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.¹⁻³ 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.⁴ and has become one of the most common surgical procedures in spine surgery.⁵,⁶ 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.⁷ Indications for ACDF include cervical degenerative disc disease (CDDD), cervical spinal stenosis, and partial ossification of the posterior longitudinal ligament (OPLL).⁸⁻¹⁰ 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).¹¹ ESS is considered a safe and effective alternative for cervical spine diseases in the future due to minor tissue damage and fewer complications.¹² 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). 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 1  The Top 100 Cited Publications in ACDF

| Rank | First Author | Year | Title                                                                                                                                                                                                 | Journal                                                                 | Total Citations | Citations Per Year |
|------|--------------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|-----------------|--------------------|
| 1    | Murrey, D    | 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    | 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   | 2013 | Assessment of the minimum clinically important difference in pain, disability, and quality of life after anterior cervical discectomy and fusion Clinical article          | Journal of Neurosurgery-Spine                                        | 175             | 19.4               |
| 4    | Buttermann, GR | 2008 | Prospective nonrandomized comparison of an allograft with bone morphogenic protein versus an iliac-crest autograft in anterior cervical discectomy and fusion | Spine Journal                                                        | 143             | 10.2               |
| 5    | Zigler, JE   | 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     | 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   | 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   | 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 | 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 | 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     | 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 | 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    | 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 Clinical article | Journal of Neurosurgery-Spine                                        | 102             | 11.3               |
| 14   | Tumialan, LM | 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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| Rank | First Author     | Year | Title                                                                 | Journal                                      | Total Citations | Citations Per Year |
|------|------------------|------|----------------------------------------------------------------------|----------------------------------------------|-----------------|--------------------|
| 15   | McAfee, PC       | 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      | 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           | 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      | 2015 | Pseudoarthrosis rates in anterior cervical discectomy and fusion: a meta-analysis | Spine Journal                               | 85              | 12.1               |
| 19   | Chau, AMT        | 2009 | Bone graft substitutes in anterior cervical discectomy and fusion      | European Spine Journal                      | 83              | 6.4                |
| 20   | McGirt, Mj       | 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       | 2012 | Anterior cervical discectomy and fusion: Comparison of titanium and polyetheretherketone cages | Bmc Musculoskeletal Disorders                | 81              | 8.1                |
| 22   | Jagannathan, J   | 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       | 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         | 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      | 2014 | The Revision Rate and Occurrence of Adjacent Segment Disease After Anterior Cervical Discectomy and Fusion | Spine                                       | 72              | 9.0                |
| 26   | Radcliff, K      | 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         | 2008 | Polyetheretherketone (PEEK) cage filled with cancellous allograft in anterior cervical discectomy and fusion | International Orthopaedics                   | 69              | 4.9                |
| 28   | Anderson, PA     | 2009 | Predictors of Outcome After Anterior Cervical Discectomy and Fusion A Multivariate Analysis | Spine                                       | 69              | 5.3                |
| 29   | Anakwenze, OA    | 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          | 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 1 (Continued).

| Rank | First Author  | Year | Title                                                                                                                                                                                                 | Journal                                      | Total Citations | Citations Per Year |
|------|---------------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|-----------------|--------------------|
| 31   | Gornet, MF    | 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   | Nassr, A      | 2009 | Does Incorrect Level Needle Localization During Anterior Cervical Discectomy and Fusion Lead to Accelerated Disc Degeneration?                                                                      | Spine                                        | 67              | 5.2                |
| 33   | Uribe, JS     | 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       | 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     | 2011 | Adjacent Segment Motion After Anterior Cervical Discectomy and Fusion Versus ProDisc-C Cervical Total Disk Arthroplasty                                                                       | Spine                                        | 65              | 5.9                |
| 36   | Hofstetter, CP | 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   | 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 | 2010 | Safety of Anterior Cervical Discectomy and Fusion Performed as Outpatient Surgery                                                                                                                  | Journal of Spinal Disorders & Techniques     | 64              | 5.3                |
| 39   | Saifi, C      | 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     | 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         | 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       | 2009 | Comparison of inpatient vs outpatient anterior cervical disc arthroplasty and fusion: a retrospective case series                                                                                | Bmc Surgery                                  | 59              | 4.5                |
| 43   | Miller, LE    | 2011 | Safety and Effectiveness of Bone Allografts in Anterior Cervical Discectomy and Fusion Surgery                                                                                            | Spine                                        | 59              | 5.4                |
| 44   | Chung, JY     | 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       | 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    | 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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| Rank | First Author | Year | Title                                                                 | Journal                                                                 | Total Citations | Citations Per Year |
|------|--------------|------|----------------------------------------------------------------------|------------------------------------------------------------------------|-----------------|--------------------|
| 47   | Buerba, RA    | 2014 | Increased Risk of Complications After Anterior Cervical Discectomy and Fusion in the Elderly | Spine                                                                | 57              | 7.1                |
| 48   | Jiang, SD     | 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       | 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       | 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      | 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   | 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   | 2013 | Evidence-based analysis of adjacent segment degeneration and disease after ACDF: a systematic review | Spine Journal                                                        | 53              | 5.9                |
| 54   | Miao, JH      | 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        | 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     | 2010 | Four-Level Anterior Cervical Discectomy and Fusion With Plate Fixation: Radiographic and Clinical Results | Neurosurgery                                                         | 51              | 4.3                |
| 57   | Jeyamohan, SB | 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      | 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  | 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     | 2011 | Feasibility of Anterior Cervical Discectomy and Fusion as an Outpatient Procedure | World Neurosurgery                                                   | 50              | 4.5                |
| 61   | Njoku, I      | 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      | 2015 | The application of zero-profile anchored spacer in anterior cervical discectomy and fusion | European Spine Journal                                               | 50              | 7.1                |
| 63   | Buttermann, GR | 2018 | Anterior Cervical Discectomy and Fusion Outcomes over 10 Years A Prospective Study | Spine                                                               | 50              | 12.5               |
| 64   | Bhadra, AK    | 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                |
| Rank | First Author | Year | Title | Journal | Total Citations | Citations Per Year |
|------|--------------|------|-------|---------|-----------------|-------------------|
| 65   | Anderson, PA  | 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  | 2013 | Cost-Effectiveness of Single-Level Anterior Cervical Disc Arthroplasty and Fusion Five Years After Surgery | Spine | 47 | 5.2 |
| 67   | Lee, YS  | 2014 | Risk Factors for Postoperative Subsidence of Single-Level Anterior Cervical Disc Arthroplasty and Fusion The Significance of the Preoperative Cervical Alignment | Spine | 47 | 5.9 |
| 68   | Bydon, M  | 2014 | Adjacent Segment Disease After Anterior Cervical Disc Arthroplasty and Fusion in a Large Series | Neurosurgery | 47 | 5.9 |
| 69   | Barbagallo, GMV | 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 | 2013 | Measuring Surgical Outcomes in Cervical Spondylosis Myelopathy Patients Undergoing Anterior Cervical Disc Arthroplasty and Fusion: Assessment of Minimum Clinically Important Difference | Plos One | 46 | 5.1 |
| 71   | Findlay, C  | 2018 | Total disc replacement versus anterior cervical disc arthroplasty 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  | 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  | 2016 | Subsequent surgery rates after cervical total disc replacement using a Mobi-C Cervical Disc Prosthesis versus anterior cervical disc arthroplasty and fusion: a prospective randomized clinical trial with 5-year follow-up | Journal of Neurosurgery-Spine | 45 | 7.5 |
| 74   | Zou, SH  | 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 | 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  | 2015 | An Updated Meta-Analysis Comparing Artificial Cervical Disc Arthroplasty (CDA) Versus Anterior Cervical Disc Arthroplasty and Fusion (ACDF) for the Treatment of Cervical Degenerative Disc Disease (CDDD) | Spine | 44 | 6.3 |
| 77   | Martin, CT  | 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  | 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  | 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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| Rank | First Author | Year | Title                                                                                                                                                                                                 | Journal                                      | Total Citations | Citations Per Year |
|------|--------------|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|-----------------|--------------------|
| 80   | Lee, CH⁹⁵    | 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, J⁹⁶ | 2017 | Predictors for Patient Discharge Destination After Elective Anterior Cervical Discectomy and Fusion                                                                                                     | Spine                                        | 42              | 8.4                |
| 82   | Karhade, AV⁹² | 2019 | Machine learning for prediction of sustained opioid prescription after anterior cervical discectomy and fusion                                                                                           | Spine Journal                                | 42              | 14.0               |
| 83   | Liu, Y⁹⁷     | 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, J⁹⁴ | 2008 | Anterior cervical discectomy with or without fusion with ray titanium cage - A prospective randomized clinical study                                                                                    | Spine                                        | 40              | 2.9                |
| 85   | Xu, RS⁹⁵     | 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, HS⁹⁶   | 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, ZM⁹⁷  | 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, E⁹⁸  | 2016 | Clinical and radiological outcome after anterior cervical discectomy and fusion with stand-alone empty polyethyetherketone (PEEK) cages                                                          | Acta Neurochirurgica                         | 40              | 6.7                |
| 89   | Phan, K⁹⁹    | 2017 | Relationship Between ASA Scores and 30-Day Readmissions in Patients Undergoing Anterior Cervical Discectomy and Fusion                                                                                   | Spine                                        | 40              | 8.0                |
| 90   | Ying, Z⁹⁰    | 2008 | Anterior cervical discectomy and fusion for unstable traumatic spondylolisthesis of the axis                                                                                                         | Spine                                        | 39              | 2.8                |
| 91   | Sugawara, T¹⁰¹ | 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, JK¹⁰² | 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, LQ¹⁰³  | 2013 | Artificial Disk Replacement Combined With Midlevel ACDF Versus Multilevel Fusion for Cervical Disk Disease Involving 3 Levels                                                                             | Orthopedics                                  | 38              | 4.2                |
| 94   | Lubelski, D¹⁰⁴ | 2015 | Reoperation rates after anterior cervical discectomy and fusion versus posterior cervical foraminotomy: a propensity-matched analysis                                                                    | Spine Journal                                | 38              | 5.4                |
| 95   | Radcliff, K¹⁰⁵ | 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, S¹⁰⁶ | 2016 | Outpatient anterior cervical discectomy and fusion: A meta-analysis                                                                                                                               | Journal of Clinical Neuroscience              | 38              | 6.3                |

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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

Table 1 (Continued).

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

Figure 1 Total number of articles published per year.
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

| Author       | Total Articles | Total Citations | Mean Citations |
|--------------|----------------|-----------------|----------------|
| Lied, B      | 3              | 167             | 55.7           |
| Sass, RC     | 2              | 240             | 120            |
| Davis, RJ    | 2              | 240             | 120            |
| Phillips, FM | 2              | 231             | 115.5          |
| Buttermann, GR | 2            | 193             | 96.5           |
| Tumiyan, 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           |

Table 2 Authors with More Than Two Articles

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

| 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          |

**Figure 3** Articles published by each country.
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), “arthrodasis” (32), “follow-up” (26), “decompression” (23), and “ACDF” (22).

Discussion
ACDF represents one of the most popular procedures in spine surgery. In 1958, Smith and Robinson firstly described the application of anterior cervical approach as the therapeutic of spine disorders. 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. 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. To date, ACDF has long been considered the initial and gold standard of anterior cervical surgery. 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).
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.\textsuperscript{117}

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.\textsuperscript{111} 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.\textsuperscript{118} 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

| 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           |
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. 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. Moreover, several publications showed that changes in the biomechanical of adjacent segments after ACDF may result in adjacent segment degeneration (ASD). CDA was introduced to protect spinal biomechanics and reduce the incidence of ASD. In 1966, Fernstrom introduced the concept of CDA. 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. Nine artificial discs have received US FDA approval: Prestige ST, Prestige LP, Prodisc-C, Bryan, Secure-C, PCM, Mobi-C, M6-C, and Simplify. 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. Although CDA has some advantages over ACDF in surgical outcomes, the indications of CDA are relatively narrow, the procedure is more complex, and the financial requirements of patients are higher, 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.

Figure 5 The number of articles published in each journal.

Table 5 Categorizing by Article Types

| Study Type   | No. of Articles | Total Citations | Mean Citations |
|--------------|-----------------|-----------------|----------------|
| Original study | 0               | 0               | 0              |
| 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           |
Food and Drug Administration (FDA) approved CDA in 2007, the growth rate of CDA has reached a steady-state, about twice that of ACDF. 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. 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. 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. However, the immaturity of the technique and the long learning cycle deter most spinal surgeons. ACDF is still the gold standard procedure for CDDD.

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. 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. 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.

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

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