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RESEARCH AND EDUCATION

The 50 most cited articles on soft tissue integration of dental implants: A bibliometric analysis

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ABSTRACT

Statement of problem. Soft tissue integration helps prevent the bacterial invasion of dental implants, but bibliometric studies on the top 50 most cited articles in the field of soft tissue integration are lacking.

Purpose. The purpose of this bibliometric study was to analyze the 50 most cited articles since 1999 to explore global trends and research hotspots.

Material and methods. A specific search strategy of the Science Citation Index Expanded (Web of Science) was devised, and relevant article-based, journal-based, and author-based parameters were analyzed. Correlation analysis was performed (α=.05).

Results. The number of citations ranged from 71 to 586. Clinical Oral Implants Research was the most cited journal (1722 citations). Berglundh, Tord was the author with the most publications (6 publications) and citations (957 citations). Dental implants and titanium were the keywords with the highest frequency. Switzerland was the country with the highest number of publications (12 publications). Correlation was found between the publication year and average annual citations (*P*<.001).

Conclusions. This study determined the scientific progress in soft tissue integration. The surface design of dental implant materials is essential for the soft tissue integration of dental implants. Soft tissue integration has been a focus of interest in the past few years, but many experiments still need to be done to improve soft tissue compatibility with innovative materials. (J Prosthet Dent 2025;133:713-723)

Implant-supported prostheses are an important way to replace missing teeth,[1,2] but the prevalence of peri-implantitis has been estimated to be about 22% and could cause the failure of up to 2% of implants after 9 years of placement.[3] The transmucosal areas are features of dental implants that provide the transition between the osseointegrated implant zone and the dental prosthesis. The integrity of the peri-implant soft tissue seal is essential to maintain peri-implant tissue health, as the soft tissue seal formed across the transmucosal area prevents bacteria from invading the underlying hard tissue.[4–6] Histologically, healthy soft tissue integration includes epithelium and connective tissue, acting as a barrier to protect bone tissue contact with implant from bacteria.[7,8] However, mucosa appears to be physically adapted on the implant rather than biologically attached, with the fibers traveling parallel, not perpendicular, to the implant,[4,9,10] and not achieving a good sealing effect. Improving the sealing of soft tissues from a biological perspective to promote osseointegration and reduce the occurrence of peri-implantitis is essential to the success rate of dental implants.[11–16]

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Clinical Implications

This bibliometric study analyzed highly cited articles in the field of soft tissue integration, including authors, countries, journals, keywords, and other information. Researchers should be aware that most innovative improvements in implant materials have not been confirmed by animal experiments or clinical trials. The study provides researchers with information on the progress of research and the future direction of the field.

Bibliometric analysis is a popular method of searching for and analyzing a large number of bibliographic and scientific data to find the nuances of research in the scientific field and discover emerging areas.[17] Bibliometric analysis explores the number of publications, quality, citations, and citation relationships of scientific articles. It analyzes the research fields and influence of scientific researchers and institutions and evaluates the impact of research results. It is also able to spot trends in scientific research and provide evidence for scientific decision-making. Bibliometric methods have been established as scientific specialties and are an integral part of the research method.[18]

Bibliometrics has been applied to the field of oral implantology, including the analysis of classical articles, implant funding sources, and clinical research trends.[19–23] However, the authors are unaware of a bibliometric analysis of soft tissue integration. Nevertheless, interest in soft tissue integration has been increasing, and many studies on dental implants have been aimed not only at improving osseointegration but also at improving soft tissue integration.[12,24–26] The authors aimed to understand the high-impact articles published in the field of soft tissue integration of implants over the past 20 years and to perform a bibliometric analysis to provide assistance to researchers in soft tissue integration. Consequently, this study analyzed the 50 most cited publications using bibliometric analysis. The research hypothesis was that the number of citations of articles on soft tissue integration would be influenced by the publication year, number of authors, journal impact factors, and authors' h-index.

MATERIAL AND METHODS

The most cited articles in soft tissue integration were identified by a search in the Science Citation Index Expanded (SCI-EXPANDED) in Web of Science on January 10, 2024. The search strategy was:

TS=[(dental implant OR titanium OR dental abutment OR healing abutment OR transmucosal collar OR oral implant OR implant dentistry OR dental implantology OR dental implantation) AND (soft tissue integration OR soft-tissue integration OR soft tissue integrity OR mucointegration OR soft tissue attachment OR connective-tissue attachment OR soft tissue seal OR biologic seal OR junctional epithelium OR soft tissue adaptation OR soft tissue barrier OR gingival fibroblast OR gingival epithelial cell OR soft tissue sealing OR peri-implant attachment OR keratinocyte)].

Inclusion criteria were articles focused on soft tissue integration, tissue structures, or cells (for example, junctional epithelium, connective tissue, fibroblasts) related to soft tissue integration. Publication years ranged from 1999 to 2023. Publications unrelated to soft tissue integration in dentistry were excluded.

A list of articles indexed in the Science Citation Index Expanded of the Web of Science was obtained and sorted by citations. Two researchers (W.Y., Z.L.) read the titles, the abstracts, and the full texts independently to select the top 50 most cited articles. If the results were inconsistent, they tried to reach a consensus after discussion. If they could not reach an agreement, a senior researcher (L.Y.) made the definitive decision.

Correlation analysis was performed using a software program (IBM SPSS Statistics, v27.0; IBM Corp). The Spearman correlation coefficient(r) was used to determine the strength of correlations: high ($r>0.60$), moderate ($0.30 < r<0.60$), and weak ($r<0.30$) (α=.05).

RESULTS

A total of 2423 articles were retrieved through the search strategy, and the 50 most cited articles were selected. Citations of the 50 most cited articles ranged from 71 to 586, as shown in Table 1 with the study design, material, surface treatment, and primary outcome. As shown in Figure 1, the number of publications showed an upward trend before 2007 and a downward trend after 2014. The number of citations per year of these 50 most cited articles on soft tissue integration increased between 2001 and 2021 (411 in 2021). The proportion of study design in the 50 most cited articles is presented in Figure 2.

A moderate correlation was found between total citations and average annual citations ($r=0.578$, $P<.001$) (Table 2). A strong correlation was found between the publication year and average annual citations ($r=0.645$, $P<.001$), while no significant correlation was found between total citations and publication year ($P>.05$). No significant correlation was found between citations and the number of authors ($P>.05$).

The journal sources of the 50 most cited articles on soft tissue integration are shown in Table 3. No statistical correlation was found between journal impact factors and total citations. *Clinical Oral Implants Research*

Table 1. Fifty most cited articles on soft tissue integration

No.	Article	Citations	Study Design	Material	Surface Treatment Method	Primary Outcome
1	A review on the wettability of dental implant surfaces II: Biological and clinical aspects.	586	review	/		
2	Systematic study of osteoblast and fibroblast response to roughness by means of surface-morphology gradients.	438	cell study	Ti	roughness gradients	Fibroblasts preferred smooth surface.
3	The significance of keratinized mucosa on implant health: A systematic review.	333	review	/		
4	The effect of material characteristics, of surface topography and of implant components and connections on soft tissue integration: A literature review.	292	review	/		
5	The junctional epithelium: From health to disease.	288	review	/		
6	Soft tissue wound healing around teeth and dental implants.	278	review	/		
7	The mucosal barrier at implant abutments of different materials.	273	animal study	Ti, ZrO_2 (ceramic), AuPt-alloy (cast-to)	/	At Au/Pt-alloy site, apical shift of barrier epithelium, and in 80-mm-wide connective tissue zone contained less collagen and fewer fibroblasts and more leukocytes.
8	Biologic width around titanium implants. A physiologically formed and stable dimension over time.	260	animal study	Ti	TPS/SLA	Changes occurred in dimensions of sulcus depth, JE and connective tissue contact, overall peri-implant soft tissues dimension not altered for 1 year.
9	Morphogenesis of the peri-implant mucosa: An experimental study in dogs.	239	animal study	Ti	/	Soft tissue barrier adjacent to Ti implants placed using nonsubmerged installation procedure developed final characteristics within 6 weeks postoperatively.
10	The dimensions of keratinized mucosa around implants affect clinical and immunological parameters.	234	clinical research	Ti	/	KM thickness and width affected clinical and immunological parameters.
11	Potential of chemically modified hydrophilic surface characteristics to support tissue integration of titanium dental implants.	222	review	/		
12	Role of the microgap between implant and abutment: A retrospective histologic evaluation in monkeys.	199	animal study	Ti	plasma sprayed	Less bone loss occurred when microgap moved coronally away from alveolar crest. Connective tissue contact range 1.1 to 1.2 mm.
13	Is there a need for keratinized mucosa around implants to maintain health and tissue stability?	180	review	/		
14	Effects of surface hydrophilicity and microtopography on early stages of soft and hard tissue integration at non-submerged titanium implants: An immunohistochemical study in dogs.	175	animal study	Ti	SLA/modSLA	STI influenced mainly by hydrophilicity.
15	Human histologic evidence of a connective tissue attachment to a dental implant.	168	clinical research	Ti	laser-lok collar	Supracrustal connective tissue attachment evident.
16	The barrier between the keratinized mucosa and the dental implant - an experimental study in the dog.	166	animal study	Ti	/	Fibroblast played role in establishment and maintenance of mucosal seal.
17	The mucosal attachment to titanium implants with different surface characteristics: An experimental study in dogs.	161	animal study	Ti	dual thermal acid-etched surface	Soft tissue attachment that formed to Ti implants not influenced by roughness.
18	Periimplant soft tissue barrier at experimental one-piece mini-implants with different surface topography in humans: A light-microscopic overview and histometric analysis.	152	clinical research	Ti	oxidized/ acid-etched/ machined surface	Oxidized and acid-etched implants revealed less epithelial downgrowth and longer connective tissue seal than machined implants.
19	Soft tissue integration versus early biofilm formation on different dental implant materials.	151	cell study	Ti, Ti-Zr alloy, ZrO_2	/	Human-gingival-fibroblasts lost race-for-the-surface against all bacterial strains on nearly all implant materials, except on smoothest Ti.

Table 1 (*Continued*)

No.	Article	Citations	Study Design	Material	Surface Treatment Method	Primary Outcome
20	Biomimetic coating of laminin-apatite composite on titanium metal and its excellent cell-adhesive properties.	148	cell study	Ti	laminin-apatite composite coating	Epithelial cell-adhesive properties of this material superior to other materials.
21	Histologic evidence of a connective tissue attachment to laser microgrooved abutments: A canine study.	139	animal study	Ti	laser-lok healing abutments	Connective tissue fibers oriented perpendicular to abutment surface as physiologic barrier to apical JE migration.
22	Soft tissue sealing around dental implants based on histological interpretation.	135	review	/		
23	The effect of microstructured surfaces and laminin–derived peptide coatings on soft tissue interactions with titanium dental implants.	132	animal study	porous Ti	$(PLL/PGA)_{6,5}$–PGA–peptide film.	Proliferation and colonization of epithelial cellse increased. Number of hemidesmosomes increased.
24	Early bacterial colonization and soft tissue health around zirconia and titanium abutments: An in vivo study in man.	124	clinical research	Ti, ZrO_2	/	No difference in health of soft tissues and early bacterial colonization.
25	Significance of the width of keratinized mucosa on the health status of the supporting tissue around implants supporting overdentures.	123	clinical research	Ti	/	Absence of adequate KM around implants associated with higher plaque accumulation, gingival inflammation, bleeding on probing, and mucosal recession.
26	The titanium surface texture effects adherence and growth of human gingival keratinocytes and human maxillar osteoblast–like cells in vitro.	118	cell study	Ti	glossy polished/airborne-particle abraded/ plasma-sprayed	Soft tissue integration and response more influenced by surface texture.
27	Soft tissue stability at the facial aspect of gingivally converging abutments in the esthetic zone: A pilot clinical study.	118	clinical research	experimental concave Ti, ZrO_2	/	Concave, gingivally converging abutments allowed for above-average soft tissue outcomes.
28	Morphogenesis of peri-implant mucosa revisited: An experimental study in humans.	110	clinical research	Ti	/	Dimension of barrier epithelium and connective tissue 1.9 mm and 1.7 mm.
29	Ultrastructural and immunoelectron microscopic studies of the peri-implant epithelium-implant (Ti–6Al–4 V) interface of rat maxilla.	109	animal study	Ti–6Al–4 V	/	PIE attached to implant with hemidesmosomes and IBL in lower region of PIE-implant interface.
30	Influence of the microgap in the peri–implant hard and soft tissues: A histomorphometric study in dogs.	109	animal study	Ti	/	Tendency of epithelium and connective tissue to be longer with deeper implant placement.
31	Fibroblast growth on surface-modified dental implants: An in vitro study.	102	cell study	Ti	TiN coating	MTT activity and total protein significantly increased in fibroblasts cultured on titanium surfaces coated with TiN.
32	Selective responses of human-gingival fibroblasts and bacteria on carbon fiber reinforced polyetheretherketone with multilevel nanostructured TiO_2.	101	cell study	carbon-fiber-reinforced polyetheretherketone	Ti PIII technique	Multilevel TiO_2 nanostructures can selectively enhance soft tissue integration and inhibit bacterial reproduction.
33	Differential behavior of fibroblasts and epithelial cells on structured implant abutment materials: A comparison of materials and surface topographies.	99	cell study	ZrO_2 and Ti alloy	machined, polished, airborne-particle abraded	Fibroblasts exhibited higher proliferation rates on ZrO_2. Cell spreading generally higher on polished and machined surfaces. Rough surface facilitated fibroblast adhesion.
34	Ultrastructural localization of laminin–5 (γ2 chain) in the rat peri-implant oral mucosa around a titanium-dental implant by immuno-electron microscopy.	97	animal study	Ti	/	Ln–5 contributes to attachment of PIE to Ti surface, and that PIE attached to Ti at apical portion of dental implant–PIE interface.
35	Temporal sequence of hard and soft tissue healing around titanium dental implants.	96	review	/		
36	Epithelial integrins with special reference to oral epithelia.	94	review	/		
37	Use of sol-gel-derived titania coating for direct soft tissue attachment.	93	animal study	Ti	nonresorbable and reactive sol–gel-derived nano-porous TiO_2 coatings	Direct attachment between soft tissue and sol–gel-derived TiO_2 coatings found in vivo after 2 days of implantation.

Table 1 (*Continued*)

No.	Article	Citations	Study Design	Material	Surface Treatment Method	Primary Outcome
38	Clinical evaluation of laser microtexturing for soft tissue and bone attachment to dental implants.	92	clinical research	Ti	laser microtexturing surface treatment of the implant collar	Consistent difference in probing depth between laser-lok and control implant demonstrated formation of stable soft-tissue seal above crestal bone.
39	The influence of surface topography of ceramic abutments on the attachment and proliferation of human oral fibroblasts.	90	cell study	aluminum oxide	full density, pressed densely sintered, pressed densely sintered and polished surfaces	More cells attached to milled and sintered surfaces than to polished one.
40	Biological characteristics of the junctional epithelium.	90	review	/		
41	Focal adhesion contact formation by fibroblasts cultured on surface-modified dental implants: An in vitro study.	89	cell study	Ti	Ti, TiN, ZrN coating applied by PVD	Strong correlation between number of FACs and surface roughness. Lowest rough surface had most FACs
42	Healing after standardized clinical probing of the perlimplant soft tissue seal: A histomorphometric study in dogs.	88	animal study	Ti	/	Peri-implant probing did not inflict irreversible damage to soft tissue seal in healthy tissues.
44	Attachment and growth behavior of human gingival fibroblasts on titanium and zirconia ceramic surfaces.	87	cell study	ZrO_2 and Ti	Ti discs with a machined surface, Y-TZP with a smooth surface, Y-TZP with 100 µm grooves.	HGFs showed comparable biological responses to both grooved ZrO_2 ceramic and pure Ti substrates.
43	The defense architecture of the human periimplant mucosa: A histological study.	87	clinical research	Ti	oxidized, machined, acid-etched surfaces	Surface texture of implants may affect orientation of collagen fibers of connective tissue at implant surface.
45	Comparative response of epithelial cells and osteoblasts to microfabricated tapered pit topographies in vitro and in vivo.	84	animal study	Ti-coated epoxy replicas	TP, IP topographies	TP topographies osteoconductive in vitro and in vivo, but their influence on epithelial migration limited.
46	Effects of surface topography on the connective tissue attachment to subcutaneous implants.	84	animal study	Ti-coated epoxy replicas	polished, finely and coarsely airborne-particle abraded, acid-etched, SLA, TPS, machined-like, micromachined grooved surfaces	Rough implant surfaces associated with stable connective tissue attachment.
47	Surface modification of zirconia with polydopamine to enhance fibroblast response and decrease bacterial activity in vitro: A potential technique for soft tissue engineering applications.	81	cell study	ZrO_2	PDA-coated	PDA coating significantly increased cell adhesion and proliferation.
48	Strategies for optimizing the soft tissue seal around osseointegrated implants.	78	review	/		
49	Race to invade: Understanding soft tissue integration at the transmucosal region of titanium dental implants.	77	review	/		
50	Dental implants modified with drug releasing titania nanotubes: Therapeutic potential and developmental challenges.	71	review	/		

FAC, focal adhesion contact; HGF, human gingival fibroblasts; IBL, internal basal lamina; IP, inverted pyramids; JE, junctional epithelium; KM, keratinized mucosa; Ln-5, Laminin-5; modSLA, chemically modified SLA; MTT, a colorimetric assay to examine fibroblast metabolism; PDA, polydopamine; PGA, poly (L-glutamic) acid; PIE, peri-implant epithelium; PIII, plasma immersion ion implantation; PLE, porcine periodontal ligament epithelial; PLL, Poly (L-lysine); PVD, physical vapor deposition; SLA, airborne-particle abraded large-grit acid-etched; STI, soft tissue integration; Ti, titanium; TiN, titanium nitride; TiO_2, titania; TP, tapered pits; TPS, titanium plasma-sprayed; Y-TZP, yttrium-stabilized tetragonal zirconia polycrystals; Zr, Zirconium; ZrN, zirconium nitride; ZrO_2, zirconia.

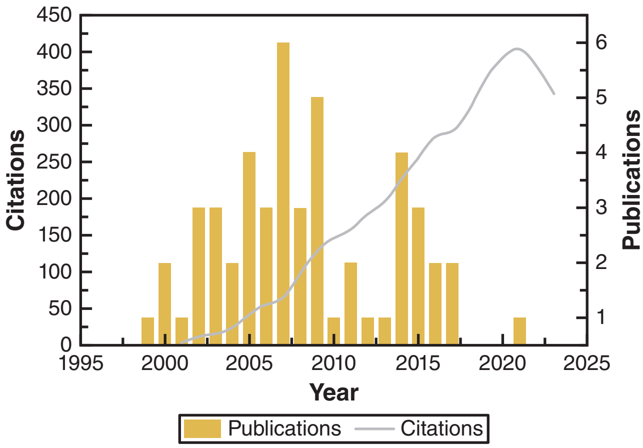

Figure 1. Distribution of number of publications and total number of citations per year.

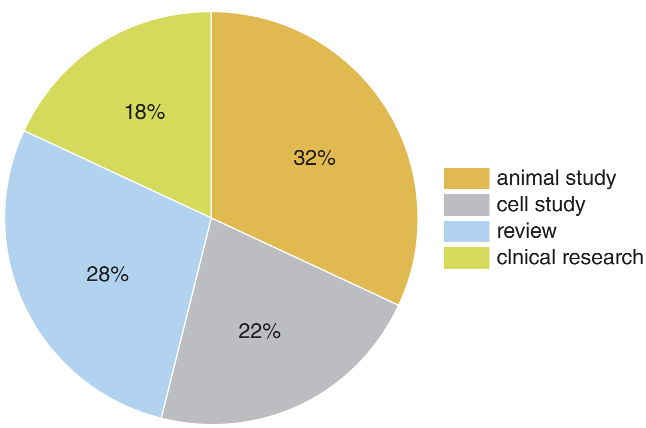

Figure 2. Study design of 50 most cited papers on soft tissue integration.

was the journal with the most citations (n=1722; 23.67% of all) and most publications (n=10). In Table 3, the 2022 Journal Impact Factor ranged from 29.4 (*Advanced Materials*) to 1.6 (*International Journal of Periodontics Restorative Dentistry; Journal of Oral Implantology*), whereas the 5 Year Journal Impact Factor ranged from 30.2 (*Advanced Materials*) to 1.5 (*Journal of Electron Microscopy*). Of the 23 journals publishing the 50 most cited articles on soft tissue integration, 13 (56.5%) were in the Category "Dentistry, Oral Surgery Medicine.".

The 10 authors with the most citations are listed in descending order in Table 4. Their h-index ranged from 7 to 119. No statistical correlation was found between h-index and citations per article for each author. Berglundh, Tord had the most publications (n=6) and citations (n=957). Among these 10 authors, 4 were from Japan, 3 from Switzerland, and 3 from Sweden. The partnerships between the author teams and between different countries are shown in Figures 3 and 4. The authors of the 50 most cited articles on soft tissue integration were from 21 different countries, including 11 European countries, 4 American countries, 5 Asian countries, Australia, and 0 African countries.

The keywords are visualized in a map according to frequency of occurrence in Figure 5. Titanium and dental implants were the most frequently used keywords in the 50 articles (25 occurrences), showing the biggest node in the map. Keywords such as roughness, fibroblasts, topography, and attachment collected 10, 10, 9, and 8 occurrences.

DISCUSSION

The research hypothesis that the number of citations of articles on soft tissue integration would be influenced by the publication year, number of authors, journal impact factors, and authors' h-index was rejected, as the findings revealed that the publication year, number of authors, journal impact factors, and authors' h-index were not statistically associated with the number of citations (P>.05). Only the average annual citations was related to the publication year (r=0.645, P<.001), indicating that researchers tend to read and cite recent articles. In this study, the 50 most cited articles, rather than the 100 most cited articles, were analyzed using bibliometric methods, because the top 50 to 100 most cited articles were not highly cited. Soft tissue integration is a niche area in oral implantology, and the related articles did not receive as many citations as those in the field of osseointegration. However, previous studies have found that soft tissue integration was essential to dental implants, as good sealing helped reduce the occurrence of infection.[5,6] Thus, it was necessary to conduct a bibliometric analysis of the 50 most cited articles on soft tissue integration to help researchers understand the research progress, explore future research directions, and identify research hotspots.

The number of publications per year and citations per year for the 50 most cited articles are depicted in Figure 1. The total number of citations per year increased from 2001

Table 2. Correlation analysis among total citations, average annual citations, number of authors, and publication year

	Total Citations	Average Annual Citations	Number of Authors	Publication Year
Total citations	1.000	/	/	/
Average annual citations	0.578***	1.000	/	/
Number of authors	−0.107	−0.151	1.000	/
Publication Year	−0.139	0.645***	0.001	1.000

*** indicates statistical significance at P<.001 level.

Table 3. Journals that published 50 most cited articles on soft tissue integration

No.	Journal Title	Number of Articles	Number of Citations	2022 Journal Impact Factor	5-Year Impact Factor	Quartile
1	Clinical Oral Implants Research	10	1722	4.3	5.7	Q1
2	Biomaterials	7	959	14.0	13.8	N/A
3	Journal of Periodontology	4	760	4.3	5.4	Q1
4	Journal of Clinical Periodontology	3	552	6.7	9.1	Q1
5	Journal of Dental Research	2	326	7.6	7.6	Q1
6	International Journal of Periodontics Restorative Dentistry	2	282	1.6	1.9	Q4
7	Clinical Implant Dentistry and Related Research	2	224	3.6	4.6	Q1
8	Dental Materials	2	211	5.0	6.0	Q1
9	Journal of Biomedical Materials Research Part A	2	181	4.9	4.6	N/A
10	International Journal of Oral Maxillofacial Implants	2	180	2.0	2.8	Q2
11	Journal of Prosthetic Dentistry	2	180	4.6	4.5	Q1
12	Acta Biomaterialia	1	559	9.7	9.9	N/A
13	Journal of Biomedical Materials Research Part B-applied Biomaterials	1	208	3.4	3.4	N/A
14	Advanced Materials	1	140	29.4	30.2	N/A
15	Journal of Prosthodontic Research	1	124	3.6	4.0	Q1
16	Journal of Oral Implantology	1	108	1.6	2.0	Q4
17	Periodontology 2000	1	88	18.6	15.8	Q1
18	Implant Dentistry	1	86	3.0 (2021)	N/A	Q2
19	Journal of Electron Microscopy	1	83	1.6 (2014)	1.5	N/A
20	Biomedical Materials	1	81	4	4.0	N/A
21	Colloids and Surfaces B-Biointerfaces	1	78	5.8	5.4	N/A
22	Advanced Healthcare Materials	1	73	10.0	10.6	N/A
23	Expert Opinion on Drug Delivery	1	70	6.6	7.0	N/A

Table 4. Top ten authors with most citations

No.	Author	Articles	Citations	Citations per Article	Country	H-index
1	Berglundh, Tord	6	957	159.5	Sweden	83
2	Abrahamsson, Ingemar	5	855	171	Sweden	38
3	Lang, Niklaus Peter	4	628	157	Switzerland	119
4	Lindhe, Jan	4	599	149.75	Sweden	109
5	Bosshardt, Dieter Daniel	3	591	197	Switzerland	49
6	Schupbach, Peter	3	336	112	Switzerland	9
7	Yamaza, Takayoshi	3	269	89.66667	Japan	40
8	Tanaka, Teruo	3	269	89.66667	Japan	33
9	Kido, Mizuho A.	3	269	89.66667	Japan	29
10	Shimono, Masayuki	3	269	89.66667	Japan	12

to 2021, reflecting the growing interest in the soft tissue integration of dental implants. The increasing number of articles focusing on soft tissue integration led to an increase in citations each year. The reason for the decline in citations in 2022 and 2023 may be that these 2 years were in the declining period of the citation life cycle of these 50 most cited articles.[27] Another reason may be that the articles about soft tissue integration of implants published since 2015 had insufficient time to be cited in the 50 most cited articles. Therefore, fewer publications of the most cited articles have been found since 2015, and the number of citations per year has declined since 2022.

The 16 animal studies (32%) were the most published, followed by the 14 review articles (28%). The number of cell research and clinical research publications was 11 (22%) and 9 (18%), respectively. Most of the research on soft tissue integration of implants was still at the preclinical animal studies stage. In particular, most research on new implant materials was still in the cell and animal research phases, indicating a significant research gap in improving implant materials for soft tissue integration. Animal experiments were often conducted to explore the anatomy of soft tissues after implant placement.[13] The implants used in animal experiments were often made of titanium or Ti-Al-V, with minimal improvements in material composition. Some studies investigated the impact of the different surface topographies and roughness of implants on soft tissue integration.[25] Implants with new surface coatings were often studied in vitro.[12] In recent years, some studies focused on surface modification of implants,[26] but most were still in vitro. To improve the soft tissue integration of implants, it is necessary not only to explore the physiological mechanisms but also to enhance soft tissue integration properties through material improvement. Much work must be done to conduct in vivo animal and clinical experiments.

The 50 most cited articles were published in 23 scientific journals, among which 42% were published in 3 journals (*Clinical Oral Implants Research, Biomaterials,*

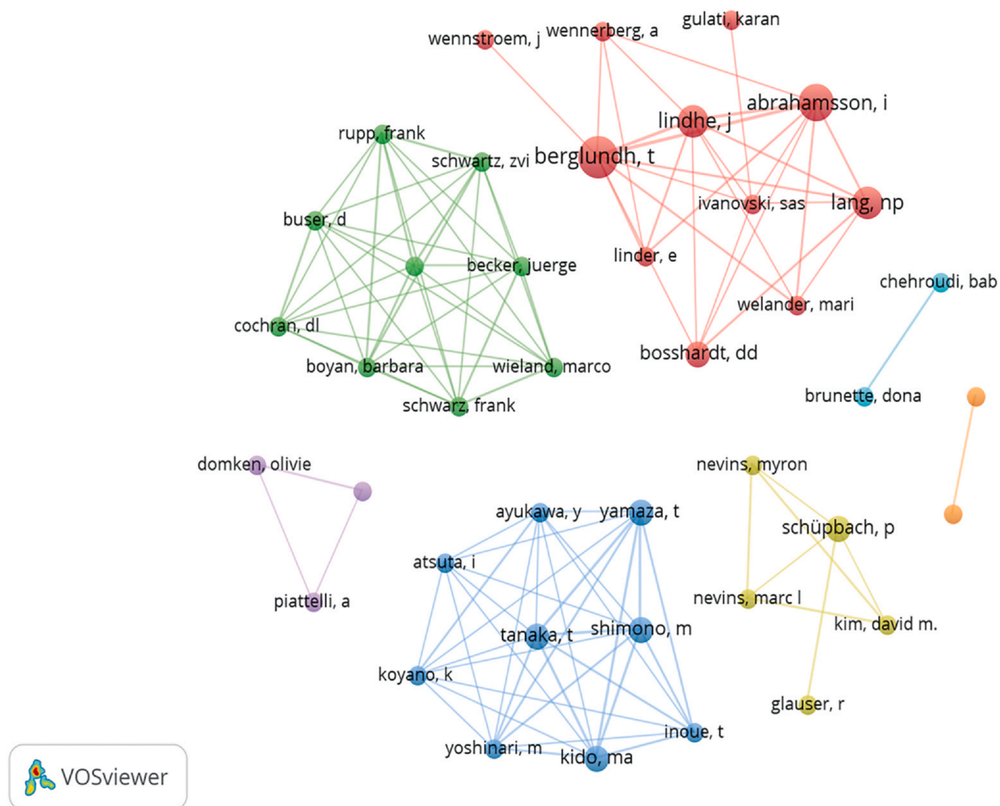

Figure 3. Co-authored bibliometric networks in top 50. Minimum number of occurrences of author: two articles. Straight line represents partnership.

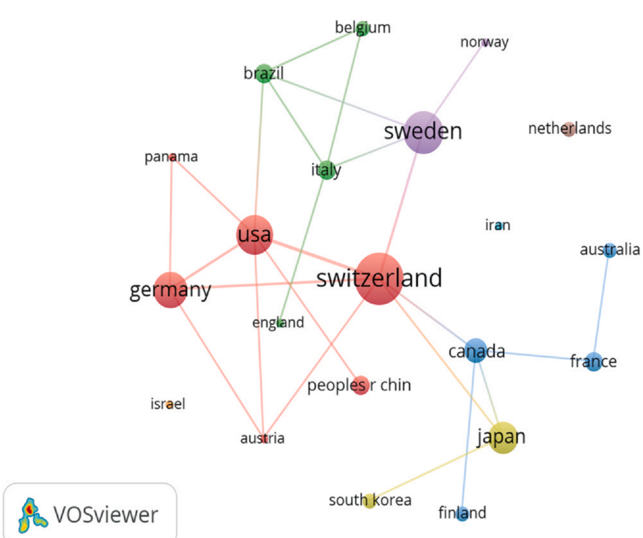

Figure 4. Map of co-authorship between countries. Minimum number of occurrences of country: 1 article. Words that correspond to largest circles are ones that have highest occurrence. Words that appear in smaller circles had smaller occurrence.

Journal of Periodontology), indicating that articles on soft tissue integration were concentered in a few scientific journals. In the 3 journals, *Biomaterials* was primarily in the category of Engineering, Biomedical. Among the 23 scientific journals, 7 were not in the category of Dentistry, Oral Surgery Medicine, indicating that soft tissue integration is a multidisciplinary field.

The journal with the highest impact factor was *Advanced Materials*, categorized under "Chemistry, Multidisciplinary; Materials Science Multidisciplinary; Physics, Condensed Matter; Nanoscience Nanotechnology; Chemistry, Physical; Physics, Applied." Journals that encompass multidisciplines usually have higher impact factors and 5-year impact factors associated with a broader audience. Multidisciplinary and medical journals tend to have higher impact factors than journals in the dental field.

Associated with the rapid development of dental implants in Switzerland and Sweden, more Swiss and Swedish scholars conducted research in related fields. Additionally, geographical advantages might incline researchers to cite articles from scholars within the same country or institution. The co-occurrence of authors with more than 2 publications is presented in Figure 3, and the authors of the 50 most cited publications formed several small groups. Most scholars cooperated closely within groups, while there was little cooperation among groups (analyzed from these 50 publications).

The osseointegration properties of titanium was first discovered by a Swedish scientist,[1] explaining why the highest number of publications were from Switzerland, Sweden, the United States, and Germany. Despite the rapid growth of the dental implant market in the

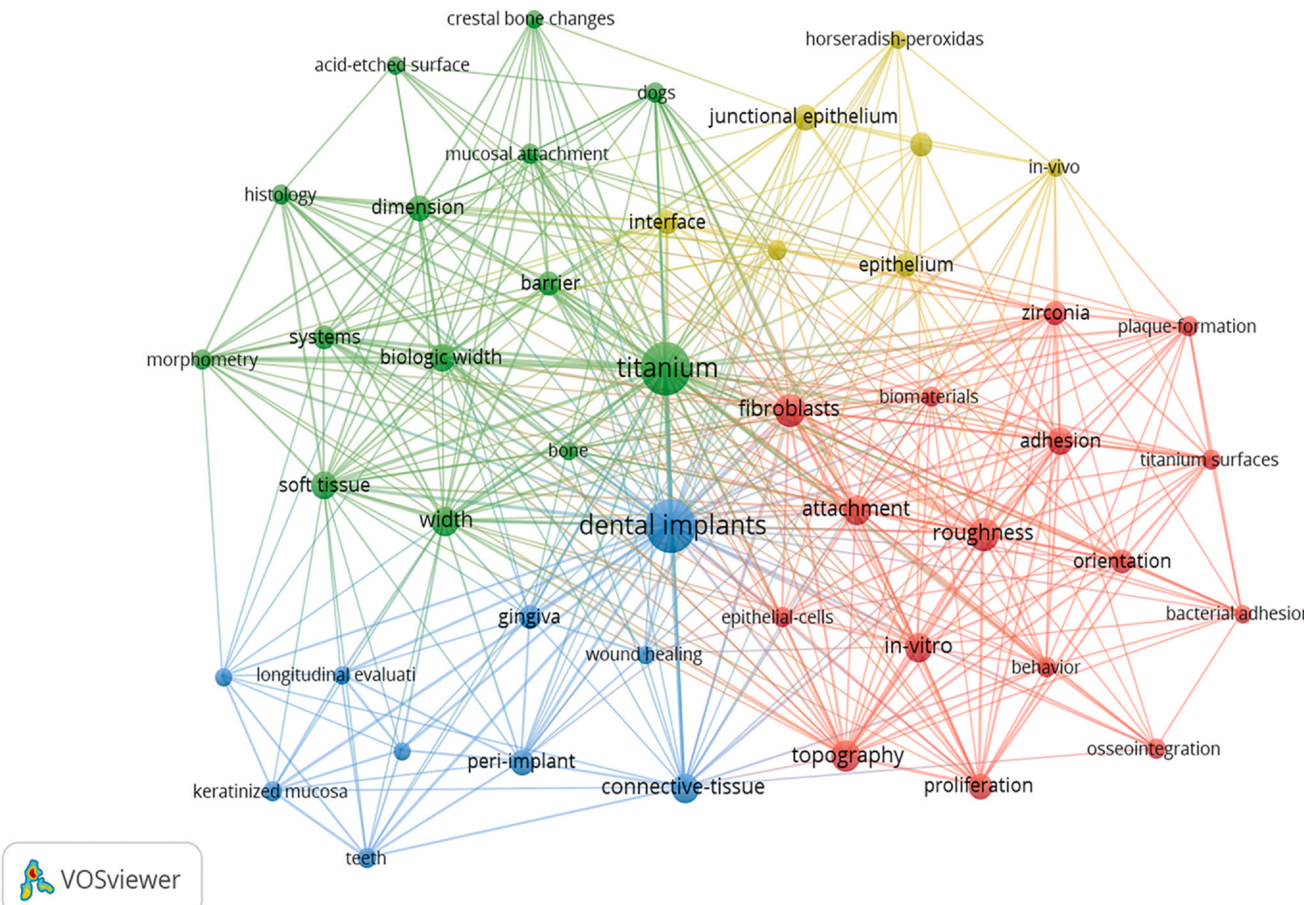

Figure 5. Network map of most used keywords among 50 most cited. Minimum number of occurrences of keyword: three articles. Words that correspond to largest circles are most common. Circles with same color indicate greater interactions between associated keywords.

Asia-Pacific region in recent years, Europe and North America still had a significant technological advantage. Kim et al[28] reported that the number of patent applications in the Asia-Pacific region has increased since 2000, whereas Europe and the United States had more patented dental implant technologies before 2000. Despite the rapid development in the number of dental implant patents and the market in the Asia-Pacific region, research on soft tissue integration of dental implants still lagged behind that of European and North American countries. The impact of soft tissue integration articles from the Asia-Pacific region still needs improvement.

The VOS viewer can be used to construct maps of keywords for a specific research area based on the co-occurrence data and analysis of the relationship of different terms.[29] In this study, the 2 most frequently appearing terms were "dental implants" and "titanium." "Dental implants" represented the main topic of the included papers. Titanium was the most common material used in dental implants and remains the standard for fabrication.[2] Other high-frequency terms included "fibroblasts," "connective tissue," "roughness," and "topography." "Fibroblasts" and "connective tissue" explained the soft tissue integration in relation to gingival fibroblasts and gingival connective tissue from a cellular and tissue perspective. "Roughness" and "topography" were also large nodes, associated with "attachment," "adhesion," and "proliferation," suggesting that altering the roughness and topography of the implant surface affected cell adhesion and proliferation.[30–33] Brunette et al[31] also reported that the roughness and irregularities of dental implant surfaces were associated with the attachment and response of connective tissue.

In the keyword co-occurrence diagram, the green section is mainly related to the influence of material surface on the connective tissue. The yellow section included keywords related to epithelium, such as "junctional epithelium," "basal lamina," "laminin", and "horseradish-peroxidase." Epithelial bonding to the implant is achieved by hemidesmosomes, resulting in a sealing effect. The junctional epithelium attachment to teeth was described as a "biological seal" or "tape," which blocks microbial colonization and infection.[25] Laminin, a main component of hemidesmosomes, and integrin laminin 332 ligation affect hemidesmosome formation and density.[8] The laminin coating has been reported to promote soft tissue integration and sealing of implants.[15,16] Due to the high technical requirements of hard tissue sectioning of implants on the nanometer scale, it is difficult to directly observe the number of hemidesmosomes around the implant under an electron microscope. Therefore, the sealing of inflamed epithelium has been tested using the horseradish peroxidase test.[34] The integration of connective tissue is closely related to fibroblasts. Enhancing the expression of integrins may promote the adhesion of fibroblasts.[12] The connective tissue around the implant includes a central area rich in fibroblasts and a lateral area rich in collagen fibers.[13] Soft tissue integration can be improved by altering the implant surface properties and increasing the expression of human gingival fibroblast adhesion proteins.[14] A structure with microgrooves has been reported to be conducive to connective tissue attachment.[7,11]

In the 50 most cited articles, Ti was the most common implant material used in animal studies and clinical trials. The most widely used surface treatment was alteration of surface roughness, with limited studies on the preparation of new coatings. Most of the coatings were metal compound coatings of Ti and Zr. Only 1 cell study and 1 animal study reported the influence of biological coatings to soft tissue integration on dental implants.[12,24] Future animal studies could explore whether new coatings can significantly enhance soft tissue integration in addition to altering the surface roughness and topography.

Limitations of this paper included that no single term could be used universally to describe soft tissue integration, resulting in various synonyms such as "soft tissue sealing" and "soft tissue attachment." This variability in terminology might have led to missed articles in the search strategy. To mitigate this bias, researchers included synonyms and related terms like "gingival fibroblasts" and "gingival epithelial cells" in the search strategy. However, no criterion is available for whether scientific research is related to soft tissue integration other than manual screening.

CONCLUSIONS

Based on the findings of this bibliometric analysis the following conclusions were drawn:

1. The number of citations to articles on dental implant soft tissue integration is increasing, indicating a strong and growing interest in this field, but it is not statistically associated with the publication year, number of authors, journal impact factors, and authors' h-index.
2. Soft tissue integration is a multidisciplinary field of study involving material science, biomedicine, and dentistry. Implants need to be improved for better soft tissue integration with additional animal studies and clinical trials.

REFERENCES

1. Albrektsson T, Brånemark PI, Hansson HA, Lindström J. Osseointegrated titanium implants: Requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. *Acta Orthop Scand*. 1981;52:155–170.
2. Osman R, Swain M. A critical review of dental implant materials with an emphasis on titanium versus zirconia. *Materials*. 2015;8:932–958.
3. Abdallah MN, Badran Z, Ciobanu O, et al. Strategies for optimizing the soft tissue seal around osseointegrated implants. *Adv Heal Mater*. 2017;6:e1700549.
4. Ivanovski S, Lee R. Comparison of peri-implant and periodontal marginal soft tissues in health and disease. *Periodontol 2000*. 2018;76:116–130.
5. Pecora GE, Ceccarelli R, Bonelli M, et al. Clinical evaluation of laser microtexturing for soft tissue and bone attachment to dental implants. *Implant Dent*. 2009;18:57–61.
6. Atsuta I, Ayukawa Y, Kondo R, et al. Soft tissue sealing around dental implants based on histological interpretation. *J Prosthodont Res*. 2016;60:3–11.
7. Nevins M, Nevins ML, Camelo M, et al. Human histologic evidence of a connective tissue attachment to a dental implant. *Int J Periodontics Restor Dent*. 2008;28:111–121.
8. Fischer NG, Aparicio C. Junctional epithelium and hemidesmosomes: Tape and rivets for solving the "percutaneous device dilemma" in dental and other permanent implants. *Bioact Mater*. 2022;18:178–198.
9. Lindhe J, Berglundh T. The interface between the mucosa and the implant. *Periodontol 2000*. 1998;17:47–54.
10. Guo T, Gulati K, Arora H, et al. Race to invade: Understanding soft tissue integration at the transmucosal region of titanium dental implants. *Dent Mater*. 2021;37:816–831.
11. Nevins M, Kim DM, Jun SH, et al. Histologic evidence of a connective tissue attachment to laser microgrooved abutments: A canine study. *Int J Periodontics Restor Dent*. 2010;30:245–255.
12. Liu M, Zhou J, Yang Y, et al. Surface modification of zirconia with polydopamine to enhance fibroblast response and decrease bacterial activity in vitro: A potential technique for soft tissue engineering applications. *Colloids Surf B Biointerfaces*. 2015;136:74–83.
13. Moon I, Berglundh T, Abrahamsson I, et al. The barrier between the keratinized mucosa and the dental implant - An experimental study in the dog. *J Clin Periodontol*. 1999;26:658–663.
14. Riivari S, Närvä E, Kangasniemi I, et al. Focal adhesion formation of primary human gingival fibroblast on hydrothermally and in-sol-made TiO_2-coated titanium. *Clin Implant Dent Relat Res*. 2023;25:583–591.
15. Liu Z, Ma S, Lu X, et al. Reinforcement of epithelial sealing around titanium dental implants by chimeric peptides. *Chem Eng J*. 2019;356:117–129.
16. Tamura RN, Oda D, Quaranta V, et al. Coating of titanium alloy with soluble laminin-5 promotes cell attachment and hemidesmosome assembly in gingival epithelial cells: Potential application to dental implants. *J Periodontal Res*. 1997;32:287–294.
17. Donthu N, Kumar S, Mukherjee D, et al. How to conduct a bibliometric analysis: An overview and guidelines. *J Bus Res*. 2021;133:285–296.
18. Ellegaard O, Wallin JA. The bibliometric analysis of scholarly production: How great is the impact? *Scientometrics*. 2015;105:1809–1831.
19. Praveen G, Chaithanya R, Alla RK, et al. The 100 most cited articles in prosthodontic journals: A bibliometric analysis of articles published between 1951 and 2019. *J Prosthet Dent*. 2020;123:724–730.
20. Borges GA, Dini C, Medeiros MMDD, et al. Funding assistance and global productivity in the field of implant overdentures: A bibliometric analysis of 35 years. *J Prosthet Dent*. 2023;130:553–563.
21. Lorusso F, Noumbissi S, Francesco I, et al. Scientific trends in clinical research on zirconia dental implants: A bibliometric review. *Materials*. 2020;13:5534.
22. Alonso-Arroyo A, Tarazona-Alvarez B, Lucas-Dominguez R, et al. The funding sources of implantology research in the period 2008–2017: A bibliometric analysis. *Clin Implant Dent Relat Res*. 2019;21:708–714.
23. Scarano A. The impact of diabetes in implant oral rehabilitations: A bibliometric study and literature review. *Acta Medica Mediterr*. 2020;6:3333–3344.
24. Werner S, Huck O, Frisch B, et al. The effect of microstructured surfaces and laminin-derived peptide coatings on soft tissue interactions with titanium dental implants. *Biomaterials*. 2009;30:2291–2301.
25. Abrahamsson I, Zitzmann N, Berglundh T, et al. The mucosal attachment to titanium implants with different surface characteristics: An experimental study in dogs. *J Clin Periodontol*. 2002;29:448–455.
26. Jayasree A, Cartmell S, Ivanovski S, Gulati K. Electrically stimulated dental implants triggers soft-tissue integration and bactericidal functions. *Adv Funct Mater*. 2024;34:e2311027.

27. Aksnes DW. Characteristics of highly cited papers. *Research Evaluation*. 2003;12:159–170.
28. Kim WJ, Cho YD, Ku Y, Ryoo HM. The worldwide patent landscape of dental implant technology. *Biomater Res*. 2022;26:59.
29. Van Eck NJ, Waltman L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*. 2010;84:523–538.
30. Gittens RA, Scheideler L, Rupp F, et al. A review on the wettability of dental implant surfaces II: Biological and clinical aspects. *Acta Biomater*. 2014;10:2907–2918.
31. Kim H, Murakami H, Chehroudi B, et al. Effects of surface topography on the connective tissue attachment to subcutaneous implants. *Int J Oral Maxillofac Implants*. 2006;21:354–365.
32. Schwarz F, Ferrari D, Herten M, et al. Effects of surface hydrophilicity and microtopography on early stages of soft and hard tissue integration at non-submerged titanium implants: An immunohistochemical study in dogs. *J Periodontol*. 2007;78:2171–2184.
33. Lauer G, Wiedmann-Al-Ahmad M, Otten J, et al. The titanium surface texture effects adherence and growth of human gingival keratinocytes and human maxillar osteoblast-like cells in vitro. *Biomaterials*. 2001;22:2799–2809.
34. Wang WR, Li J, Gu JT, et al. Optimization of lactoferrin-derived amyloid coating for enhancing soft tissue seal and antibacterial activity of titanium implants. *Adv Healthc Mater*. 2023;12:e2203086.

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