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SYSTEMATIC REVIEW

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Finite element methods in evaluating the stress distribution of dental implant on bone tissue: a bibliometric study

Métodos de elementos finitos na avaliação da distribuição de tensão do implante dentário no tecido ósseo: um estudo bibliométrico

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ABSTRACT

Finite element method FEM is a very useful method that facilitates the numerical analysis of evaluating mechanical stress of different and complex geometries like dental implants. **Objective:** Identifying the published articles that use FEM to evaluate and solve problems regarding the biomechanical behavior of dental implants and the stress distribution on bone tissue. **Material and Methods:** The present study is a bibliometric analysis of the publications in the Scopus database, summarizing studies that analyze the stress distribution of dental implants on the bone using the FEM, during the period between 2003 and 2023, the study was conducted based on the PRISMA framework, the documents were analyzed using VOSviewer software to visualize the bibliometric network. **Results:** 606 articles were identified, the publication rate increased during the period studied, indicating an increased interest in this field. *T*he *International Journal of Oral and Maxillofacial Implants was* the most prolific journal published by *Quintessence Publishing Company*. Brazil represents the most productive country in the published studies on dental implant stress distribution using the FEM. **Conclusion:** FEM has shown an important role in predicting stress distribution in bone around the dental implant device, which paves the way for more improvement in achieving the long-term integrity of dental implants.

KEYWORDS

Bibliometric study; Bone tissue; Dental implant; Finite element method; Stress distribution.

RESUMO

O método de elementos finitos MEF é um método muito útil que facilita a análise numérica da avaliação do estresse mecânico de geometrias diferentes e complexas, como os implantes dentários. **Objetivo:** Identificar os artigos publicados que utilizam o MEF para avaliar e resolver problemas relacionados ao comportamento biomecânico de implantes dentários e à distribuição de tensão no tecido ósseo. **Material e Métodos:** O presente estudo é uma análise bibliométrica das publicações no banco de dados Scopus, resumindo estudos que analisam a distribuição de tensão de implantes dentários no osso usando o MEF, durante o período entre 2003 e 2023, o estudo foi realizado com base na estrutura PRISMA, os documentos foram analisados usando o software VOSviewer para visualizar a rede bibliométrica. **Resultados:** Foram identificados 606 artigos, a taxa de publicação aumentou

durante o período estudado, indicando um aumento do interesse nesse campo. O International Journal of Oral and Maxillofacial Implants foi o periódico mais representativo publicado pela Quintessence Publishing Company. O Brasil representa o país mais produtivo nos estudos publicados sobre distribuição de tensão em implantes dentários usando o MEF. **Conclusão:** O MEF demonstrou um papel importante na previsão da distribuição de tensão no osso ao redor do implante dentário, o que abre caminho para mais melhorias na obtenção da integridade de longo prazo dos implantes dentários.

PALAVRAS-CHAVE

Estudo bibliométrico; Tecido ósseo; Implante dentário; Método de elementos finitos; Distribuição de tensão.

INTRODUCTION

Tooth loss constitutes a global health issue [1]. The loss of anterior teeth impacts the aesthetic, whereas loss in the posterior sector will impact the masticatory function [2]. The restoration treatment of partial or total loss requires a variety of techniques [3], dental implants are commonly utilized to replace one or multiple missing teeth [4], and provide support for the placement of dental prostheses [5]. In modern dentistry, after the first observation of the titanium screw discovered by Dr. Per-Ingvar. Brånemark a professor at the University of Gothenburg (Sweden), while conducting an interesting experiment on rabbits by inserting titanium chambers into their femurs, the metal was completely integrated into the bone [6,7]. The usage of dental implants, therefore, has increased significantly [8]. Then the notion of "osseointegration" emerged with his implant, defined by Brånemark as "*a direct structural and functional connection between ordered, living bone, and the surface of a load-carrying implant*" [9,10].

Biomechanics comprise the study of forces that act on and generated whithin the body, as well as the impact on tissue, fluids or material utilized in research purpose [11], biomechanical concepts in oral implantology are as important as the clinical factors required for oral rehabilitation [12]. Dental Implant distribute the load of the masticatory forces, to the surrounding bone tissue [13], An effective Stress distribution from Implant to the bone is among the reasons for dental implants success [14], in turn the load transfer relies to several factors such surrounding bone quality and quantity, type of loading, prosthesis and Implant materials, the Implant shape, length and diameter, Implant surface structure and the bone-Implant contact, and thus influence stress distribution [15,16].

The finite element method (FEM) represents one of the most frequent methods used for simulating the micromechanical behavior of biological structures, enabling the modeling of highly complicated structures like teeth, bone, dental implants, and many other structures [17]. The FEM discretization minimizes the problem by dividing a continuum body studied into small finite elements [18]. these elements are connected to one another by nodes, and the FEM, therefore, solves the main problem examined [19]. The FEM demonstrate an important role in medical research to observe and analyze complicated biomechanical systems to predict the mechanical tissue response, that could be complex to be examined in vivo or in vitro [20], which are constrained by materials properties and conditions of experimentation, FEM provides exact control and modification of variables and leads to more precise of biomechanical phenomena. The FEM constitutes a widely utilized engineering tool regarding dental applications [21]. Research studies on dental implant stress distribution has led to interest in the field of oral implantology, FEM allows therefore researchers to predict the stress distribution in the contact area of dental implant with surrounding bone [16], and the understanding of the way that the clinical situation affects the stress distribution allows for improved prosthesis design, which can lead to a decrease in the mechanical failures [22].

Multiple scientific research have been conducted to analyze the mechanical behavior of dental implant, bone tissue, material, prosthesis using FEM, this study represents a bibliometric study which is a quantitative examination of the academic production in the area of interest [23], that helps to learn about the development of publications of the subject studied, knowing the most significant authors, papers, and journals. VOSviewer was used which is a software for constructing and visualizing bibliometric networks, these networks may include, journals, researchers,

and publications, they can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship relations [24]. The study was carried out to know several variables regarding the studies on dental implant stress analysis using finite element methods during the last 2 decades, the data was extracted from the Scopus Database, to achieve and respond to the following research questions:

1. What is the distribution of publications on dental implant stress analysis using finite element methods during the last 2 decades?
2. What are the most significant Journals in the period studied?
3. Who are the most productive authors and what countries are the most productive in the field studied?
4. What are the important research keywords for dental implant stress analysis using finite element methods during the last 2 decades?

By solving these questions, this study offers a comprehensive path for future research on the use of FEM in the dental implant field, by identifying the important contributors to the field studied.

METHOD

This study employs the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Figure 1) [25]. The bibliometric study was conducted, based upon the research publications retrieved from the Scopus database (access date: 25/08/2024), used keywords with the syntax: ((“dental implant” OR “Tooth Implant”) AND (“finite element method” OR “FEM” OR “finite element analysis” OR “FEA”) AND (“bone” OR “osseointegration” AND “stress distribution”)) AND NOT TITLE-ABS-KEY (“animal*”) AND NOT TITLE-ABS-KEY (“in vivo”)). The initial results hit 829 articles, then the search was refined, the period was chosen to be from 2003 to 2023. The choice of the period was determined based on the increased number of publications observed since 2003, with the beginning of the publication of the first article in 1975 in the area studied (Figure 2). Only English articles document types at their final publication stage were considered and any other type of document or language was excluded. Moreover, after removing the duplicated article. There were 606 studies included in the study; the “Analyze results” function in Scopus was used to extract the analysis results base. VOSviewer software was used for constructing and visualizing bibliometric networks, co-occurrence analyses was utilized to reveal the keywords clusters within the use of FEM to analyze dental implant stress distribution research subject.

RESULTS

Research question 1

This study investigated into dental implant stress distribution using finite element analysis. The first findings respond to the first research question regarding the distribution of publications in the research area studied during the period between 2003 and 2023. Figure 2 shows that the number of published documents increased in the period studied in Scopus databases, ranging from 7 documents in 2003 to 60 documents in 2023 which represents the highest number of documents, indicating a growing significance of the use of FEM in dental implant application.

Research question 2

The second objective was to identify the 5 relevant journals to the field of dental implant stress distribution using finite element analysis from 2003 to 2023 as shown in Table I. The “*International Journal Of Oral And Maxillofacial Implants*” was the first prolific journal with a cite score of 3.3 published by the Quintessence Publishing Company. The most significant article in this journal in 2023 was *Machine Learning and Artificial Intelligence: A Web-Based Implant Failure and Peri-implantitis Prediction Model for Clinicians,* with 7 citations. The second journal was ” *Journal Of Oral Implantology* ” published by Allen Press with a 2.3 cite score, with 282 total publications and 636 representing total citations, The most relevant article in this journal is *Digital Workflow for Designing CAD-CAM Custom Abutments of Immediate Implants Based on the Natural Emergence Profile of the Tooth to be Extracted* with 7 citations. The third journal was ” *Journal of Prosthetic Dentistry* ” published by Elsevier with a 7.0 cite score, with 1333 total publications and 9336representing total citations, The most cited article in this journal was *Artificial intelligence applications in implant dentistry: A systematic review*, with 68 citations.

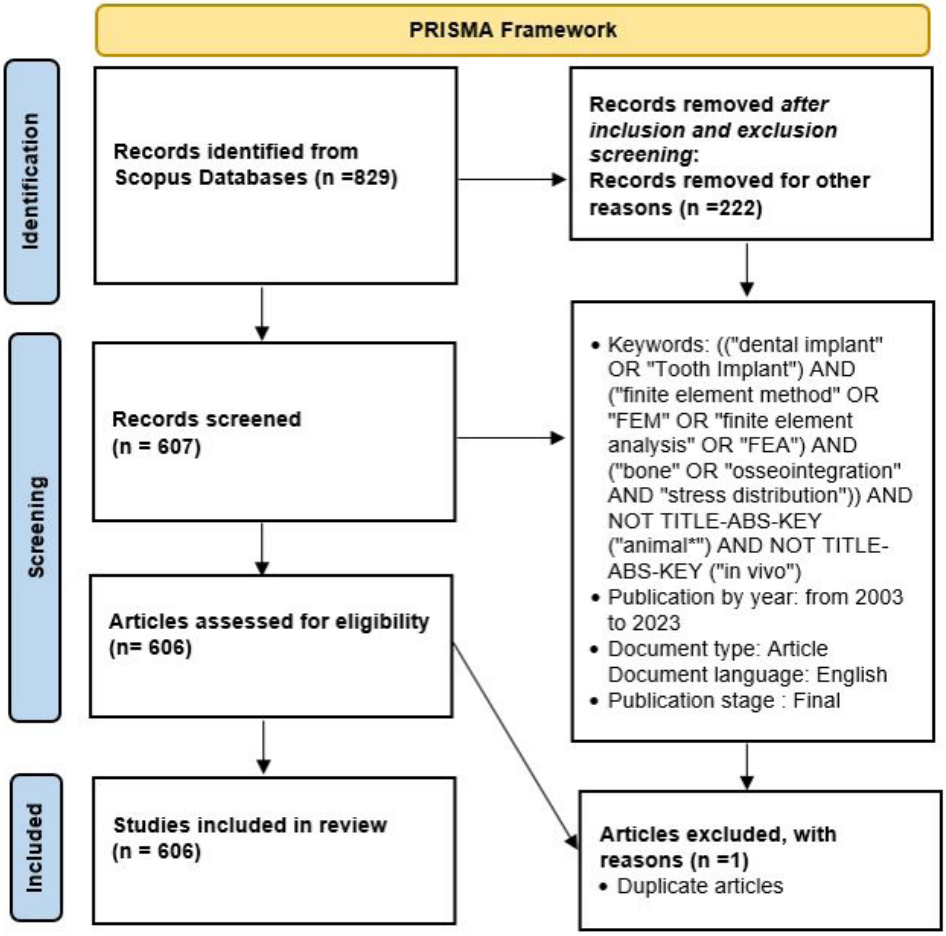

Figure 1 - PRISMA framework for this review.

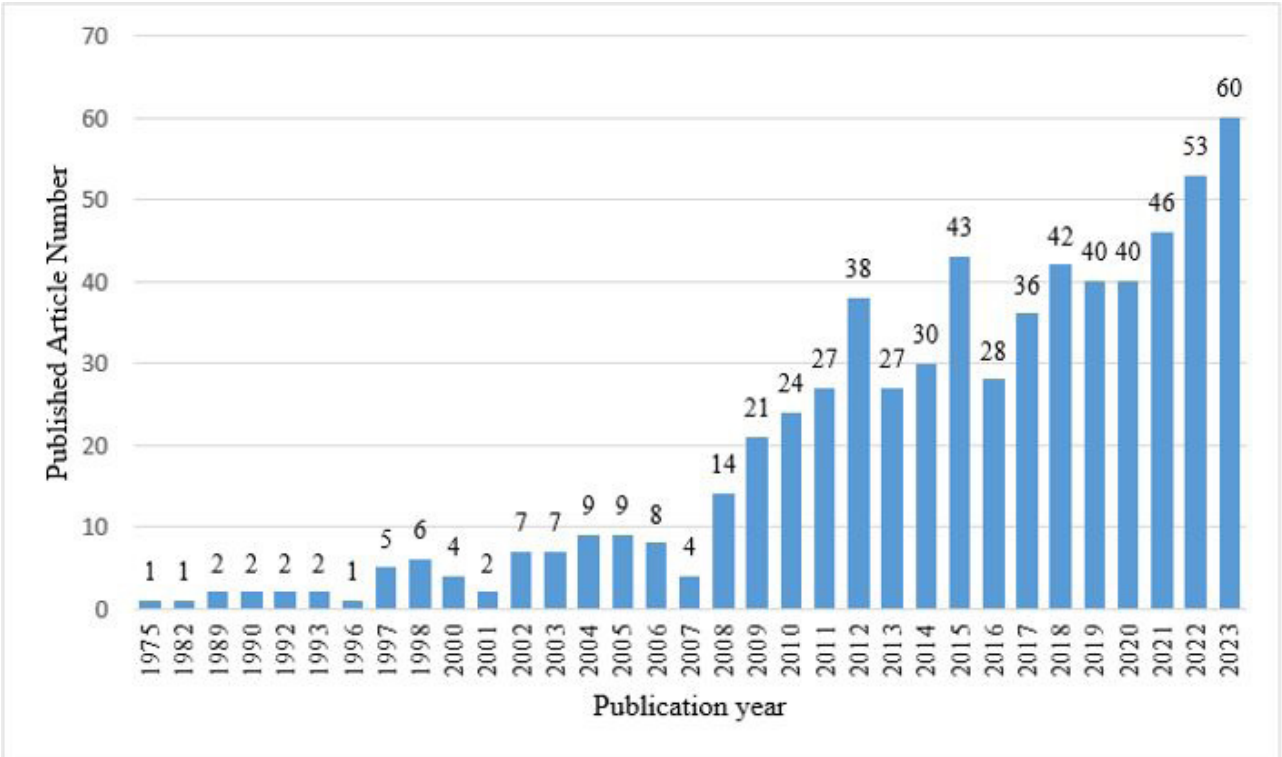

Figure 2 - Distribution of publications per year.

Table I - The top 5 prolific Journals

Journal	Publisher	TP	TC	Cite score	The most cited article in 2023	Times cited in 2023
International Journal Of Oral And Maxillofacial Implants	Quintessence Publishing Company	544	1802	3.3	Machine Learning and Artificial Intelligence: A Web-Based Implant Failure and Peri-implantitis Prediction Model for Clinicians	7
Journal Of Oral Implantology	Allen Press	282	636	2.3	Digital Workflow for Designing CAD-CAM Custom Abutments of Immediate Implants Based on the Natural Emergence Profile of the Tooth to be Extracted	7
Journal of Prosthetic Dentistry	Elsevier	1333	9336	7.0	Artificial intelligence applications in implant dentistry: A systematic review	68
Journal of Prosthodontics	John Wiley & Sons	516	4073	7.9	A Comparison of the Surface and Mechanical Properties of 3D Printable Denture-Base Resin Material and Conventional Polymethylmethacrylate (PMMA)	46
Computer Methods In Biomechanics And Biomedical Engineering	Taylor & Francis	587	2393	4.1	Analysis of stress and stabilization in adolescents with osteoporotic idiopathic scoliosis: finite element method	22

TP = total publication; TC = total citation.

Table II - The 10 prolific Authors

Author	Year of first publication	TP	H-index	TC	Current affiliation	Country
Piza Pellizzer, Eduardo Piza	2007	255	34	4588	Universidade Estadual Paulista "Júlio de Mesquita Filho"	Brazil
Ramos Verri, Fellippo Ramos	2007	86	28	2066	Universidade Estadual Paulista "Júlio de Mesquita Filho"	Brazil
Noritomi, Pedro Yoshito	2007	98	23	1453	Three-Dimensional Technologies Division, Campinas	Brazil
Consani, Rafael L.X.	2001	135	24	1896	Universidade Estadual de Campinas	Brazil
Lemos, Cleidiel Aparecido Arauj	2015	105	26	2116	Universidade Federal de Juiz de Fora	Brazil
Mesquita, M. F.	1999	136	30	2056	Universidade Estadual de Campinas	Brazil
Tribst, J. P.M.	2017	204	26	2507	Academisch Centrum Tandheelkunde Amsterdam	Netherlands
Rocha, Eduardo Passos	2000	77	21	1335	Universidade Estadual Paulista "Júlio de Mesquita Filho"	Brazil
Bacchi, Ataís	2012	97	22	1365	Paulo Picanço School of Dentistry (FACPP), Fortaleza	Brazil
Barão, Valentim Adelino Ricardo	2006	277	38	5220	Universidade Estadual de Campinas	Brazil

Research question 3

The objective aimed to determine the most productive authors. The Table II provides the scientific productivity of the top 10 authors over time on dental implant stress analysis using finite element methods topic. Two authors represent the most productive with 23 publications in the field during the period studied, thus researchers are co-authors in the most of articles, the first was *Piza Pellizzer, Eduardo Piza* with a total publication of 255, who started publishing in 2007 and achieved an h-index of 34 with 4588 citations, affiliated *to Universidade Estadual Paulista* in Brazil, and from the same university *Ramos Verri, Fellippo Ramos* who started

Table III - The 10 prolific countries

Educational Institution	Country	Total Publications
Universidade Federal Do Paraná, Curitiba	Brazil	113
School of Dentistry, University of Selcuk, Konya	Turkey	79
First Affiliated Hospital of Wenzhou Medical College	China	67
School of Dentistry, University of Dundee, Dundee, DD1 4HN, United Kingdom	India	67
Faculty of Engineering, Imam Khomeini International University	Iran	53
Department of Orthodontics, Division of Clinical Research, Dental Research Center, Tokyo,	Japan	38
College of Engineering and Mineral Resources, West Virginia University	United States	31
School of Mechanical Engineering, Yonsei University, Seoul	South Korea	27
University of Rome Tor Vergata, School of Dentistry, School of Medical Engineering, Rome	Italy	25
Department of Mechanical Engineering, Chang Gung University, Tao-yuan, Taiwan	Taiwan	24

with his first document in 2007, published 86 documents and achieved an h-index of 28 with 2066 citations. Of the top 10 productive authors Barão, Valentim Adelino Ricardo has the highest number of publications of 277, and the highest total citation of 5220, an h-index of 38 since he began his research publication in 2006 in *Universidade Estadual de Campinas* in Brazil.

The research question 3 aimed also to identify the most productive countries. The Table III illustrates the analytical results of productive countries in the field of dentistry. Brazil was the most productive country and places first demonstrating its significant publication output, with 113 total publications, the Universidade Federal Do Paraná Curitiba represent the major contributor. Turkey ranks second illustrating the impactful research contribution, with 79 publications, strongly supported by the University of Selcuk, Konya. China and India follows nearly showing high research impact with 67 publications each. Iran contributes significantly with 53 publication, Japan contributes with 38 publication demonstrating the valuable contribution, United States illustrate a significant research engagement with 31 publications, South Korea, Italy and Taiwan with approximately matched publications number (27, 25 and 24 respectively) each contribute meaningfully and completes the top ten countries on the topic of dental implant stress analysis using finite element methods.

Research question 4

The objective of the question was to determine the keywords co-occurrence network (Figure 3), using VOSviewer the minimum number of occurrences of a keyword chosen was 20, and then the minimum link strength is 321. Overall, 117 keywords met the threshold criteria. There are three clusters of keywords identified: Cluster 1 shown in red (n = 50), Cluster 2 shown in green (n=43), and Cluster 3 shown in blue (n =24). The Table IV shows the clusters items and the keywords used. The keywords "Finite element analysis" with co-occurrence of 526 and "Dental implants" with co-occurrence of 413 were the author's keywords frequently occurring in the majority of the publication examined in this study Table V.

DISCUSSION

Finite element analysis (FEA) is useful for analyzing numerical strain and stress inside materials and has been used widely in dentistry [26]. The FEA is used to simulate the stress distribution in the implant system, the results reportedly contribute to improving knowledge of the biomechanical behavior of dental implants [27]. The objective and research questions of this bibliometric study have been answered and treated in sequence, considering the findings of the documents analyzed, collected from the Scopus database.

The distribution of publications on dental implant stress analysis using finite element methods during the last 2 decades from 2003 to 2023, shows an increasing number of published articles, starting with 7 articles a year, and that in 2003, the number of publications subsequently increased to 60 article in 2023, thus bringing the highest number of articles published in the period studied.

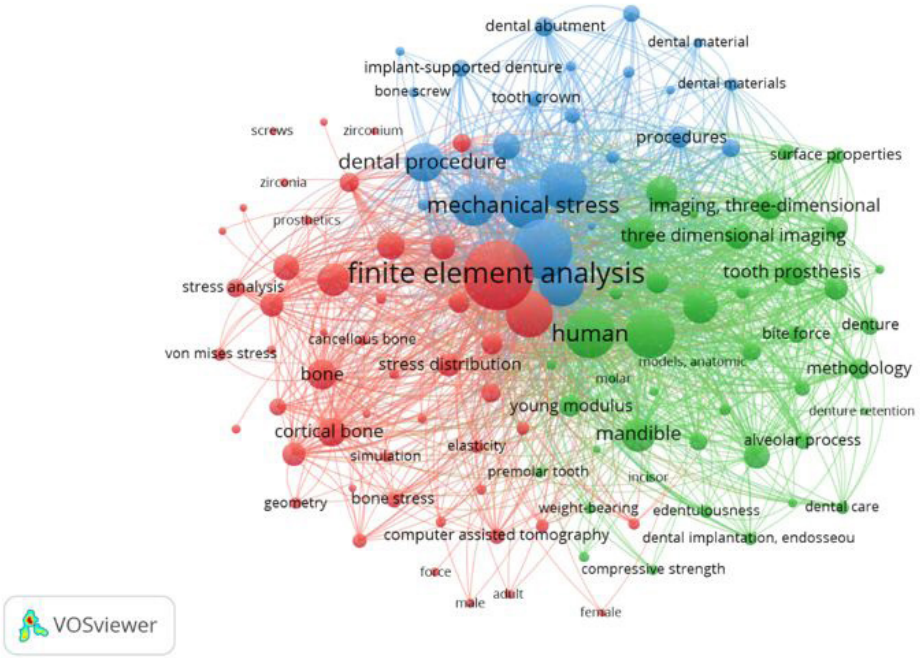

Figure 3 - Network visualization map based on co-occurrence relation between all keywords, clustering is shown using colors, and the circle's size represents how many times a keyword has been used.

Table IV - Cluster of keywords and items of research

Cluster	Themes	Keywords 117
1 [red]	Finite element analysis and osseointegration. [50 keywords]	Adult, alveolar bone, biomechanics, bone, bone and bones, bone density, bone remodeling, bone stress, bone tissue, cancellous bone, computer aided design, computer assisted tomography, cone beam computed tomography, controlled study, cortical bone, dental implant, dental prostheses, dental prosthesis, elasticity, female, finite element analyse, finite element analysis, finite element method, force, geometry, implant, loading, male, maxilla, osseointegration, osteolysis, peri-implant bones, physiological stress, prosthesis design, prosthesis, screws, simulation, stress, stress analysis, stress concentration, stress distribution, stresses distribution, tensile strength, three dimensional finite element analysis, titanium, tomography x-ray computed, trabecular bone, von mises stress, zirconia, zirconium,
2 [green]	Human tooth implantation, denture, and mastication [43 keywords]	Alveolar process, biological model, bite force, bone regeneration, comparative study, compressive strength, computer simulation, dental care, dental implantation endosseous, dental models, dental prosthesis design, dental prosthesis implant-supported, denture, denture design, denture retention, denture overlay, denture partial fixed, edentulousness, elastic modulus, human, humans, imaging three dimensional, incisor, jaw, jaw edentulous, mandible, mastication, methodology, models anatomic, models biological, molar, molar tooth, overlay denture, periodontal ligament, premolar tooth, surface properties, surface property, three dimensional imaging, tooth implantation, tooth prosthesis, weight bearing, weight-bearing, young modulus
3 [blue]	Mechanical stress. Dental materials and computer-aided design programs [24 keywords]	Biomechanical phenomena, bone screw, bone screws, computer program, computer-aided design, crowns, dental abutment, dental abutments, dental alloys, dental implant-abutment design, dental implants, dental material, dental materials, dental porcelain, dental procedure, dental stress analysis, implant-supported denture, materials testing, mechanical stress, procedures, software, stress mechanical, tooth crown, tooth implant

Moreover this study, shows that the most relevant journals publishing on dental implant and FEM areas was the *International Journal Of Oral And Maxillofacial Implants*, the highly referenced article focused on *Machine Learning and Artificial Intelligence: A Web-Based Implant Failure and Peri-implantitis Prediction Model for Clinicians,* the purpose of this article was the development of a machine learning model as a way that could predict peri-implantitis

Table V - Keywords the most used

N°	Keywords	Occurrence
1	Finite element analysis	526
2	Dental implants	413
3	Human	320
4	Humans	307
5	Mechanical stress	300
6	Stress, Mechanical	289
7	Biomechanics	286
8	Dental stress analysis	271
9	Tooth implant	259
10	Computer simulation	189

and dental failure for purpose to increase the implant success [28]. These data about journals and publications have a significant impact on scientific research for researchers, professionals, and students in the subject of dental implant field, enabling to know more about the principal research contributors, particularly in this area.

Furthermore, the prolific authors in this study were *Piza Pellizzer*, *Eduardo Piza* and *Ramos Verri, Fellippo Ramos* from *Universidade Estadual Paulista "Júlio de Mesquita Filho"* in Brazil, they co-author a scientific article titled *Stress analyzed in bone tissue around single implants with different diameters and veneering materials: A 3-D Finite element study*, which represents the highest citation of 74, the study used the 3D finite element method to evaluate the distribution of stress on the alveolar bone to a single prosthesis supported by implant, different variables are studied (e.g. implant diameter, veneering materials and loads), the results indicates that an implant increased diameter was more essential in distributing occlusal stresses on the bone tissue than a changing in veneering material [29]. These findings agree with the studies [30,31] which concluded that an increase in dental implant diameter was more significant in improving stress regarding a smaller dental implant diameter. Based on the findings publications many variables are also studied to evaluate the stress distribution that used the FEM, for example; the evaluation of the effects of bone types on stress distributions around the dental implant examined in the studies [32-34]. The evaluation of dental implant design presented in the studies [35,36].The implant design also has a good correlation with the load on the surrounding bone and the distribution of biomechanical stress [37,38].

In addition, the findings shows that Brazilian dental research has produced significant contributions in the use of FEM in dental research area; it is shown also by the productive authors, who represent 9 of 10 among the top 10 authors in this study. The presence of author from the Netherlands among the top ten authors highlights the importance of the topic of studying dental implant stress distribution on bone tissue using FEM and illustrates the globally work being made, illustrating a growing research community to advance understanding on this field. Demonstrating the first rank occupied by Brazil which was the leading country in terms of the total number of publications. The country pays great attention to this field as seen by the high number of research centers, with about 544 dental schools and 23 dental specialties recognized by the Federal Council of Dentistry [39,40]. Additionally the top 10 countries showed a great quantitative engagement in dentistry field, by contributing a significant number of publications, indicating the effort to advance scientific research in area of using FEM to study the dental implant stress distribution on the surrounding bone.

Furthermore, the analysis of keywords based on co-occurrence relation using VOSviewer showed that the dental implant stress analysis using finite element methods research area formed clusters. Cluster 1 (50 keywords): the main theme can be discussed by the finite element analysis and osseointegration; Cluster 2 (43 keywords) the theme was about Human tooth implantation, denture, and mastication; Cluster 3 (24 keywords) the theme was about the mechanical stress, dental materials, and the computer-aided design. In addition, the keywords most often used by authors represent areas of interest through the study period, the most common keywords used are "Finite element analysis" and "Dental implants", showing the greatest significant growth over time.

Despite certain limits, FEM is a computational study, and the clinical conditions may not be perfectly replicated, in the most of the studies the stress is often performed under static loads although the fact that this is not the case in reality [41]; while the anisotropic nature of the bone has to be considered [16,42], in summary,

the use of FEM to evaluate stress distribution of dental implants has shown a great evolution and was observed by an increased publication studies regarding our research area. Multiple factors can influence the load transferred at the bone implant interface and could be examined using FEM like dental implant length, diameter, design, bone quality, number of implants used, and the change in prosthesis material. The possibility of repeating the experiments and changing variables depending on the intended study was easier when it could be difficult to study in vivo or clinically. The results obtained may lead to improvements in dental implant design for the long-term longevity of the device and patient satisfaction.

This study presents some limitations that may be addressed in future bibliometric studies, consisting of the use of only one database for publication searching, other sources could provide different citation scores or numbers of research articles. Additionally, the findings of the study are only relevant for the time point of the study's data extraction (25/08/2024), as citation and publication volume vary over time.

CONCLUSION

The successful oral implantology treatment relies on both the clinical protocols and the biomechanical principles. The FEM provide valuable utility as a tool for evaluating the biomechanical behavior of the dental implant, enabling further understand of the stress distribution on the surrounding bone, providing insight into the dental implant system functions, this can lead to more improvements in implant design and achieving the long term integrity of the dental implant. This bibliometric study provides a complete overview of the development trajectory of the FEM in regarding dentistry research area, during the period studied from 2003 to 2023 the number of publications has increased remarkably. The researchers recognize the significance of this research area, particularly in light of the current digital revolution.

Author's Contributions

YH: Resources, Data Curation, Writing – Original Draft Preparation, Writing – Review & Editing, Visualization, Methodology, Software. EMB: Supervision, Methodology, Visualization, Writing – Original Draft Preparation, Validation. CO: Supervision, Conceptualization, Writing – Review & Editing, Validation. AM: Supervision, Validation, Formal Analysis, Writing – Review & Editing. AD: Conceptualization, Validation. LB: Conceptualization, Validation. AER: Supervision, Validation, Formal Analysis, Writing – Review & Editing.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Regulatory Statement

This study allows analyzing the bibliographic data of the scientific production using bibliometric processing tools, and does not involve any experimentation involving human or animal subjects.

List of abbreviations

CAD-CAM: Computer-aided design and Computer-aided manufacturing

FEM: Finite element method

FEA: Finite element analysis

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

TC: Total citation

TP: Total publication

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