

# A Bibliometric Analysis of the Top 100 Cited Articles in Anterior Cervical Discectomy and Fusion

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**Study design:** A bibliometric analysis.

**Objective:** To identify and analyze the top 100 cited articles in anterior cervical discectomy and fusion.

**Summary of Background Data:** Anterior cervical discectomy and fusion (ACDF) is one of the most routine surgical procedures in spine surgery. Many surgeons and academics have researched ACDF thoroughly and published numerous articles. However, there is no relevant bibliometric analysis. Therefore, our study aims to identify and analyze the top 100 cited articles in ACDF to identify the research trends.

**Methods:** We searched the Web of Science (WOS) Core Collection database with restrictions and identified the top 100 cited publications in ACDF for analysis.

**Results:** The citation counts of the top 100 cited publications ranged from 37 to 361 (mean 67.42). All studies were published between 2008 and 2019, with 2013 and 2015 the most prolific years. The journals *Spine* and *Journal of Neurosurgery-Spine* provided the majority of the articles. Overall, the 100 articles came from 12 countries, with the United States being the top producer, followed by China and South Korea. The most frequent keywords were “spine”, “anterior cervical discectomy and fusion”, “interbody fusion”, ‘arthrodesis’, “follow-up”, “decompression”, and “ACDF”.

**Conclusion:** ACDF has been regarded as a classical gold standard in anterior cervical surgery, and the emergence of new surgical procedures has not affected its status. Cervical disc arthroplasty still needs further research and development. As the first bibliometric analysis of ACDF, this bibliometric study is meant to provide guidance for clinicians and scholars to research the development trend of this field.

**Keywords:** anterior cervical discectomy and fusion, ACDF, citation analysis, bibliometric, Web of Science, VOSviewer

## Introduction

Compared with the lumbar sacral or thoracic spine, anterior access to the cervical is very typical.<sup>1-3</sup> Since the introduction of anterior cervical discectomy and fusion (ACDF) in the 1950s, it has been commonly used for treating cervical spine diseases due to its superior clinical efficacy and credible safety<sup>4</sup> and has become one of the most common surgical procedures in spine surgery.<sup>5,6</sup> The procedure involves the removal of the diseased disc and the implantation of autogenous or allograft implants to restore the stability of the operative vertebral body and achieve direct anterior decompression.<sup>7</sup> Indications for ACDF include cervical degenerative disc disease (CDDD), cervical spinal stenosis, and partial ossification of the posterior longitudinal ligament (OPLL).<sup>8-10</sup> In recent years, cervical disc arthroplasty (CDA), endoscopic spine surgery (ESS), and other procedures have developed rapidly and have been used to treat cervical spine diseases. CDA preserves the operating segment's range of motion and reduces the occurrence of adjacent segment degeneration (ASD).<sup>11</sup> ESS is considered a safe and effective alternative for cervical spine diseases in the future due to minor tissue damage and fewer complications.<sup>12</sup> However, whether CDA and ESS will affect the development trend of ACDF is still unknown.

There are many clinicians and scholars who study ACDF procedure worldwide and have published a large number of valuable reference articles. In recent years, with the rise of surgical methods such as CDA and cervical endoscopic surgery, as well as the development of precision medicine and rehabilitation medicine, the development trend of ACDF

may also change. However, to the best of our knowledge, no scholar has conducted a comprehensive analysis of ACDF to identify the most influential research in this field. Therefore, our study is meant to define and analyze the list of top 100 cited papers in ACDF, summarize the research types, identify the research trend in this field, and analyze whether the emergence of new technologies will impact the status of ACDF as the gold standard.

Bibliometrics analysis is the qualitative and quantitative evaluation of research in a specific field by applying multiple methods, which have been commonly used in spine surgery. The number of citations for each article is one of the indicators to evaluate the value of the article. A high citation number means more scholars' recognition and greater contribution to the field's development. To our knowledge, this study is the first bibliometric analysis of ACDF. We analyzed research trends based on the most influential articles in ACDF in our study.

## Materials and Methods

### Search Strategy

We thoroughly searched the WOS Core Collection database to ascertain the top 100 cited articles in ACDF published between 1985 and 2022 on JAN 22, 2022. The specific search strategies are as follows: using CNKI (China national knowledge infrastructure) to identify keywords and synonyms: "anterior cervical discectomy and fusion", "anterior cervical discectomy with fusion" and "ACDF". Then, search the WOS Core Collection database with the keywords and synonyms identified. Select "Article" or "Review" publications published in English between 1985 and 2022.

The query is as follows: (((TI=(anterior cervical discectomy with fusion OR anterior cervical discectomy and fusion OR ACDF)) AND DT=(Article OR Review)) AND LA=(English)) AND PY=(1985–2022). A total of 890 articles were searched. All articles were arranged from most to least cited. The top 100 were exported, with title, author, citation number, country, journal, year of publication, and article number noted for further analysis.

### Data Analysis

According to the title and abstract, each publication was allocated to a study type and grouped into diagnostic, therapeutic, prognostic, economic, systemic, or non-systemic reviews. The data was analyzed using VOSviewer and Microsoft Excel 2019. VOSviewer is a Java-based software that can analyze and visualize bibliometrics data. We used VOSviewer to build visual co-occurrence networks of the author, keyword, and year of publication. We used Microsoft Excel 2019 to convert data from the WOS Core Collection database into tables and figures.

## Result

### Basic Characteristics

A total of 890 ACDF-related publications were retrieved and ranked in descending order according to citation frequency. We selected the top 100 articles and marked them from No.1 to 100 (Table 1).<sup>6,9,13–110</sup> The citations of the top 100 papers were between 37 and 361 times, with 6742 total and 67.42 mean. Among the articles,

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

by Murrey, D et al was the highest cited article.

There were seventeen systematic reviews, nine non-systematic reviews, and seventy-four primary studies among the top 100 publications.

### Distribution of Publication Years

All studies were published between 2008 to 2019. From 2013 to 2015, 42 highly cited articles were published, which was the most active period. The most productive year was 2013 (17 publications), followed by 2015 (14 publications) (Figure 1). The earliest article was "Anterior cervical discectomy and fusion for unstable traumatic spondylolisthesis of

**Table I** The Top 100 Cited Publications in ACDF

Rank	First Author	Year	Title	Journal	Total Citations	Citations Per Year
1	Murrey, D <sup>13</sup>	2009	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 Journal	361	27.8
2	Sasso, RC <sup>14</sup>	2011	Results of Cervical Arthroplasty Compared with Anterior Discectomy and Fusion: Four-Year Clinical Outcomes in a Prospective, Randomized Controlled Trial	Journal of Bone And Joint Surgery-American Volume	178	16.2
3	Parker, SL <sup>15</sup>	2013	Assessment of the minimum clinically important difference in pain, disability, and quality of life after anterior cervical discectomy and fusion	Journal of Neurosurgery-Spine	175	19.4
4	Buttermann, GR <sup>16</sup>	2008	Prospective nonrandomized comparison of an allograft with bone morphogenetic protein versus an iliac-crest autograft in anterior cervical discectomy and fusion	Spine Journal	143	10.2
5	Zigler, JE <sup>17</sup>	2013	ProDisc-C and Anterior Cervical Discectomy and Fusion as Surgical Treatment for Single-Level Cervical Symptomatic Degenerative Disc Disease Five-Year Results of a Food and Drug Administration Study	Spine	143	15.9
6	Kim, SW <sup>18</sup>	2009	Comparison of radiographic changes after ACDF versus Bryan disc arthroplasty in single and bi-level cases	European Spine Journal	138	10.6
7	Davis, RJ <sup>19</sup>	2015	Two-level total disc replacement with Mobi-C cervical artificial disc versus anterior discectomy and fusion: a prospective, randomized, controlled multicenter clinical trial with 4-year follow-up results	Journal of Neurosurgery-Spine	121	17.3
8	Davis, RJ <sup>20</sup>	2013	Cervical total disc replacement with the Mobi-C cervical artificial disc compared with anterior discectomy and fusion for treatment of 2-level symptomatic degenerative disc disease: a prospective, randomized, controlled multicenter clinical trial	Journal of Neurosurgery-Spine	119	13.2
9	Phillips, FM <sup>21</sup>	2015	Long-term Outcomes of the US FDA IDE Prospective, Randomized Controlled Clinical Trial Comparing PCM Cervical Disc Arthroplasty With Anterior Cervical Discectomy and Fusion	Spine	117	16.7
10	Veeravagu, A <sup>22</sup>	2014	Revision rates and complication incidence in single- and multilevel anterior cervical discectomy and fusion procedures: an administrative database study	Spine Journal	116	14.5
11	Niu, CC <sup>23</sup>	2010	Outcomes of Interbody Fusion Cages Used in 1 and 2-levels Anterior Cervical Discectomy and Fusion Titanium Cages Versus Polyetheretherketone (PEEK) Cages	Journal of Spinal Disorders & Techniques	115	9.6
12	Phillips, FM <sup>24</sup>	2013	A Prospective, Randomized, Controlled Clinical Investigation Comparing PCM Cervical Disc Arthroplasty With Anterior Cervical Discectomy and Fusion 2-Year Results From the US FDA IDE Clinical Trial	Spine	114	12.7
13	Coric, D <sup>25</sup>	2013	Prospective randomized study of cervical arthroplasty and anterior cervical discectomy and fusion with long-term follow-up: results in 74 patients from a single site Presented at the 2012 Joint Spine Section Meeting	Journal of Neurosurgery-Spine	102	11.3
14	Tumialan, LM <sup>26</sup>	2008	The safety and efficacy of anterior cervical discectomy and fusion with polyetheretherketone spacer and recombinant human bone morphogenetic protein-2: a review of 200 patients	Journal of Neurosurgery-Spine	96	6.9

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Table I (Continued).

Rank	First Author	Year	Title	Journal	Total Citations	Citations Per Year
15	McAfee, PC <sup>27</sup>	2010	Lower Incidence of Dysphagia With Cervical Arthroplasty Compared With ACDF in a Prospective Randomized Clinical Trial	Journal of Spinal Disorders & Techniques	94	7.8
16	Janssen, ME <sup>28</sup>	2015	ProDisc-C Total Disc Replacement Versus Anterior Cervical Discectomy and Fusion for Single-Level Symptomatic Cervical Disc Disease Seven-Year Follow-up of the Prospective Randomized US Food and Drug Administration Investigational Device Exemption Study	Journal of Bone And Joint Surgery-American Volume	94	13.4
17	Gao, Y <sup>29</sup>	2013	A Meta-Analysis Comparing the Results of Cervical Disc Arthroplasty with Anterior Cervical Discectomy and Fusion (ACDF) for the Treatment of Symptomatic Cervical Disc Disease	Journal of Bone And Joint Surgery-American Volume	87	9.7
18	Shriver, MF <sup>30</sup>	2015	Pseudoarthrosis rates in anterior cervical discectomy and fusion: a meta-analysis	Spine Journal	85	12.1
19	Chau, AMT <sup>31</sup>	2009	Bone graft substitutes in anterior cervical discectomy and fusion	European Spine Journal	83	6.4
20	McGirt, MJ <sup>32</sup>	2015	Quality analysis of anterior cervical discectomy and fusion in the outpatient versus inpatient setting: analysis of 7288 patients from the NSQIP database	Neurosurgical Focus	82	11.7
21	Cabraja, M <sup>33</sup>	2012	Anterior cervical discectomy and fusion: Comparison of titanium and polyetheretherketone cages	Bmc Musculoskeletal Disorders	81	8.1
22	Jagannathan, J <sup>34</sup>	2008	Radiographic and clinical outcomes following single-level anterior cervical discectomy and allograft fusion without plate placement or cervical collar	Journal of Neurosurgery-Spine	80	5.7
23	Adamson, T <sup>35</sup>	2016	Anterior cervical discectomy and fusion in the outpatient ambulatory surgery setting compared with the inpatient hospital setting: analysis of 1000 consecutive cases	Journal of Neurosurgery-Spine	80	13.3
24	Song, KJ <sup>36</sup>	2012	Efficacy of multilevel anterior cervical discectomy and fusion versus corpectomy and fusion for multilevel cervical spondylotic myelopathy: a minimum 5-year follow-up study	European Spine Journal	78	7.8
25	van Eck, CF <sup>37</sup>	2014	The Revision Rate and Occurrence of Adjacent Segment Disease After Anterior Cervical Discectomy and Fusion	Spine	72	9.0
26	Radcliff, K <sup>38</sup>	2016	Five-year clinical results of cervical total disc replacement compared with anterior discectomy and fusion for treatment of 2-level symptomatic degenerative disc disease: a prospective, randomized, controlled, multicenter investigational device exemption clinical trial	Journal of Neurosurgery-Spine	71	11.8
27	Liao, JC <sup>39</sup>	2008	Polyetheretherketone (PEEK) cage filled with cancellous allograft in anterior cervical discectomy and fusion	International Orthopaedics	69	4.9
28	Anderson, PA <sup>40</sup>	2009	Predictors of Outcome After Anterior Cervical Discectomy and Fusion A Multivariate Analysis	Spine	69	5.3
29	Anakwenze, OA <sup>41</sup>	2009	Sagittal Cervical Alignment After Cervical Disc Arthroplasty and Anterior Cervical Discectomy and Fusion Results of a Prospective, Randomized, Controlled Trial	Spine	68	5.2
30	Lied, B <sup>42</sup>	2010	Anterior cervical discectomy with fusion in patients with cervical disc degeneration: a prospective outcome study of 258 patients (181 fused with autologous bone graft and 77 fused with a PEEK cage)	Bmc Surgery	68	5.7

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Table I (Continued).

Rank	First Author	Year	Title	Journal	Total Citations	Citations Per Year
31	Gornet, MF <sup>43</sup>	2015	Cervical disc arthroplasty with PRESTIGE LP disc versus anterior cervical discectomy and fusion: a prospective, multicenter investigational device exemption study	Journal of Neurosurgery-Spine	68	9.7
32	Nassar, A <sup>44</sup>	2009	Does Incorrect Level Needle Localization During Anterior Cervical Discectomy and Fusion Lead to Accelerated Disc Degeneration?	Spine	67	5.2
33	Uribe, JS <sup>45</sup>	2009	Comparison between anterior cervical discectomy fusion and cervical corpectomy fusion using titanium cages for reconstruction: analysis of outcome and long-term follow-up	European Spine Journal	65	5.0
34	Park, Y <sup>46</sup>	2010	Comparison of anterior cervical fusion after two-level discectomy or single-level corpectomy: sagittal alignment, cervical lordosis, graft collapse, and adjacent-level ossification	Spine Journal	65	5.4
35	Kelly, MP <sup>47</sup>	2011	Adjacent Segment Motion After Anterior Cervical Discectomy and Fusion Versus ProDisc-C Cervical Total Disk Arthroplasty	Spine	65	5.9
36	Hofstetter, CP <sup>48</sup>	2015	Zero-profile Anchored Spacer Reduces Rate of Dysphagia Compared With ACDF With Anterior Plating	Journal of Spinal Disorders & Techniques	65	9.3
37	Gruskay, JA <sup>49</sup>	2016	Factors Affecting Length of Stay and Complications After Elective Anterior Cervical Discectomy and Fusion A Study of 2164 Patients From The American College of Surgeons National Surgical Quality Improvement Project Database (ACS NSQIP)	Clinical Spine Surgery	65	10.8
38	Garringer, SM <sup>50</sup>	2010	Safety of Anterior Cervical Discectomy and Fusion Performed as Outpatient Surgery	Journal of Spinal Disorders & Techniques	64	5.3
39	Saifi, C <sup>51</sup>	2018	Trends in resource utilization and rate of cervical disc arthroplasty and anterior cervical discectomy and fusion throughout the United States from 2006 to 2013	Spine Journal	64	16.0
40	Sasso, RC <sup>52</sup>	2008	Motion analysis of Bryan cervical disc arthroplasty versus anterior discectomy and fusion: Results from a prospective, randomized, multicenter, clinical trial	Journal of Spinal Disorders & Techniques	62	4.4
41	Hu, Y <sup>53</sup>	2016	Mid- to Long-Term Outcomes of Cervical Disc Arthroplasty versus Anterior Cervical Discectomy and Fusion for Treatment of Symptomatic Cervical Disc Disease: A Systematic Review and Meta-Analysis of Eight Prospective Randomized Controlled Trials	Plos One	60	10.0
42	Liu, JT <sup>54</sup>	2009	Comparison of inpatient vs outpatient anterior cervical discectomy and fusion: a retrospective case series	Bmc Surgery	59	4.5
43	Miller, LE <sup>55</sup>	2011	Safety and Effectiveness of Bone Allografts in Anterior Cervical Discectomy and Fusion Surgery	Spine	59	5.4
44	Chung, JY <sup>56</sup>	2014	Clinical adjacent-segment pathology after anterior cervical discectomy and fusion: results after a minimum of 10-year follow-up	Spine Journal	59	7.4
45	Ren, CP <sup>57</sup>	2014	Mid- to long-term outcomes after cervical disc arthroplasty compared with anterior discectomy and fusion: a systematic review and meta-analysis of randomized controlled trials	European Spine Journal	58	7.3
46	Gornet, MF <sup>58</sup>	2017	Cervical disc arthroplasty with the Prestige LP disc versus anterior cervical discectomy and fusion, at 2 levels: results of a prospective, multicenter randomized controlled clinical trial at 24 months	Journal of Neurosurgery-Spine	58	11.6

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Table I (Continued).

Rank	First Author	Year	Title	Journal	Total Citations	Citations Per Year
47	Buerba, RA <sup>59</sup>	2014	Increased Risk of Complications After Anterior Cervical Discectomy and Fusion in the Elderly	Spine	57	7.1
48	Jiang, SD <sup>60</sup>	2012	Anterior cervical discectomy and fusion versus anterior cervical corpectomy and fusion for multilevel cervical spondylosis: a systematic review	Archives of Orthopaedic And Trauma Surgery	56	5.6
49	Lied, B <sup>61</sup>	2008	Immediate (0–6 h), early (6–72 h) and late (> 72 h) complications after anterior cervical discectomy with fusion for cervical disc degeneration; discharge six hours after operation is feasible	Acta Neurochirurgica	54	3.9
50	Lee, SH <sup>62</sup>	2011	Effect of Retropharyngeal Steroid on Prevertebral Soft Tissue Swelling Following Anterior Cervical Discectomy and Fusion A Prospective, Randomized Study	Spine	54	4.9
51	Singh, K <sup>63</sup>	2012	Factors affecting reoperations after anterior cervical discectomy and fusion within and outside of a Federal Drug Administration investigational device exemption cervical disc replacement trial	Spine Journal	54	5.4
52	Qureshi, SA <sup>64</sup>	2013	Cost-effectiveness analysis: comparing single-level cervical disc replacement and single-level anterior cervical discectomy and fusion	Journal of Neurosurgery-Spine	54	6.0
53	Carrier, CS <sup>65</sup>	2013	Evidence-based analysis of adjacent segment degeneration and disease after ACDF: a systematic review	Spine Journal	53	5.9
54	Miao, JH <sup>66</sup>	2013	Early Follow-Up Outcomes of a New Zero-profile Implant Used in Anterior Cervical Discectomy and Fusion	Journal of Spinal Disorders & Techniques	53	5.9
55	Lu, DC <sup>67</sup>	2013	Multilevel anterior cervical discectomy and fusion with and without rhBMP-2: a comparison of dysphagia rates and outcomes in 150 patients	Journal of Neurosurgery-Spine	53	5.9
56	Chang, SW <sup>68</sup>	2010	Four-Level Anterior Cervical Discectomy and Fusion With Plate Fixation: Radiographic and Clinical Results	Neurosurgery	51	4.3
57	Jeyamohan, SB <sup>69</sup>	2015	Effect of steroid use in anterior cervical discectomy and fusion: a randomized controlled trial	Journal of Neurosurgery-Spine	51	7.3
58	Chong, E <sup>70</sup>	2015	The design evolution of interbody cages in anterior cervical discectomy and fusion: a systematic review	Bmc Musculoskeletal Disorders	51	7.3
59	Tumialan, LM <sup>71</sup>	2010	Management of unilateral cervical radiculopathy in the military: the cost effectiveness of posterior cervical foraminotomy compared with anterior cervical discectomy and fusion	Neurosurgical Focus	50	4.2
60	Trahan, J <sup>72</sup>	2011	Feasibility of Anterior Cervical Discectomy and Fusion as an Outpatient Procedure	World Neurosurgery	50	4.5
61	Njoku, I <sup>73</sup>	2014	Anterior cervical discectomy and fusion with a zero-profile integrated plate and spacer device: a clinical and radiological study	Journal of Neurosurgery-Spine	50	6.3
62	Wang, ZW <sup>74</sup>	2015	The application of zero-profile anchored spacer in anterior cervical discectomy and fusion	European Spine Journal	50	7.1
63	Buttermann, GR <sup>75</sup>	2018	Anterior Cervical Discectomy and Fusion Outcomes over 10 Years A Prospective Study	Spine	50	12.5
64	Bhadra, AK <sup>76</sup>	2009	Single-level cervical radiculopathy: clinical outcome and cost-effectiveness of four techniques of anterior cervical discectomy and fusion and disc arthroplasty	European Spine Journal	49	3.8

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Table I (Continued).

Rank	First Author	Year	Title	Journal	Total Citations	Citations Per Year
65	Anderson, PA <sup>77</sup>	2012	Kinematics of the Cervical Adjacent Segments After Disc Arthroplasty Compared With Anterior Discectomy and Fusion A Systematic Review and Meta-Analysis	Spine	47	4.7
66	Carreon, LY <sup>78</sup>	2013	Cost-Effectiveness of Single-Level Anterior Cervical Discectomy and Fusion Five Years After Surgery	Spine	47	5.2
67	Lee, YS <sup>9</sup>	2014	Risk Factors for Postoperative Subsidence of Single-Level Anterior Cervical Discectomy and Fusion The Significance of the Preoperative Cervical Alignment	Spine	47	5.9
68	Bydon, M <sup>79</sup>	2014	Adjacent Segment Disease After Anterior Cervical Discectomy and Fusion in a Large Series	Neurosurgery	47	5.9
69	Barbagallo, GMV <sup>80</sup>	2013	Zero-P: a new zero-profile cage-plate device for single and multilevel ACDF. A single Institution series with four years maximum follow-up and review of the literature on zero-profile devices	European Spine Journal	46	5.1
70	Auffinger, BM <sup>81</sup>	2013	Measuring Surgical Outcomes in Cervical Spondylotic Myelopathy Patients Undergoing Anterior Cervical Discectomy and Fusion: Assessment of Minimum Clinically Important Difference	Plos One	46	5.1
71	Findlay, C <sup>82</sup>	2018	Total disc replacement versus anterior cervical discectomy and fusion A SYSTEMATIC REVIEW WITH META-ANALYSIS OF DATA FROM A TOTAL OF 3160 PATIENTS ACROSS 14 RANDOMIZED CONTROLLED TRIALS WITH BOTH SHORT-AND MEDIUM-TO LONG-TERM OUTCOMES	Bone & Joint Journal	46	11.5
72	Lied, B <sup>83</sup>	2013	Outpatient anterior cervical discectomy and fusion for cervical disk disease: a prospective consecutive series of 96 patients	Acta Neurologica Scandinavica	45	5.0
73	Jackson, RJ <sup>84</sup>	2016	Subsequent surgery rates after cervical total disc replacement using a Mobi-C Cervical Disc Prosthesis versus anterior cervical discectomy and fusion: a prospective randomized clinical trial with 5-year follow-up	Journal of Neurosurgery-Spine	45	7.5
74	Zou, SH <sup>6</sup>	2017	Anterior cervical discectomy and fusion (ACDF) versus cervical disc arthroplasty (CDA) for two contiguous levels cervical disc degenerative disease: a meta-analysis of randomized controlled trials	European Spine Journal	45	9.0
75	Karikari, IO <sup>85</sup>	2014	Impact of Subsidence on Clinical Outcomes and Radiographic Fusion Rates in Anterior Cervical Discectomy and Fusion A Systematic Review	Journal of Spinal Disorders & Techniques	44	5.5
76	Gao, FQ <sup>86</sup>	2015	An Updated Meta- Analysis Comparing Artificial Cervical Disc Arthroplasty (CDA) Versus Anterior Cervical Discectomy and Fusion (ACDF) for the Treatment of Cervical Degenerative Disc Disease (CDDD)	Spine	44	6.3
77	Martin, CT <sup>87</sup>	2014	Thirty-Day Morbidity After Single-Level Anterior Cervical Discectomy and Fusion: Identification of Risk Factors and Emphasis on the Safety of Outpatient Procedures	Journal of Bone And Joint Surgery-American Volume	43	5.4
78	Nunley, PD <sup>88</sup>	2009	Choice of plate may affect outcomes for single versus multilevel ACDF: results of a prospective randomized single-blind trial	Spine Journal	42	3.2
79	Song, KJ <sup>89</sup>	2010	Plate augmentation in anterior cervical discectomy and fusion with cage for degenerative cervical spinal disorders	European Spine Journal	42	3.5

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Table I (Continued).

Rank	First Author	Year	Title	Journal	Total Citations	Citations Per Year
80	Lee, CH <sup>90</sup>	2013	Comparative Analysis of 3 Different Construct Systems for Single-level Anterior Cervical Discectomy and Fusion Stand-alone Cage, Iliac Graft Plus Plate Augmentation, and Cage Plus Plating	Journal of Spinal Disorders & Techniques	42	4.7
81	Di Capua, J <sup>91</sup>	2017	Predictors for Patient Discharge Destination After Elective Anterior Cervical Discectomy and Fusion	Spine	42	8.4
82	Karhade, AV <sup>92</sup>	2019	Machine learning for prediction of sustained opioid prescription after anterior cervical discectomy and fusion	Spine Journal	42	14.0
83	Liu, T <sup>93</sup>	2011	ACDF With the PCB Cage-Plate System Versus Laminoplasty for Multilevel Cervical Spondylotic Myelopathy	Journal of Spinal Disorders & Techniques	41	3.7
84	Hauerberg, J <sup>94</sup>	2008	Anterior cervical discectomy with or without fusion with ray titanium cage - A prospective randomized clinical study	Spine	40	2.9
85	Xu, RS <sup>95</sup>	2014	Adjacent Segment Disease After Anterior Cervical Discectomy and Fusion Clinical Outcomes After First Repeat Surgery Versus Second Repeat Surgery	Spine	40	5.0
86	Yang, HS <sup>96</sup>	2015	Zero-profile integrated plate and spacer device reduces rate of adjacent-level ossification development and dysphagia compared to ACDF with plating and cage system	Archives of Orthopaedic And Trauma Surgery	40	5.7
87	Zhong, ZM <sup>97</sup>	2016	Reoperation After Cervical Disc Arthroplasty Versus Anterior Cervical Discectomy and Fusion: A Meta-analysis	Clinical Orthopaedics And Related Research	40	6.7
88	Shiban, E <sup>98</sup>	2016	Clinical and radiological outcome after anterior cervical discectomy and fusion with stand-alone empty polyetheretherketone (PEEK) cages	Acta Neurochirurgica	40	6.7
89	Phan, K <sup>99</sup>	2017	Relationship Between ASA Scores and 30-Day Readmissions in Patients Undergoing Anterior Cervical Discectomy and Fusion	Spine	40	8.0
90	Ying, Z <sup>100</sup>	2008	Anterior cervical discectomy and fusion for unstable traumatic spondylolisthesis of the axis	Spine	39	2.8
91	Sugawara, T <sup>101</sup>	2009	Long term outcome and adjacent disc degeneration after anterior cervical discectomy and fusion with titanium cylindrical cages	Acta Neurochirurgica	38	2.9
92	Burkhardt, JK <sup>102</sup>	2013	A comparative effectiveness study of patient-rated and radiographic outcome after 2 types of decompression with fusion for spondylotic myelopathy: anterior cervical discectomy versus corpectomy	Neurosurgical Focus	38	4.2
93	Kang, LQ <sup>103</sup>	2013	Artificial Disk Replacement Combined With Midlevel ACDF Versus Multilevel Fusion for Cervical Disk Disease Involving 3 Levels	Orthopedics	38	4.2
94	Lubelski, D <sup>104</sup>	2015	Reoperation rates after anterior cervical discectomy and fusion versus posterior cervical foraminotomy: a propensity-matched analysis	Spine Journal	38	5.4
95	Radcliff, K <sup>105</sup>	2015	Costs of Cervical Disc Replacement Versus Anterior Cervical Discectomy and Fusion for Treatment of Single-Level Cervical Disc Disease An Analysis of the Blue Health Intelligence Database for Acute and Long-term Costs and Complications	Spine	38	5.4
96	McClelland, S <sup>106</sup>	2016	Outpatient anterior cervical discectomy and fusion: A meta-analysis	Journal of Clinical Neuroscience	38	6.3

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**Table 1** (Continued).

Rank	First Author	Year	Title	Journal	Total Citations	Citations Per Year
97	Oliver, JD <sup>107</sup>	2018	Comparison of Outcomes for Anterior Cervical Discectomy and Fusion With and Without Anterior Plate Fixation A Systematic Review and Meta-Analysis	Spine	38	9.5
98	Purger, DA <sup>108</sup>	2018	Outpatient vs Inpatient Anterior Cervical Discectomy and Fusion: A Population-Level Analysis of Outcomes and Cost	Neurosurgery	38	9.5
99	Zhu, YH <sup>109</sup>	2016	Cervical Disc Arthroplasty Versus Anterior Cervical Discectomy and Fusion for Incidence of Symptomatic Adjacent Segment Disease A Meta-Analysis of Prospective Randomized Controlled Trials	Spine	37	6.2
100	Liu, YJ <sup>110</sup>	2016	Comparison of a zero-profile anchored spacer (ROI-C) and the polyetheretherketone (PEEK) cages with an anterior plate in anterior cervical discectomy and fusion for multilevel cervical spondylotic myelopathy	European Spine Journal	37	6.2

the axis” by Ying, Z et al in Feb 2008. The latest article was “Machine learning for prediction of sustained opioid prescription after anterior cervical discectomy and fusion” published in 2019 by Karhade, AV et al

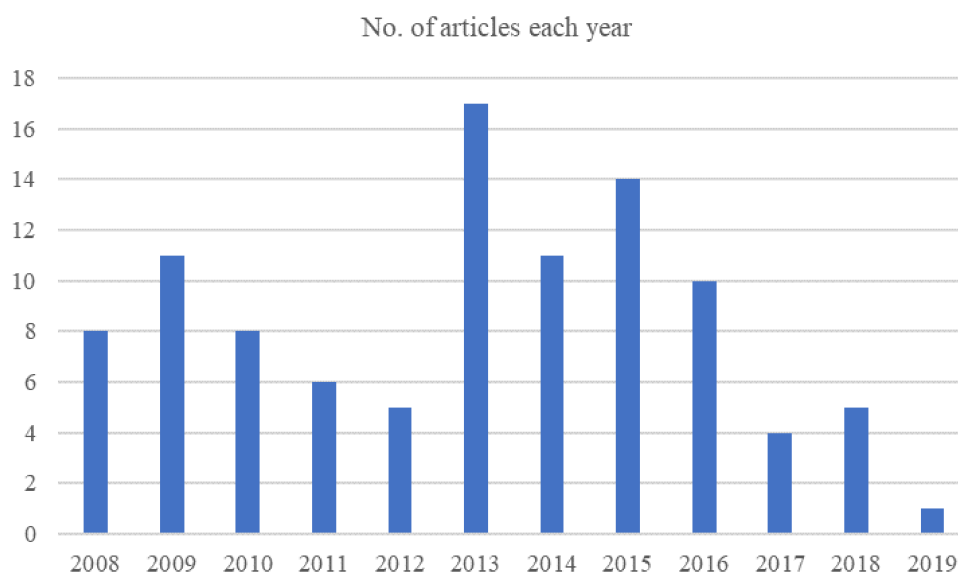
## Distribution of Authors

In terms of the number of author publications, there are 89 first authors among the top 100 articles and ten first authors with more than two articles. With three articles (No.30, 52, 74 in Table 1), Lied, B was considered the most prolific first author, and the other nine authors contributed two articles per person (Table 2).

VOSviewer’s Density Visualization function visualizes the co-author relations between all authors by clustering them (Figure 2). Phillips FM, McAfee PC, Howell KM, and five other authors were part of the primary cluster. Anderson PA and three additional authors formed another significant cluster.

## Distribution of Country/Region and Institution

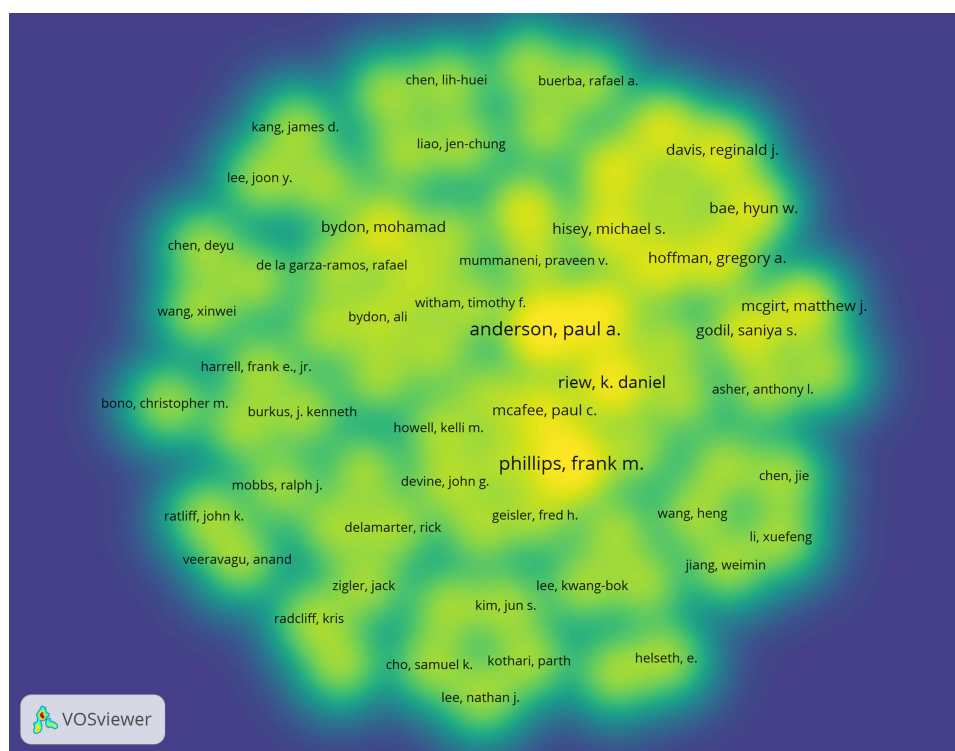
We identified 81 institutions based on correspondence addresses, and 15 institutions had repeatedly published articles (Table 3). The top three institutions were Rush Univ, USA, Carolina Neurosurg & Spine Associates, USA, and Soochow

**Figure 1** Total number of articles published per year.

**Table 2** Authors with More Than Two Articles

Author	Total Articles	Total Citations	Mean Citations
Lied, B	3	167	55.7
Sasso, RC	2	240	120
Davis, RJ	2	240	120
Phillips, FM	2	231	115.5
Buttermann, GR	2	193	96.5
Tumialan, LM	2	146	73
Gornet, MF	2	126	63
Song, KJ	2	120	60
Anderson, PA	2	116	58
Radcliff, K	2	109	54.5

Univ, China, with three publications each. In terms of countries and regions, twelve different countries and regions contributed to the top 100 articles, among which the United States, with 65 articles, contributed 60.2% of all articles and 66.5% of total citations, followed by China (17 articles) and Korea (8 articles) (Figure 3). Moreover, all articles from North America were contributed by the United States, with 65 articles and 4671 citations. China, Korea, and Japan are the primary sources of Asian articles, with 27 articles and 1537 citations in total. Articles from Europe were composed of seven countries (Norway, United Kingdom, Germany, Italy, Netherlands, Denmark, and Switzerland), with 12 articles

**Figure 2** VOSviewer density visualization shows co-authorship and clusters among all authors in the top 100 cited articles.

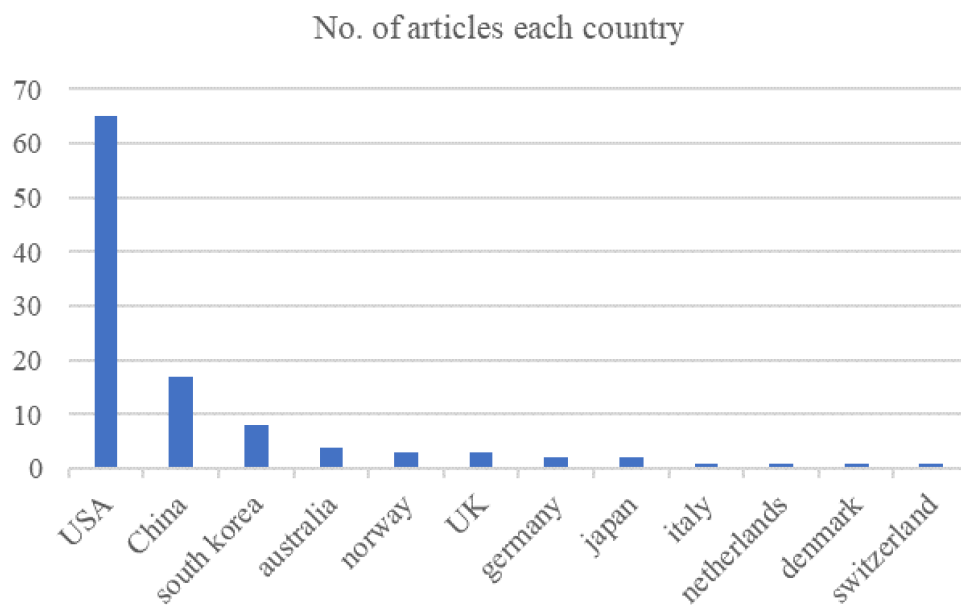
**Table 3** Institutions with More Than Two Articles

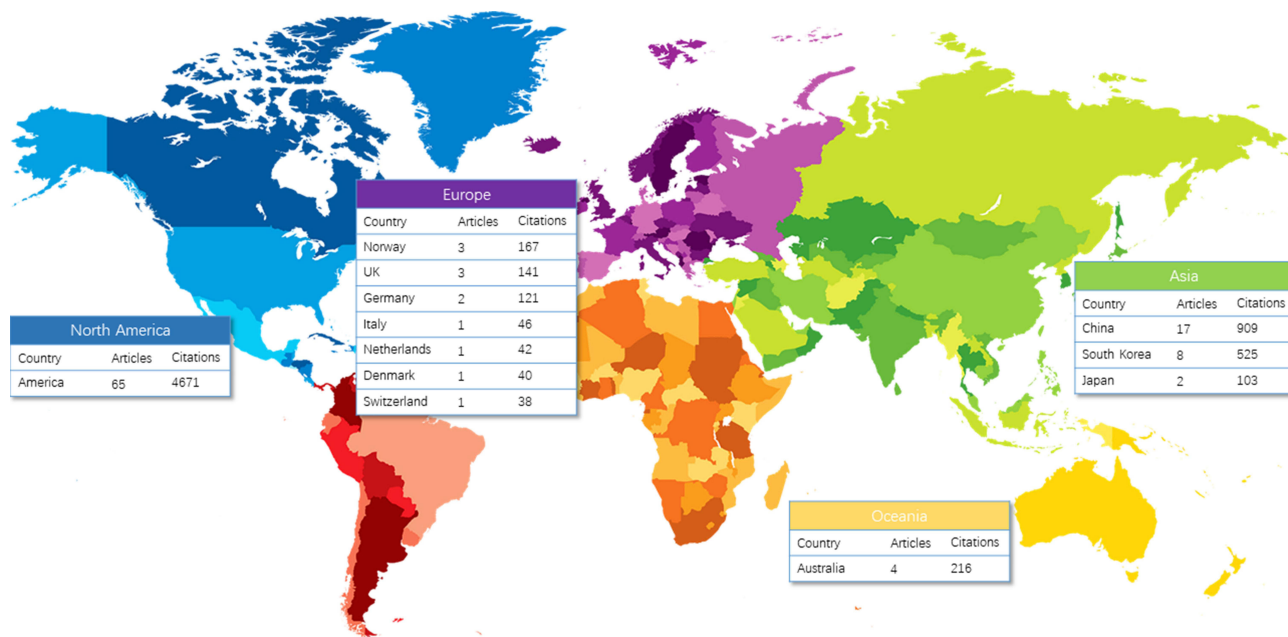
Institution	Country	No. of Articles	Total Citations	Mean Citations
Rush Univ	USA	3	285	95
Carolina Neurosurg & Spine Associates	USA	3	264	88
Soochow Univ	China	3	128	42.7
Greater Baltimore Neurosurg Associates	USA	2	240	120
Chang Gung Univ	China	2	184	92
Stanford Univ	USA	2	154	77
Sichuan Univ	China	2	145	72.5
Univ Penn	USA	2	132	66
Orthoped Ctr St Louis	USA	2	126	63
Yale Univ	USA	2	122	61
Univ Wisconsin	USA	2	116	58
Oslo Univ Hosp	Norway	2	113	56.5
Thomas Jefferson Univ	USA	2	109	54.5
Mayo Clin	USA	2	105	52.5
Johns Hopkins Univ	USA	2	87	43.5

and 595 citations. Oceania had only four articles (216 citations) published by Australia. Yet, no publications from South America and Africa were included (Figure 4).

### Distribution of Publication Journals

The top 100 articles retrieved in our study were from 21 different journals (Table 4), and the top three journals account for 51% of all articles. Spine ranked first with 24 articles, followed by Journal of Neurosurgery-Spine (15 articles) and

**Figure 3** Articles published by each country.



**Figure 4** Map of worldwide research productivity.

Spine Journal (12 articles) (Figure 5). Unsurprisingly, Spine has an absolute advantage in the total number of citations (1434 times). However, the journal with the highest average citations was *Journal of Bone And Joint Surgery-American Volume* (100.5 times), followed by *Spine Journal* (93.5 times) and *Journal of Neurosurgery-Spine* (81.5 times).

## Distribution of Article Types and Keywords

Categorizing all the articles, we found that “therapeutic” (n=65) was the most common type, followed by systemic reviews (n=17), non-systemic reviews (n=9), and “prognostic” (n=9) (Table 5).

The co-occurrence network analysis function of VOSviewer was used to analyze the keywords with a minimum frequency of eight. The 33 high-frequency keywords were divided into “procedure”, “disease and symptoms”, and “prognosis” (Figure 6). Overall, the most frequent keyword was “spine” (38), followed by “anterior cervical discectomy and fusion” (36), “interbody fusion” (34), “arthrodesis” (32), “follow-up” (26), “decompression” (23), and “ACDF” (22).

## Discussion

ACDF represents one of the most popular procedures in spine surgery.<sup>111,112</sup> In 1958, Smith and Robinson firstly described the application of anterior cervical approach as the therapeutic of spine disorders.<sup>113</sup> Since then, with numerous modifications introduced by surgeons, ACDF has been considered a gold standard for cervical spondylosis, and the number of related publications has steadily increased. As far as we know, no scholar has conducted a comprehensive analysis of ACDF to define the most significant studies. Our article is the first to analyze ACDF by bibliometric analysis.

According to our study, the publications related to ACDF showed a steady increasing trend before 2013, while the number of articles published in 2013 increased by 240% compared with 2012. From 2013 to 2019, 62% of highly cited articles were published in the seven years. This trend indicated that ACDF research had attracted more attention in recent years, which may relate to an increased risk of cervical spondylosis caused by the aging population and lousy lifestyle such as using smartphones for a long time.<sup>114</sup> The earliest article in our study was published by Ying, Z et al on February 1, 2008, and the most cited one was published by Murrey, D et al in April 2009. ACDF was initially described in 1958, and Cloward used Wiltberger’s lumbar interbody dowel fusion procedure on the cervical spine in November of the same year.<sup>4</sup> To date, ACDF has long been considered the initial and gold standard of anterior cervical surgery.<sup>115–117</sup> Interestingly, Ying, Z et al creatively described the application of ACDF in treating spondylolisthesis of the axis. They believed ACDF might be a feasible surgical procedure for unstable traumatic spondylolisthesis of the axis (TSA),<sup>100</sup>

**Table 4** The Total Amount of Articles in Each Journal

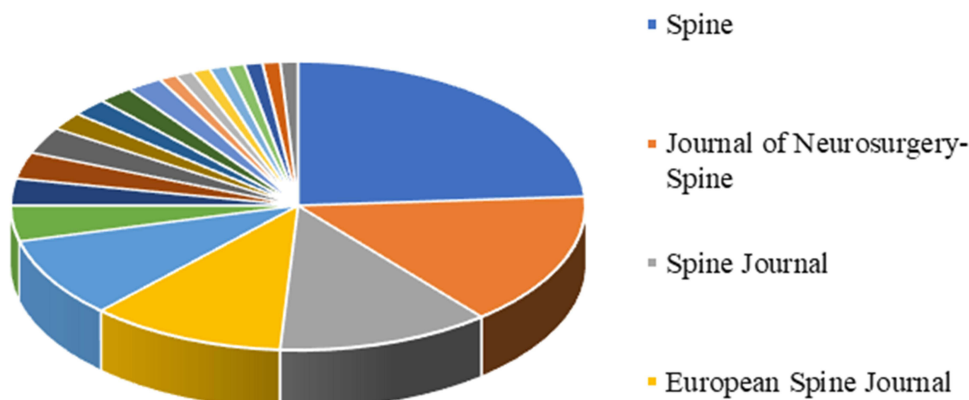
Journal	Number of Articles	Total Citations	Mean Citations
Spine	24	1434	59.8
Journal of Neurosurgery-Spine	15	1223	81.5
Spine Journal	12	1122	93.5
European Spine Journal	11	691	62.8
Journal of Spinal Disorders & Techniques	9	580	64.4
Journal of Bone And Joint Surgery-American Volume	4	402	100.5
Neurosurgical Focus	3	170	56.7
Neurosurgery	3	136	45.3
Acta Neurochirurgica	3	132	44.0
Bmc Musculoskeletal Disorders	2	132	66.0
Bmc Surgery	2	127	63.5
Plos One	2	106	53.0
Archives of Orthopaedic And Trauma Surgery	2	96	48.0
International Orthopaedics	1	69	69.0
Clinical Spine Surgery	1	65	65.0
World Neurosurgery	1	50	50.0
Bone & Joint Journal	1	46	46.0
Acta Neurologica Scandinavica	1	45	45.0
Clinical Orthopaedics And Related Research	1	40	40.0
Journal of Clinical Neuroscience	1	38	38.0
Orthopedics	1	38	38.0

which provided a reference for applying ACDF in treating other cervical spine diseases. The surgical procedure of ACDF has been unchanged for more than 60 years, recognizing its reliability and effectiveness. However, more trials and innovations are necessary to push it forward.<sup>117</sup>

In terms of national publications, the United States dominates with 65% of the total (Figure 3). This might be due to the following reasons: As previously mentioned, the ACDF was first described and modified by American scholars. Among the first ten articles in the top 100, nine articles were published by institutions in the United States. Moreover, in the United States, ACDF is the most routinely performed cervical spine procedure, with more than 500,000 ACDF procedures performed between 1990 to 1999 alone. The clinical outcomes of most cases were good or excellent.<sup>111</sup> According to a recent study, 1,212,475 ACDFs were performed in the United States between 2004 and 2014, accounting for more than 80% of cervical spine procedures.<sup>118</sup> The United States still dominated the institution publications: 11 of the 15 most productive institutions were affiliated to the United States (Table 3), explaining why the United States leads the world in total publications.

In terms of research topic and hotspot, we found the top four high-frequency keywords were “spine”, “anterior cervical discectomy and fusion”, “interbody fusion”, and “arthrodesis”. Meanwhile, through the analysis of the title and abstract, we found that the procedures comparison (n=36) was the most common topic type, especially ACDF versus CDA (n=28). Therefore, we concluded that the comparison between ACDF and CDA was a contemporary research

## Number of journal publications

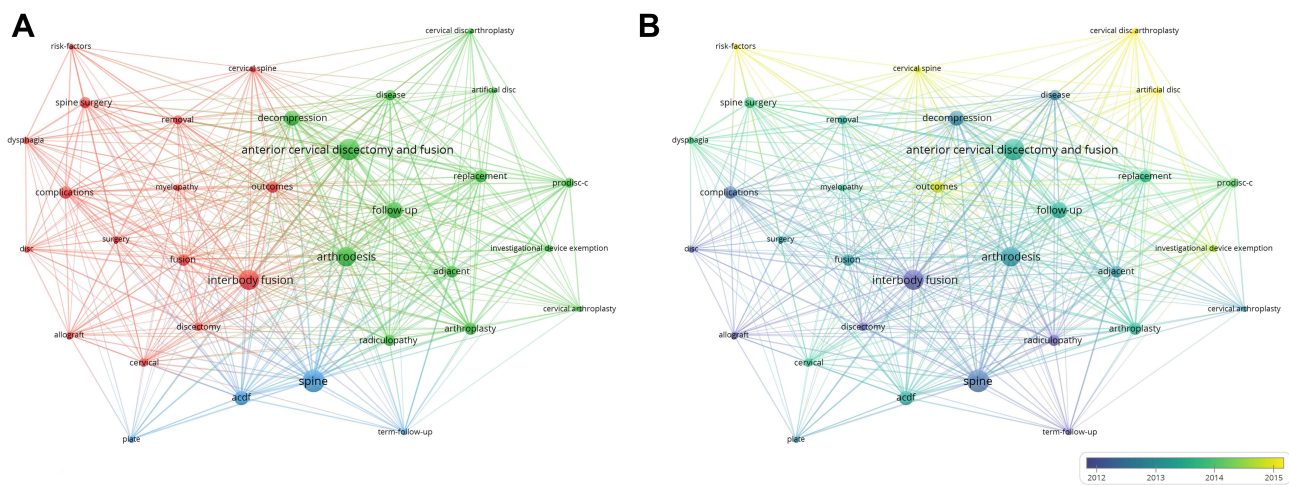


**Figure 5** The number of articles published in each journal.

hotspot in cervical surgery and had received significant attention. The articles by Murrey, D et al with the most total cited and the highest average number of citations and their latest publication on cervical surgery were reviews involving the ACDF versus CDA. ACDF is regarded as the standard surgical procedure for CDDD.<sup>119</sup> However, in addition to the common complications of ACDF, there are rare but disastrous complications, such as esophageal tear, pharyngeal perforation, and even expectoration of the entire ACDF construct.<sup>120</sup> Moreover, several publications showed that changes in the biomechanical of adjacent segments after ACDF may result in adjacent segment degeneration (ASD).<sup>121</sup> CDA was introduced to protect spinal biomechanics and reduce the incidence of ASD.<sup>122</sup> In 1966, Fernstrom introduced the concept of CDA.<sup>123</sup> Limited by the technology available at the time, the initial device was a ball bearing implanted in the lumbar disc space. After more than 50 years of development, the artificial discs used in the clinic have the characteristics of bionic, stable, and shock absorption.<sup>124</sup> Nine artificial discs have received US FDA approval: Prestige ST, Prestige LP, Prodisc-C, Bryan, Secure-C, PCM, Mobi-C, M6-C, and Simplify.<sup>125</sup> Compared with ACDF, CDA was superior or equivalent in terms of length of stay (LOS), clinical indicators, range of motion (ROM) of the cervical spine, adverse events, and reoperation rates.<sup>29,97,109,126</sup> Although CDA has some advantages over ACDF in surgical outcomes, the indications of CDA are relatively narrow, the procedure is more complex,<sup>117,119</sup> and the financial requirements of patients are higher,<sup>127</sup> all of which limit the application of CDA in the clinic. Some scholars believe that postoperative complications of CDA, such as heterotopic ossification (HO), osteolysis, and aseptic loosening caused by abrasion, spontaneous fusion, and postoperative hematoma, are also one of the factors limiting its wide application.<sup>125,128</sup> Since

**Table 5** Categorizing by Article Types

Study Type	No. of Articles	Total Citations	Mean Citations
Original study			
Diagnostic	0	0	0
Therapeutic	65	4635	71.3
Prognostic	9	663	73.7
Economic	0	0	0
Review			
Systematic	17	888	52.2
Non-systematic	9	556	61.8



**Figure 6 (A)** Network visualization map showed clustering of high-frequency keywords. **(B)** Network visualization map showed the variation trend of high-frequency keywords over time. The colors were determined based on the mean year the keywords appear in the articles.

Food and Drug Administration (FDA) approved CDA in 2007, the growth rate of CDA has reached a steady-state, about twice that of ACDF.<sup>129</sup> In a recent investigation by Comron Saifi et al, in the United States alone, approximately 132,000 ACDFs are performed each year compared to only 1600 CDAs, with a ratio of 81:1.<sup>51</sup> Junbo He et al analyzed the top 100 cited publications on anterior cervical surgery and found that 80% of the publications were related to ACDF.<sup>117</sup> As a representative of minimally invasive spine surgeries (MISS), endoscopic spine surgery is expected to become the mainstream direction of spine surgery due to its characteristics of fewer complications and minor tissue damage.<sup>130</sup> However, the immaturity of the technique and the long learning cycle deter most spinal surgeons. ACDF is still the gold standard procedure for CDDD.<sup>11,130,131</sup>

Concerning research trends, CDA and artificial disc have been the research hotspots in recent years (Figure 6). Despite advances in artificial discs in the material, design, and manufacturing technology, wear remains the most influential factor in prosthesis implantation success.<sup>132</sup> Aseptic loosening propagated by implant wear is the primary reason for implant failure and reoperation. Meanwhile, debris from wear induces an inflammatory response at the surgical level, leading to pain in the area surrounding the prosthesis.<sup>124</sup> Researchers argued that disc neovascularization is the cornerstone of new-onset pain, and more investigations into this factor should be increased over the next five years.<sup>133</sup>

As a bibliometric to analyze the top 100 cited articles, our study has the following limitations: firstly, all the articles were published between 2008 to 2019. Like other bibliometric studies, “cumulative effect” is inevitable in our study, which means the earlier articles may have more citations. In contrast, the high-quality articles published recently may not be included due to the low citation.<sup>134,135</sup> Secondly, we only retrieved English publications from the WOS, which might have omitted high-impact articles from other databases or languages. Finally, citation numbers may not be the sole standard to measure the quality and influence of an article. Other factors should be taken into account comprehensively in the future.

## Conclusion

This bibliometric study identified the top 100 cited publications in ACDF, demonstrated the significance of ACDF in spine surgery, and identified the most prominent authors, institutions, countries, and journals. Generally, as the birthplace of ACDF, the United States is the country with the most thorough research in the world and has made outstanding contributions to the development of ACDF. CDA, as an alternative procedure for ACDF, has many limitations and needs further research for improvement. Endoscopic spine surgery is limited in clinical due to its immaturity and long learning period. Therefore, ACDF is still the gold treatment for cervical disc degeneration disease, the emergence of new procedures has not affected its position. As the first bibliometric analysis of ACDF, our study is expected to provide effective guidance for surgeons and researchers to familiarize the most influential publications in this field.

## Data Sharing Statement

Research data supporting this publication are available from the Web of Science at located at [www.webofknowledge.com](http://www.webofknowledge.com).

## Ethical Approval

The authors confirmed that no ethical approval is required.

## Device Status/Drug Statement

The manuscript submitted does not contain information about medical device(s)/drug(s).

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## Disclosure

The authors have no competing interests to declare that are relevant to the content of this article.

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