Critical Review
Dentistry

Application of lasers in dentistry: a bibliometric study of the top 100 most-cited papers

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Abstract: This bibliometric study analyzed the 100 most-cited papers about the use of lasers and their modalities in dentistry. A search strategy was created using specific keywords related to the topic. A comprehensive search was then conducted in the Web of Science Core Collection (WoS-CC) database up to July 2021. Papers that addressed the application of any type of laser and its modalities in dentistry were included. Each paper was cross-matched with the number of citations on Scopus and Google Scholar. The following data were extracted from papers: title, number of citations, authorship, country, year of publication, journal, study design, subject, laser type, and oral health outcomes. The VOSviewer software was used to generate bibliometric networks. The total number of citations ranged from 120 to 4,124 and 23 papers received more than 200 citations. Papers were published from 1964 to 2015. Most papers were from Europe (42%) and Anglo-Saxon America (27%). The USA was the country with more top 100 papers (25%). Papers were published mainly in *Lasers in Surgery and Medicine* (15%) and *Lasers in Medical Science* (7%). VOSviewer maps demonstrated the existence of national and international research collaborations among institutions and authors. Most studies had a laboratory design (57%) and were about restorative dentistry (32%) and periodontics (21%). This bibliometric study of the top 100 most-cited papers on lasers in dentistry allowed a quantitative and qualitative analysis of this very promising research field, revealing a net of collaboration and the importance of this topic in dentistry.

Keywords: Bibliometrics; Index; Laser Therapy.

Declaration of Interests: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

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https://doi.org/10.1590/1807-3107bor-2022.vol36.0104

Submitted: April 26, 2021
Accepted for publication: November 3, 2021
Last revision: March 25, 2022

Introduction

It is currently recognized that oral diseases have become a worldwide epidemic and a major public health problem that affects the population and causes great impacts on vital oral functions, self-esteem, and quality of life.[1,2] A wide range of diseases and disorders affects the soft and hard tissues of the craniofacial complex. For instance, oral cancer is the 8th most common cancer globally, while dental caries and periodontal disease are highly prevalent throughout the life course.[3-7]

The introduction of lasers in the health field, specifically applied in the oral cavity, gave researchers and clinicians an opportunity to provide a new perspective for the treatment and management of oral diseases; and monochromaticity, directionality, and coherence are the main characteristics of lasers, with two different types based on applicability.[1,8] Lasers have a wide range of applications, such as tissue ablation and surgical procedures, using, classically, high-power lasers, such as Nd:YAG, diodes, and Er:YAG.[9] On the other hand, when laser therapy focuses on biological functions (i.e., tissue repair), regeneration and/or modulation of the inflammation, and pain process, it is then referred to as photobiomodulation therapy (PBMT), which includes the acronyms LLLT and LED for low-level laser therapy and light-emitting diode therapy.[10] PBMT devices have an output below 500mW and the combined use of both laser types comprises, in an adjuvant manner, practically, all oral disorders in different fields of dentistry. Still, other two laser technology modalities are currently used: a) the antimicrobial photodynamic therapy (APT), commonly known as photodynamic therapy (PDT), which focuses on oral decontamination using a combination of oxygen, a photosensitizing drug (*i.e.*, dyes), and a light source, resulting in cytotoxic compounds that are able to kill microorganisms; and b) laser-induced fluorescence for dental caries diagnosis and caries detection, which detects changes in the organic content of an early carious lesion.[11-13]

Considering the versatility of lasers, the number of scientific publications in the health sciences field, especially in dentistry, has grown progressively. Yet, to conduct a commendable literature review and to determine the academic importance of an article or research group and its impact on research is not an easy task. One way to do that is by employing bibliometric analysis.[14] Bibliometric analysis provides a quantitative review of the literature in any field of research based on the citation frequency of the conducted research. This analysis identifies organizations, institutions, international partnerships, and authors affiliated with the most prominent scientific investigations.[15] Moreover, this approach can demonstrate the association between the impact and growth of a specific subject, detect knowledge trends, recognize key study topics and study types, and investigate updated ideas and concepts.[16] A bibliometric analysis is justified because citations are an indicator of the scientific impact of a paper, journal, researcher, and/or investigation group.

To the best of our knowledge and according to the literature review, an analysis of the most-cited articles on lasers and its modalities applied in dentistry has not been performed yet. Therefore, in order to highlight the most-cited authors, centers of excellence, prominent topics, and study types in the laser field over time, the aim of this study was to perform a bibliometric analysis of the 100 most-cited articles about the application of lasers in dentistry.

Methodology

A bibliometric study was carried out in July 14, 2021 to retrieve and analyze the 100 most-cited papers on laser use in dentistry. A comprehensive search was conducted in the Web of Science Core Collection (WoS-CC) database in the category "Dentistry, Oral Surgery & Medicine" using the following search strategy: TS= (laser OR photobiomodulation OR PBM OR PBMT) AND TS= (mouth OR tooth OR teeth OR gingiva* OR facial OR maxilla* OR mandib* OR alveol* OR periodont* OR dent* OR oral OR odont*). There were no restrictions on language or on year of publication.

The resultant list of papers was arranged in decreasing order by the number of citations in WoS-CC. A panel of four researchers selected the papers. Disagreement about paper inclusion or exclusion was resolved by consensus. Papers addressing the study and/or application of any type of laser and its modalities in dentistry were included. Conference papers were excluded. The selection was concluded when the 100th most-cited paper was retrieved. On the same day, a cross-match with the number of citations of each paper on the top 100 list was conducted in Scopus and Google Scholar databases for further comparisons.

The following bibliometric parameters were extracted from each paper: title of the paper, number of citations in WoS-CC, Scopus, and Google Scholar, WoS-CC citation density (mean number of citations received per year),[17] authorship (names, number), country and continent (based on the affiliation of the corresponding author at the time of the publication), year of publication, the title of the journal, study design, subject, type of laser used, and oral health outcomes. The data were double-checked for accuracy. The final position of papers on the top 100 list was based on the highest number of citations in WoS-CC. In case of a tie, the position of a paper on the list was based on the highest WoS-CC citation density, followed by the highest number of citations in Scopus.

The study designs were classified according to the Cochrane Collaboration Glossary as laboratory-based studies (*in vitro*, *in vivo*, *in situ*, *ex vivo*), randomized clinical trial, non-randomized clinical trial, case report, observational studies (cross-sectional, case-control, or cohort studies), non-systematic reviews, and systematic reviews/meta-analysis. Based on the study subject, the papers were grouped into the following subjects: basic sciences, endodontics, orthodontics, pathology/stomatology, periodontics, restorative dentistry (including cariology and diagnostics), and mixed (when at least two specialties were involved). Oral health outcomes were grouped as dental bleaching, dental caries, dental hypersensitivity, necrosis/periapical lesions, oral cancer, oral lesions, oral mucositis, orthodontic movement, periodontal diseases, and peri-implantitis.

The VOSviewer software was used to generate co-authorship and keyword maps. On the co-authorship map, authors are linked to each other based on the number of co-authored papers. The software assigns the nodes in a network to clusters; therefore, a cluster is a set of closely related nodes.[18] Each cluster was represented by a color. More important terms had more intense colors and strongly related terms were closer to each other.[18] On the keyword map, an overlay visualization was set, where node colors ranged from blue (keywords used in older papers) to red (keywords used in recent papers).

Data analysis was performed using the statistical software package SPSS for Windows (SPSS, version 24.0, IBM Corp, Chicago, USA). The Kolmogorov-Smirnov test was used to assess the normality of data distribution. As the data were not normally distributed, Spearman's rank correlation coefficient test was used to assess the correlations among the number of citations of papers in each database. The significance level was set at 5%.

Results

The search strategy in WoS-CC yielded a total of 25,109 papers. After displaying the list in decreasing order by the number of citations, some papers were excluded for not focusing on laser applications in dentistry or for being conference papers. The 100 most-cited papers on the use of lasers in dentistry are listed in Table 1. These papers received a total of 21,627 citations in WoS-CC (range: 120 to 4,124). Two papers received more than 1,000 citations and 23 papers received more than 200 citations. Self-citations corresponded to 1.38% of the total citations. Besides, the top 100 papers received 23,813 citations in Scopus and 40,955 citations in Google Scholar. Positive correlations were found between the number of citations in WoS-CC and Scopus ($r = 0.93$; $p < 0.001$) and WoS-CC and Google Scholar ($r = 0.75$; $p < 0.001$). The oldest paper was published in 1964 and the most recent was published in 2015. Most papers were published between 2000 and 2010 (55%). The most-cited paper was "Cancer cell imaging and photothermal therapy in the near-infrared region by using gold nanorods", by Huang et al. [19] with 4,124 citations in WoS-CC, 4,335 in Scopus, and 5,446 in Google Scholar published in the Journal of the American Chemical Society in 2006. These authors were from the University of California, USA.

The majority of the most-cited papers was from Europe (42 papers; 7,490 citations) followed by Anglo-Saxon America (27 papers; 9,253 citations), and Asia (21 papers; 3,226 citations). Latin America was represented only by Brazil (seven papers; 1,192 citations). On the other hand, Africa was the only continent with no papers. Furthermore, the USA (25 papers; 8,988 citations), Japan (15 papers; 2,383 citations), and Germany (11 papers; 2,284 citations) were the countries with most-cited papers (Figure 1). Tokyo Medical and Dental University, Japan (seven papers; 1,1201 citations) was the institution with most top 100 papers, followed by the University of California, the USA (four papers; 5,442 citations) and

Table 1. The 100 most-cited papers on the use of lasers in dentistry.

Rank	Paper	Number of citations (Citation density[a])			
		Web of Science	Scopus	Google Scholar	Mean citations[b]
1	Huang X, El-Sayed IH, Qian W, El-Sayed MA. Cancer cell imaging and photothermal therapy in the near-infrared region by using gold nanorods. J Am Chem Soc. 2006 Feb; 128 (6): 2115-20. doi: 10.1021/ja057254a. PMID: 16464114.	4,124 (257.75)	4,335 (270.94)	5,446 (340.38)	260.33
2	El-Sayed IH, Huang X, El-Sayed MA. Selective laser photo-thermal therapy of epithelial carcinoma using anti-EGFR antibody conjugated gold nanoparticles. Cancer Lett. 2006 Jul; 239 (1): 129-35. doi: 10.1016/j.canlet.2005.07.035. Epub 2005 Sep 28. PMID: 16198049.	1,011 (202.20)	1,090 (218.00)	1,572 (314.40)	161.67
3	Hibst R, Keller U. Experimental studies of the application of the er yag laser on dental hard substances .1. Measurement of the ablation rate. Lasers Surg Med. 1989 ; 9 (4) : 338-44. doi: 10.1002/lsm.1900090405. PMID: 2761329.	571 (95.17)	667 (111.17)	1,172 (195.33)	151.00
4	Keller U, Hibst R. Experimental studies of the application of the er yag laser on dental hard substances. 2. Light microscopic and sem investigations. Lasers Surg Med. 1989; 9 (4): 345-51. doi: 10.1002/lsm.1900090406. PMID: 2503667.	381 (63.50)	434 (72.33)	757 (126.17)	243.00
5	Lussi A, Imwinkelried S, Pitts N, Longbottom C, Reich E. Performance and reproducibility of a laser fluorescence system for detection of occlusal caries in vitro. Caries Res. 1999 Jul-Aug ; 33 (4): 261-66. doi: 101159/000016527. PMID: 10343088.	289 (41.29)	332 (47.43)	619 (88.43)	190.33
6	Wigdor HA, Walsh Jr JT, Featherstone D, Visuri SR, Fried D, Waldvogel JL. Lasers in Dentistry. Lasers Surg Med. 1995; 16 (2): 103-33. doi: 10.1002/lsm.1900160202. PMID: 7769957.	289 (41.29)	341 (48.71)	606 (86.57)	174.00
7	Almeida-Lopes L, Rigau J, Zângaro RA, Guidugli-Neto J, Jaeger MM. Comparison of the low level laser therapy effects on cultured human gingival fibroblasts proliferation using different irradiance and same fluence. Lasers Surg Med.2001 ; 29 (2): 179-84. doi: 10.1002/lsm.1107. PMID: 11553908.	287 (31.89)	306 (34.00)	556 (61.78)	210.00
8	Pereira AN, Eduardo CA, Matson E, Marques MM. Effect of low-power laser irradiation on cell growth and procollagen synthesis of cultured fibroblasts. Lasers Surg Med. 2002; 31 (4): 263-67. doi: 10.1002/lsm.10107. PMID: 12355572.	259 (28.78)	291 (32.33)	523 (58.11)	160.67
9	Fowler BO, Kuroda S. Changes in heated and in laser-irradiated human tooth enamel and their probable effects on solubility. Calcif Tissue Int. 1986 Apr; 38 (4): 197-208. doi : 10.1007/BF02556711. PMID: 3011230.	250 (27.78)	263 (29.22)	423 (47.00)	154.67
10	Lussi A, Megert B, Longbottom C, Reich E, Francescut P. Clinical performance of a laser fluorescence device for detection of occlusal caries lesions. Eur J Oral Sci. 2001 Feb; 109 (1): 14-19. doi: 10.1034/j.1600-0722.2001.109001014.x. PMID: 11330928.	247 (22.45)	282 (25.64)	556 (50.55)	164.33
11	Aoki A, Ishikawa I, Yamada T, Otsuki M, Watanabe H, Tagami J, Ando Y, Yamamoto H. Comparison between Er : YAG laser and conventional technique for root caries treatment in vitro. J Dent Res. 1998 Jun; 77 (6): 1404-14. doi: 10.1177/00220345980770060501. PMID: 9649169.	233 (21.18)	259 (23.55)	427 (38.82)	174.67
12	Aoki A, Sasaki KM, Watanabe H, Ishikawa I. Lasers in nonsurgical periodontal therapy. Periodontol 2000. 2004; 36 (1): 59-97. doi: 10.1111/j.1600-0757.2004.03679.x. PMID: 15330944.	232 (19.33)	269 (22.42)	582 (48.50)	191.00
13	Ceballo L, Toledano M, Osorio R, Tay FR, Marshall GW. Bonding to Er-YAG-laser-treated dentin. J Dent Res. 2002 Feb; 81 (2): 119-22. PMID: 11827256.	226 (18.83)	240 (20.00)	389 (32.42)	243.67
14	Visuri SR, Gilbert JL, Wright DD, Wigdor HA, Walsh Jr JT. Shear strength of composite bonded to Er:YAG laser-prepared dentin. J Dent Res. 1996 Jan ; 75 (1) : 599-605. doi: 101177/00220345960750011401. PMID: 8655766.	225 (18.75)	239 (19.92)	430 (35.83)	164.00
15	Komerik N, Nakanish H, MacRobert AJ, Henderson B, Speight P, Wilson M. In vivo killing of Porphyromonas gingivalis by toluidine blue-mediated photosensitization in an animal model. Antimicrob Agents Chemother. 2003 Mar; 47 (3): 932-40. doi: 10.1128/AAC.47.3.932-940.2003. PMID: 12604524.	221 (22.10)	244 (24.40)	397 (39.70)	99.33
16	Grant WE, Hopper C, MacRobert AJ, Speight PM, Bown SG. Photodynamic therapy of oral-cancer - photosensitization with systemic aminolevulinic acid. Lancet. 1993 Jul; 17: 147-8. doi: 10.1016/0140-673 (93)91347-o. PMID: 7687318.	221 (18.42)	233 (19.42)	316 (26.33)	185.67
17	Mackey MA, Ali MRK, Austin LA, Near RD, El-Sayed M. The most effective gold nanorod size for plasmonic photothermal therapy: theory and in vitro experiments. J Phys Chem B. 2014 Feb; 118 (5): 1319-26. doi : 10.1021/jp409298f. Epub 2014 Jan 23. PMID: 24433049.	218 (19.82)	235 (21.36)	276 (25.09)	175.67

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18	Shi XQ, Welander U, Angmar-Mansson B. Occlusal caries detection with KaVo DIAGNOdent and radiography: an in vitro comparison. Caries Res. 2000 Mar-Apr; 34 (2): 151-8. doi : 10.1159/000016583. PMID: 10773633.	213 (17.75)	254 (21.17)	430 (35.83)	197.67
19	Kawasaki K, Shimizu N. Effects of low-energy laser irradiation on bone remodeling during experimental tooth movement in rats. Lasers Surg Med. 2000; 26 (3): 282-91. doi: 10.1002/ (sici)1096-9101 (2000)26:3<282::aid-lsm6>3.0.co;2-x. PMID: 10738291.	211 (16.23)	237 (18.23)	436 (33.54)	247.00
20	Martínez-Insua A, Dominguez LDS, Rivera FG, Santana-Penín UA. Differences in bonding to acid-etched or Er : YAG-laser-treated enamel and dentin surfaces. J Prosthet Dent. 2000 Sep; 84 (3): 280-8. doi : 10.1067/mpr.2000.108600. PMID: 11005900.	207 (17.25)	219 (18.25)	374 (31.17)	171.67
21	Huang X, Qian W, El-Sayed IH, El-Sayed MA. The potential use of the enhanced nonlinear properties of gold nanospheres in photothermal cancer therapy. Lasers Surg Med. 2007 Oct; 39 (9): 747-53. doi : 10.1002/lsm.20577. PMID: 17960762.	206 (17.17)	227 (18.92)	308 (25.67)	160.00
22	Muller MG, Valdez TA, Georgakoud I, Backman V, Fuentes C, Kabani S, Laver N, Wang Z,Boone CW, Dasari RR, Shapshay SM, Feld MS. Spectroscopic detection and evaluation of morphologic and biochemical changes in early human oral carcinoma. Cancer. 2003 Apr; 97 (7): 1681-92. doi: 10.1002/cncr.11255. PMID: 12655525.	200 (15.38)	218 (16.77)	350 (26.92)	180.67
23	Ando Y, Aoki A, Watanabe H, Ishikawa I. Bactericidal effect of erbium YAG laser on periodontopathic bacteria. Lasers Surg Med. 1996; 19 (2): 190-200. doi :10.1002/ (SICI)10969101 (1996)19:2<190::AID-LSM11>3.0.CO;2-B. PMID:8887923.	200 (15.38)	235 (18.08)	472 (36.31)	179.33
24	Buchalla W, Attin T. External bleaching therapy with activation by heat, light or laser - A systematic review. Dent Mater. 2007 May; 23 (5): 586-96. doi: 10.1016/j.dental.2006.03.018. Epub 2006 Jul 3. PMID: 16820199.	198 (16.50)	242 (20.17)	571 (47.58)	200.33
25	Zanin ICJ, Gonçalves RB, Brugnera Junior A, Hope CK, Pratten J. Susceptibility of Streptococcus mutans biofilms to photodynamic therapy: an in vitro study. J Antimicrob Chemother.2005 Aug; 56 (2):324-30. doi: 10.1093/jac/dki232. Epub 2005 Jun 27. PMID: 15983029.	195 (15.00)	209 (16.08)	350 (26.92)	203.67
26	Wilson M. Lethal photosensitisation of oral bacteria and its potential application in the photodynamic therapy of oral infections. Photochem Photobiol Sci. 2004 May; 3 (5): 412-8. doi: 10.1039/b211266c. Epub 2004 Feb 5. PMID: 15122357.	194 (14.92)	217 (16.69)	404 (31.08)	337.00
27	Jong EJ, Sundström F, Westerling H, Tranaeus S, ten Bosch JJ, Angmar-Mansson B. A new method for in-vivo quantification of changes in initial enamel caries with laser fluorescence. Caries Res. 1995; 29 (1): 2-7. doi: 10.1159/000262032. PMID: 7867045.	189 (13.50)	212 (15.14)	247 (17.64)	294.67
28	Cobb CM. Lasers in periodontics: A review of the literature. J Periodontol 2006 Apr; 77 (4): 545-64. doi: 10.1902/jop.2006.050417. PMID: 16584335	180 (12.86)	211 (15.07)	493 (35.21)	4635.00
29	Bader JD, Shugars DA. A systematic review of the performance of a laser fluorescence device for detecting caries. J Am Dent Assoc. 2004 Oct; 135 (10): 1413-26. doi: 10.14219/jada.archive.2004.0051. PMID: 15551982	179 (12.79)	205 (14.64)	397 (28.36)	1224.33
30	Kimura Y. Wilder-Smith P. Yonaga K. Matsumoto K. Treatment of dentine hypersensitivity by lasers: a review. J Clin Periodontol. 2000 Oct; 27 (10): 715-21. doi: 10.1034/j.1600-051x.2000.027010715.x. PMID: 11034117.	179 (11.93)	218 (14.53)	437 (29.13)	251.33
31	Mehl A, Gloger W, Kunzelmann KH, Hickel R. A new optical 3-D device for the detection of wear. J Dent Res. 1997 Nov; 76 (11): 1799-807. doi: 10.1177/00220345970760111201. PMID: 9372798.	179 (11.93)	197 (13.13)	329 (21.93)	190.67
32	Visuri SR, Walsh Jr JT, Wigdor HA. Erbium laser ablation of dental hard tissue: effect of water cooling. Lasers Surg Med. 1996 ; 18 (6): 294-300. doi: 10.1002/ (SICI)1096-9101 (1996)18 :3<294 ::AID-LSM11>3.0.CO ;2-6. PMID: 8778525.	177 (11.80)	188 (12.53)	284 (18.93)	199.67
33	Burkes Jr EJ, Hoke J, Gomes E, Wolbarsht M. Wet versus dry enamel ablation by er-yag laser. J Prosthet Dent. 1992 Jun; 67 (6): 847-51. doi: 10.1016/0022-3913 (92)90599-6. PMID: 1403876	176 (11.73)	204 (13.60)	373 (24.87)	171.00
34	Kim YD, Kim SS, Kim SJ, Kwon DW, Jeon ES, Son WS. Low-level laser irradiation facilitates fibronectin and collagen type I turnover during tooth movement in rats. Lasers Med Sci. 2010 Jan; 25 (1): 25-31. doi : 10.1007/s10103-008-0585-8. Epub 2008 Jul 4. PMID: 18600290.	174 (10.88)	41 (2.56)	83 (5.19)	230.00
35	Keller U, Hibst R, Geurtsen W, Schilke R, Heidemann D, Klaiber B, Raab WH. Erbium : YAG laser application in caries therapy. Evaluation of patient perception and acceptance. J Dent. 1998 Nov; 26 (8): 649-56. doi:10.1016/s0300-5712 (97)000365. PMID: 9793286.	174 (10.88)	192 (12.00)	358 (22.38)	242.00

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36	Braun A, Dehn C, Krause F, Jepsen S. Short-term clinical effects of adjunctive antimicrobial photodynamic therapy in periodontal treatment: a randomized clinical trial. J Clin Periodontol. 2008 Oct ; 35 (10): 877-84. doi: 10.1111/j.1600-051X.2008.01303.x. Epub 2008 Aug 17. PMID: 18713259.	171 (10.69)	189 (11.81)	371 (23.19)	361.00
37	Sakurai Y, Yamaguchi M, Abiko Y. Inhibitory effect of low-level laser irradiation on LPS-stimulated prostaglandin E-2 production and cyclooxygenase-2 in human gingival fibroblasts. Eur J Oral Sci. 2000 Feb;108 (1):29-34. doi: 10.1034/j.1600-0722.2000.00783.x. PMID: 10706474.	170 (10.63)	193 (12.06)	368 (23.00)	178.00
38	Fan KF, Hopper C. Speight PM, Buonaccorsi G, MacRobert AJ, Bown SG. Photodynamic therapy using 5-aminolevulinic acid for premalignant and malignant lesions of the oral cavity. Cancer. 1996 Oct; 78 (7): 1374-83. doi : 10.1002/ (SICI)1097-0142 (19961001)78:7<1374 ::AID-CNCR2>3.0.CO;2-L. PMID: 8839541.	169 (10.56)	173 (10.81)	233 (14.56)	166.67
39	Featherstone JD, Barrett-Vespone NA, Fried D, Kantorowitz Z, Seka W. CO2 laser inhibition of artificial caries-like lesion progression in dental enamel. J Dent Res. 1998 Jun ; 77 (6): 1397-403. doi: 10.1177/00220345980770060401. PMID: 9649168.	168 (10.50)	186 (11.63)	329 (20.56)	169.33
40	Aoki A, Ando Y, Watanabe H, Ishikawa I. In-vitro studies on laser scaling of subgingival calculus with an erbium-yag laser. J Periodontol. 1994. Dec; 65 (12): 1097-106. doi: 10.1902/jop.1994.65.12.1097. PMID: 7877081.	165 (10.31)	176 (11.00)	358 (22.38)	271.67
41	Dobson J, Wilson M. Sensitization of oral bacteria in biofilms to killing by light from a low-power laser. Arch Oral Biol. 1992 Nov; 37 (11): 883-7. doi: 10.1016/0003-9969 (92)90058-g. PMID: 1334649.	164 (10.25)	177 (11.06)	340 (21.25)	240.00
42	Moritz A, Schoop U, Goharkhay K, Schauer P, Doertbudak O, Wernisch J, Sperr W. Treatment of periodontal pockets with a diode laser. Laser Surg Med. 1998; 22 (5): 302-11. doi: 10.1002/ (sici)1096-9101 (1998)22:5<302::aid-lsm7>3.0.co ;2-t. PMID: 9671997.	160 (9.41)	206 (12.12)	417 (24.53)	265.33
43	Walsh LJ. The current status of low level laser therapy in dentistry .1. Soft tissue applications. Aust Dent J. 1997 Aug; 42 (4): 247-54. doi: 10.1111/j.1834-7819.1997. tb00129.x. PMID: 9316312.	158 (9.29)	190 (11.18)	428 (25.18)	208.33
44	Schoop U, Kluger W, Moritz A, Nedjelik N, Georgopoulos A, Sperr Wolfgang. Bactericidal effect of different laser systems in the deep layers of dentin. Lasers Surg Med. 2004; 35 (2):111-6. doi : 10.1002/lsm.20026. PMID: 15334613.	156 (2.79)	179 (3.20)	391 (6.98)	269.33
45	Van Meerbeek BV, Munck JD, Mattar D, Van Landuyt K, Lambrechts P. Microtensile bond strengths of an etch&rinse and self-etch adhesive to enamel and dentin as a function of surface treatment. Oper Dent. 2003 Sep-Oct; 28 (5): 647-60. PMID: 14531614.	155 (9.12)	169 (9.94)	301 (17.71)	202.67
46	Walsh LJ. The current status of laser applications in dentistry. Aust Dent J. 2003 Sep; 48 (3): 146-55 quiz 198. doi: 10.1111/j.1834-7819.2003.tb00025x. PMID: 14640367.	154 (9.06)	188 (11.06)	454 (26.71)	256.00
47	Nelson DG, Wefel JS, Jongebloed WL, Featherstone JD. Morphology, histology and crystallography of human dental enamel treated with pulsed low-energy infrared-laser radiation. Caries Res. 1987; 21 (5): 411-26. doi: 10.1159/000261047. PMID: 3477323.	154 (9.06)	155 (9.12)	279 (16.41)	215.67
48	Wilson M. Photolysis of oral bacteria and its potential use in the treatment of caries and periodontal-disease. J Appl Bacteriol. 1993 Oct; 75 (4): 299-306. Doi: 10.1111/j.1365-2672.1993.tb02780.x. PMID: 8226389.	147 (8.65)	165 (9.71)	277 (15.39)	287.33
49	Wigdor H, Abt E, Ashrafi S, Walsh Jr JT. The effect of lasers on dental hard tissues. J Am Assoc. 1993 Feb; 124 (2): 65-70. doi : 10.14219/jada.archive.1993.0041. PMID: 8429186.	147 (8.65)	165 (9.71)	340 (20.00)	160.67
50	Cruz DR, Kohara EK, Ribeiro MS, Wetter NU. Effects of low intensity laser therapy on the orthodontic movement velocity of human teeth: a preliminary study. Lasers Surg Med. 2004; 35 (2): 117-20. doi: 10.1002/lsm.20076. PMID : 15334614.	145 (8.06)	167 (9.28)	378 (21.00)	357.67
51	Dortbudak O, Hass R, Bernhart T, Mailath-Pokorny. Lethal photosensitization for decontamination of implant surfaces in the treatment of peri-implantitis. Clin Oral Implants Res. 2001 Apr; 12 (2): 104-8. doi: 10.1034/j.1600-0501.2001.012002104.x. PMID: 11251658.	144 (8.00)	171 (9.50)	352 (19.56)	182.33
52	Gursoy H, Ozcakir-Tomruk C, Tanalp J, Yilmaz S. Photodynamic therapy in dentistry: a literature review. Clin Oral Investig. 2013 May; 17 (4): 1113-25. doi: 10.1007/s00784-012-0845-7.PMID: 23015026.	143 (7.94)	159 (8.83)	269 (14.94)	285.00

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53	Munck JD, Van Meerbeek B, Yudhira R, Lambrechts P, Vanherle G. Micro-tensile bond strength of two adhesives to Erbium : YAG-lased vs. bur-cut enamel and dentin. Eur J Oral Sci. 2002 Aug; 110 (4): 322-9. doi: 10.1034/j.1600-0722.2002.21281.x. PMID: 12206595.	143 (7.53)	157 (8.26)	247 (13.00)	383.00
54	Cowen D, Tardieu C, Schubert M, Peterson D, Resbeut M, Faucher C, Franquin C. Low energy helium-neon laser in the prevention of oral mucositis in patients undergoing bone marrow transplant: results of a double blind randomized trial. Int J Radiat Oncol Biol Phys. 1997 Jul; 38 (4): 697-703. doi: 10.1016/s0360-3016 (97)00076-x. PMID: 9240635.	143 (7.53)	179 (9.42)	302 (15.89)	361.67
55	Garcez A, Ribeiro MS, Tegos GP, Nunez SC, Jorge AOC, Hamblin MR. Antimicrobial photodynamic therapy combined with conventional endodontic treatment to eliminate root canal biofilm infection. Lasers Surg Med. 2007 Jan; 39 (1): 59-66. doi: 10.1002/lsm.20415. PMID: 17066481.	142 (7.47)	161 (8.47)	308 (16.21)	195.67
56	Luk K, Tam L, Hubert M. Effect of light energy on peroxide tooth bleaching. J Am Dent Assoc. 2004 Feb; 135 (2): 194-201 ; quiz 228-9. doi: 10.14219/jada.archive.2004.0151. PMID: 15005435.	142 (7.10)	178 (8.90)	400 (20.00)	212.00
57	Chan Y, Lai CH. Bactericidal effects of different laser wavelengths on periodontopathic germs in photodynamic therapy. Lasers Med Sci. 2003; 18 (1): 51-5. doi: 10.1007/s10103-002-0243-5. PMID: 12627274.	142 (7.47)	166 (8.74)	339 (17.84)	222.33
58	Schwarz F, Sculean A, Rothamel D, Schwenzer K, Georg T, Becker J. Clinical evaluation of an Er: YAG laser for nonsurgical treatment of peri-implantitis: a pilot study. Clin Oral Implants Res. 2005 Feb; 16 (1): 44-52. doi: 10.1111/j.1600-0501.2004.01051.x. PMID: 15642030.	141 (6.71)	147 (7.00)	311 (14.81)	157.33
59	Kreisler M, Christoffers AB, Willershausen B, d'Hoedt B. Effect of low-level GaAlAs laser irradiation on the proliferation rate of human periodontal ligament fibroblasts: an in vitro study. J Clin Periodontol. 2003 Apr ; 30 (4): 353-8. doi: 10.1034/j.1600-051x.2003.00001.x. PMID: 12694435.	141 (6.71)	155 (7.38)	312 (14.86)	159.00
60	Bjordal JM, Bensadoun R, Tuner J, Frigo L, Gjerde K, Lopes-Martins RA. A systematic review with meta-analysis of the effect of low-level laser therapy (LLLT) in cancer therapy-induced oral mucositis. Support Care Cancer. 2011 Aug; 19 (8): 1069-77. doi : 10.1007/s00520-011-1202-0. Epub 2011 Jun 10. PMID: 21660670.	140 (7.00)	179 (8.95)	311 (15.55)	187.00
61	White JM, Goodis HE, Rose CL. Use of the pulsed nd-yag laser for intraoral soft-tissue surgery. Lasers Surg Med. 1991; 11 (5): 455-61. doi: 10.1002/lsm.1900110511. PMID: 1816481.	139 (6.95)	188 (9.40)	323 (16.15)	169.67
62	Goldman L, Hornby P, Meyer R, Goldman B. Impact of laser on dental caries. Nature. 1964 Jul; 203 (4943): 417-417. doi : 10.1038/203417a0. PMID: 14197393.	139 (7.32)	164 (8.63)	505 (26.58)	278.00
63	Qadri T, Miranda L, Tuner J, Gustafsson A. The short-term effects of low-level lasers as adjunct therapy in the treatment of periodontal inflammation. J Clin Periodontol. 2005 Jul; 32 (7):714-9. doi: 10.1111/j.1600-051X.2005.00749.x. PMID: 15966876.	137 (6.85)	149 (7.45)	286 (14.30)	266.67
64	Periodontal treatment with an Er : YAG laser compared to scaling and root planing. A controlled clinical study. J Periodontol. 2001 Mar; 72 (3): 361-7. doi: 10.1902/jop.2001.72.3.361. PMID : 11327064.	137 (6.85)	147 (7.35)	303 (15.15)	299.00
65	Safavi SM, Kazemi B, Esmaeili M, Fallah A, Modarresi A, Mir M. Effects of low-level He-Ne laser irradiation on the gene expression of IL-1 beta, TNF-alpha, IFN-gamma, TGF-beta, bFGF, and PDGF in rat's gingiva. Lasers Med Sci. 2008 Jul; 23 (3): 331-5. doi: 10.1007/s10103-007-0491-5. Epub 2007 Sep 5. PMID: 17786499.	135 (6.75)	145 (7.25)	235 (11.75)	294.67
66	Youssef M, Ashkar S, Hamade E, Gutknecht N, Lampert F, Mir Maziar. The effect of low-level laser therapy during orthodontic movement: a preliminary study. Lasers Med Sci. 2008 Jan; 23 (1): 27-33. doi : 10.1007/s10103-007-0449-7. Epub 2007 Mar 15. PMID: 17361391.	134 (6.70)	151 (7.55)	316 (15.80)	243.67
67	Hopper C, Kubler A, Lewis H, Tan IB, Putnam G. mTHPC-mediated photodynamic therapy for early oral squamous cell carcinoma. Int J Cancer. 2004 Aug; 111 (1): 138-46. doi : 10.1002/ijc.20209. PMID: 15185355.	134 (6.34)	145 (6.90)	221 (10.52)	413.33
68	Cozean C, Arcoria CJ, Pelagalli J, Powell GL. Dentistry for the 21st century? Erbium:YAG laser for teeth. J Am Dent Assoc. 1997 Aug; 128 (8): 1080-7. doi: 10.14219/jada.archive.1997.0364. PMID: 9260417.	134 (6.09)	169 (7.68)	316 (14.36)	241.33

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69	Keller U, Hibst R. Effects of Er:YAG laser in caries treatment: a clinical pilot study. Lasers Surg Med. 1997; 20 (1): 32-8. doi: 10.1002/ (sici)1096-9101 (1997)20:1<32::aid-lsm5>3.0.co;2-#. PMID: 9041505.	133 (6.05)	145 (6.59)	238 (10.82)	261.00
70	Kimura Y, Wilder-Smith P, Matsumoto K. Lasers in endodontics: a review. Int Endod J. 2000 May; 33 (3): 173-85. doi: 10.1046/j.1365 2591.2000.00280.x. PMID: 11307433.	132 (6.00)	148 (6.73)	356 (16.18)	306.33
71	Chondros P, Nikolidakis D, Christodoulides N, Rossler R, Gutknecht N, Sculean A. Photodynamic therapy as adjunct to non-surgical periodontal treatment in patients on periodontal maintenance: a randomized controlled clinical trial. Lasers Med Sci. 2009 Sep; 24 (5): 681-8. doi: 10.1007/s10103-008-0565-z. Epub 2008 May 9. PMID: 18465191.	130 (5.65)	133 (5.78)	264 (11.48)	227.67
72	Christodoulides N, Nikolidakis D, Chondros P, Becker J, Schwarz F, Rossler R, Sculean A. Photodynamic therapy as an adjunct to non-surgical periodontal treatment: a randomized, controlled clinical trial. J Periodontol. 2008 Sep; 79 (9): 1638-44. doi: 10.1902/jop.2008.070652. PMID: 1877136.	130 (5.91)	145 (6.59)	298 (13.55)	235.00
73	Arany PR, Cho A, Hunt TD, Sidhu G, Shin K, Hahm E, Huang GX, Weaver J, Chen AC, PadwaBL, Hamblin MR, Barcellos-Hoff MH, Kulkarni AB, Mooney DJ. Photoactivation of Endogenous Latent Transforming Growth Factor-beta 1 Directs Dental Stem Cell Differentiation for Regeneration. Sci Transl Med. 2014 May; 238 (6): 238ra69. doi: 10.1126/scitranslmed.3008234. PMID: 24871130.	129 (5.61)	126 (5.48)	198 (8.61)	258.67
74	Garcez AS, Nunez SC, Hamblin MR, Ribeiro S. Antimicrobial effects of photodynamic therapy on patients with necrotic pulps and periapical lesion. J Endod. 2008 Feb; 34 (2): 138-42. doi: 10.1016/j.joen.2007.10.020.Epub 2007 Dec 21. PMCID: PMC2808698. PMID: 18215668.	129 (5.61)	154 (6.70)	310 (13.48)	206.33
75	Dortbudak O, Haas R, Mallath-Pokorny G. Biostimulation of bone marrow cells with a diode soft laser. Clin Oral Implants Res. 2000 Dec; 11 (6): 540-5. doi: 10.1034/j.1600-0501.2000.011006540.x. PMID: 11168247.	129 (5.61)	147 (6.39)	285 (12.39)	208.00
76	Li ZZ, Code JE, Van De Merwe WP. Er-yag laser ablation of enamel and dentin of human teeth - determination of ablation rates at various fluences and pulse repetition rates. Lasers Surg Med. 1992; 12 (6): 625-30. doi : 10.1002/lsm. 1900120610. PMID: 1453865.	129 (5.61)	140 (6.09)	261 (11.35)	172.00
77	Khadra M, Lyngstadaas SP, Haanaes HR, Mustafa K. Effect of laser therapy on attachment, proliferation and differentiation of human osteoblast-like cells cultured on titanium implant material. Biomaterials. 2005 Jun; 26 (17): 3503-9. doi: 10.1016/j.biomaterials.2004.09.033. PMID: 15621240.	128 (5.33)	142 (5.92)	243 (10.13)	302.33
78	Kuroda S, Fowler BO. Compositional, structural, and phase-changes in invitro laser-irradiated human tooth enamel. Calcif Tissue Int. 1984 Jul; 36 (4): 361-9. doi: 10.1007/BF02405347. PMID: 6435835.	128 (5.33)	134 (5.58)	207 (8.63)	191.67
79	Migliorati C, Hewson I, Lalla RV, Antunes HS, Estilo CL, Hodgson B, Lopes NNF, Schubert MM, Bowen J, Elad S. Systematic review of laser and other light therapy for the management of oral mucositis in cancer patients. Support Care Cancer. 2013 Jan; 21 (1): 333-41. doi: 10.1007/s00520-012-1605-6. PMID: 23001179.	127 (5.29)	148 (6.17)	247 (10.29)	216.33
80	Khadra M, Kasem N, Haanaes HR, Ellingsen JE, Lyngstadaas SP. Enhancement of bone formation in rat calvarial bone defects using low-level laser therapy. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2004 Jun ; 97 (6): 693-700. doi: 10.1016/j.tripleo.2003.11.008. PMID: 15184850.	127 (5.29)	141 (5.88)	240 (10.00)	298.00
81	Shimizu N, Yamaguchi M, Goseki T, Shibata Y, Takiguchi H, Iwasawa T, Abiko Y. Inhibition of prostaglandin e (2) and interleukin-1-beta production by low-power laser irradiation in stretched human periodontal-ligament cells. J Dent Res. 1995 Jul; 74 (7): 1382-8. doi: 10.1177/00220345950740071001. PMID: 7560389.	127 (4.70)	149 (5.52)	255 (9.44)	217.33
82	Saygun I, Karacay S, Serdar M, Ural AU, Sencimen M, Kurtis B. Effects of laser irradiation on the release of basic fibroblast growth factor (bFGF), insulin like growth factor-1 (IGF-1), and receptor of IGF-1 (IGFBP3) from gingival fibroblasts. Lasers Med Sci. 2008 Apr; 23 (2): 211-5. doi: 10.1007/s10103-007-0477-3. Epub 2007 Jul 10. PMID: 17619941.	126 (4.67)	132 (4.89)	222 (8.22)	205.67
83	Fimple JL, Fontana CR, Foschi F, Ruggiero K, Song X, Pagonis TC, Tanner ACR, Kent R, Doukas AG, Stashenko PP, Soukos NS. Photodynamic treatment of endodontic polymicrobial infection in vitro. J Endod. 2008 Jun; 34 (6): 728-34. doi: 10.1016/j.joen.2008.03.011. Epub 2008 Apr 25. PMID: 18498901. PMCID: PMC2596687.	125 (4.81)	143 (5.50)	289 (11.12)	196.33

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84	Rodrigues JA, Hug I, Diniz MB, Lussi A. Performance of fluorescence methods, radiographic examination and ICDAS II on occlusal surfaces in vitro. Caries Res. 2008; 42 (4): 297-304. doi: 10.1159/000148162. Epub 2008 Jul 29. PMID: 18663299.	125 (4.63)	133 (4.93)	234 (8.67)	233.00
85	Schubert MM, Eduardo FP, Guthrie KA, Franquin JC, Bensadoun RJJ, Migliorati CA, Lloids ME, Eduardo CP, Walter NF, Marques MM, Hamdi M. A phase III randomized double-blind placebo-controlled clinical trial to determine the efficacy of low level laser therapy for the prevention of oral mucositis in patients undergoing hematopoietic cell transplantation. Support Care Cancer. 2007 Oct; 15 (10): 1145-54. doi: 10.1007/s00520-007-0238-7. Epub 2007 Mar 29. PMID: 17393191.	125 (5.00)	154 (6.16)	259 (10.36)	216.00
86	Oliveira RR, Schwartz-Filho HO, Novaes Jr AB, Taba Jr M. Antimicrobial photodynamic therapy in the non-surgical treatment of aggressive periodontits: a preliminary randomized controlled clinical study. J Periodontol. 2007 Jun; 78 (6): 965-73. doi : 10.1902/jop.2007.060494. PMID : 17539707.	125 (5.00)	131 (5.24)	286 (11.44)	412.00
87	Pick RM, Colvard MD. Current status of lasers in soft-tissue dental surgery. J Periodontol. 1993 Jul; 64 (7): 589-602. doi: 10.1902/jop.1993.64.7.589. PMID: 8366410.	125 (4.63)	131 (4.85)	361 (13.37)	256.67
88	Pereira CA, Romeiro RL, Costa ACBP, Machado AKS, Junqueira JC, Jorge AOC. Susceptibility of Candida albicans, Staphylococcus aureus, and Streptococcus mutans biofilms to photodynamic inactivation: an in vitro study. Lasers Med Sci. 2011 May; 26 (3): 341-8. doi: 10.1007/s10103-010-0852-3. Epub 2010 Nov 11. PMID: 21069408.	124 (4.96)	131 (5.29)	209 (8.36)	177.00
89	De Groot SD, Verhaagen B, Versluis M, Wu M-K, Wesselink PR, van der Sluis LWM. Laser-activated irrigation within root canals: cleaning efficacy and flow visualization. Int Endod J. 2009 Dec; 42 (12): 1077-83. doi : 10.1111/j.1365-2591.2009.01634.x. PMID: 19912378.	124 (4.96)	126 (5.04)	243 (9.72)	196.00
90	Sinha UK, Gallagher LA. Effects of steel scalpel, ultrasonic scalpel, Co-2 laser, and monopolar and bipolar electrosurgery on wound healing in guinea pig oral mucosa. Laryngoscope. 2003 Feb; 113 (2): 228-36. doi: 10.1097/00005537-200302000-00007. PMID: 12567074.	124 (3.44)	140 (3.89)	218 (6.06)	182.33
91	Cavalcanti AN, Foxton RM, Watson TF, Oliveira MT, Giannini M, Marchi GM. Bond Strength of Resin Cements to a Zirconia Ceramic with Different Surface Treatments. Oper Dent. May-Jun 2009; 34 (3): 280-7. doi: 10.2341/08-80. PMID: 19544816.	123 (3.42)	145 (4.03)	256 (7.11)	156.33
92	Lim HM, Lew KK, Tay DK. A clinical investigation of the efficacy of low level laser therapy in reducing orthodontic postadjustment pain. Am J Orthod Dentofacial Orthop. 1995 Dec;108 (6):614-22. doi: 10.1016/s0889-5406 (95)70007-2. PMID: 7503039.	123 (3.73)	143 (4.33)	322 (9.76)	196.00
93	Oho T, Morioka T. A possible mechanism of acquired acid resistance of human dental enamel by laser irradiation. Caries Res. 1990; 24 (2): 86-92. doi: 10.1159/000261245. PMID: 2160327.	123 (3.97)	133 (4.29)	279 (9.00)	312.00
94	Dederich DN, Zakariasen KL, Tulip J. Scanning electron-microscopic analysis of canal wall dentin following neodymium-yttrium-aluminum-garnet laser irradiation. J Endod. 1984 Sep;10 (9):428-31. doi: 10.1016/S0099-2399 (84)80264-2. PMID:6593419.	123 (3.62)	153 (4.50)	271 (7.97)	803.33
95	Aoki A, Mizutani K, Schwarz F, Sculean A, Yukna RA, Takasaki AA, Romanos GE, Taniguchi Y, Sasaki KM, Zeredo JL, Koshy G, Coluzzi DJ, White JM, Abiko Y, Ishikawa I, Izumi Y. Periodontal and peri-implant wound healing following laser therapy. Periodontol 2000. 2015 Jun; 68 (1): 217-69. doi: 10.1111/prd.12080. PMID: 25867988.	122 (3.94)	130 (4.19)	233 (7.52)	524.00
96	Schwarz F, Sahm N, Iglhaut G, Becker J. Impact of the method of surface debridement and decontamination on the clinical outcome following combined surgical therapy of peri-implantitis: a randomized controlled clinical study. J Clin Periodontol. 2011 Mar; 38 (3): 276-84. doi: 10.1111/j.1600-051X.2010.01690.x. Epub 2011 Jan 11. PMID: 21219392.	122 (4.07)	124 (4.13)	236 (7.87)	178.33
97	Ishikawa I, Aoki A, Takasaki AA. Potential applications of Erbium : YAG laser in periodontics. J Periodontal Res. 2004 Aug; 39 (4): 275-85. doi: 10.1111/j.1600-0765.2004.00738.x. PMID: 15206922.	121 (4.17)	134 (4.62)	279 (9.62)	216.67
98	Shi XQ, Tranaeus S, Angmar-Mansson B. Comparison of QLF and DIAGNOdent for quantification of smooth surface caries. Caries Res. 2001 Jan-Feb; 35 (1): 21-6. doi: 10.1159/000047426. PMID:11125192.	121 (4.32)	139 (4.96)	249 (8.89)	176.67
99	Hossain M, Nakamura Y, Yamada Y, Kimura Y, Nakamura G, Matsumoto K. Ablation depths and morphological changes in human enamel and dentin after Er : YAG laser irradiation with or without water mist. J Clin Laser Med Surg. 1999 Jun; 17 (3): 105-9. doi: 10.1089/clm.1999.17.105.	120 (4.29)	136 (4.86)	221 (7.89)	251.00
100	Hossain M, Nakamura Y, Yamada Y, Kimura Y, Matsumoto N, Matsumoto K. Effects of Er,Cr : YSGG laser irradiation in human enamel and dentin: Ablation and morphological studies. J Clin Laser Med Surg. 1999 ; 17 (4): 155-9. doi: 10.1089/clm.1999.17.155. PMID: 11199838.	120 (4.29)	129 (4.61)	223 (7.96)	227.00

[a]Citation density: mean number of citations received per year; [b]Mean citations: mean number of citations between Web of Science, Scopus, and Google Scholar.

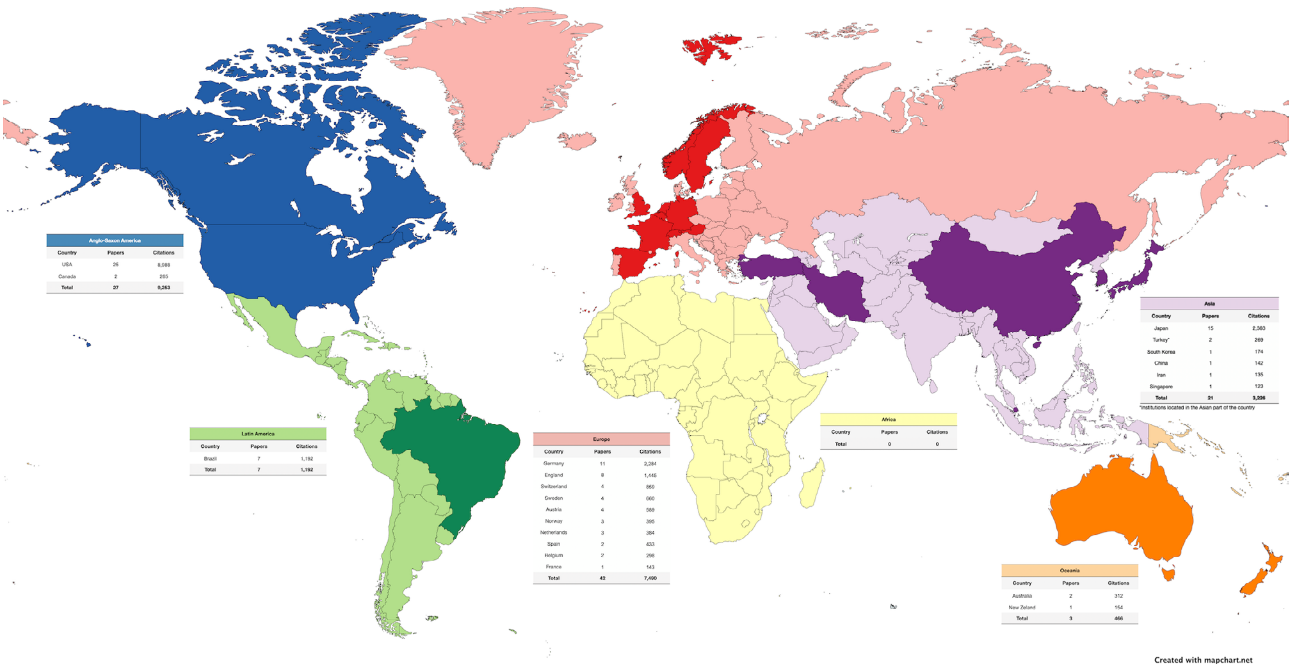

Figure 1. Global distribution of the top 100 most-cited papers on the use of lasers in dentistry.

Table 2. Institutions with the highest number of top 100 papers on the use of lasers in dentistry.

Institution	Country	Number of papers	Number of citations
Tokyo Medical and Dental University	Japan	7	1,201
University of California	USA	4	5,442
University of Vienna	Austria	4	589
University of São Paulo	Brazil	3	671
University of Bern	Switzerland	3	661
Karolinska Institute	Sweden	3	539
Nihon University	Japan	3	508
Showa University	Japan	3	431
University of Ulm	Germany	2	952
Ravenswood Hospital Medical Center	USA	2	436

the University of Vienna, Austria (four papers; 589 citations) (Table 2).

The 100 most-cited papers were published in 41 journals. *Lasers in Surgery and Medicine* (15 papers; 3,425 citations) and *Lasers in Medical Science* (seven papers; 965 citations) were the journals that obtained the largest number of most-cited publications. The authors who appeared in more papers on the top 100 list were Ishikawa I (six papers; 1,073 citations) and Aoki A (six papers; 924 citations), followed by Walsh JT (five papers; 861 citations), Sculean A (five papers; 660 citations), and Schwarz F (five papers; 652 citations) (Table 3). The author map shows six different clusters of authors, and the largest one contains 12 authors (Figure 2).

The three most frequent study designs were laboratory-based studies (57 papers; 14,871 citations) followed by non-randomized clinical trials

Table 3. Bibliometric indicators of authors with at least four manuscripts on the list of the 100 most-cited papers on the use of lasers in dentistry.

Authors	Number of 100 most-cited papers on lasers in dentistry	Number of citations in 100 most-cited papers on lasers in dentistry	Number of papers in WoS-CC	Number of citations in WoS-CC	H-index
Ishikawa I	6	1,073	241	9,173	54
Aoki A	6	924	110	2,82	28
Walsh J	5	861	122	3,437	37
Sculean A	5	660	464	6,685	59
Schwarz F	5	652	298	6,249	60
El-Sayed M	4	5,559	579	53,636	111
Keller U	4	1,259	81	2	21
Watanabe H	4	830	19	297	11
Wilson M	4	726	270	8,239	64

WoS-CC: Web of Science Core Collection; H-index was extracted from Web of Science.

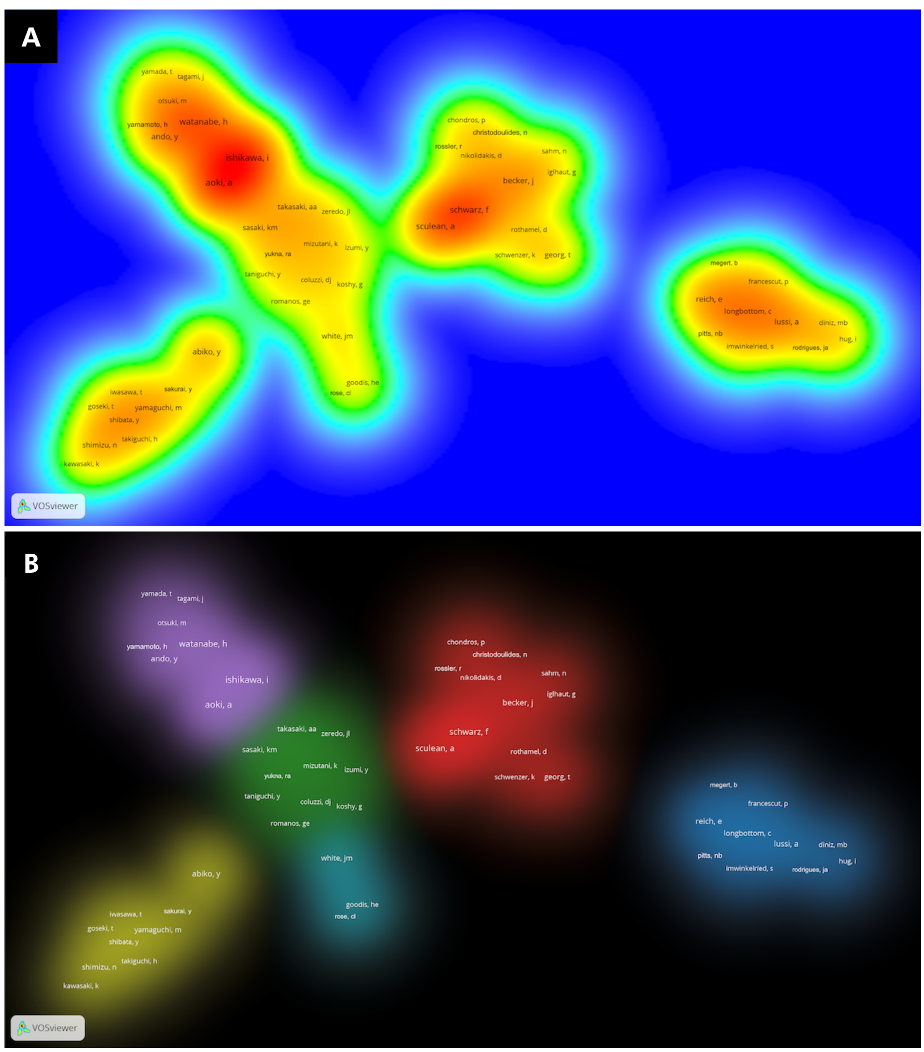

Figure 2. Co-authorship map showing clusters and national and international collaboration between authors of the top 100 most-cited papers on the use of lasers in dentistry.

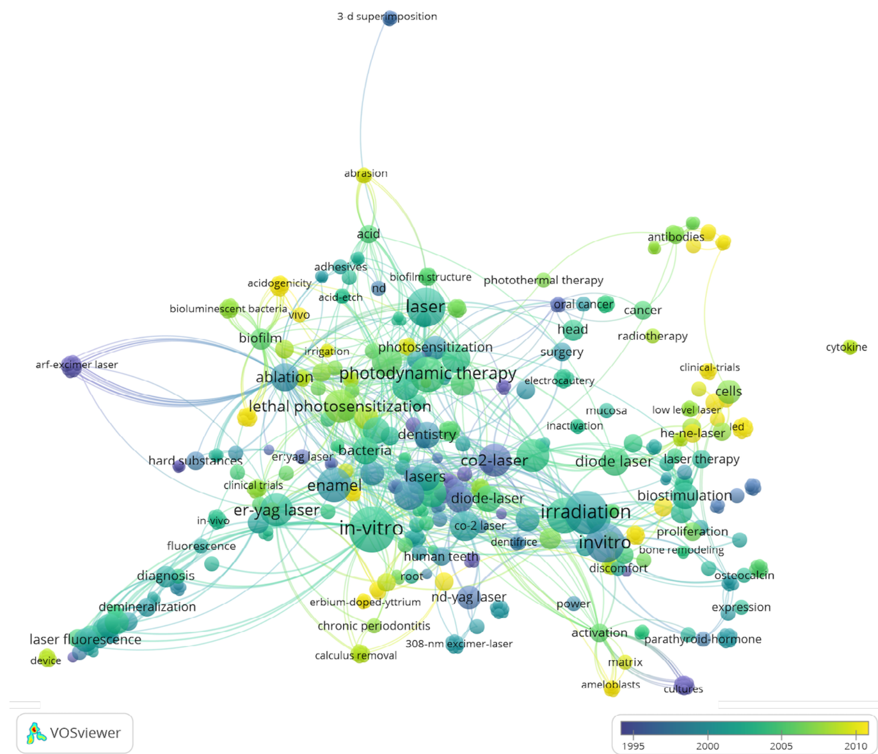

Figure 3. VOSviewer density map of co-occurrence of keywords of the top 100 most-cited papers on the use of lasers in dentistry.

(13 papers; 2,277 citations) or randomized clinical trials (12 papers; 1,937 citations). Regarding the study subject, most of the papers were related to restorative dentistry (32 papers; 5,438 citations) and periodontics (21 papers; 3,400 citations), followed by pathology/stomatology (14 papers; 7,646 citations). The oral health outcomes most frequently addressed were periodontal diseases (22 papers; 3,393 citations) and dental caries (19 papers; 3,409 citations). Besides, 69 studies used low-level laser (16,488 citations), whereas 30 papers used high-level laser (4,992 citations) and one paper used low- and high-level laser (147 citations).

The co-occurrence keyword map revealed a total of 237 keywords. "Laser", "photodynamic therapy", and "diode laser" were the most frequently used keywords (Figure 3). Also, it was possible to observe changes in the focus of papers over time. Older papers tended to use high-level lasers in ablation and surgery, while more recent papers tended to use low-level lasers focused on prevention and pain/inflammation treatment.

Discussion

The current bibliometric study identified and analyzed the top 100 most-cited papers on the use of lasers and its modalities in dentistry. A bibliometric scientific method was applied to classify the citations in some known databases. Moreover, a concomitant analysis was conducted aiming to investigate research groups, collaboration networks, and the most productive countries and universities as well. Study types, subjects, and oral health outcomes were reported, allowing a quantitative and qualitative bibliometric study.

In terms of absolute citation numbers, the top 100 papers received a total of 21,627 citations. By comparing this finding with that of other bibliometric studies in dentistry, this number is similar to that of other areas such as periodontology (21,276 citations).[20] In relation to citation classics or highly cited papers (papers that exceed the threshold of 100 citations in a specific area),[2,21,22] all 100 papers surpassed this metric. This score was equal when compared with that of implant dentistry and orthodontics[2,23,24] and higher than in other dental fields such as pediatric dentistry (34 papers), endodontics (27 papers), and regenerative endodontics (16 papers).[2,25,26] These comparisons should be made with caution, given that laser is a specific/particular field and is used as an adjuvant when compared with other general areas in dentistry.

There was a larger number of publications in the first decade of the new millennium with almost 50% of articles published between 2001 and 2010. This way, the oldest and most recent publications were from the years 1964 and 2015, ranking 61st and 96th with 139 and 122 citations, respectively. Citation analysis is disparaged owing to the influence of time, as citations are generally time-dependent; older articles get ample time to enjoy global circulation and stand a higher chance for receiving added citations, regardless of their scientific value.[2,27] Thus, it is useful to consider not only the total amount of citations, but also citation density, a strategy adopted in the present study. However, the first decade of the 2000s was considered the most productive, as stated by other bibliometric studies.[2,22] These results may be associated with advances in techniques, technology, and materials triggering scientific growth and research, especially in the first two decades of the 2000s, considered the era of the exponential growth of scientific publications.[2,28]

Twenty-five percent of the 100 most-cited papers were from the USA, which attests to the leading role and tradition of its institutions.[2,21,23,24,29,30] Japan, Germany, England, and Brazil (only country representing Latin America) also achieved great prominence. Furthermore, the findings demonstrate the academic potential of Anglo-Saxon American, European, and Asian institutions. One of the main reasons behind the participation of Brazil is the presence of specific centers focused on laser application, such as the Special Laboratory of Laser in Dentistry (LELO) of the University of São Paulo (since 1995), with a partnership of the Nuclear and Energy Research Institute. Interestingly, LELO had a strong participation and collaboration of Japanese institutions and, recently, a productive and massive partnership with Germany, demonstrating the quality of Brazilian papers, which rank 7th and 8th on the list of 100 most-cited papers. It is also important to highlight the intense national and international collaboration among institutions in the publication of the top 100 most-cited papers. These collaborations help to increase the quality and impact of the investigations, consequently increasing the number of citations and research visibility.

The analysis of the most productive authors showed that Ishikawa I from Bergen University (Norway) and Aoki A from the Brazilian National Cancer Institute (Brazil) secured the first two positions of authors on the list of the 100 most-cited papers. As demonstrated, the co-authorship network presented six different clusters, reflecting the national and international collaboration among authors. To compare these data with other published data is not an easy task because other bibliometric studies focused on the international collaboration map instead of using an analysis similar to the one performed here. It can be inferred, however, that the higher degree of international collaborations boosts the chances of citations.

The papers ranked in this investigation were published in 41 journals. Three journals accounted for 30% of the top 100 most-cited papers: *Lasers in Surgery and Medicine* (established in 1980), *Lasers in Medical Sciences* (established in 1986), and *Caries Research* (established in 1967). Note that two of them are specific to laser treatments. As part of the qualitative analysis, the most-cited keywords were "laser", "diode laser", and "photodynamic therapy". In consonance with these findings, when the types of lasers used over the years were analyzed, high-level lasers tended to be used more frequently from the early 1960s to the mid-1990s, having been described in 30 papers, whereas low-level lasers, appearing in 69 papers, have been used more recently (from the late 1980s to the mid-2000s). We can speculate that, thanks to large investments in education/technology, lasers, including handheld ones, tend to be more accessible, thus facilitating their use and applications at affordable prices. Other modalities, such as diagnostics and decontamination by means of photodynamic effects, may help explain the widespread use of this specific type of laser, highlighting the versatility of laser devices applied in health sciences.

Interestingly, once the use of lasers in clinical practice has been more common, their mechanism of action, characteristics, and cell/animal interactions/behavior were of relevance in this investigation, as pointed out by the large number of laboratory-based studies. Also, given that laser devices have a clinical appeal, and as they have become more accessible over the years because of their low cost, the great number of interventional studies addressing laser application for the treatment of different conditions in restorative dentistry and periodontics comes as no surprise. Indeed, most papers investigated the use of lasers in dental caries and periodontal diseases with an attempt to help with the diagnosis and treatment of these two worldwide prevalent oral health problems.[1]

Conclusion

This bibliometric quantitative and qualitative analysis provided an interesting insight into the application and trends of lasers and their modalities in dentistry. Most of the papers were from Europe, had a laboratory design, and dealt with restorative dentistry and periodontics. The importance of international partnership was underscored, leading to better-quality studies and citations and to the widespread use of low-level lasers in daily dental practice.

Acknowledgments

This study was supported by the Federal University of Minas Gerais (UFMG) and financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (Capes) – Finance Code 001, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (Fapemig), and Pró-Reitoria de Pesquisa da Universidade Federal de Minas Gerais (PRPq/UFMG).

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