Review Article

The most influential publications in cervical myelopathy

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Abstract: Management of cervical myelopathy (CM) has continued to evolve through a better understanding of the long-term outcomes of this diagnosis as well as improved diagnostic guidelines. More recent literature continues to expand the field, but certain publications can be distinguished from others due to their lasting impact. Using the Clarivate Analytics Web of Science, search phrases were used to identify publications pertaining to CM. The fifty most cited articles were isolated. The frequency of citations, year of publication, country of origin, journal of publication, level of evidence (LOE), article type, as well as contributing authors and institutions were recorded. We also highlighted the five most cited articles (per year) from the past 10 years. Publications included ranged from 1952–2011, with the plurality of articles published during 2000–2009 (n=21; 42%). The most cited paper was Hillibrand's 1999 reporting of adjacent segment disease rates following cervical fusions, followed by Hirabayashi's 1983 review of his cervical laminoplasty outcomes. The third most cited was Brain's 1952 review of the manifestations of cervical spondylosis. *Spine* contributed the most publications (n=26; 52%). A LOE of III was the most common (n=30; 60%). Clinical outcome articles were the most frequent type (n=28; 56%). Osaka University (Japan) and Kazou Yonenobu had the most contributions. Ames or Fehlings were the first or last author in each of the five most influential articles from the past 10 years. This bibliometric citation analysis identifies the most influential articles regarding CM. There are few publications with a high LOE, and more high powered studies are needed. Knowledge of these "classic" publications allows for a better overall understanding of the diagnosis, treatment, and future direction of research of CM.

Keywords: Cervical myelopathy (CM); cervical spondylotic myelopathy; bibliometric review; spine; neurosurgery; most influential; adjacent segment disease;

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Introduction

The management of spinal pathology has developed significantly in recent decades, an evolution perhaps best exemplified by the advances in care of patients with cervical myelopathy (CM). The field has been informed via publications from a broad variety of clinicians, institutions, and study designs that have collectively shaped our current understanding of this condition. From the pathophysiology and epidemiology to expected outcomes of surgical and nonsurgical management, understanding of this condition and the standards of care are vastly different from those employed just half a century ago. A thorough understanding of prior studies may help clinicians in their development of subsequent trials.

Citation analysis is a unique tool that has long been

utilized in medical literature to quantify the effects that publications have on their respective fields (1). While direct impact on clinical practice is difficult to accurately quantify, reference of an article by other scholarly papers has been used as a proxy for data distribution and incorporation into academic discussion of a topic. Specifically, spine surgery has benefited from many bibliometric reviews that help highlight literature trends and deficiencies, as well as centers that are advancing the field (2-10). Additionally, these analyses can be used by those entering a particular field as an encompassing resource to efficiently identify some of the most discussed and shared publications. It can also be used as an imperfect gauge to measure the relative influence of publications as well as journals.

We sought to collect and review the 50 most cited articles discussing the management of CM to quantify the factors that resulted in a high degree of influence and to highlight those that have advanced the field. By describing the chronology of the field's most significant developments, the demographics of the international cohort of contributing authors, and the quality of data published, we present a novel context with which to consider the current state of the art and to examine future advances in care for patients with CM.

Methods

Clarivate Analytics Web of Science, formerly known as Thomson Reuters Web of Science, was used to conduct a search for articles pertaining to CM. Web of Science is a search database that provides detailed citation information. Queries were conducted using varied Boolean search terms as of May 2018. The broadest search returning the greatest number of results was carried forward; the Boolean search phrases of the final search included the following: [(myelopathy OR cervical spondylotic myelopathy OR spondylosis OR laminoplasty OR JOA OR mJOA OR Nurick OR OPLL OR "ossification of the posterior longitudinal ligament") AND (spine OR cervical OR subaxial OR C-spine OR neck)].

The search was not restricted to any particular language or data range. Articles from both medical and non-medical journals were included in the initial screen. The search results were refined to include only peer-reviewed articles, review papers, and proceedings papers. The resulting articles were sorted by descending number of citations. For inclusion, publications must have pertained to compression of the spinal cord in a medically relevant discussion in an area such as causes, diagnosis, associated signs and symptoms, treatments, anatomy, physiology, or mechanics. The articles were then screened by title and abstract with the goal of isolating 50 articles related to CM. These articles were additionally screened and verified by the first author (CJD), removing articles that did not pertain to CM specifically. For instance, an article related to cancers of the spine that briefly discusses CM would not be included.

To determine the order for articles with equal number of overall citations, the number of citations in the most recent year was used as a tiebreaker. Level of evidence (LOE), article type, and institution data were manually recorded for each article after reviewing each paper. LOE was determined based on the Oxford evidence-based medicine levels of evidence table. Categories for article types were determined from individual reviews of each manuscript. All supporting institutions for each article were recorded.

The final 50 articles were further analyzed via Web of Science for the following attributes: year of publication, country of origin, journal of publication, article type, total number of citations, average citations per year, citations in 2017, authorship frequency, LOE, and contributing institutions. A comparison of the Web of Science analyses, the Web of Science exported citation summary, and manually recorded data from web searches of the individual articles was used for final analysis.

As a secondary objective we wanted to highlight the more recent publications that may have not made the initial list due to the limited time of publication. To illustrate the more recent influential publications we used the same above parameters, but we restricted our search to articles from the past 10 years. We then ranked results by frequency of citation per year, as opposed to total citations.

Results

The initial search yielded 8,249 preliminary results, of which we needed to review the first 3,000 to eventually identify 50 publications pertaining to the CM criteria (*Figure 1*). This list of the 50 most cited articles were published from 1952 to 2011. The top ranked paper was cited 776 times; the 50th ranked paper was cited 130 times (*Table 1*). Of these 50 articles, the average total number of citations per publication was 193. The average number of citations per year since the year of article publication was 9.2. In 2017 the mean number of citations for these 50 articles was 15.5.

The earliest publication within this list is the Brain *et al.* paper from 1952, which reviews prior papers that

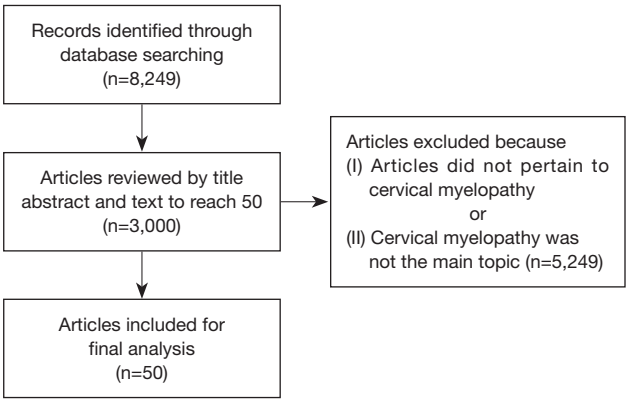

Figure 1 Modified PRISMA flowchart.

documented the pathology of cervical spondylosis. Interestingly, articles from the first half of the 20th century were included in the original search, but zero articles from this time period qualified for the final list.

The most prolific time periods were the 1990s (34%) and 2000s (42%). The most prolific single year of publication was tied between 2001 and 2003, each of which yielded 6 papers (12%). No articles were published in the 1970s. A positive correlation between decade and number of articles was noted between the 1950s and the 2000s (*Figure 2*). Japan and the United States were the two most prolific countries contributing to these publications (46% and

Table 1 Fifty most cited publications on cervical myelopathy

Rank	Publication	Total citations	Citations/year of publication until 2018	Citations in 2017
1	Hilibrand AS, Carlson GD, Palumbo MA, *et al.* Radiculopathy and myelopathy at segments adjacent to the site of a previous anterior cervical arthrodesis. J Bone Joint Surg Am 1999;81A:519-28.	774	38.7	66
2	Hirabayashi K, Watanabe K, Wakano K, *et al.* Expansive Open-Door Laminoplasty for Cervical Spinal Stenotic Myelopathy. Spine 1983;8:693-9.	371	10.31	26
3	Brain WR, Northfield D, Wilkinson M. The Neurological Manifestations of Cervical Spondylosis. Brain 1952;75:187-225.	340	5.07	9
4	Fountas KN, Kapsalaki EZ, Nikolakakos LG, *et al.* Anterior cervical Discectomy and fusion associated complications. Spine 2007;32:2310-7.	324	27	65
5	Baba H, Furusawa N, Imura S, *et al.* Late Radiographic Findings After Anterior Cervical Fusion for Spondylotic Myeloradiculopathy. Spine 1993;18:2167-73.	259	9.96	13
6	Emery SE, Bohlman HH, Bolesta MJ, *et al.* Anterior Cervical Decompression and Arthrodesis for The Treatment of Cervical Spondylotic Myelopathy - Two to Seventeen-Year Follow-Up. J Bone Joint Surg Am 1998;80A:941-51.	243	11.57	20
7	Goffin J, Geusens E, Vantomme N, *et al.* Long-Term Follow-Up After Interbody Fusion of the Cervical Spine. J Spinal Disord & Techniques 2004;17:79-85.	231	15.4	29
8	Satomi K, Nishu Y, Kohno T, *et al.* Long-Term Follow-Up-Studies of Open-Door Expansive Laminoplasty for Cervical Stenotic Myelopathy. Spine 1994;19:507-10.	221	8.84	12
9	Hosono N, Yonenobu K, Ono K. Neck and Shoulder Pain After Laminoplasty - A Noticeable Complication. Spine 1996;21:1969-73.	217	9.43	19
10	Benzel EC, Lancon J, Kesterson L, *et al.* Cervical Laminectomy and Dentate Ligament Section for Cervical Spondylotic Myelopathy. J Spinal Disord 1991;4:286-95.	215	7.68	29
11	Clarke E, Robinson PK. Cervical Myelopathy - A Complication of Cervical Spondylosis. Brain 1956;79:483-510.	211	3.35	10
12	Katsuura A, Hukuda S, Saruhashi Y, *et al.* Kyphotic Malalignment After Anterior Cervical Fusion Is One of the Factors Promoting the Degenerative Process in Adjacent Intervertebral Levels. Eur Spine J 2001;10:320-4.	208	11.56	23

Table 1 *(continued)*

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Rank	Publication	Total citations	Citations/year of publication until 2018	Citations in 2017
13	Goffin J, Van Calenbergh F, van Loon J, *et al.* Intermediate Follow-Up After Treatment of Degenerative Disc Disease with The Bryan Cervical Disc Prosthesis: Single-Level and Bi-Level. Spine 2003;28:2673-8.	207	12.94	12
14	Wada E, Suzuki S, Kanazawa A, *et al.* Subtotal Corpectomy Versus Laminoplasty for Multilevel Cervical Spondylotic Myelopathy - A Long-Term Follow-Up Study Over 10 Years. Spine 2001;26:1443-7.	190	10.56	13
15	Crandall PH, Batzdorf U. Cervical Spondylotic Myelopathy. J Neurosurg 1966;25:57.	184	3.47	3
16	Sakaura H, Hosono N, Mukai Y, *et al.* C5 Palsy After Decompression Surgery for Cervical Myelopathy - Review of The Literature. Spine 2003;28:2447-51.	183	11.44	18
17	Itoh T, Tsuji H. Technical Improvements and Results of Laminoplasty for Compressive Myelopathy in The Cervical Spine. Spine 1985;10:729-36.	183	5.38	5
18	Seichi A, Takeshita K, Ohishi I, *et al.* Long-Term Results of Double-Door Laminoplasty for Cervical Stenotic Myelopathy. Spine 2001;26:479-87.	182	10.11	16
19	Ratliff JK, Cooper PR. Cervical Laminoplasty: A Critical Review. J Neurosurg 2003;98:230-8.	179	11.19	20
20	Yonenobu K, Abumi K, Nagata K, *et al.* Interobserver and Intraobserver Reliability of the Japanese Orthopaedic Association Scoring System for Evaluation of Cervical Compression Myelopathy. Spine 2001;26:1890-4.	177	9.83	38
21	Goffin J, Casey A, Kehr P, *et al.* Preliminary Clinical Experience with The Bryan Cervical Disc Prosthesis. Neurosurgery 2002;51:840-5.	171	10.06	8
22	Saunders RL, Bernini PM, Shirreffs TG, *et al.* Central Corpectomy for Cervical Spondylotic Myelopathy - A Consecutive Series with Long-Term Follow-Up Evaluation. J Neurosurg 1991;74:163-70.	171	6.11	6
23	Chiba K, Ogawa Y, Ishii K, *et al.* Long-Term Results of Expansive Open-Door Laminoplasty for Cervical Myelopathy - Average 14-Year Follow-Up Study. Spine 2006;31:2998-3005.	169	13	23
24	Tsuyama N. Ossification of The Posterior Longitudinal Ligament of the Spine. Clin Orthop Relat Res 1984:71-84.	169	4.83	13
25	Coric D, Nunley PD, Guyer RD, *et al.* Prospective, Randomized, Multicenter Study of Cervical Arthroplasty: 269 Patients from The Kineflexic Artificial Disc Investigational Device Exemption Study with A Minimum 2-Year Follow-Up Clinical Article. J Neurosurg-Spine 2011;15:348-58.	168	21	31
26	Abumi K, Kaneda K. Pedicle Screw Fixation for Nontraumatic Lesions of the Cervical Spine. Spine 1997;22:1853-63.	167	7.59	10
27	Suda K, Abumi K, Ito M, *et al.* Local Kyphosis Reduces Surgical Outcomes of Expansive Open-Door Laminoplasty for Cervical Spondylotic Myelopathy. Spine 2003;28:1258-62.	165	10.31	22
28	Zdeblick TA, Bohlman HH. Cervical Kyphosis and Myelopathy - Treatment by Anterior Corpectomy and Strut-Grafting. J Bone Joint Surg Am 1989;71A:170-82.	163	5.43	5
29	Ebersold MJ, Pare MC, Quast LM. Surgical-Treatment for Cervical Spondylitic Myelopathy. J Neurosurg 1995;82:745-51.	162	6.75	7
30	MacDonald RL, Fehlings MG, Tator CH, *et al.* Multilevel Anterior Cervical Corpectomy and Fibular Allograft Fusion for Cervical Myelopathy. J Neurosurg 1997;86:990-7.	161	7.32	4
31	Yonenobu K, Hosono N, Iwasaki M, *et al.* Neurologic Complications of Surgery for Cervical Compression Myelopathy. Spine 1991;16:1277-82.	161	5.75	6

Table 1 *(continued)*

Table 1 *(continued)*

Rank	Publication	Total citations	Citations/year of publication until 2018	Citations in 2017
32	Heller JG, Edwards CC, Murakami H, *et al.* Laminoplasty Versus Laminectomy and Fusion for Multilevel Cervical Myelopathy - An Independent Matched Cohort Analysis. Spine 2001;26:1330-6.	158	8.78	21
33	Kaptain GJ, Simmons NE, Replogle RE, *et al.* Incidence and Outcome of Kyphotic Deformity Following Laminectomy for Cervical Spondylotic Myelopathy. J Neurosurg 2000;93:199-204.	158	8.32	15
34	Yonenobu K, Hosono N, Iwasaki M, *et al.* Laminoplasty Versus Subtotal Corpectomy - A Comparative-Study of Results in Multisegmental Cervical Spondylotic Myelopathy. Spine 1992:17:1281-4.	152	5.63	9
35	Wang MC, Chan L, Maiman DJ, *et al.* Complications and Mortality Associated with Cervical Spine Surgery for Degenerative Disease in The United States. Spine 2007;32:342-7.	151	12.58	22
36	Edwards CC, Heller JG, Murakami H. Corpectomy Versus Laminoplasty for Multilevel Cervical Myelopathy - An Independent Matched-Cohort Analysis. Spine 2002;27:1168-75.	150	8.82	15
37	Sasso RC, Ruggiero RA, Reilly TM, *et al.* Early Reconstruction Failures After Multilevel Cervical Corpectomy. Spine 2003;28:140-2.	149	9.31	16
38	Iwasaki M, Kawaguchi Y, Kimura T, *et al.* Long-Term Results of Expansive Laminoplasty for Ossification of the Posterior Longitudinal Ligament of the Cervical Spine: More Than 10 Years Follow Up. J Neurosurg 2002;96:180-9.	149	8.76	10
39	Mehalic TF, Pezzuti RT, Applebaum BI. Magnetic-Resonance-Imaging and Cervical Spondylotic Myelopathy. Neurosurg 1990;26:217-27.	146	5.03	9
40	Morio Y, Teshima R, Nagashima H, *et al.* Correlation Between Operative Outcomes of Cervical Compression Myelopathy and MRI of The Spinal Cord. Spine 2001;26:1238-45.	145	8.06	12
41	Sampath P, Bendebba M, Davis JD, *et al.* Outcome of Patients Treated for Cervical Myelopathy - A Prospective, Multicenter Study with Independent Clinical Review. Spine 2000;25:670-6.	143	7.53	18
42	Hukuda S, Mochizuki T, Ogata M, *et al.* Operations for Cervical Spondylotic Myelopathy - A Comparison of the Results of Anterior and Posterior Procedures. J Bone Joint Surg Br 1985;67:609-15.	141	4.15	6
43	Ogino H, Tada K, Okada K, *et al.* Canal Diameter, Anteroposterior Compression Ratio, And Spondylotic Myelopathy of the Cervical-Spine. Spine 1983;8:1-15.	139	3.86	5
44	Fujiwara K, Yonenobu K, Ebara S, *et al.* The Prognosis of Surgery for Cervical Compression Myelopathy - An Analysis of the Factors Involved. J Bone Joint Surg Br 1989;71:393-8.	138	4.6	6
45	Okada Y, Ikata T, Yamada H, *et al.* Magnetic-Resonance-Imaging Study On the Results of Surgery for Cervical Compression Myelopathy. Spine 1993;18:2024-9.	136	5.23	6
46	Yonenobu K, Fuji T, Ono K, *et al.* Choice of Surgical-Treatment for Multisegmental Cervical Spondylotic Myelopathy. Spine 1985;10:710-6.	135	3.97	7
47	Demir A, Ries M, Moonen CT, *et al.* Diffusion-Weighted MR Imaging with Apparent Diffusion Coefficient and Apparent Diffusion Tensor Maps in Cervical Spondylotic Myelopathy. Radiology 2003;229:37-43.	133	8.31	8
48	Eleraky MA, Llanos C, Sonntag VK. Cervical Corpectomy: Report of 185 Cases and Review of the Literature. J Neurosurg 1999;90:35-41.	132	6.6	8
49	Herman JM, Sonntag VK. Cervical Corpectomy and Plate Fixation for Postlaminectomy Kyphosis. J Neurosurg 1994;80:963-70.	132	5.28	3
50	Majd ME, Vadhva M, Holt RT. Anterior Cervical Reconstruction Using Titanium Cages with Anterior Plating. Spine 1999;24:1604-10.	130	6.5	4

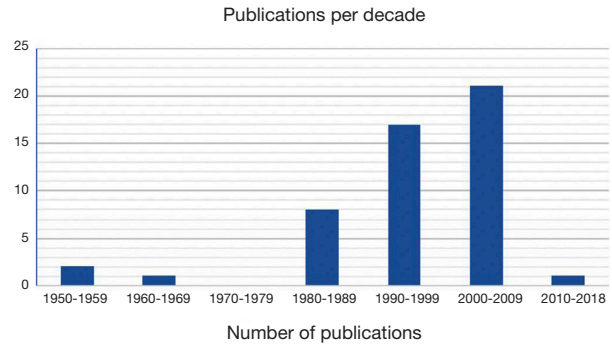

Figure 2 Frequency of articles published between the 1950s and 2010s.

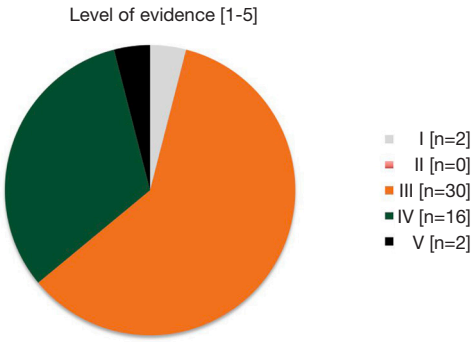

Figure 4 Number of articles at each level of evidence.

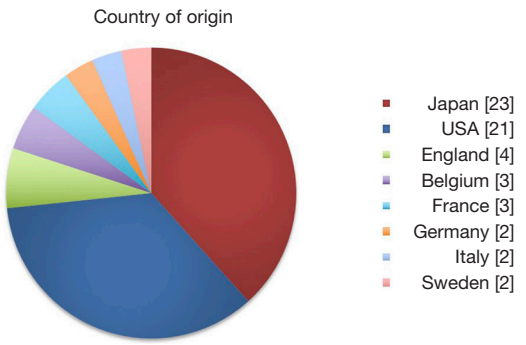

Figure 3 Publication origin by country.

Table 2 Journal of origin

Journal name	Number of publications
Spine	26
Journal of Neurosurgery	10
Journal of Bone And Joint Surgery (American Volume)	3
Journal of Bone And Joint Surgery (British Volume)	2
J Spinal Disord and Techniques (now Clinical Spine Surgery)	2
Neurosurgery	2
Brain	2
Clin Orthop Relat Res	1
Eur Spine J	1
Radiology	1

42%, respectively). Interestingly, eight different countries contributed to the articles within the final list (*Figure 3*).

There were 10 different journals represented within this list, with *Spine* accounting for 26 (52%) of the publications (*Table 2*). The second was the *J Neurosurg*, which accounted for 10 (20%) publications. More than half of the papers had a LOE of III. The numbers of papers for LOE I, II, III, IV, and V was 2 (4%), 0 (0%), 30 (60%), 16 (32%), and 2 (4%), respectively (*Figure 4*). When indicated, a single article may contain more than one LOE.

The majority of publications were associated within the article type called clinical outcomes (n=28; 57%). An additional 9 articles (18%) were assigned the article type called Imaging. The remaining publications were classified as follows: surgical technique (n=4), general review (n=4), complications (n=3), questionnaire development (n=1), and anatomic (n=1). Interestingly, 25 authors contributed to at least 2 papers within the list, and 9 authors contributed to at least 3 papers within the list. The most prolific authors were Yonenobu K (n=9; 18%) and Ono K (n=6; 12%) (*Table 3*).

Additionally, in terms of institutional contribution, 6 institutions contributed to 3 or more articles on this list. Osaka University (Japan) was the institution with the greatest number of articles, contributing to 10 articles (20%). Five institutions were tied for the second greatest number of articles, each contributing to 3 articles (*Table 4*).

In terms of Clarivate Analytics Web of Science publication categories, 43 articles (86%) were classified as neurosciences/neurology papers while 34 articles were classified as orthopedics papers (68%). When indicated, a single article can be placed into more than one publication categories. Each of the top 50 publications were presented in English.

As a secondary objective we wanted to identify influential articles published within the past 10 years. We highlighted the 5 most frequently cited publications since 2008, based

Table 3 Author frequency

Author	Number of papers
Yonenobu K	9
Ono K	6
Hosono N	4
Abumi K	3
Bohlman HH	3
Goffin J	3
Iwasaki M	3
Van Calenbergh F	3
Van Loon J	3

Authors with 3 or more contributions were included.

Table 4 Contributing institution

Name of institution	Location of institution	Number of articles
Osaka University	Osaka, Japan	10
Case Western Reserve University	Cleveland, Ohio, USA	3
Centre Hospitalier Universatier	Bordeaux, France	3
Hokkaido University	Sapporo, Japan	3
University College London Hospital	London, UK	3
University Hospital Gasthuisberg	Leuven, Belgium	3

Institutions with 3 or more contributions were included.

on number of citations per year as opposed to ranking by total number of citations to gather the Top 50 mentioned above. Interestingly, we found that the authors either Ames and Fehlings were 1st or last author on for the 5 most influential articles from the past 10 years (*Table 5*).

Discussion

By performing a citation analysis of "Cervical Myelopathy" we aimed to identify the articles that have been most influential on the field. While the total number of article citations does not necessarily indicate the publication quality or active practice utilization, it does address readership and overall influence based on recognition by peers in the field (11-15). Further analysis of the qualities of each of these articles promotes a better understanding of factors associated with article importance and understanding of the demographics related to the study and management of CM.

In our analysis, we found that the most cited article pertaining to CM is the 1999 article by Hilibrand *et al.* (774 citations) identifying the incidence, prevalence, and progression of adjacent segment disease following anterior cervical fusion (16). Interestingly, this article also has the highest citation rate per year (38.7) as well as the highest citation rate in 2017 [66] indicating its lasting influence in this field.

The second most cited article was the 1983 article by

Table 5 Most cited per year publications from the past 10 years

Rank	Publication	Citations/year of publication until 2018	Total citations	Citations in 2017
1	Nouri A, Tetreault L, Singh A, *et al.* Degenerative Cervical Myelopathy Epidemiology, Genetics, and Pathogenesis. Spine 2015;40:E675-93.	20.25	81	35
2	Scheer JK, Tang JA, Smith JS, *et al.* Cervical spine alignment, sagittal deformity, and clinical implications-A review. J Neurosurg-Spine 2013;19:141-59.	18.67	112	40
3	Ames CP, Blondel B, Scheer JK, *et al.* Cervical Radiographical Alignment Comprehensive Assessment Techniques and Potential Importance in Cervical Myelopathy. Spine 2013;38:S149-60.	17.83	107	40
4	Fehlings MG, Wilson JR, Kopjar B, *et al.* Efficacy and Safety of Surgical Decompression in Patients with Cervical Spondylotic Myelopathy Results of the AOspine North America Prospective Multi-Center Study. J Bone Joint Surg Am 2013;95A:1651-8.	16.83	101	45
5	Tang JA, Scheer JK, Smith JS, *et al.* The Impact of Standing Regional Cervical Sagittal Alignment on Outcomes in Posterior Cervical Fusion Surgery. Neurosurgery 2012;71:662-9.	16.71	117	36

Hirabayashi *et al.* (371 citations) which introduced the open door laminoplasty as a treatment options for CM secondary to ossification of the posterior longitudinal ligament (17). Similarly, this sentinel article continues to be highly relevant with a yearly citation rate of 10.31 and 26 citations in 2017.

Evaluation of author affiliations revealed Japan and specifically Osaka University as some of the most prolific locations for CM publications. This high prevalence of CM research output by Japan is likely related to the higher incidence of OPLL within Asian population as well as the aging Japanese society, both of which predispose a patient to CM (17-19). The Japanese authors Yonenobu, Ono, and Hosona were some of the most cited. It should be noted that our methods counted an author's contribution regardless of author order, which varied from many prior bibliometric studies that only counted the first and/or last author (7,20). This is important to highlight because Yonenobu, Ono, and Hosona practice from the same institutions and so have regularly published together with differing primary, secondary or senior author status. Their many contributions to the field distinguishes them as leaders in CM management.

By evaluating all contributing authors and institutions as opposed to simply counting the first or last author, we were able to more effectively which groups are the leading contributors to the field. Additionally, our novel methods limit potential bias of overlooking second and third authors who may have contributed in a similar capacity to the first or last author in multicenter or review studies. A critic of analyzing authorship contributions regardless of author order in the final analysis may note that this approach could result in an inflated overall impact of a given individual to the field. An association with a high-output institution may predispose individual authors to a higher rate of publications if they are included as a reviewer of colleagues' work. In the absence of weighting or biasing author order, the potentially lesser-impact contributions of second, third and fourth authors are interpreted as equal in our analysis to those who were deemed appropriate for a first or senior author position.

There were no articles from 2012 onward, which might be expected given the nature of this analysis being based subsequent research citing prior publications. An inherent flaw in a bibliometric analysis model is that there is a time delay regard to articles gaining citations which creates a disadvantage for more recently published articles (21). To that end, this review is also unique in that we attempt to account for this selection bias through an evaluation of the more recent publications (*Table 5*). We limit our selection bias by evaluating the most influential articles from the past 10 years by number of citations per year. We identified the five most influential articles and interestingly noted strong similarities. Primarily, either Ames or Fehlings was the first or last author. Secondarily, 3 of these 5 recent articles pertained to cervical spine sagittal alignment. It is important for spine surgeons at every level to be familiar with the newer publications as more emphasis is placed on proper techniques, indications and radiographic parameters that were not as appreciated more than a decade ago.

The most recent article from the initial top 50 CM list (#24) is from 2011 by Coric *et al.* (22). This article presents the preliminary outcome results of a randomized control trial of cervical disc replacement (CDR) versus a traditional anterior cervical discetcomy and fusion (ACDF), indicating improved outcomes in the CDR group. This article has the second highest citation rate (21 citations per year) and fourth highest number of citations in 2017 (n=31) which explains the heightened position of such a relatively recent article on the list of top 50. One should expect some of the most influential publications in the future to pertain to CDR as the technology improves and follow-up time lengthens.

As opposed to less expansive bibliometric reviews, our analysis and initial search was not restricted to a preset list of certain journals. Altogether, 10 journals were represented from the 50 publications with 36 of the 50 articles identified (72%) represented by two journals, *Spine* and *J Neurosurg. Spine* accounted the majority of publications which is consistent with 2 previous bibliometric studies analyzing cervical spine surgery (7,20). Moreover, we noted that the overwhelming majority of articles pertained to clinical outcomes, which would be expected as their results would be supported or challenged in subsequent citing papers. Similarly, 18% of the top 50 papers (based on total citations) pertained to Imaging, just as 3 of the 5 more recent influential CM papers (based on citations per year) also pertained to imaging. Likely there will continue to be publications that authors deem influential pertaining to imaging as our technology advances and the community develops a further appreciation of spine balancing.

The average LOE was III, which differs from a previous bibliometric study of all "cervical spine surgery" demonstrating a plurality of level 4 evidence (7). That bibliometric analysis by Rüegsegger *et al*. also noted increasing levels of evidence over time, a trend that has also be noted in orthopaedic sport literature (7,23). The

difference in average LOE represented by our study is likely attributed to the low number of articles prior to 1980 within our study. Interestingly, we found the most prolific decade of publication of CM articles was the 2000s. This trend mirrors that of many other fields that have highlighted a rise in publication rates possibly due to due the digital ease of manuscript drafting, increase in number of journals, emphasis on publication for career development, and increase in author collaboration (24-27).

Additionally, an overwhelming majority (82%) of the listed studies relevant to CM are concerned specifically with surgical management. Surgical treatment publications, especially those specifically pertaining to anterior cervical fusion (34%) and laminoplasty (20%), have had the long lasting impact on the field of CM. Crandall's description of CM in 1966 and Tsuyama's 1984 review of its pathogenesis largely stand alone as widely cited publications that are not primarily written to describe, report or compare surgical procedures. This scarcity of literature may result from a historical lack of consensus regarding optimal management, and a severity of clinical symptoms that demand surgical intervention of some sort. As the condition has long been understood to be primarily structural, the many factors impacting surgical intervention and outcomes have likely been of more pressing concern than academic curiosity regarding its pathogenesis (28). Interestingly, the most cited publication of the past 10 years is Nouri's 2015 review of advances in understanding of the pathophysiology and natural history of CM, potentially indicating a recognized need for further understanding of the biology of this condition (29).

There are many inherent limitations with any citation analysis study. In this review, we chose to order the articles based on total citation number as opposed to citation rate in an attempt to focus on the "classic" papers in CM. The citation rate (per year) is another method to demonstrate article importance, which we did utilize to highlight an additional 5 articles more recently published. However, basing an analysis on citation rate alone could have caused "classic" papers to be over looked as overall citation rates per year of new articles are expected to increase over time due to the broad expansion of digital technology and scholarly literature. Another factor is a concept referred to as "obliteration by incorporation" which describes the incorporation of classic articles into the accepted medical knowledge therefore decreasing their citation rate going forward (7). An additional limitation to this review is that some articles may have been missed in our search criteria as we only included peer-reviewed articles. Therefore, citations that occur in chapters or non-peer reviewed literature (such as a website or news story) were not included thereby potentially underreporting the influence of certain publications.

Conclusions

This review highlights the centers and authors that have been at the forefront of influential advancements in the management of CM. Japan and the United States have been instrumental in producing CM related research. Studies dedicated to clinical outcomes and imaging have been the most influential, and likely will be in the future should trends continue. Interestingly, there are few high level studies regarding CM, possibly as a result of the limited ability to randomize patients into non-surgical management for a condition well treated with surgery. Knowledge of the most well cited papers provides physicians and other members of the medical community an informed context of the state of the art of a given topic and allows for a broader background from which to carry out future projects.

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Footnote

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