International Journal of Infectious Diseases 96 (2020) 696–709

Contents lists available at ScienceDirect

International Journal of Infectious Diseases

journal homepage: www.elsevier.com/locate/ijid

The global state of clinical research and trends in periprosthetic joint infection: A bibliometric analysis

Cheng Li[a], Cristina Ojeda-Thies[b], Nora Renz[a], Donara Margaryan[a], Carsten Perka[a], Andrej Trampuz[a,*]

[a] Charité – Universitätsmedizin Berlin, corporate member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health, Centre for Musculoskeletal Surgery (CMSC), Berlin, Germany
[b] Hospital Universitario 12 de Octubre, Madrid, Spain

ARTICLE INFO

Article history:
Received 5 April 2020
Received in revised form 1 May 2020
Accepted 3 May 2020

Keywords:
Bibliometrics
Arthroplasty
Periprosthetic joint infection
Publications
Medical information sciences

ABSTRACT

Objectives: The purpose of this study was to estimate the trends and state of research in periprosthetic joint infection (PJI).
Methods: Publications on PJI published between 1998 and 2018 were searched in the Web of Science database and analyzed using bibliometrics. The Altmetric score and Research Interest score were combined to provide a weighted count. The scope of the Altmetric score includes >16 weighted composite scores from websites such as Twitter, Facebook, and YouTube, whereas the Research Interest score is calculated from information derived from ResearchGate.
Results: Total of 3245 published documents were identified. The largest contribution was made by the United States, with the institution contributing most being the Rothman Institute. The most relative articles were published by the *Journal of Arthroplasty*, whereas the highest citation frequency journal was *Clinical Orthopaedics and Related Research*. There was a positive correlation between citation counts and Research Interest scores, while the Altmetric Attention score showed a negative value for highly cited articles.
Conclusions: Based on the current trends of globalization, there is a rising trend in publications on PJI, with the largest annual contributions made by the United States. The most influential contributors are researchers from the United States and Europe. Twitter is used as a platform to communicate knowledge by most PJI researchers. The most recent research has focused on the diagnosis and risk factors of PJI.

Introduction

Arthroplasty is a common surgical procedure used by orthopedic surgeons and significantly improves quality of life in patients with joint disease. However, infection after joint replacement remains difficult and challenging, not only because infection cannot be avoided in the short-term, but also due to the lack of gold standards in managing periprosthetic joint infection (PJI). In special cases, such as rheumatoid arthritis patients, this further increases the difficulty of diagnosis and treatment (Fagotti et al., 2018; Premkumar et al., 2018). The recent literature has reported that infection has become a major complication after joint replacement (Jafari et al., 2010; Kulshrestha et al., 2019). Therefore, the management of PJI has become increasingly important.

Bibliometrics – a method of statistical analysis – can be used to assess the characteristics and major developmental trends of a given research subject based on published research. Bibliometric analysis has been used previously to evaluate orthopedic research based on orthopedic disease, orthopedic journal, operative site, surgical technique, and the development of a country's conditions (Ahmad et al., 2014; Jia et al., 2015; Seetharam et al., 2018; Vaishya et al., 2018; Jani et al., 2019). However, a bibliometric analysis of PJI has not yet been performed.

Traditionally, the number of citations has been the best method available to assess the quality of a publication. However, in today's social network era, citations no longer represent the only means of evaluating an academic article (Bellini, 2012; 2017). Due to the increasing numbers of individuals who read, share, or comment on

* Corresponding author at: Centre for Musculoskeletal Surgery, Charité – University Medicine Berlin, Charitéplatz 1, D-10117 Berlin, Germany.
E-mail address: andrej.trampuz@charite.de (A. Trampuz).

https://doi.org/10.1016/j.ijid.2020.05.014

literature online, altmetrics provides another means to alternative or complementary citation metrics, which is mainly based on network data (Priem et al., 2010). The Research Interest score and Altmetric score are two different altmetric tools to evaluate the impact of publications; however, there is no article in the literature simultaneously contrasting the relationship between these two tools and citations.

The aim of this study was to provide a comprehensive understanding for further advancement in the field. First, a bibliometric analysis of PJI was performed. Second, all keywords were exported from the identified articles to identify hot topics. Third, the top 50 most cited articles were collected and analyzed via logistic regression to determine the relationship between altmetric tools, impact factor, publication year, and citations in highly cited papers. Social media data from Altmetric scores were also analyzed to determine the social media habits of researchers.

Methods

Search strategy

Data were retrieved from the Web of Science (WoS) electronic database (SCI-Expanded), which is optimal for bibliometric analysis (Aggarwal et al., 2016). A search for articles published between 1998 and 2018 was performed using all fields with the terms “periprosthetic joint infection or prosthetic joint infection” without any language restriction.

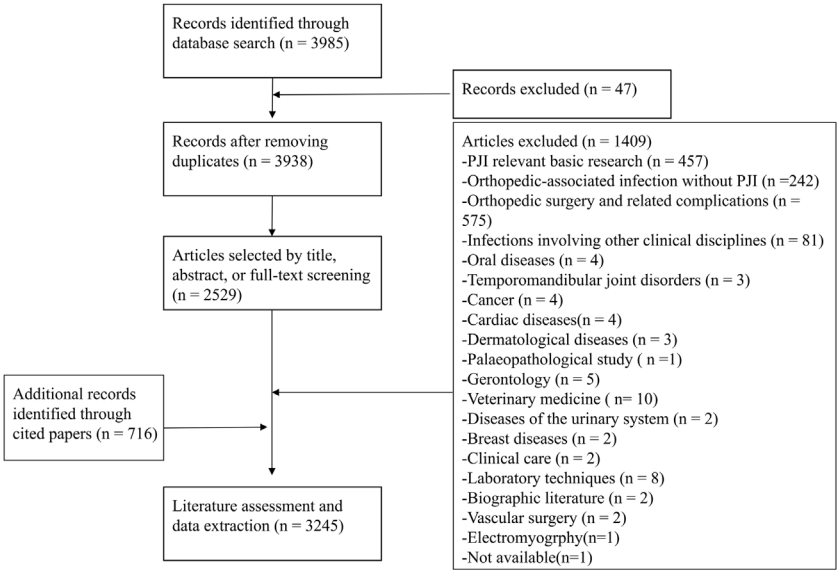


Figure 1. Flowchart of the identification of relevant articles.

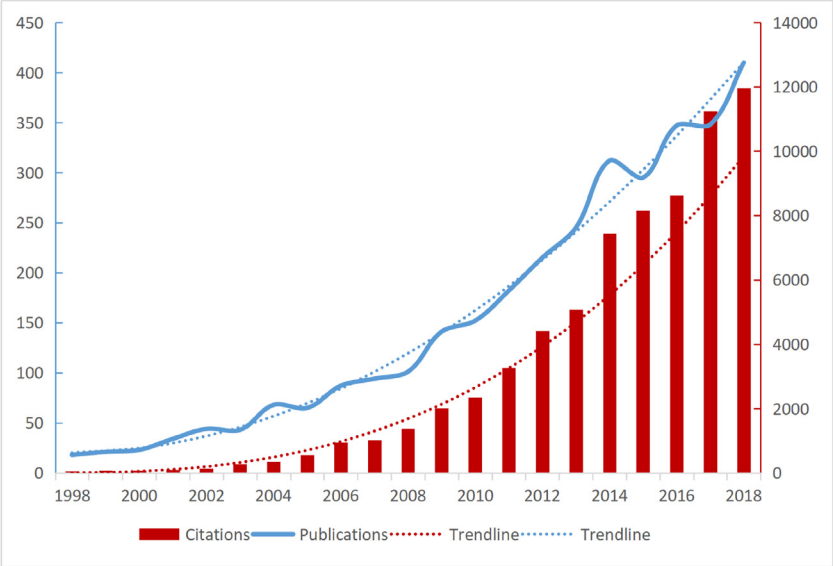


Figure 2. The total annual number and citation of publications.

Data collection

Two authors (CL and COT) independently screened the literature and extracted data. All fundamental research was excluded (such as biofilm or antibiotic studies, in vitro and animal experiments), and references in eligible studies were reviewed. In the case of disagreement, a third author (DM) was consulted to reach a consensus.

Full records from the WoS database were exported to plain text. Microsoft Excel (Microsoft, Redmond, WA, USA) and Endnote reference manager software version X9 (Thomson Reuters, New York, NY, USA) were used to analyze all keywords from the literature.

The top 50 most cited articles were exported from the WoS database. The Research Interest score was searched by title or digital object identifier (DOI) number in ResearchGate (https://www.researchgate.net/). The Altmetric score was determined using the Altmetric bookmarklet (https://www.altmetric.com). All information, including the number of citations, Research Interest score, Altmetric score, and social media habits for the top 50 most cited articles were also collected. Only social media information from Facebook and Twitter was included, as some social media information cannot be traced using the Altmetric website.

Extraction of keywords and most cited paper for different subjects

In the Endnote database, the articles were divided into different groups according to the title or abstract: location, prevention, risk factor, diagnosis, microorganism, and treatment. Some undefined literature articles were included or excluded through further full-text reads. Publications on location were separated into hip, knee, shoulder, elbow, and ankle. Keywords from publications on treatment were divided into surgery and antibiotic therapy. The

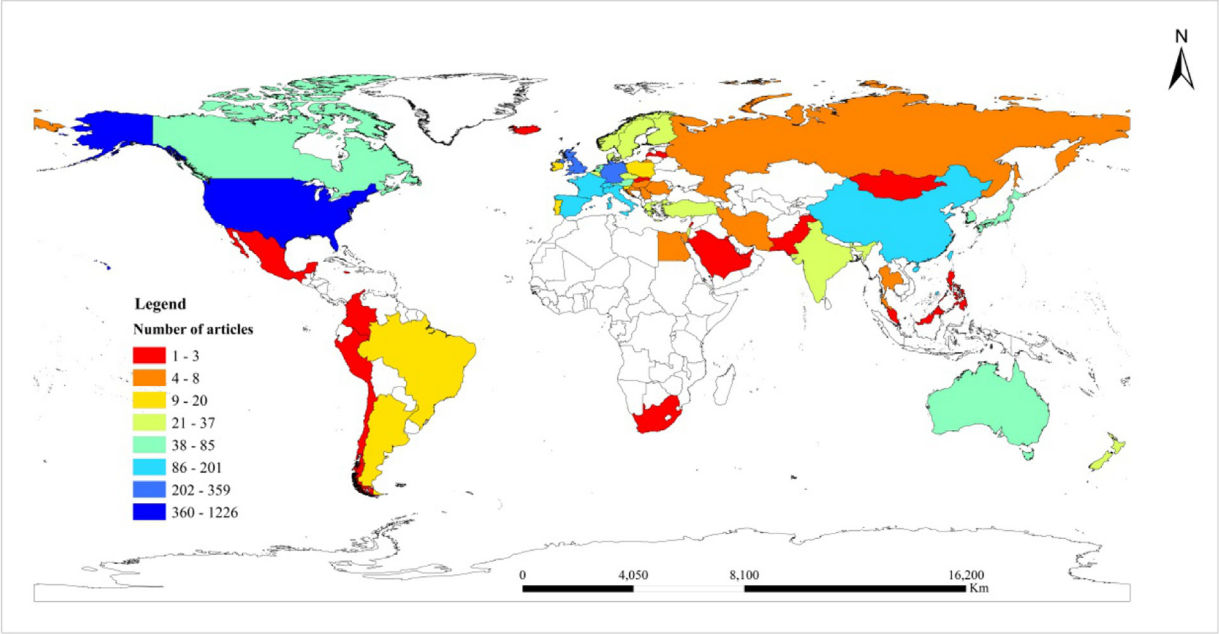
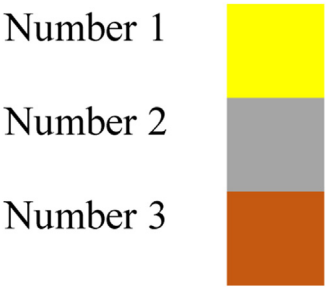


Figure 3. Global distribution of PJI research.

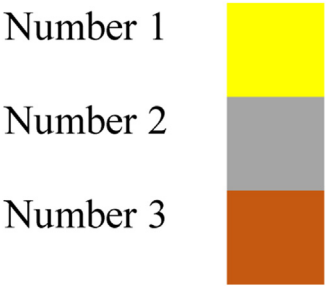
Table 1
List of top 10 countries according to the total number of publications, number of times cited, average citations per item, and h-index.

Rank	Country	Number of articles	Sum of times cited	Average citations per item	h-Index
1	USA	1226	37 238	36.28	98
2	Germany	358	4728	16.18	40
3	United Kingdom	298	6304	27.73	47
4	Spain	200	2813	17.43	31
5	France	196	2889	17.54	30
6	China	171	1460	11.41	25
7	Switzerland	151	5647	42.71	35
8	Italy	130	1682	15.74	26
9	Canada	84	2322	31.89	26
10	Netherlands	81	1406	20.9	21

Table 2
List of top 10 countries according to total number of publications annually.



Year	USA	Germany	England [Au?2]	Spain	France	China	Switzerland	Italy	Canada	Netherlands	Proportion
1998	7	2	4	1	1	0	1	1	0	0	94.44%
1999	10	1	1	0	1	0	0	3	2	0	80.95%
2000	9	3	6	1	0	0	0	1	0	1	91.30%
2001	15	1	3	1	5	1	0	3	1	0	85.29%
2002	24	1	8	2*	1	1	0	0	1	0	84.09%
2003	17	6	2	3	5	1	2	0	2	1	90.70%
2004	26	9	6	1	9	1	8	4	1	1	97.06%
2005	31	9	9	2	0	1	3	2	1	1	89.23%
2006	25	10	8	9	10	2	8	0	3	2	87.36%



*Finland = 2.

top five most cited articles related to the subject were included. The top 10 keywords in the different areas were calculated, and the most relevant and frequent keyword was included. In the event that the keyword had the same occurrence number, sorting was performed according to alphabetical order. To show more valuable information, high-frequency keywords, such as “periprosthetic joint infection”, “prosthetic joint infection”, and “infection”, were deleted.

Visualized analysis

VOSviewer (Leiden University, Leiden, The Netherlands) was used for visualization and analysis of the literature. VOSviewer

Table 3
List of top 10 contributing institutions and countries.

Name of institution	Country	Publications
Rothman Institute	USA	245
Mayo Clinic	USA	219
Cleveland Clinic	USA	80
Rush University	USA	80
University of Barcelona	Spain	79
University of California System	USA	75
Harvard University	USA	70
Charité Medical University of Berlin	Germany	59
Hospital for Special Surgery	USA	54
Helios ENDO-Klinik Hamburg	Germany	52

Table 4
List of top 10 authors with most publications and the h-index, average citations, country, specialized subject, and institution.

Author	Number of publications	h-Index	Average citations per item	Country	Specialized subject	Institution
Javad Parvizi	204	57	51.69	USA	Orthopedic surgery	Rothman Institute
Arlen D. Hanssen	85	38	66.09	USA	Orthopedic surgery	Mayo Clinic
Douglas R. Osmon	77	37	75.52	USA	Infectious diseases	Mayo Clinic
Alex Soriano	64	21	21.16	Spain	Infectious diseases	University of Barcelona
Craig J. Della Valle	60	29	43.45	USA	Orthopedic surgery	Rush University
Andrej Trampuz	53	22	83.85	Germany	Infectious diseases	Charité Medical University of Berlin
Elie F. Berbari	49	25	68.82	USA	Infectious diseases	Mayo Clinic
Robin Patel	48	23	70.77	USA	Clinical microbiology	Mayo Clinic
Michael A. Mont	43	18	29.6	USA	Orthopedic surgery	Cleveland Clinic
Thorsten Gehrke	40	19	33.88	Germany	Orthopedic surgery	Helios ENDO-Klinik Hamburg

Table 5
List of top 10 journals with the most publications and their impact factors.

Journal	Number of publications	Impact factor
Journal of Arthroplasty	466	3.524
Clinical Orthopaedics and Related Research	276	4.154
Journal of Bone and Joint Surgery American Volume	156	4.716
Bone Joint Journal	147	3.652
International Orthopaedics	100	2.384
Acta Orthopaedica	72	3.217
Journal of Clinical Microbiology	71	4.959
Clinical Infectious Diseases	63	9.055
Journal of Shoulder and Elbow Surgery	60	2.865
HIP International	52	1.25

software was used for bibliographic coupling, co-citation analysis, and co-occurrence analysis. If the VOSviewer database had the author's name, country, and similar terms in duplicate, a thesaurus file was created and used to combine the identical information.

Statistical analysis

All data were analyzed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, NY, USA). Spearman rank correlation was used for non-normally distributed data. For normally distributed data or approximate normal distribution, the equation of linear regression was established. A p-value of <0.05 (two-sided) was considered statistically significant.

Results

Of the 3985 primary literature articles retrieved, 47 were excluded due to duplication. An additional 1456 were excluded following a review of the title, abstract, and full article. Altogether, 11 026 cited references without self-citations from 2529 articles published between 1998 and 2018 were reviewed. Finally, 716 publications were included. A flowchart of the study search strategy is given in Figure 1.

General data

A total of 3245 articles on PJI were collected from the WoS. Most of these articles were in English (94%), followed by German and Spanish. Of these, 2626 (81%) were original articles. The total number of citations of these articles was 69 358. The number of publications and citations peaked in 2018. From 1998 to 2018, the global publications and total citations showed an upward annual trend (Figure 2).

Countries

Publications originated from 58 countries, with most from Europe ($n = 32$), followed by Asia ($n = 16$) and the Americas ($n = 9$). The country with the most publications in Asia was China, in Africa was Egypt, in Europe was Germany, in South America was Brazil, in Oceania was Australia, and in North America was the United States (Figure 3).

Out of the 58 nations, the United States had the highest total number of publications, total citations, and h-index. The top average number of citations was found for publications originating from Switzerland (42.71), followed by the United States (36.28) and Canada (31.89) (Table 1).

Table 6
List of top 10 journals by highest impact factor, with the number of publications.

Journal	Impact factor	Number of publications
New England Journal of Medicine	70.67	6
Lancet	59.102	2
BMJ British Medical Journal	27.604	3
Lancet Infectious Diseases	27.516	7
Clinical Microbiology Reviews	17.75	2
Annals of the Rheumatic Diseases	14.299	4
American Journal of Gastroenterology	10.241	1
Clinical Infectious Diseases	9.055	63
Arthritis and Rheumatism	9.002	3
BMC Medicine	8.285	2

Table 7
The 50 most cited publications ranked by citation.

Rank	Title	Times cited	Impact factor	Research Interest score	Attention score	Media use habits[a]
1	Zimmerli W, Trampuz A, Ochsner PE. Prosthetic-joint infections. N Engl J Med 2004; 351: 1645–1654.	1461	70.67	946	13	Twitter
2	Trampuz A, Piper KE, Jacobson MJ, et al. Sonication of removed hip and knee prostheses for diagnosis of infection. N Engl J Med 2007; 357: 654–663.	672	70.67	382.3	18	Twitter
3	Osmon DR, Berbari EF, Berendt AR, et al. Executive summary: diagnosis and management of prosthetic joint infection: clinical practice guidelines by the Infectious Diseases Society of America. Clin Infect Dis 2013; 56: 1–10.	587	9.055	353.7	57	Twitter
4	Pulido L, Ghanem E, Joshi A, Purtill JJ, Parvizi J. Periprosthetic joint infection: the incidence, timing, and predisposing factors. Clin Orthop Relat Res 2008; 466: 1710–1715.	572	4.154	349.9	7	None
5	Kurtz SM, Lau E, Watson H, Schmier JK, Parvizi J. Economic burden of periprosthetic joint infection in the United States. J Arthroplasty 2012; 27: 61–65.e1.	543	3.524	304.5	21	None
6	Kurtz SM, Lau E, Schmier J, Ong KL, Zhao K, Parvizi J. Infection burden for hip and knee arthroplasty in the United States. J Arthroplasty 2008; 23: 984–991.	486	3.524	268.2	3	None
7	Bozic KJ, Kurtz SM, Lau E, et al. The epidemiology of revision total knee arthroplasty in the United States. Clin Orthop Relat Res 2010; 468: 45–51.	482	4.154	280	14	Twitter
8	Parvizi J, Jacovides C, Zmistowski B, Jung KA. Definition of Periprosthetic joint infection: is there a consensus? Clin Orthop Relat Res 2011; 469: 3022–3030.	470	4.154	64.4	1	Twitter, Facebook
9	Spangehl MJ, Masri BA, O'Connell JX, Duncan CP. Prospective analysis of preoperative and intraoperative investigations for the diagnosis of infection at the sites of two hundred and two revision total hip arthroplasties. J Bone Joint Surg Am 1999; 81: 672–683.	464	4.716	269.3	3	None
10	Berbari EF, Hanssen AD, Duffy MC, et al. Risk factors for prosthetic joint infection: case–control study. Clin Infect Dis 1998; 27: 1247–1254.	455	9.055	298.7	6	None
11	Peersman G, Laskin R, Davis J, Peterson M. Infection in total knee replacement: a retrospective review of 6489 total knee replacements. Clin Orthop Relat Res 2001; (392): 15–23.	436	4.154	214.4	NA*	None
12	Del Pozo JL, Patel R. Infection associated with prosthetic joints. N Engl J Med 2009; 361: 787–794.	407	70.67	257.5	18	None
13	Atkins BL, Athanasou N, Deeks JJ, et al. Prospective evaluation of criteria for microbiological diagnosis of prosthetic-joint infection at revision arthroplasty. J Clin Microbiol 1998; 36: 2932–2939.	384	4.959	110.6	NA	None
14	Havelin LI, Engesaeter LB, Espehaug B, Furnes O, Lie SA, Vollset SE. The Norwegian Arthroplasty Register: 11 years and 73 000 arthroplasties. Acta Orthop Scand 2000; 71: 337–353.	346	3.217	194.8	NA	None
15	Tunney MM, Patrick S, Curran MD, et al. Detection of prosthetic hip infection at revision arthroplasty by immunofluorescence microscopy and PCR amplification of the bacterial 16S rRNA gene. J Clin Microbiol 1999; 37: 3281–3290.	311	4.959	178.9	NA	None
16	Tande AJ, Patel R. Prosthetic joint infection. Clin Microbiol Rev 2014; 27: 302–345.	308	17.75	172.6	33	Twitter, Facebook
17	Bozic KJ, Ries MD. The impact of infection after total hip arthroplasty on hospital and surgeon resource utilization. J Bone Joint Surg Am 2005; 87: 1746–1751.	299	4.716	142.9	6	None
18	Trampuz A, Hanssen AD, Osmon DR, Mandrekar J, Steckelberg JM, Patel R. Synovial fluid leukocyte count and differential for the diagnosis of prosthetic knee infection. Am J Med 2004; 117: 556–562.	296	4.76	198.2	22	Twitter
19	Parvizi J, Gehrke T, Chen AF. Proceedings of the International Consensus on Periprosthetic Joint Infection. Bone Joint J 2013; 95-B: 1450–1452.	294	3.652	182.2	19	Twitter, Facebook
20	Kurtz SM, Ong KL, Lau E, Bozic KJ, Berry D, Parvizi J. Prosthetic joint infection risk after TKA in the Medicare population. Clin Orthop Relat Res 2010; 468: 52–56.	293	4.154	177.1	NA	None
21	Phillips JE, Crane TP, Noy M, Elliott TSJ, Grimer RJ. The incidence of deep prosthetic infections in a specialist orthopedic hospital: a 15-year prospective survey. J Bone Joint Surg Br 2006; 88: 943–948.	285	3.652	174.7	7	None
22	Marculescu CE, Berbari EF, Hanssen AD, et al. Outcome of prosthetic joint infections treated with debridement and retention of components. Clin Infect Dis 2006; 42: 471–478.	271	9.055	164.6	NA	None
23	Segawa H, Tsukayama DT, Kyle RF, Becker DA, Gustilo RB. Infection after total knee arthroplasty. A retrospective study of the treatment of eighty-one infections. J Bone Joint Surg Am 1999; 81: 1434–1445.	262	4.716	163.2	3	None
24	Trampuz A, Widmer AF. Infections associated with orthopedic implants. Curr Opin Infect Dis 2006; 19: 349–356.	253	3.752	189.2	17	None
25	Patel VP, Walsh M, Sehgal B, Preston C, DeWal H, Di Cesare PE. Factors associated with prolonged wound drainage after primary total hip and knee arthroplasty. J Bone Joint Surg Am 2007; 89: 33–38.	249	4.716	153.9	10	Twitter
26	Schinsky MF, Della Valle CJ, Sporer SM, Paprosky WG. Perioperative testing for joint infection in patients undergoing revision total hip arthroplasty. J Bone Joint Surg Am 2008; 90: 1869–1875.	245	4.716	151.6	3	None

Table 7 (*Continued*)

Rank	Title	Times cited	Impact factor	Research Interest score	Attention score	Media use habits[a]
27	Schäfer P, Fink B, Sandow D, Margull A, Berger I, Frommelt L. Prolonged bacterial culture to identify late periprosthetic joint infection: a promising strategy. Clin Infect Dis 2008; 47: 1403–1409.	237	9.055	150.9	17	Twitter
28	Lentino JR. Prosthetic joint infections: bane of orthopedists, challenge for infectious disease specialists. Clin Infect Dis 2003; 36: 1157–1161.	237	9.055	152.7	10	None
29	Bauer TW, Parvizi J, Kobayashi N, Krebs V. Diagnosis of periprosthetic infection. J Bone Joint Surg Am 2006; 88: 869–882.	235	4.716	135	NA	None
30	Trampuz A, Zimmerli W. Prosthetic joint infections: update in diagnosis and treatment. Swiss Med Wkly 2005; 135: 243–251.	235	1.821	144.8	NA	None
31	Piper KE, Jacobson MJ, Cofield RH, et al. Microbiologic diagnosis of prosthetic shoulder infection by use of implant sonication. J Clin Microbiol 2009; 47: 1878–1884.	230	4.959	126.5	6	None
32	Jiranek WA, Hanssen AD, Greenwald AS. Antibiotic-loaded bone cement for infection prophylaxis in total joint replacement. J Bone Joint Surg Am 2006; 88: 2487–2500.	227	4.716	121	6	None
33	Jämsen E, Huhtala H, Puolakka T, Moilanen T. Risk factors for infection after knee arthroplasty. A register-based analysis of 43 149 cases. J Bone Joint Surg Am 2009; 91: 38–47.	224	4.716	138.1	10	None
34	Ong KL, Kurtz SM, Lau E, Bozic KJ, Berry DJ, Parvizi J. Prosthetic joint infection risk after total hip arthroplasty in the Medicare population. J Arthroplasty 2009; 24: 105–109.	223	3.524	138.7	NA	None
35	Zimmerli W, Ochsner PE. Management of infection associated with prosthetic joints. Infection 2003; 31: 99–108.	223	2.927	151.1	NA	None
36	Parvizi J, Zmistowski B, Berbari EF, et al. New definition for periprosthetic joint infection: from the Workgroup of the Musculoskeletal Infection Society. Clin Orthop Relat Res 2011; 469: 2992–2994.	212	4.154	352.3	16	Facebook
37	Hailer NP, Garellick G, Kärrholm J. Uncemented and cemented primary total hip arthroplasty in the Swedish Hip Arthroplasty Register: evaluation of 170 413 operations. Acta Orthop 2010; 81: 34–41.	212	3.217	12.4	NA	None
38	Namba RS, Inacio MCS, Paxton EW. Risk factors associated with deep surgical site infections after primary total knee arthroplasty: an analysis of 56 216 knees. J Bone Joint Surg Am 2013; 95: 775–782.	207	4.716	107.9	16	Twitter
39	Sperling JW, Kozak TK, Hanssen AD, Cofield RH. Infection after shoulder arthroplasty. Clin Orthop Relat Res 2001; (382): 206–216.	204	4.154	119.1	3	None
40	Crockarell JR, Hanssen AD, Osmon DR, Morrey BF. Treatment of infection with debridement and retention of the components following hip arthroplasty. J Bone Joint Surg Am 1998; 80: 1306–1313.	204	4.716	126	NA	None
41	Bozic KJ, Lau E, Kurtz S, et al. Patient-related risk factors for periprosthetic joint infection and postoperative mortality following total hip arthroplasty in Medicare patients. J Bone Joint Surg Am 2012; 94: 794–800.	202	4.716	105.4	11	Twitter, Facebook
42	Parvizi J, Gehrke T, International Consensus Group on Periprosthetic Joint Infection. Definition of periprosthetic joint infection. J Arthroplasty 2014; 29: 1331.	201	3.524	61.2	NA	None
43	Spirt AA, Assal M, Hansen ST Jr. Complications and failure after total ankle arthroplasty. J Bone Joint Surg Am 2004; 86: 1172–1178.	200	4.716	121.8	NA	None
44	Osmon DR, Berbari EF, Berendt AR, et al. Diagnosis and management of prosthetic joint infection: clinical practice guidelines by the Infectious Diseases Society of America. Clin Infect Dis 2013; 56: e1–25.	198	9.055	181.7	57	Twitter, Facebook
45	Kerkhoffs GMMJ, Servien E, Dunn W, Dahm D, Bramer JAM, Haverkamp D. The influence of obesity on the complication rate and outcome of total knee arthroplasty: a meta-analysis and systematic literature review. J Bone Joint Surg Am 2012; 94: 1839–1844.	192	4.716	92.6	10	None
46	Berbari E, Mabry T, Tsaras G, et al. Inflammatory blood laboratory levels as markers of prosthetic joint infection: a systematic review and meta-analysis. J Bone Joint Surg Am 2010; 92: 2102–2109.	191	4.716	126.9	1	None
47	Cui Q, Mihalko WM, Shields JS, Ries M, Saleh KJ. Antibiotic-impregnated cement spacers for the treatment of infection associated with total hip or knee arthroplasty. J Bone Joint Surg Am 2007; 89: 871–882.	191	4.716	122.4	11	Twitter, Facebook
48	Saleh K, Olson M, Resig S, et al. Predictors of wound infection in hip and knee joint replacement: results from a 20 year surveillance program. J Orthop Res 2002; 20: 506–515.	191	3.043	128	4	Twitter
49	Malinzak RA, Ritter MA, Berend ME, Meding JB, Olberding EM, Davis KE. Morbidly obese, diabetic, younger, and unilateral joint arthroplasty patients have elevated total joint arthroplasty infection rates. J Arthroplasty 2009; 24: 84–88.	189	3.524	106.6	19	Twitter
50	Berbari EF, Marculescu C, Sia I, et al. Culture-negative prosthetic joint infection. Clin Infect Dis 2007; 45: 1113–1119.	184	9.055	119.2	NA	None

[a] Not available.

From 1998 to 2018, the United States had the greatest number of publications, followed by Germany ($n = 12$) and United Kingdom ($n = 8$). Germany had the greatest number of third place ($n = 5$), followed by Spain ($n = 4$). The top 10 countries with the greatest numbers of publications encompassed most of the global publications, particularly in 1998, 2004, and 2006 (Table 2).

Institutions

The first-ranking institution was the Rothman Institute, with 245 articles, followed by the Mayo Clinic ($n = 219$) and Cleveland Clinic and Rush University ($n = 80$ each). Seven institutions in the United States were in the top 10 for the highest number of publications on PJI, while the remaining three institutions were in Europe (Table 3).

Authors

The author with the highest number of publications and highest h-index was Javad Parvizi (204 and 57, respectively), followed by Arlen D. Hanssen (85 and 38, respectively) and Douglas R. Osmon (77 and 37, respectively). The top average number of citations was observed for Andrej Trampuz (83.85), followed by Douglas R. Osmon (75.52) and Robin Patel (70.77).

All authors in the top 10 for the number of publications were from the top 10 institutions. Seven of the positions were occupied by authors from the United States, with Javad Parvizi the first ranked author. In Spain, the first ranked author was Alex Soriano, whereas in Germany, Andrej Trampuz was the first ranked author, followed by Thorsten Gehrke (Table 4).

Journals

Articles were published in 362 different journals. The *Journal of Arthroplasty* (14.4%) had the highest number of publications, followed by *Clinical Orthopaedics and Related Research* (8.5%). Third on the list was the *Journal of Bone and Joint Surgery* (4.8%) (Table 5). Based on the WoS database, 325 journals had an impact factor in 2018. The highest impact factor was for *The New England Journal of Medicine* (70.67), followed by *The Lancet* (59.10), and the *British Medical Journal* (27.60) (Table 6).

Top 50 most cited publications

The 50 most cited articles on PJI (Table 7) were cited between 184 and 1461 times. The most cited article was a study by Zimmerli et al. (Zimmerli et al., 2004). The second most cited article was one by Trampuz et al. (Trampuz et al., 2007) and the third was by Osmon et al. (Osmon et al., 2013). All papers were published in English. Of the 14 journals that published these articles, *The New England Journal of Medicine* (70.67) had the highest impact factor, followed by *Clinical Microbiology Reviews* (17.75) and *Clinical Infectious Diseases* (9.055). Most publications were from the *Journal of Bone and Joint Surgery* ($n = 15$), followed by *Clinical Infectious Diseases* and *Clinical Orthopaedics and Related Research* ($n = 7$ each).

Univariate analysis demonstrated that the Research Interest score and impact factor were associated with the number of times cited ($p < 0.05$). There was no significant association between the Attention score or year and the number of times cited ($p > 0.05$). Multivariate analysis showed no significant difference between impact factor or year and the number of times cited ($p > 0.05$). The Research Interest score was positively correlated with the number of citations, whereas a negative correlation was found for the Attention score (Table 8).

Keywords and most cited paper for the different subjects

Significant keywords were screened to show potential trending topics. To obtain a better understanding of PJI, different infection sites were also analyzed (Table 9).

Table 8
Multivariate analysis.

	β	SE	t	p-Value	95% CI for β	
					Lower	Upper
Constant	2.55	0.552	4.618	0	1.422	3.677
Research Interest	0.742	0.113	6.547	0	0.511	0.974
Attention score	−0.178	0.063	−2.803	0.009	−0.307	−0.048
Impact factor	0.129	0.067	1.912	0.066	−0.009	0.266
Year	−0.225	0.147	−1.533	0.136	−0.525	0.075

SE, standard error; CI, confidence interval.

Table 9
List of top 10 keywords and top 5 most cited articles on various topics.

Year	USA	Germany	England [Au?2]	Spain	France	China	Switzerland	Italy	Canada	Netherlands	Proportion
1998	7	2	4	1	1	0	1	1	0	0	94.44%
1999	10	1	1	0	1	0	0	3	2	0	80.95%
2000	9	3	6	1	0	0	0	1	0	1	91.30%
2001	15	1	3	1	5	1	0	3	1	0	85.29%
2002	24	1	8	2*	1	1	0	0	1	0	84.09%
2003	17	6	2	3	5	1	2	0	2	1	90.70%
2004	26	9	6	1	9	1	8	4	1	1	97.06%
2005	31	9	9	2	0	1	3	2	1	1	89.23%
2006	25	10	8	9	10	2	8	0	3	2	87.36%

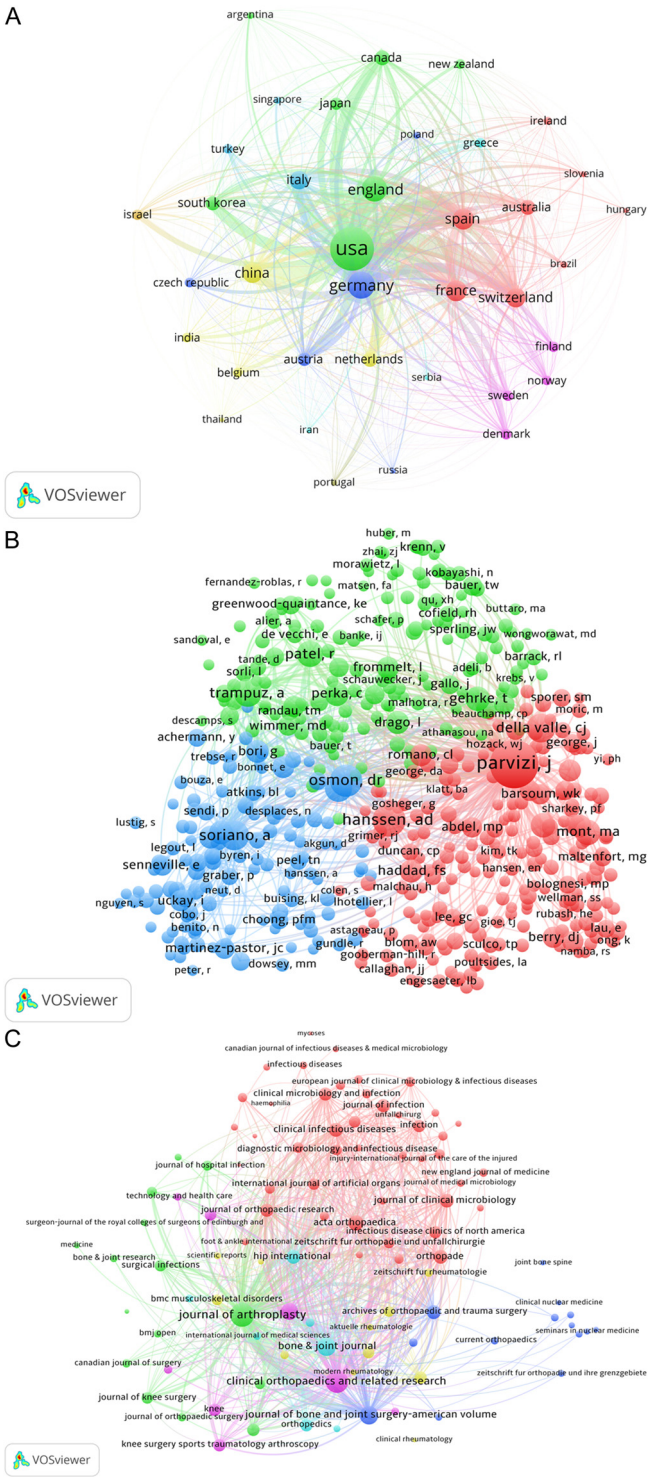


Figure 4. (a) Bibliographic coupling analysis of country; (b) Bibliographic coupling analysis of author; (c) Bibliographic coupling analysis of journal.
Note: the line between the two journals indicates the degree of similarity between both items.

Visualized analysis

Bibliographic coupling analysis

Of the 58 countries, the minimum threshold of five publications stemming from a particular country was met by 37 countries (Figure 4a). The top three countries with the highest total link strengths were the United States ($n = 941\,808$), Germany ($n = 417\,402$), and United Kingdom($n = 313\,201$).

Five hundred authors were identified with a minimum threshold of five publications from a single author

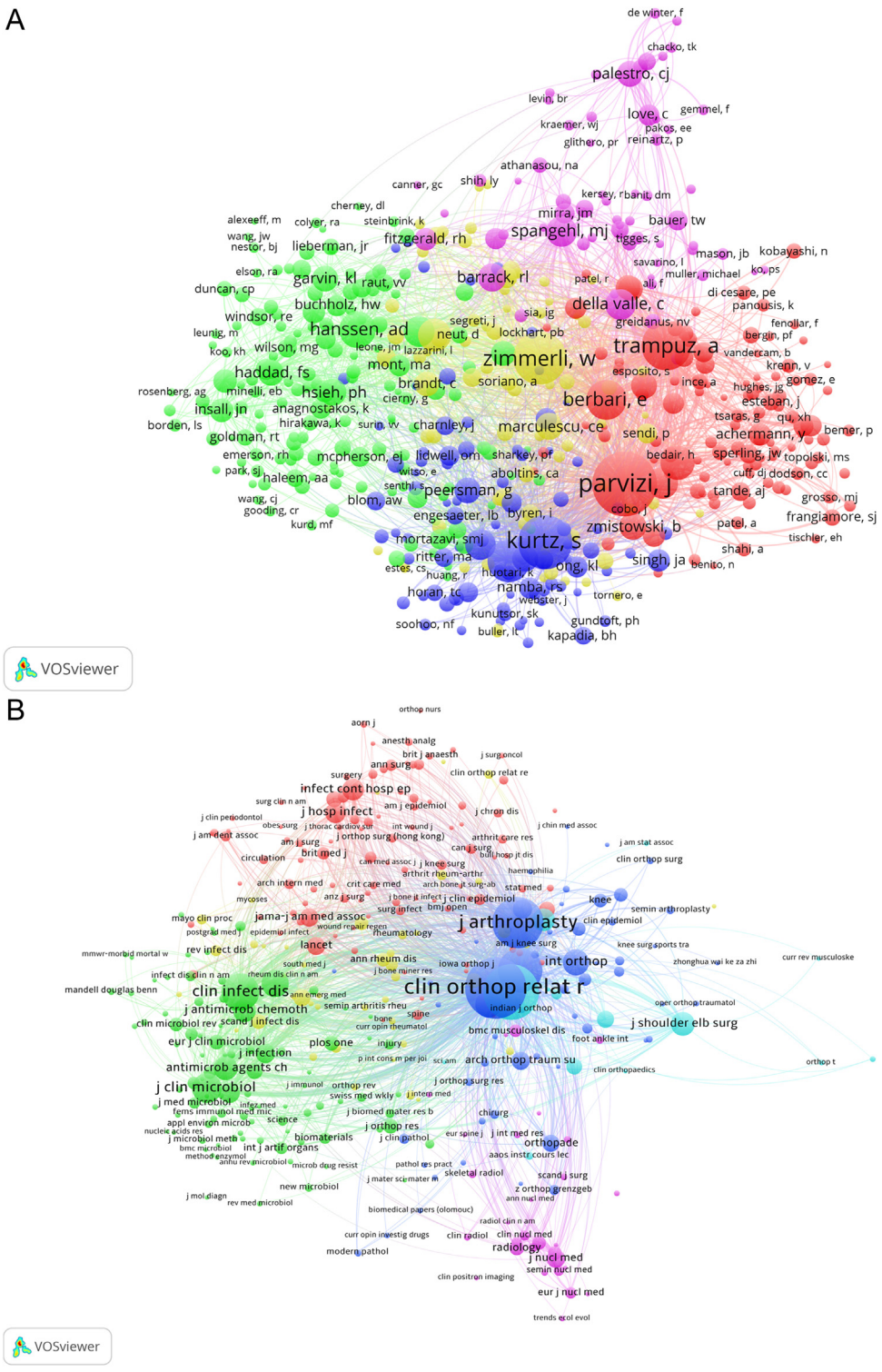


Figure 5. (a) Co-citation analysis of first author. (b) Co-citation analysis of journal.
Note: the size of the circle is dependent on the citation of the journals and first author. The line between the two journals indicates co-citation between both journals, the closer the two circles, the stronger the correlation.

(Figure 4b). The top three authors with greatest total link strengths were Javad Parvizi ($n = 639\,792$), Douglas R. Osmon ($n = 235\,931$), and Arlen D. Hanssen ($n = 230\,809$).

Of the 362 journals, 100 met the minimum threshold of five (Figure 4c). The top three journals with the greatest total link strengths were the *Journal of Arthroplasty* ($n = 334\,278$), *Clinical Orthopaedics and Related Research* ($n = 256\,512$), and *Journal of Bone and Joint Surgery* ($n = 143\,655$).

Co-citation analysis

Journals with a minimum of 20 citations were included. Criteria were met by 349 journals (Figure 5b). The top three journals with

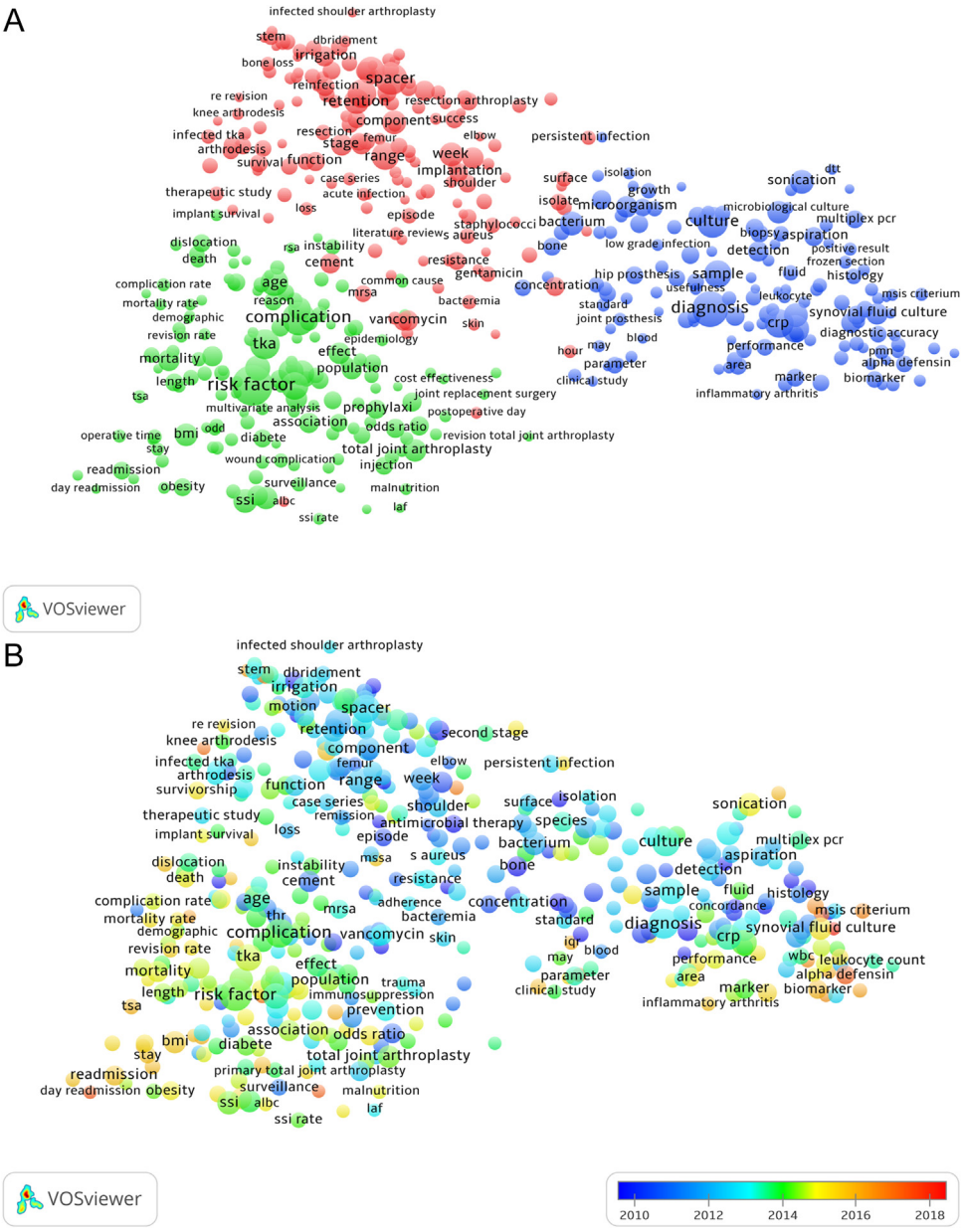


Figure 6. (a) Co-occurrence analysis of keywords according to frequency; (b) Co-occurrence analysis of keywords according to year.
Note: a tendency towards red indicates a more recent item, whereas a tendency to blue indicates that it appears earlier.

greatest total link strengths were *Clinical Orthopaedics and Related Research* ($n = 465\,160$), *Journal of Bone and Joint Surgery* ($n = 383\,465$), and *Journal of Arthroplasty* ($n = 312\,366$).

Five hundred authors with a minimum of 20 citations were identified (Figure 5a). The top three authors with greatest total link strengths were Javad Parvizi ($n = 37\,408$), Werner Zimmerli ($n = 28\,627$), and Andrej Trampuz ($n = 27\,744$).

Co-occurrence analysis

Hot topics and research areas were identified through co-occurrence analysis. Identified keywords were divided into three clusters: “diagnosis”, “treatment”, and “risk factor and prevention” (Figure 6a). In the cluster “diagnosis”, the most frequently used keywords were culture, C-reactive protein, and synovial fluid culture, whereas the primary keywords in the cluster “treatment” were spacer, debridement, and week. The main keywords for the “risk factor and prevention” cluster were complication, total knee arthroplasty, and age.

The most recent studies focused on “diagnosis” and “risk factor and prevention”. In the “diagnosis” cluster, new topics included synovial fluid culture, alpha-defensin, and dithiothreitol, whereas new topics in the “risk factors and prevention” cluster included body mass index, operative time, and day readmission (Figure 6b).

The most frequent keywords used from 2010 to 2018 were also exported from VOSviewer. 'Diagnosis' was the most frequently used word in 2010–2013, 2015, and 2018, in contrast to 'risk factor' in 2016 and 2017. 'Treatment' was the most frequently used word in 2014.

Discussion

Bibliometric analysis is a significant evaluation method that can be used to reflect the current research status and trends. This study presents the first comprehensive analysis of PJI based on publications from the WoS database.

Over the 21 years of reporting on PJI studied (1998–2018), there was an increasing annual trend of global publications. Articles in the field originated from 58 countries. However, most publications originated from 10 countries. The United States contributed most to global research in terms of both the quantity and quality of publications, followed by Germany and United Kingdom. China was the only Asian country amongst the top 10 contributors, placed third in 2017 and 2018.

The most influencing scholars in PJI research were from the United States and Europe. All of the top 10 authors with the highest numbers of publications originated from the top 10 institutions with the greatest contributions. Amongst the top 10 authors, five were orthopedic surgeons, four were infectious disease experts, and one was a microbiologist, demonstrating a multidisciplinary approach in the management of PJI. A report by the European Bone and Joint Infection Society Survey has also provided evidence that infectious diseases specialists and microbiologists represent the most common medical specialists cooperating with orthopedic surgeons (Leite et al., 2016). Ntalos et al. (Ntalos et al., 2019) found a better outcome in patients with PJI when managed by an interdisciplinary team, with a significantly shorter in-hospital stay, reduction in surgery, and reduction in the number of antibiotics. In the Proceedings of the International Consensus Meeting (ICM) on PJI in 2018, 98% of participants agreed that a multidisciplinary approach achieves better results with lower complication rates for PJI patients (Abblitt et al., 2019). Although PJI is a highly relevant topic for orthopedic surgeons, the diagnostic procedure and treatment are complex; therefore, collaboration in a multidisciplinary team is required.

The majority of PJI research was published in five orthopedic journals, namely Journal of Arthroplasty, Clinical *Orthopaedics* and Related Research, Journal of Bone and Joint Surgery, Bone and Joint Journal, and International *Orthopaedics*. Coupling analysis demonstrated that these journals were the most relevant. Clinical *Orthopaedics* and Related Research had the highest citation frequency amongst all journals, followed by Journal of Bone and Joint Surgery and Journal of Arthroplasty. The New England Journal of Medicine had the highest impact factor.

The Altmetric score and Research Interest score are two different altmetric types used to evaluate the literature, both combined to provide a weighted count. However, the scope of the Altmetric score is much broader than that of the Research Interest score, with more than 16 weighted composite scores from websites such as Twitter, Facebook, and YouTube. In contrast, the Research Interest score is calculated from information on ResearchGate (Table 10). The top 50 research articles on PJI were collected and analyzed to determine the relationships between the numbers of times cited, impact factor, publication year, and the Research Interest and Altmetric scores. Most publications at the top of the list were published in *Clinical Orthopaedics and Related Research*,*Journal of Bone and Joint Surgery*, and *Clinical Infectious Diseases*. Regression analysis demonstrated that the year and impact factor did not correlate with citations ($p > 0.05$). A negative correlation was observed between the Altmetric score and number of citations; however, the results are somewhat controversial. Previous studies have demonstrated no or a negative correlation between the number of citations and the Altmetric score (Banshal et al., 2018; Azer and Azer, 2019; Heydari et al., 2019). In contrast, several studies have shown a weak positive correlation between the number of citations and the Altmetric score in highly cited articles (Barbic et al., 2016; Chang et al., 2019). The Altmetric score could be used as a supplementary tool to help assess articles rather than replacing the number of citations. Based on information from the

Table 10
Weighted Altmetric and Research Interest scores.

Altmetric score		Research Interest score	
Source	Weighted score	Source	Weighted score
News	8	Read[2]	0.05
Blog	5		
Policy document (per source)	3		
Patent	3		
Wikipedia	3		
Twitter (tweets and retweets[1])	1	Full-text read[3]	0.15
Peer review (Publons, PubPeer)	1		
Weibo (not trackable since 2015, but historical data kept)	1		
Google + (not trackable since 2019, but historical data kept)	1		
F1000	1		
Syllabi (Open Syllabus)	1	Recommendation	0.25
LinkedIn (not trackable since 2014, but historical data kept)	0.5		
Facebook (only a curated list of public pages)	0.25		
Reddit	0.25		
Pinterest (not trackable since 2013, but historical data kept)	0.25		
Q&A (Stack Overflow)	0.25	Citation	0.5
YouTube	0.25		
Number of Mendeley readers	0		
Number of Dimensions and Web of Science citations	0		

[1] Re-tweets and re-posts count for 0.85, rather than 1, as they are second-hand attention rather than original attention.
[2] A 'read' is when someone views a publication summary or clicks on a figure.
[3] A 'full-text read' is counted when someone views or downloads the full-text.

Altmetric score, most researchers were found to use Twitter rather than Facebook to disseminate knowledge. A recent study also demonstrated that Twitter is more popular than Facebook for scholarly communication (Heydari et al., 2019). In contrast to the Altmetric score, the present study found a positive correlation between the citation count and the Research Interest score. This is a useful supplement in evaluating the academic impact based on citations; however, further research is required to confirm this relationship (Delgado López-Cózar and Orduña Malea, 2019).

Following the extraction of keywords into various subgroups, terms were counted by Endnote and VOSviewer, with these two approaches found to complement one another. Identification was made through keywords or from titles and abstracts. The Endnote database revealed that most research had focused on the hip and knee, followed by the shoulder. Future studies should focus on the ankle and elbow. In the clusters "prevention", "risk factor", "diagnosis", and "treatment", keywords were included, which were used in PJI recommendations written by recognized international organizations (Marschall et al., 2013; Ariza et al., 2017; Caola et al., 2017; Schwarz et al., 2019; Sconfienza et al., 2019). Results from VOSviewer showed that the hot topics in recent years were diagnosis and risk factors.

This study has several limitations. The bibliometric analysis was only based on WoS; hence, literature from the Scopus database was not included. Although the WoS database covers a wide area and is highly similar to the Scopus database (Aghaei Chadegani et al., 2013), there remains an impact on the comprehensive analysis. In addition, experimental research, such as studies on bacterial biofilm or antibiotics, and in vitro and animal experiments, was not within the scope of this study. As implant-related infection is a broad topic and relevant to numerous clinical specialties, only clinical studies on PJI were analyzed to reduce the impact of other subjects. Furthermore, the Altmetric and Research Interest score results were a combination of multiple indicators, with the relationship between number of times cited and the total number of Altmetric and Research Interest scores analyzed. However, although a detailed score could provide relevant information between citations and each indicator score, this was not performed in the present study. Several websites protect their content behind login pages, preventing Altmetric from accessing any of their data. Therefore, it is no longer possible to track some indicators as sources.

In conclusion, this appears to be the first bibliometric analysis of global research on PJI. The largest contribution was made by the United States, with rapid development made by China in the last 2 years. Although most research originated from the top 10 contributing countries, enhanced international collaboration in resolving PJI issues is required. The most influential scholars in the field were from the United States and Europe. The results of this study and new evidence demonstrate that an increasing number of articles and scholars support the facilitation of modern PJI management by interdisciplinary teams to obtain optimal results. This review also found a positive correlation between citation counts and Research Interest scores, while the Attention score was found to be negatively correlated with highly cited PJI articles. Twitter was found to be the most popular social networking tool for researchers. Moreover, keywords from VOSviewer and Endnote were highly related to the hot topic and trends in the clinical correlation with PJI, which may aid the PJI researcher. Risk factors and diagnostic methods are hot topics under research.

Funding

This work was supported by an unrestricted educational grant from the PRO-IMPLANT Foundation, Berlin, Germany (www.pro-implant.org), a non-profit organization supporting research, education, global networking, and care of patients with bone, joint or implant-associated infections.

Conflict of interest

We declare no competing interests.

Author contributions

Project conceptualization: CL and AT; methodology: CL, COT, NR, DM; software: CL; validation: CP, DM, NR, AT; formal analysis: CL; investigation: CL; resources, CL, NR, COT; data curation: CL; writing—original draft preparation: CL; writing—review and editing: COT, CL, DM, NR, CP; visualization: CL, AT; supervision: COT, CP, AT. All authors have read and agreed to the submitted version of the manuscript.

References

Abblitt WP, Ascione T, Bini S, Bori G, Brekke AC, Chen AF, et al. Hip and knee section, outcomes: proceedings of international consensus on orthopedic infections. J Arthroplasty 2019;34(February (2S)):S487–95.
Aggarwal A, Lewison G, Idir S, Peters M, Aldige C, Boerckel W, et al. The state of lung cancer research: a global analysis. J Thorac Oncol 2016;11(July (7)):1040–50.
Aghaei Chadegani A, Salehi H, Yunus M, Farhadi H, Fooladi M, Farhadi M, et al. A comparison between two main academic literature collections: web of science and scopus databases. 2013 Available from: https://papers.ssrn.com/abstract=2257540.
Ahmad SS, Evangelopoulos DS, Abbasian M, Röder C, Kohl S. The hundred most-cited publications in orthopaedic knee research. J Bone Joint Surg Am 2014;96 (November (22)):e190.
Ariza J, Cobo J, Baraia-Etxaburu J, Benito N, Bori G, Cabo J, et al. Executive summary of management of prosthetic joint infections. Clinical practice guidelines by the Spanish Society of Infectious Diseases and Clinical Microbiology (SEIMC). Enferm Infecc Microbiol Clin 2017;35(March (3)):189–95.
Azer SA, Azer S. Top-cited articles in medical professionalism: a bibliometric analysis versus altmetric scores. BMJ Open 2019;9(July (7)):e029433.
Banshal SK, Basu A, Singh VK, Muhuri PK. Scientific vs public attention: a comparison of top cited papers in WoS and Top Papers by Altmetric Score. Altmetrics for research outputs measurement and scholarly information management. . p. 81–95.
Barbic D, Tubman M, Lam H, Barbic S. An analysis of altmetrics in emergency medicine. Acad Emerg Med 2016;23(March (3)):251–68.
Bellini C. Cited or read?. Lancet 2012;379(January (9813)):314.
Caola I, Drago L, De Vecchi E, Tessarolo F, Ambretti S, Ascione T, et al. Percorso diagnostico di laboratorio per le infezioni di protesi articolari e mezzi di osteosintesi. Percorso diagnostico AMCLI; 2017 Available from: http://www.microdttect.com/1/upload/percorso_diagnostico_pji_03_05_2017.pdf.
Chang J, Desai N, Gosain A. Correlation between altmetric score and citations in pediatric surgery core journals. J Surg Res 2019;243(November):52–8.
Delgado López-Cózar E, Orduña Malea E. Research interest score: el nuevo indicador bibliométrico que mide la influencia de las publicaciones de un autor en ResearchGate. 2019 Available from: https://riunet.upv.es/handle/10251/118197.
Fagotti L, Tatka J, Salles MJC, Queiroz MC. Risk factors and treatment options for failure of a two-stage exchange. Curr Rev Musculoskelet Med 2018;11 (September (3)):420–7.
Heydari S, Shekofteh M, Kazerani M. Relationship between altmetrics and citations: a study on the highly cited research papers. DESIDOC J Library Inf Technol 2019;39(4):169–74.
Jafari SM, Coyle C, Mortazavi SMJ, Sharkey PF, Parvizi J. Revision hip arthroplasty: infection is the most common cause of failure. Clin Orthop Relat Res 2010;468 (August (8)):2046–51.
Jani RH, Prabhu AV, Zhou JJ, Alan N, Agarwal N. Citation analysis of the most influential articles on traumatic spinal cord injury. J Spinal Cord Med 2019;14 (February):1–8.
Jia Z, Ding F, Wu Y, He Q, Ruan D. The 50 most-cited articles in orthopaedic surgery from Mainland China. Clin Orthop Relat Res 2015;473(July (7)):2423–30.
Kulshrestha V, Datta B, Mittal G, Kumar S. Epidemiology of revision total knee arthroplasty: a single center's experience. Indian J Orthop 2019;53(March (2)):282–8.

Leite PS, Figueiredo S, Sousa R. Prosthetic joint infection: report on the one versus two-stage exchange EBJIS survey. J Bone Jt Infect 2016;1 (January):1–6.
Marschall J, Lane MA, Beekmann SE, Polgreen PM, Babcock HM. Current management of prosthetic joint infections in adults: results of an Emerging Infections Network survey. Int J Antimicrob Agents 2013;41 (March (3)):272–7.
Ntalos D, Berger-Groch J, Rohde H, Grossterlinden LG, Both A, Luebke A, et al. Implementation of a multidisciplinary infections conference affects the treatment plan in prosthetic joint infections of the hip: a retrospective study. Arch Orthop Trauma Surg 2019;139(April (4)):467–73.
Osmon DR, Berbari EF, Berendt AR, Lew D, Zimmerli W, Steckelberg JM, et al. Executive summary: diagnosis and management of prosthetic joint infection: clinical practice guidelines by the Infectious Diseases Society of America. Clin Infect Dis 2013;56(January (1)):1–10.
Premkumar A, Morse K, Levack AE, Bostrom MP, Carli AV. Periprosthetic joint infection in patients with inflammatory joint disease: prevention and diagnosis. Curr Rheumatol Rep 2018;20(September (11)):68.
Priem J, Taraborelli D, Groth P, Neylon C. Altmetrics: a manifesto. 2010.
Schwarz EM, Parvizi J, Gehrke T, Aiyer A, Battenberg A, Brown SA, et al. 2018 international consensus meeting on musculoskeletal infection: research priorities from the general assembly questions. J Orthop Res 2019;37(May (5)):997–1006.
Sconfienza LM, Signore A, Cassar-Pullicino V, Cataldo MA, Gheysens O, Borens O, et al. Diagnosis of peripheral bone and prosthetic joint infections: overview on the consensus documents by the EANM, EBJIS, and ESR (with ESCMID endorsement). Eur Radiol 2019;29(December (12)):6425–38.
Seetharam A, Ali MT, Wang CY, Schultz KE, Fischer JP, Lunsford S, et al. Authorship trends in the Journal of Orthopaedic Research: a bibliometric analysis. J Orthop Res 2018;36(November (11)):3071–80.
Trampuz A, Piper KE, Jacobson MJ, Hanssen AD, Unni KK, Osmon DR, et al. Sonication of removed hip and knee prostheses for diagnosis of infection. N Engl J Med 2007;357(August (7)):654–63.
Vaishya R, Patralekh MK, Vaish A, Agarwal AK, Vijay V. Publication trends and knowledge mapping in 3D printing in orthopaedics. J Clin Orthop Trauma 2018; 9(July (3)):194–201.
Zimmerli W, Trampuz A, Ochsner PE. Prosthetic-joint infections. N Engl J Med 2004; 351(October (16)):1645–54.