Spine

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Bibliometric and visualized analysis of the top 100 most-cited articles on anterior cervical surgery

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- Anterior cervical surgery (ACS) owes its development to various pioneering individuals whose revolutionary works form key advances and guide current medical decisions. This bibliometric study aimed to identify, analyse and visualize the main features of the most-cited papers in ACS.
- The citation count for the top 100 most-cited articles ranged from 148 to 1,197, and citations per year ranged from 3.1 to 89.8. The articles were published from 1958 to 2016, with the 2000s being the most active decade. There was an inverse correlation between the average citations per year since publication and article age.
- The oldest as well as most-cited two articles were both published in 1958 by Smith and Robinson, and Cloward, respectively. In their studies, the authors individually described the technique of anterior cervical discectomy with fusion (ACDF).
- The most popular keywords were: 'fusion' (22), 'spine' (20), 'cervical spine' (16), 'complications' (15), 'arthrodesis' (13), 'interbody fusion' (13), 'bone morphogenetic protein' (13), and 'radiculopathy' (12).
- ACDF was the most frequent surgical procedure (80%), while cervical disc arthroplasty is of gradual greater impact.
- The surgical techniques of ACDF have remained unaltered for over 60 years. More attempts are needed to promote its development.

Keywords: anterior cervical surgery; bibliometric analysis; VOSviewer

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Introduction

Anterior cervical surgery (ACS) is one of the most commonly used cervical surgical approaches.[1] It has been widely applied as a standard procedure for various cervical degenerative, traumatic, neoplastic, vascular, and infectious diseases since the 1950s.[2–4] Generally, the commonly used ACS procedures include anterior cervical discectomy (ACD), anterior cervical discectomy with fusion (ACDF), anterior cervical corpectomy with fusion (ACCF), and cervical disc arthroplasty (CDA). Each technique has its proponents and inherent drawbacks mainly related to the adequacy of decompression of the spinal cord and nerve roots, maintenance of the stability of the spinal column, duration of the procedure and blood loss, and time required to recover from surgery and be discharged from the hospital.[5–8] During the last 60 years, numerous studies have made considerable progress in the development of ACS. However, with an increase in the number of publications regarding ACS, gathering critical information from literature remains challenging. Thus, identifying the most impactful publications and trends in research hotspots is of great significance.

The bibliometric analysis applies multiple methods to qualitatively and quantitatively evaluate trends in research in a certain field. The number of citations per paper is one of the markers of scientific merit.[9,10] A high number of citations indicates the influence of a paper on knowledge development. VOSviewer is a software tool for creating maps based on bibliographic data and for visualizing and exploring these maps.[11] Though there have been such studies on spinal disorders[12] and spinal image research as a whole,[13] little is known about the most important literature on ACS and only a few studies have been visualized. Herein, we conducted a bibliometric analysis coupled with visualization tools using the Web of Science database to identify the top 100 most influential articles on ACS published in any journal from 1950 to 2021. This may help identify trends, focal points, and novelties that have defined ACS.

Materials and methods

Data source and search strategy

The Web of Science Core Collection database was comprehensively searched in May 2021 to identify the 100 most-cited articles focusing on ACS. The search strategy combined the following terms: "anterior cervical", "anterior cervical surgery", "anterior cervical spine surgery", "anterior cervical approach", or "cervical disc". Only English-language articles were included for analysis. Conference papers were excluded. No limitation was imposed on publishing time. The cited articles were independently reviewed by two authors and discrepancies were resolved by consensus. The search results were ranked from the highest to lowest and the top 100 most-cited articles were obtained for publication trend analysis. The senior author reviewed each article to ensure its relevance to ACS.

Data analysis

The following basic information was extracted: title, authorship, year of publication, country and institution of publication, number of citations, citations per year, topic, and surgical types. All data were imported into Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) and analysed quantitatively and qualitatively. Every publication was assigned to the type of study. The type of study was categorized as diagnostic, therapeutic, prognostic, economic and basic studies, and reviews. Levels of evidence of original articles were classified based on criteria established by the *Journal of Bone and Joint Surgery American Volume*.[14] Reviews were not assigned to a level of evidence. Moreover, VOSviewer (Leiden University, Leiden, Netherlands), a free Java program, was used for analysing and visualizing the co-occurrence of authors and co-occurrence of keywords. Meanwhile, the SPSS software version 24.0 (IBM Corporation, Armonk, NY, USA) was used for standard statistical analysis. Associations were investigated using Pearson or Spearman correlation tests. Differences between two groups were considered significant when the P-value was less than 0.05.

Results

Basic characteristics

The main characteristics of the top 100 most-cited studies are shown in Table 1. This search yielded 18,556 results, which were then sorted in descending order per the number of total citations. A total of 541 papers were cited 100 times or more, of which 327 precisely matched the search criteria. Collectively, the included studies covered the four major surgical types: ACD, ACDF, ACCF, and CDA. The top paper was cited 1,197 times, the 100th paper 148 times, and the median number of citations of the top 100 most-cited studies was 193.5, with a total of 25,810 citations. The number of citations since 2013 was between 0 and 128 (median, 12). Since publication, the average citations per year ranged from 3.1 to 89.8 (median, 10.9). Additionally, the number of pages in the included studies ranged from 3 to 30 (median, 7).

Among the top 100 most-cited papers, seven were systematic reviews, six were non-systematic reviews, and 87 were primary studies. Of the 87 original articles, 13 articles had level I evidence, 14 articles had level II evidence, 35 articles had level III evidence, 21 articles had level IV evidence, and four articles had level V evidence. Of note, articles with level IV evidence had the highest number of mean and total citations (402.3 citations per article, 8,448 citations, respectively).

Distribution of articles by years of publication

All studies were published between 1958 and 2016. The two oldest articles were by Cloward[3] and Smith and Robinson[4] which were both published in 1958. The most recent article was published in 2016 by James et al.[15]

About 85% of the top 100 most-cited papers were published after 1990, with the 2000s as the most active decade with 48 highly cited papers (Table 1; Fig. 1A). The most prolific year was 2007 with eight articles, followed by 2003 and 2005 with seven articles each. Moreover, there was an inverse correlation between average citations per year since publication and article age ($r = –0.773$; $P < 0.05$) (Fig. 1B).

Distribution of authors

Eighty-nine first authors contributed to the top 100 articles. Eight authors were represented multiple times in the top 100 articles (Table 2). Among these, Goffin J was regarded as the most productive first author with four articles (Article 21, 36, 48, 92 in Table 1), followed by Sasso RC with three articles (Article 77, 78, 82 in Table 1)..

VOSviewer map detailed through clusters the co-authorship relationships among all authors from the top 100 articles (Fig. 2). The main cluster contained prominent authors, including Heller JG, Vaccaro AR, Bohlman HH, and Hilibrand AS, gathering with 17 other authors. Another large cluster was formed by Goffin J and Casey A, gathering with 16 other different authors.

Distribution of articles by country and institution

There were 70 institutions from the correspondence addresses. Sixteen institutions were represented multiple times in the top 100 articles (Table 3). The top six institutions with the most productive articles were Case Western Reserve University, USA, Emory University, USA, Catholic University of Leuven, Belgium, Medical College of Wisconsin, USA, Osaka University, Japan, and Johns

Table 1. The top 100 cited articles on anterior cervical surgery

Rank	Title	First author	Total citations	Citations per year	Level of evidence
1	The anterior approach removal of ruptured cervical disks	Cloward, RB	1197	19.0	IV
2	The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion	Smith, GW	1102	17.5	IV
3	Radiculopathy and myelopathy at segments adjacent to the site of a previous anterior cervical arthrodesis	Hilibrand, AS	975	44.3	IV
4	A critical review of recombinant human bone morphogenetic protein-2 trials in spinal surgery: emerging safety concerns and lessons learned	Carragee, EJ	898	89.8	NA
5	Donor site morbidity after anterior iliac crest bone harvest for single-level anterior cervical discectomy and fusion	Silber, JS	588	32.7	IV
6	Robinson anterior cervical discectomy and arthrodesis for cervical radiculopathy	Bohlman, HH	585	20.9	IV
7	Anterior cervical discectomy and fusion associated complications	Fountas, KN	494	35.3	IV
8	Adverse effects associated with high-dose recombinant human bone morphogenetic protein-2 use in anterior cervical spine fusion	Shields, LBE	485	32.3	IV
9	Complications following autologous bone graft harvesting from the iliac crest and using the RIA: A systematic review	Dimitriou, R	393	39.3	NA
10	Clinical and radiographic analysis of cervical disc arthroplasty compared with allograft fusion: a randomized controlled clinical trial	Mummaneni, PV	393	28.1	I
11	Stabilization of the cervical spine by anterior fusion	Bailey, RW	378	6.2	IV
12	Results of the prospective, randomized, controlled multicenter Food and Drug Administration investigational device exemption study of the ProDisc-C total disc replacement versus anterior discectomy and fusion for the treatment of 1-level symptomatic cervical disc disease	Murrey, D	351	29.3	I
13	Comparison of BRYAN cervical disc arthroplasty with anterior cervical decompression and fusion	Heller, JG	329	27.4	I
14	Prevalence, complications, and hospital charges associated with use of bone-morphogenetic proteins in spinal fusion procedures	Cahill, KS	317	26.4	III
15	Cervical laminectomy and dentate ligament section for cervical spondylotic myelopathy	Benzel, EC	307	10.2	III
16	Anterior cervical fusion for degenerated or protruded disks - a review of 146 patients	Gore, DR	303	8.2	III
17	Effectiveness and harms of recombinant human bone morphogenetic protein-2 in spine fusion	Fu, RW	296	37.0	NA
18	The results of anterior interbody fusion of the cervical spine	Robinson, RA	294	5.0	IV
19	A review of the clinical side effects of bone morphogenetic protein-2	James, AW	293	58.6	NA
20	Increased swelling complications associated with off-label usage of rhBMP-2 in the anterior cervical spine	Smucker, JD	289	19.3	III
21	Long-term follow-up after interbody fusion of the cervical spine	Goffin, J	288	16.9	IV
22	Late radiographic findings after anterior cervical fusion for spondylotic myeloradiculopathy	BABA, H	285	10.2	III
23	Anterior cervical plating enhances arthrodesis after discectomy and fusion with cortical allograft	Kaiser, MG	283	14.9	III
24	Anterior cervical decompression and arthrodesis for the treatment of cervical spondylotic myelopathy- two to seventeen-year follow-up	Emery, SE	280	12.2	III
25	Kyphotic malalignment after anterior cervical fusion is one of the factors promoting the degenerative process in adjacent intervertebral levels	Katsuura, A	265	13.3	III
26	Neck and shoulder pain after laminoplasty - A noticeable complication	Hosono, N	263	10.5	III
27	Anterior surgery for cervical disc disease-part 1: treatment of lateral cervical disc herniation in 253 cases	Lunsford, LD	262	6.4	III
28	Anterior approaches to fusion of the cervical spine: a meta analysis of fusion rates	Fraser, JF	249	17.8	III
29	C5 palsy after decompression surgery for cervical myelopathy	Sakaura, H	249	13.8	IV
30	Assessment of adjacent-segment disease in patients treated with cervical fusion or arthroplasty: a prospective 2-year study	Robertson, JT	248	15.5	II
31	Early failure of long segment anterior cervical plate fixation	Vaccaro, AR	248	10.8	III
32	Anterior cervical fusion and caspar plate stabilization for cervical trauma	Caspar, W	245	7.7	IV
33	A comparative analysis of fusion rates and donor-site morbidity for autogeneic rib and iliac crest bone grafts in posterior cervical fusions	Sawin, PD	234	10.2	III
34	Direct anterior approach to the upper cervical spine	Fang, HSY	234	4.0	IV
35	Strain on intervertebral discs after anterior cervical decompression and fusion	Matsunaga, S	230	10.5	III
36	Intermediate follow-up after treatment of degenerative disc disease with the Bryan Cervical Disc Prosthesis: Single-level and bi-level	Goffin, J	229	12.7	II
37	Anterior cervical interbody fusion using autogeneic and allogeneic bone graft substrate: a prospective comparative analysis	Bishop, RC	228	9.1	II
38	Complications with use of bone morphogenetic protein-2 (BMP-2) in spine surgery	Tannoury, CA	225	32.1	NA
39	Subtotal corpectomy versus laminoplasty for multilevel cervical spondylotic myelopathy-A long-term follow-up study over 10 years	Wada, E	224	11.2	III
40	Prospective, randomized, multicenter study of cervical arthroplasty: 269 patients from the Kineflex|C artificial disc investigational device exemption study with a minimum 2-year follow-up	Coric, D	223	22.3	I

(continued)

Table 1. (continued)

Rank	Title	First author	Total citations	Citations per year	Level of evidence
41	Psychosocial predictors and correlates for chronic post-surgical pain (CPSP) – A systematic review	Hinrichs-Rocker, A	216	18.0	NA
42	Safety and effectiveness of recombinant human bone morphogenetic protein-2 for spinal Fusion-A meta-analysis of individual-participant data	Simmonds, MC	215	26.9	NA
43	Adjacent level intradiscal pressure and segmental kinematics following a cervical total disc arthroplasty-An in vitro human cadaveric mode	Dmitriev, AE	212	13.3	V
44	A prospective, randomized, controlled cervical fusion study using recombinant human bone morphogenetic protein-2 with the CORNERSTONE-SR™ allograft ring and the ATLANTIS™ anterior cervical plate	Baskin, DS	211	11.7	I
45	Persistent iliac crest donor site pain: independent outcome assessment	Heary, RF	210	11.1	III
46	The use of freeze-dried allograft bone for anterior cervical fusions	Zdeblick, TA	209	7.0	III
47	Complications and mortality associated with cervical spine surgery for degenerative disease in the United States	Wang, MC	199	14.2	II
48	Preliminary clinical experience with the Bryan Cervical Disc prosthesis	Goffin, J	196	10.3	II
49	Complications of anterior cervical discectomy without fusion in 450 consecutive patients	Bertalanffy, H	194	6.1	IV
50	A prospective randomized multicenter clinical evaluation of an anterior cervical fusion cage	Hacker, RJ	193	9.2	I
51	Cervical radiculopathy	Carette, S	192	12.0	NA
52	Long-term clinical and radiographic outcomes of cervical disc replacement with the Prestige disc: results from a prospective randomized controlled clinical trial Presented at the 2009 Joint Spine Section Meeting Clinical article	Burkus, JK	190	17.3	I
53	Increased fusion rates with cervical plating for two-level anterior cervical discectomy and fusion	Wang, JC	190	9.0	III
54	Comparison of transcranial electric motor and somatosensory evoked potential monitoring during cervical spine surgery	Hilibrand, AS	187	11.0	I
55	Surgical-treatment for cervical spondylitic myelopathy	Ebersold, MJ	185	7.1	III
56	Cervical Spondylotic Myelopathy: The Clinical Phenomenon and the Current Pathobiology of an Increasingly Prevalent and Devastating Disorder	Kalsi-Ryan, S	184	23.0	NA
57	Prospective analysis of incidence and risk factors of dysphagia in spine surgery patients - Comparison of anterior cervical, posterior cervical, and lumbar procedures	Smith-Hammond, CA	183	10.8	II
58	Off-Label Use of Bone Morphogenetic Proteins in the United States Using Administrative Data	Ong, KL	181	16.5	II
59	Adverse swelling associated with use of rh-BMP-2 in anterior cervical discectomy and fusion: a case study	Perri, B	181	12.9	IV
60	Corpectomy Versus laminoplasty for multilevel cervical myelopathy - An independent matched-cohort analysis	Edwards, CC	181	9.5	III
61	Biomechanics of the cervical spine Part 2. Cervical spine soft tissue responses and biomechanical modeling	Yoganandan, N	181	9.1	V
62	Hybrid multidirectional test method to evaluate spinal adjacent-level effects	Panjabi, MM	180	12.9	V
63	Increasing rates of cervical and lumbar spine surgery in the united-states,1979-1990	Davish, H	180	6.7	II
64	A comparsion of anterior cervical fusion, cervical laminectomy, and cervical laminoplasty for the surgical-management of multiple level spondylotic radiculopathy	Herkowitz, HN	180	5.5	III
65	Complications of anterior cervical discectomy and fusion using recombinant human bone morphogenetic protein-2	Vaidya, R	179	12.8	III
66	Central corpectomy for cervical spondylotic myelopathy-aconsecutive series with long-term follow-up evaluation	Saunders, RL	179	6.0	III
67	Outcome of patients treated for cervical myelopathy - A prospective, multicenter study with independent clinical review	Sampath, P	178	8.5	II
68	Analysis of harvest morbidity and radiographic outcome using autograft for anterior cervical fusion	Schnee, CL	177	7.4	III
69	Neurologic complications of surgery for cervical compression myelopathy	Yonenobu, K	177	5.9	III
70	Influence of an artificial cervical joint compared with fusion on adjacent-level motion in the treatment of degenerative cervical disc disease	Wigfield, C	175	9.2	II
71	Multilevel anterior cervical corpectomy and fibular allograft fusion for cervical myelopathy	Macdonald, RL	175	7.3	IV
72	A comprehensive review of the safety profile of bone morphogenetic protein in spine surgery	Benglis, D	174	13.4	NA
73	Anterior cervical fusion: Outcome analysis of patients fused with and without anterior cervical plates	Connolly, PJ	174	7.0	III
74	The results of anterior interbody fusion of the cervical spine. Review of ninety-three consecutive cases	Riley, LH	174	3.3	III
75	Cervical kyphosis and myelopathy. Treatment by anterior corpectomy and strut-grafting	Zdeblick, TA	172	5.4	III
76	Heterotopic ossification in total cervical artificial disc replacement	Mehren, C	170	11.3	II
77	Early reconstruction failures after multilevel cervical corpectomy	Sasso, RC	170	9.4	III

(continued)

Table 1. (continued)

Rank	Title	First author	Total citations	Citations per year	Level of evidence
78	Results of Cervical Arthroplasty Compared with Anterior Discectomy and Fusion: Four-Year Clinical Outcomes in a Prospective, Randomized Controlled Trial	Sasso, RC	167	16.7	I
79	National trends in surgical procedures for degenerative cervical spine disease: 1990-2000	Patil, PG	166	10.4	II
80	Laminoplasty versus subtotal corpectomy. A comparative study of results in multisegmental cervical spondylotic myelopathy	Yonenobu, K	165	5.7	III
81	Full-endoscopic cervical posterior foraminotomy for the operation of lateral disc herniations using 5.9-mm endoscopes - A prospective, randomized, controlled study	Ruetten, S	164	12.6	I
82	Artificial disc versus fusion - A prospective, randomized study with 2-year follow-up on 99 patients	Sasso, RC	164	11.7	I
83	Neurologic complications of anterior cervical interbody fusion	Flynn, TB	164	4.2	II
84	Influence of anterior cervical plate design on dysphagia - A 2-year prospective longitudinal follow-up study	Lee, MJ	163	10.2	II
85	Complications in spine surgery A review	Nasser, R	162	14.7	NA
86	Dysphagia after anterior cervical decompression and fusion - Prevalence and risk factors from a longitudinal cohort study	Riley, LH	162	10.1	III
87	Treatment of neoplastic spinal cord compression: results of a prospective study	Sundaresan, N	162	5.4	IV
88	Cervical Spondylotic Myelopathy	Tracy, JA	159	14.5	NA
89	Anterior discectomy and fusion for painful cervical disc disease - A report of 50 patients with an average follow-up of 21 years	Gore, DR	158	6.9	IV
90	Long-lasting cervical radicular pain managed with surgery, physiotherapy, or a cervical collar - A prospective, randomized study	Persson, LCG	158	6.6	I
91	Assessment of the minimum clinically important difference in pain, disability, and quality of life after anterior cervical discectomy and fusion	Parker, SL	156	19.5	I
92	Long-term results after anterior cervical fusion and osteosynthetic stabilization for fractures and/or dislocations of the cervical spine	Goffin, J	156	6.0	IV
93	Subsidence of stand-alone cervical cages in anterior interbody fusion: warning	Gercek, E	155	8.6	IV
94	Cervical spondylotic myelopathy: A common cause of spinal cord dysfunction in older persons	Young, WF	155	7.4	NA
95	Increased fusion rates with cervical plating for three-level anterior cervical discectomy and fusion	Wang, JC	154	7.7	III
96	Operations for cervical spondylotic myelopathy. A comparison of the results of anterior and posterior procedures	Hukuda, S	154	4.3	III
97	Biomechanical testing of an artificial cervical joint and an anterior cervical plate	DiAngelo, DJ	153	8.5	V
98	Anterior interbody fusion for severe cervical disc degeneration	DePalma, AF	153	3.1	IV
99	Airway complications associated with surgery on the anterior cervical spine	Sagi, HC	149	7.8	III
100	Is autograft the gold standard in achieving radiographic fusion in one-level anterior cervical discectomy and fusion with rigid anterior plate fixation?	Samartzis, D	148	9.3	III

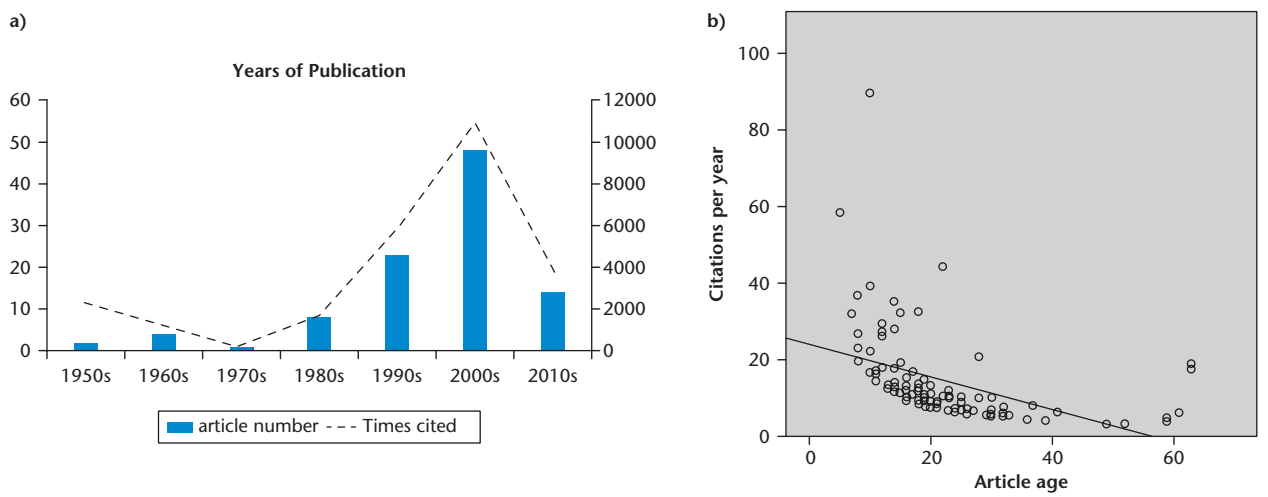

Fig. 1 Overview of the publication year distribution. (A) Number and citations of the top 100 most-cited articles per decade. (B) Correlation between article age and average citations per year since publication.

Table 2. First authors with multiple publications

First author	No. of articles	Total citations
Goffin, J	4	869
Hilibrand, AS	2	1162
Sasso, RC	3	501
Gore, DR	2	461
Zdeblick, TA	2	381
Wang, JC	2	344
Yonenobu, K	2	342
Riley, LH	2	336

Hopkins University, USA, with four publications each. Concerning country and region of origin, the top 100 articles originated from seven different countries, with the United States contributing 74% of all articles and 78.4% of all citations. Moreover, articles from Europe were represented by four countries (Germany, United Kingdom, Belgium, and Sweden) with 14 articles and 3,033 citations. Asia was only represented by articles from Japan (nine papers; 2,012 citations). However, Latin America, Oceania, and Africa had no papers included (Fig. 3).

Distribution of published journals

All articles were published in 22 different journals, with the top three journals publishing 57% of the articles (Table 4). The most contributed journal was *Spine* with 38 papers, followed by the *Journal of Bone and Joint Surgery American Volume* with 10 papers and the *Journal of Neurosurgery* with nine papers. Naturally, *Spine* had the highest number of citations (8,545 citations). However, the *Journal of Bone and Joint Surgery American Volume* had the highest number of mean citations (437.4 citations), followed by *Spine Journal* (413.8 citations).

Distribution of study types and topics

The most common study types were reports of 'therapeutic' ($n = 73$), followed by 'prognostic' ($n = 9$), non-systematic reviews ($n = 7$), systematic reviews ($n = 6$), 'basic' ($n = 4$), and 'diagnostic' ($n = 1$) (Table 5). Concerning topics, most articles were assigned to more than one type of surgery. Overall, ACDF was the most frequent surgical procedure. Eighty per cent (80/100) of the top 100 articles related to ACDF, while only seven papers applied ACD as the research object. Further, 28 and 15 papers were assigned to ACCF and CDA, respectively.

Moreover, keywords were analysed using a co-occurrence network analysis tool in the VOSviewer software with a minimum number of keyword occurrences of five (Fig. 4). A total of 32 keywords were identified and classified into three clusters: 'surgical procedures', 'disorders and symptoms', and 'complications'. Overall, the most popular keywords were: 'fusion' (22), 'spine' (20),

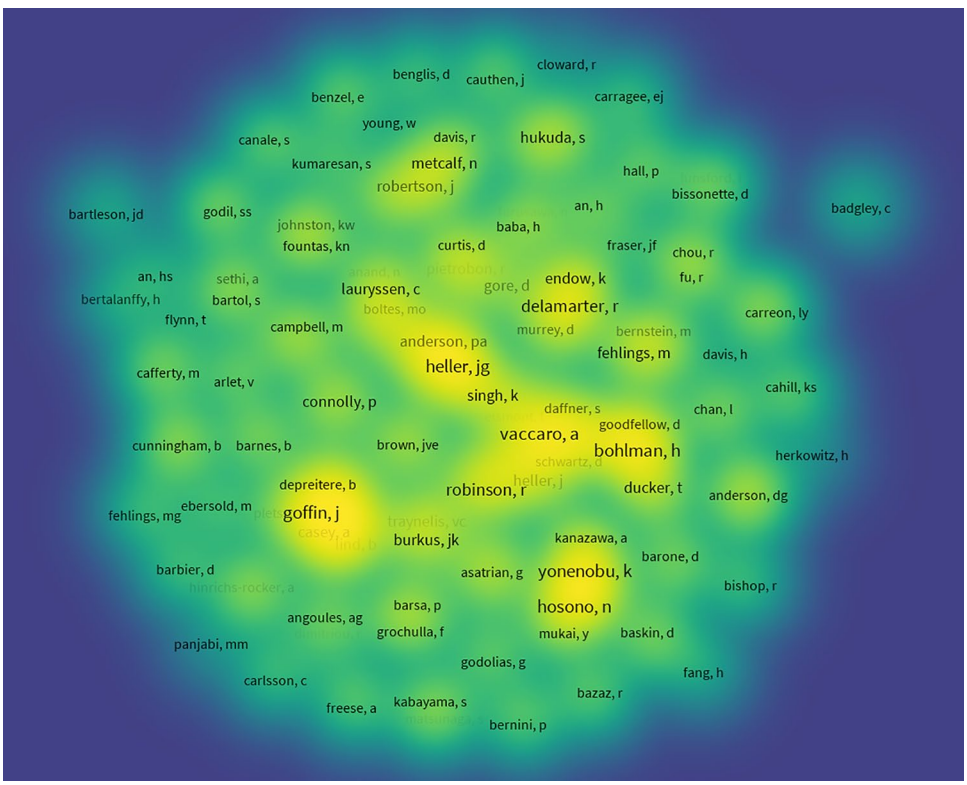

Fig. 2 VOSviewer co-authorship map illustrating author density and the existence of clusters among all authors of the 100 most-cited articles.

Table 3. Institutions with multiple publications*

Institution	No. of articles	Total citations	Mean citations
Case Western Reserve University	4	2003	500.8
Emory University	4	1082	270.5
Catholic University of Leuven	4	869	217.3
Medical College of Wisconsin	4	841	210.3
Osaka University	4	815	203.8
Johns Hopkins University	4	808	202.0
University of California, Los Angeles	3	637	212.3
Indiana University	3	501	167.0
University of California, San Francisco	2	542	271.0
Thomas Jefferson University	2	410	205.0
University of Tennessee	2	401	200.5
University of Wisconsin, Madison	2	381	190.5
University of Witten/ Herdecke	2	380	190.0
University of Toronto	2	376	188.0
Duke University	2	349	174.5
Mayo Clinic	2	344	172.0

*From correspondence address.

'cervical spine' (16), 'complications' (15), 'arthrodesis' (13), 'interbody fusion' (13), 'bone morphogenetic protein (BMP)' (13), and 'radiculopathy' (12).

Discussion

To the best of our knowledge, the current study is the first to analyse the quality and quantity of studies using bibliometric analysis and visualization tools in ACS. Research on ACS has progressed significantly since its inception, especially in recent years.[6,16] Our study revealed a steady increase in the number of ACS publications, with 62% of highly cited papers published in the last two decades (Fig. 1A). This trend demonstrates that ACS research has progressed rapidly and attracted more attention, which may be due to the global increase in the incidence of refractory cervical degenerative disc disease (CDDD).[5,17] The Global Burden of Disease 2015 study revealed that the incidence of neck pain has increased yearly over the past 25 years, and that the number of years lived with disability caused by neck pain has increased by 21% from 2005 to 2015, ranking fourth in all 315 diseases after being combined with low back pain.[18] Moreover, the emergence of CDA, a motion-preserving and highly cost-effective surgical procedure, made a considerable contribution to the development of ACS.[19] However, the research has been extensive and relatively non-conforming, and analysis of research hotspots and trends is largely lacking. Thus, identifying classic works may provide insight into the history, development, and current state of ACS and help to capture emerging themes and future tendencies of ACS.

The oldest as well as most-cited two articles in our study were both published in the United States in 1958.[3,4] Interestingly, in their studies, Smith and Robinson, and Cloward individually described a novel anterior approach to the cervical spine for the removal of cervical intervertebral discs, which is currently known as ACDF and its usage in 14 and 47 patients, respectively. Generally speaking, Smith and Robinson first described the ACDF technique in 1955,[2] and Cloward was the first to publish the approach

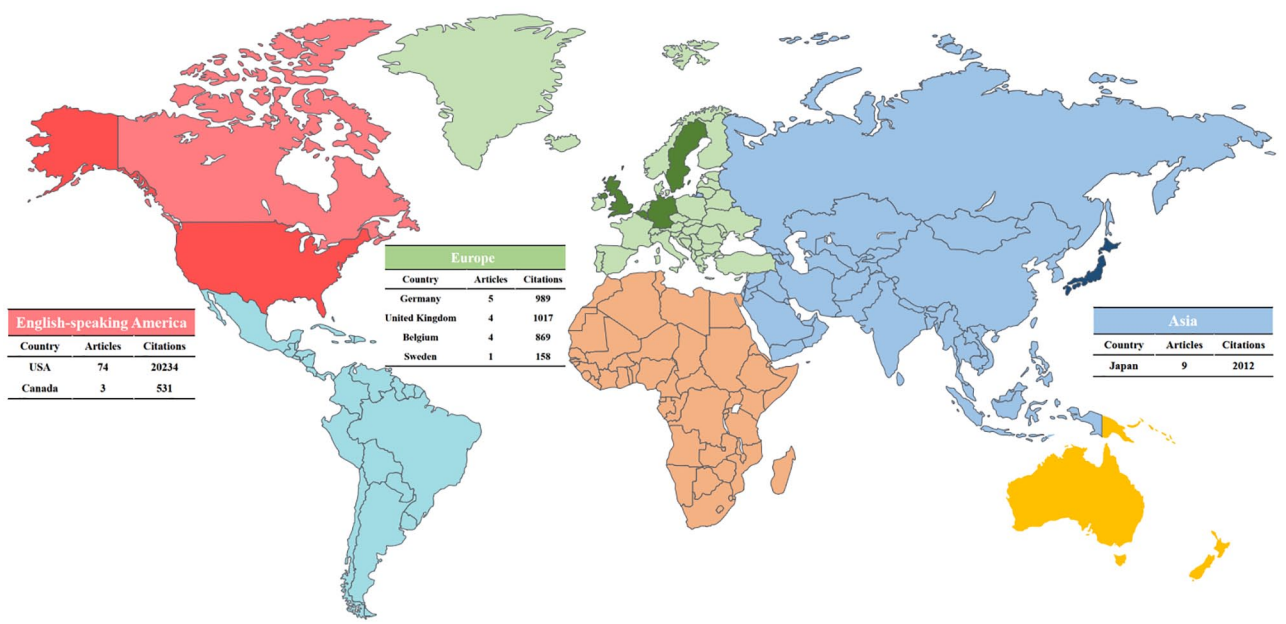

Fig. 3 Map of worldwide research productivity.

Table 4. Journals with multiple publications

Journal	No. of articles	Total citations	Mean citations
Spine	38	8545	224.9
Journal of Bone and Joint Surgery American Volume	10	4374	437.4
Journal of Neurosurgery	9	2809	312.1
Journal of Neurosurgery–Spine	7	1621	231.6
*Journal of Spinal Disorders**	7	1489	212.7
Neurosurgery	7	1436	205.1
Spine Journal	4	1655	413.8
European Spine Journal	3	599	199.7
Annals of Internal Medicine	2	511	255.5
Clinical Biomechanics	2	361	180.5

*Continued by *Journal of Spinal Disorders & Techniques* (2002–2015) and *Clinical Spine Surgery* (2016–present).

Table 5. Distribution of study types

Study type	No. of articles	Total citations	Mean citations
Original study			
Diagnostic	1	187	187.0
Therapeutic	73	18594	254.7
Prognostic	9	2741	304.6
Economic	0	0	0
Basic	4	726	181.5
Review			
Systematic	6	2180	363.3
Non-systematic	7	1382	197.4

in the neurosurgical literature in 1958. Compared with Smith and Robinson's approach, cosmetic horizontal skin crease incision is applied in Cloward's approach, and a trephine, instead of pituitary rongeurs and curettes, is used to deal with the disc space.[3,4,20] More importantly, the final results of these two articles showed that ACDF could completely remove both soft tissue and bony elements encroaching the nerve roots or the spinal cord and relieve symptoms safely and effectively. Until now, ACDF has been regarded as the original form of ACS and a classic gold standard.[1,6,16,21] The 80% attendance rate of ACDF in the results of this current study proves this point as well. In the current study, 80% of the top 100 articles were related to ACDF, which confirms the above results. However, surgical techniques of ACDF have remained unaltered for over 60 years. Although this reflects the recognition of its safety and efficacy, it also suggests that more attempts are needed to promote its development.

Regarding the distribution of countries, we found that the United States dominated (74%) the top 100 most-cited papers when compared with other countries (Fig. 3). This can be explained by several potential reasons. First, as previously mentioned, ACS originated in the US. Of the first 11 articles in our list, 10 were conducted by US institutions. Second, ACS has been one of the most commonly used cervical spine surgeries in North America for the past few decades, and its application is still soaring. In terms of ACDF alone, a population-based database analysis showed that the 15 years between 1990 and 2014 witnessed a significant increase in the number of ACDF procedures in the United States from about 60,000 (1990–1994) to over 450,000 (2000–2004).[21] In a recent investigation, a total of 1,212,475 ACDF cases were identified between 2004 and 2014 in the US,[22] and this procedure now accounts for over 80% of all cervical spine surgeries.[1] Our research also showed that four of the six most productive institutions and six of the eight most productive authors were

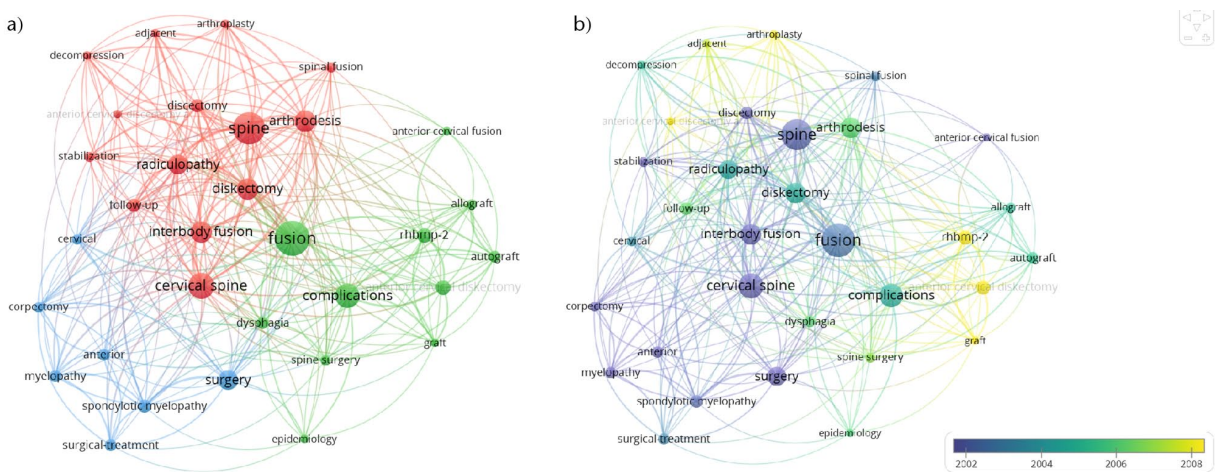

Fig. 4 Keyword analysis. (A) Network visualization map showing cluster analysis of keywords associated with ACS. (B) Overlay visualization map showing trends of keyword frequency over time. Colours were assigned according to the average year in which keywords appeared in articles.

Note. ACS, anterior cervical surgery.

from the US (Table 3; Fig. 2). Of note, Japan was the second most productive country in the current analysis (n = 9). Out of these nine papers, seven were related to the procedure of ACCF. This could be due to the higher incidence rate of ossification of the posterior longitudinal ligament in East Asia.[23] It often requires a larger resection and decompression range, which is a unique advantage and major surgical indication of ACCF.[24]

Concerning research topics and hotspots, half of the most popular keywords were related to fusion. Consequently, approaches promoting bony fusion have been continuously reported and received great attention, such as bone morphogenetic protein (BMP) with 11 papers and anterior cervical plating with nine papers in our analysis. Herein, the article by Carragee et al[25] with the highest average number of citations and the most recent article by James et al[15] were both reviews involving the application and complications of BMP-2 on ACDF. However, the effect of BMP-2 on improving the fusion rate in spinal surgery is controversial.[26] Moreover, three highly cited studies in our list warned against using high-dose BMP-2 in anterior cervical fusion, especially due to its life-threatening cervical spine swelling.[27–29] Contrary to BMP, previous literature demonstrated that the use of anterior cervical plating could enhance arthrodesis.[6,30–32] However, the influence of the plate on the prevertebral soft tissue and the consequent dysphagia have raised concerns.[33,34] Another highly cited article by Lee et al indicated that a smaller and smoother profile plate reduces the incidence of dysphagia after ACDF.[35] Furthermore, some recent high-level evidence articles revealed that zero-profile spacer was better than the cage-plate in terms of dysphagia.[36,37]

In terms of research trends, the emergence and development of CDA were noted (Fig. 4). Our overlay visualization map clearly illustrates the rise of 'arthroplasty' in the 2000s. Nevertheless, the initial philosophy of CDA was firstly proposed by Fernström in the 1960s, when it was designed to restore disc spacing and articulation in patients who had failed conservative measures of treatment.[38] In addition, Reitz and Joubert reported the application of the prosthesis in 32 patients in the 1960s, but due to the serious subsidence and displacement of the prosthesis, and the immobility of the replacement level, the usage and promotion of CDA have been greatly restricted.[39] Until it was reintroduced in Europe (Bryan, Prestige ST) in the late 1990s,[40–42] and the US Food and Drug Administration (FDA) approved the first two artificial cervical disc prostheses (Prestige ST, Prodisc-C) in 2007,[19,43] CDA was then gradually spread globally. Most of the early studies of CDA were randomized controlled trials (Table 1).[19,43–48] This explains why the level of evidence in CDA-related studies is generally higher, and more than half of the articles with level I evidence (7/13) in our list were from CDA. More importantly, although CDA is a contemporary research hotspot, the surgical indications of CDA are relatively narrow and the surgical technique is more complex. Therefore, it is inappropriate to completely consider CDA as an alternative to another ACS.[49]

As a bibliometric citation analysis, our study has several limitations. Initially, the majority of the top 100 cited papers were published after 1990. Consistent with previous bibliometric studies, older articles are likely to accrue more citations due to the 'cumulative effect'.[13,50] Nonetheless, our study revealed that annual citation rate and article age were negatively correlated (Fig. 1B). This resulted in a higher average citation per year of recent papers compared to older ones in the top 100 most-cited ACS articles. Therefore, the annual citation rate might be a better citation impact marker of the literature to a certain extent. Contrary to the first point, current articles affected by the phenomenon of 'obliteration by incorporation' may less frequently cite classic papers, resulting in their absorption into the body of current knowledge.[50,51] Finally, citation count from a single database (Web of Science Core Collection) may not be the sole marker of an article's scientific quality and influence, which should be critically considered in the future.

Conclusion

The current study attempted to develop a resource with detailed information on the top 100 most-cited articles on ACS. It demonstrated essential advances in ACS and identified influential authors, institutions, countries, and journals that had made outstanding contributions in this field. Generally, the United States, as the birthplace of ACS, has the most in-depth and influential research and has made the most prominent contribution to the development of ACS. Although the most common ACS is ACDF, CDA is of gradual greater impact. These insights into priorities and trends of the research could help future academic pursuits.

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REFERENCES

1. **Liu CY, Zygourakis CC, Yoon S, et al.** Trends in utilization and cost of cervical spine surgery using the National Inpatient Sample Database, 2001 to 2013. *Spine* 2017;42:E906–E913.

2. **Robinson RA, Smith GW.** Anterior lateral disc removal and interbody fusion for cervical disc syndrome. *Bull Johns Hopkins Hosp* 1955;96:223–224.

3. **Cloward RB.** The anterior approach for removal of ruptured cervical disks. *J Neurosurg* 1958;15:602–617.

4. **Smith GW, Robinson RA.** The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion. *J Bone Joint Surg [Am]* 1958;40-A:607–624.

5. **Kavanagh RG, Butler JS, O'Byrne JM, Poynton AR.** Operative techniques for cervical radiculopathy and myelopathy. *Adv Orthop* 2012;2012:794087.

6. **Fraser JF, Härtl R.** Anterior approaches to fusion of the cervical spine: a metaanalysis of fusion rates. *J Neurosurg Spine* 2007;6:298–303.

7. **Caspar W, Barbier DD, Klara PM.** Anterior cervical fusion and Caspar plate stabilization for cervical trauma. *Neurosurgery* 1989;25:491–502.

8. **Theodore N.** Degenerative cervical spondylosis. *N Engl J Med* 2020;383:159–168.

9. **Garfield E.** Citation analysis as a tool in journal evaluation. *Science* 1972;178:471–479.

10. **Moed HF.** New developments in the use of citation analysis in research evaluation. *Arch Immunol Ther Exp (Warsz)* 2009;57:13–18.

11. **van Eck NJ, Waltman L.** Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* 2010;84:523–538.

12. **Badhiwala JH, Nassiri F, Witiw CD, et al.** Highly cited works in spinal disorders: the top 100 most cited papers published in spine journals. *Spine* 2018;43:1746–1755.

13. **Das JP, Aherne E, Kavanagh E.** Imaging of the spine: a bibliometric analysis of the 100 most-cited articles. *Spine* 2019;44:1593–1598.

14. **Marx RG, Wilson SM, Swiontkowski MF.** Updating the assignment of levels of evidence. *J Bone Joint Surg [Am]* 2015;97-A:1–2.

15. **James AW, LaChaud G, Shen J, et al.** A review of the clinical side effects of bone morphogenetic protein-2. *Tissue Eng Part B Rev* 2016;22:284–297.

16. **Sugawara T.** Anterior cervical spine surgery for degenerative disease: a review. *Neurol Med Chir (Tokyo)* 2015;55:540–546.

17. **Zhuang L, Wang L, Xu D, Wang Z, Liang R.** Association between excessive smartphone use and cervical disc degeneration in young patients suffering from chronic neck pain. *J Orthop Sci* 2021;26:110–115.

18. **Vos T, Allen C, Arora M, et al; GBD 2015 Disease and Injury Incidence and Prevalence Collaborators.** Global, regional, and national incidence, prevalence, and years lived with disability for 310 diseases and injuries, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet* 2016;388:1545–1602.

19. **Mummaneni PV, Burkus JK, Haid RW, Traynelis VC, Zdeblick TA.** Clinical and radiographic analysis of cervical disc arthroplasty compared with allograft fusion: a randomized controlled clinical trial. *J Neurosurg Spine* 2007;6:198–209.

20. **Baker ADL.** *The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion*. Classic Papers in Orthopaedics; London, Springer-Verlag, 2014:293–295.

21. **Marawar S, Girardi FP, Sama AA, et al.** National trends in anterior cervical fusion procedures. *Spine* 2010;35:1454–1459.

22. **Perez-Roman RJ, Luther EM, McCarthy D, et al.** National trends and correlates of dysphagia after anterior cervical discectomy and fusion surgery. *Neurospine* 2021;18:147–154.

23. **Matsunaga S, Sakou T.** Ossification of the posterior longitudinal ligament of the cervical spine: etiology and natural history. *Spine* 2012;37:E309–E314.

24. **Mizuno J, Nakagawa H.** Ossified posterior longitudinal ligament: management strategies and outcomes. *Spine J* 2006;6:282S–288S.

25. **Carragee EJ, Hurwitz EL, Weiner BK.** A critical review of recombinant human bone morphogenetic protein-2 trials in spinal surgery: emerging safety concerns and lessons learned. *Spine J* 2011;11:471–491.

26. **Guppy KH, Paxton EW, Harris J, Alvarez J, Bernbeck J.** Does bone morphogenetic protein change the operative nonunion rates in spine fusions? *Spine* 2014;39:1831–1839.

27. **Shields LB, Raque GH, Glassman SD, et al.** Adverse effects associated with high-dose recombinant human bone morphogenetic protein-2 use in anterior cervical spine fusion. *Spine* 2006;31:542–547.

28. **Vaidya R, Carp J, Sethi A, Bartol S, Craig J, Les CM.** Complications of anterior cervical discectomy and fusion using recombinant human bone morphogenetic protein-2. *Eur Spine J* 2007;16:1257–1265.

29. **Smucker JD, Rhee JM, Singh K, Yoon ST, Heller JG.** Increased swelling complications associated with off-label usage of rhBMP-2 in the anterior cervical spine. *Spine* 2006;31:2813–2819.

30. **Kaiser MG, Haid RW Jr, Subach BR, Barnes B, Rodts GE Jr.** Anterior cervical plating enhances arthrodesis after discectomy and fusion with cortical allograft. *Neurosurgery* 2002;50:229–236.

31. **Wang JC, McDonough PW, Endow KK, Delamarter RB.** Increased fusion rates with cervical plating for two-level anterior cervical discectomy and fusion. *Spine* 2000;25:41–45.

32. **Wang JC, McDonough PW, Kanim LE, Endow KK, Delamarter RB.** Increased fusion rates with cervical plating for three-level anterior cervical discectomy and fusion. *Spine* 2001;26:643–646.

33. **Fountas KN, Kapsalaki EZ, Nikolakakos LG, et al.** Anterior cervical discectomy and fusion associated complications. *Spine* 2007;32:2310–2317.

34. **Riley LH III, Skolasky RL, Albert TJ, Vaccaro AR, Heller JG.** Dysphagia after anterior cervical decompression and fusion: prevalence and risk factors from a longitudinal cohort study. *Spine* 2005;30:2564–2569.

35. **Lee MJ, Bazaz R, Furey CG, Yoo J.** Influence of anterior cervical plate design on Dysphagia: a 2-year prospective longitudinal follow-up study. *J Spinal Disord Tech* 2005;18:406–409.

36. Nambiar M, Phan K, Cunningham JE, Yang Y, Turner PL, Mobbs R. Locking stand-alone cages versus anterior plate constructs in single-level fusion for degenerative cervical disease: a systematic review and meta-analysis. *Eur Spine J* 2017;26:2258–2266.

37. Xiao S, Liang Z, Wei W, Ning J. Zero-profile anchored cage reduces risk of postoperative dysphagia compared with cage with plate fixation after anterior cervical discectomy and fusion. *Eur Spine J* 2017;26:975–984.

38. Fernström U. Arthroplasty with intercorporal endoprothesis in herniated disc and in painful disc. *Acta Chir Scand Suppl* 1966;357:154–159.

39. Reitz H, Joubert MJ. Intractable headache and cervico-brachialgia treated by complete replacement of cervical intervertebral discs with a metal prosthesis. *S Afr Med J* 1964;38:881–884.

40. Goffin J, Van Calenbergh F, van Loon J, et al. Intermediate follow-up after treatment of degenerative disc disease with the Bryan Cervical Disc Prosthesis: single-level and bi-level. *Spine* 2003;28:2673–2678.

41. Goffin J, Casey A, Kehr P, et al. Preliminary clinical experience with the Bryan Cervical Disc Prosthesis. *Neurosurgery* 2002;51:840–845.

42. Wigfield C, Gill S, Nelson R, Langdon I, Metcalf N, Robertson J. Influence of an artificial cervical joint compared with fusion on adjacent-level motion in the treatment of degenerative cervical disc disease. *J Neurosurg* 2002;96:17–21.

43. Murrey D, Janssen M, Delamarter R, et al. Results of the prospective, randomized, controlled multicenter Food and Drug Administration investigational device exemption study of the ProDisc-C total disc replacement versus anterior discectomy and fusion for the treatment of 1-level symptomatic cervical disc disease. *Spine J* 2009;9:275–286.

44. Heller JG, Sasso RC, Papadopoulos SM, et al. Comparison of BRYAN cervical disc arthroplasty with anterior cervical decompression and fusion: clinical and radiographic results of a randomized, controlled, clinical trial. *Spine* 2009;34:101–107.

45. Coric D, Nunley PD, Guyer RD, et al. Prospective, randomized, multicenter study of cervical arthroplasty: 269 patients from the Kineflex|C artificial disc investigational device exemption study with a minimum 2-year follow-up: clinical article. *J Neurosurg Spine* 2011;15:348–358.

46. Burkus JK, Haid RW, Traynelis VC, Mummaneni PV. Long-term clinical and radiographic outcomes of cervical disc replacement with the Prestige disc: results from a prospective randomized controlled clinical trial. *J Neurosurg Spine* 2010;13:308–318.

47. Sasso RC, Anderson PA, Riew KD, Heller JG. Results of cervical arthroplasty compared with anterior discectomy and fusion: four-year clinical outcomes in a prospective, randomized controlled trial. *J Bone Joint Surg [Am]* 2011;93-A:1684–1692.

48. Sasso RC, Smucker JD, Hacker RJ, Heller JG. Artificial disc versus fusion: a prospective, randomized study with 2-year follow-up on 99 patients. *Spine* 2007;32: 2933–2940.

49. Health Quality Ontario. Cervical artificial disc replacement versus fusion for cervical degenerative disc disease: a health technology assessment. *Ont Health Technol Assess Ser* 2019;19:e1–e223.

50. Zhang Y, Wumaier M, He D, Xiao B, Zhang J. The 100 top-cited articles on spinal deformity: a bibliometric analysis. *Spine* 2020;45:275–283.

51. Garfield E. 100 citation classics from the *Journal of the American Medical Association*. *JAMA* 1987;257:52–59.