	*Photodiagnosis and Photodynamic Therapy 25 (2019) 349–353*	2019	Conduct in vitro research on the relationships of structural changes on the titanium implant surface with the use of photodynamic therapy in order to obtain sound conclusions.
14	Plasma of Argon Treatment of the Implant Surface, Systematic Review of In Vitro Studies	Massimo Carossa, Davide Cavagnetto, Francesca Mancini , Alessandro Mosca Balma and Federico Mussano	*Biomolecules 2022, 12, 1219.*	2022	Perform in vivo studies to improve the scientific evidence of Argon Plasma on implant surfaces and demonstrate the long-term efficacy of the treatment.
15	Nanostructured Titanium Implant Surface Facilitating Osseointegration from Protein Adsorption to Osteogenesis: The Example of TiO2 NTAs	Bingfeng Wu, Yufei Tang, Kai Wang, Xuemei Zhou, Lin Xiang	International Journal of Nanomedicine 2022:17	2022	Identify the corresponding biological effect using different TiO2 NTAs, keeping an integrated perspective to achieve efficient single to multi-phase regulation.

16	Microbial Biofilm Decontamination on Dental Implant Surfaces: A mini review	Jagjit Singh Dhaliwal, Nurul Adhwa Abd Rahman,Long Chiau Ming, Sachinjeet Kaur Sodhi Dhaliwal, Joe Knights, Rubens Ferreira Albuquerque Junior	Frontiers in Cellular and Infection Microbiology, 2021	2021	Identify the optimal implant surface property that presents an effective antimicrobial treatment and does not compromise osseointegration.
17	Plant-Derived Nanobiomaterials as a Potential Next Generation Dental Implant Surface Modifier	Jaison Jeevanandam, Michael K. Danquah, Sharadwata Pan	Frontiers in Materials, 2021	2021	Incorporate new techniques in the plant-mediated synthesis of nanomaterials to eliminate limitations and improve their efficiency.
18	Effects of metformin on the bioactivity and osseointegration of dental implants: A systematic review	Vrushank Patel, Muhammad S. Sadiq, Shariq Najeeb, Zohaib Khurshid, Muhammad S. Zafar and Artak Heboyan	Journal of Taibah University Medical Sciences (2023) 18(1), 196e206	2023	Increase the quality of animal studies and clinical trials to determine the effects of metformin on dental implant osseointegration.
19	Antibacterial effect of Er,Cr:YSGG laser in the treatment of peri-implantitis and their effect on implant surfaces: a literature review	Khaled Smeo, Riman Nasher, Norbert Gutknecht	Lasers in Dental Science (2018) 2:63–71	2018	Identify suitable Er, Cr: YSGG (2780 nm) laser settings, such as irradiation distance, duration, and frequency, to treat peri-implantitis without negative effects on implant surfaces.
20	Titanium dioxide dental implants surfaces related oxidative stress in bone remodeling: a systematic review	Elaf Akram Abdulhameed, Natheer H. Al-Rawi, Marzuki Omar, Nadia Khalifa, Rani Samsudin	PeerJ 10:e12951, 2022	2022	Confirm through well-designed, large sample randomized controlled clinical trials on TiO2 nanotube-coated titanium implants.

Source: Authors, 2023.

4.2 Systemization of research gaps

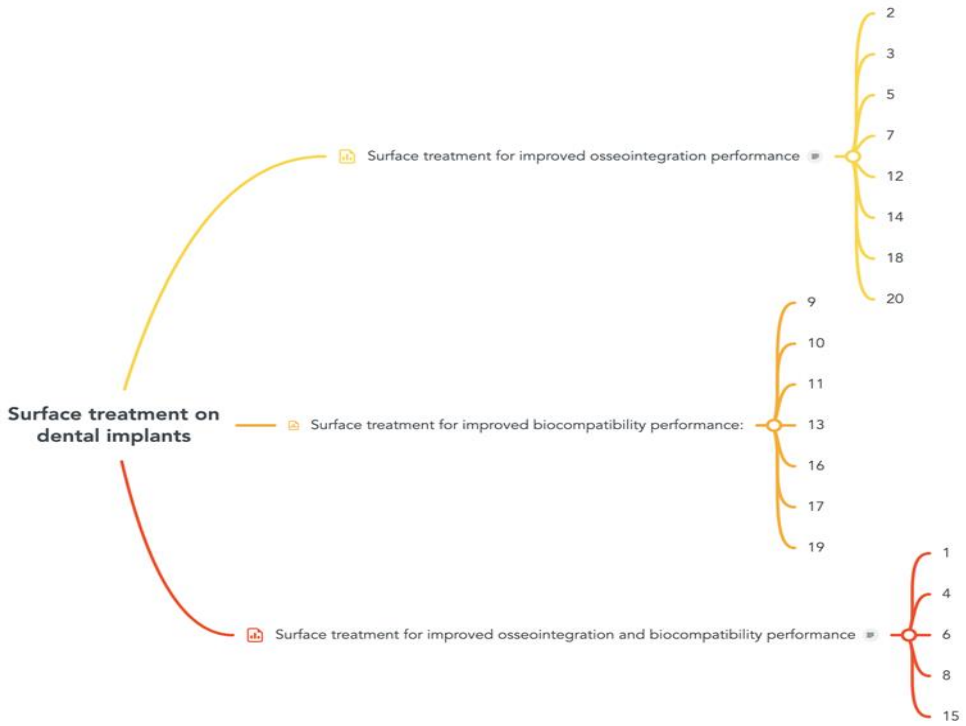

Figure 1. It was systematized in research trends based on the information contained in (Table 1). Source: Authors, 2023.

4.3 Surface treatment for improved osseointegration performance

We can describe "osseointegration" as the direct contact between implant and bone, which can be revealed using the light microscope (Branemark et al., 1977). Nowadays, one of the focuses of engineers to improve osseointegration has been nanoscale surfaces, which impact complex biological events bringing more control over protein adsorption, blood clot formation, migration, adhesion, and differentiation of cells (Rasouli et al., 2018).

The findings on micro and nanoscale modifications and some technological advances in implant surfaces are unavailable because of the cost and lack of clinical validation for these recent surfaces. Because of structural similarities with natural extracellular matrices, they enhance cellular responses such as adhesion, growth, survival, and differentiation, which are indispensable for improving osseointegration (Hanawa, 2010). The importance of osseointegration for the success of dental implants is evident. Still, it needs for further research is to improve and decrease the time of osseointegration and achieve mechanical interfacial properties more harmonious with bone tissue (Rasouli et al., 2018).

4.4 Surface treatment for improved biocompatibility performance

Biocompatibility is understood as "the ability of an implant to perform an appropriate host response in a specific application." (Nair; Laurencin, 2007; Wu et al., 2022), i.e., it is the interaction between the implant and surrounding tissues, causing the least possible adversity. It has been proven that polymicrobial infections such as biofilm accumulation and dysbiosis are the leading causes of the development and progression of peri-implantitis (Renvert; Quirynen, 2015)

Technological biomimetic methods are a growing area with relevant potential for surface modification of implants and biomaterials for localized drug delivery. This localized drug delivery system aims to induce cellular interactions with improved biocompatibility aspects, namely the enhancement of biological, reparative, and clinical processes, reduction of biofilm formation, and destructive inflammatory processes (Kunrath et al., 2020).

Many studies have been conducted to promote the antibacterial effect on Titanium surfaces. Still, most of the research has been shown in laboratory settings such as in vitro and animals, with the result that only a few

surfaces developed can be used for clinical research. (Costa et al., 2021)

4.5 Surface treatment for improved osseointegration performance and biocompatibility

Patients, as well as dentists, want shorter implant treatment times. Therefore, recent research has used nanotechnology to improve the properties related to osseointegration time and decreased biofilm accumulation (Rasouli et al., 2018).

The ideal implant lies in the balance between antimicrobial activity, and osteoconductive properties are indispensable (Hickok et al., 2018). This balance is difficult to achieve, as higher surface roughness promotes better osseointegration but is directly proportional to bacterial retention, which can promote long-term biofilm formation (Berglundh et al., 2007).

It is interesting to evaluate the combination of methods considering the micro and nanoscale to improve both the osseointegration process and the anti-biofilm effect. Studies on dental implant design are also necessary to fit the peri-implant anatomical aspects to maintain long-term health status and avoid pathological bone loss (Souza et al. 2019).

5. Conclusions

The study aimed to analyze the main trends in research on surface treatments for dental implants based on the leading publications on the subject, and it was duly achieved. The main academic contribution of this article was to systematize the trends, allowing a better understanding of the current surface treatments on dental implants already in use and their limitations and the studies that are still in progress to solve these limitations, bringing evidence about the promising advances that are being made in this area.

The most crucial applied contribution was to bring the studies on surface treatments on dental implants studied in vitro and in vivo to be applied clinically in the future. The main limitations are related to the search criteria and the database using only journal review articles to survey research gaps. As a proposal for future studies, it is suggested to modify these search parameters and use different databases to add new scenarios and actions to this framework.

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7. Auhors' Contributions

Talita Rodrigues de Almeida: conceptualization, methodology, validation, formal analysis, investigation, resources, original draft preparation, review and editing, visualization, supervision, funding acquisition, submission and article publication. *Rubens Guimarães Filho*: conceptualisation, methodology, validation, formal analysis, invertigation, visualization, supervision, and project administration.

8. Conflicts of Interest

No conflicts of interest.

9. Ethics Approval

Not applicable.

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