The 100 most-cited articles in spinal oncology

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OBJECTIVE The authors' objective was to identify the 100 most-cited research articles in the field of spinal oncology.

METHODS The Thomson Reuters Web of Science service was queried for the years 1864–2015 without language restrictions. Articles were sorted in descending order of the number of times they were cited by other studies, and all titles and abstracts were screened to identify the research areas of the top 100 articles. Levels of evidence were assigned on the basis of the North American Spine Society criteria.

RESULTS The authors identified the 100 most-cited articles in spinal oncology, which collectively had been cited 20,771 times at the time of this writing. The oldest article on this top 100 list had been published in 1931, and the most recent in 2008; the most prolific decade was the 1990s, with 34 articles on this list having been published during that period. There were 4 studies with Level I evidence, 3 with Level II evidence, 9 with Level III evidence, 70 with Level IV evidence, and 2 with Level V evidence; levels of evidence were not assigned to 12 studies because they were not on therapeutic, prognostic, or diagnostic topics. Thirty-one unique journals contributed to the 100 articles, with the *Journal of Neurosurgery* contributing most of the articles (n = 25). The specialties covered included neurosurgery, orthopedic surgery, neurology, radiation oncology, and pathology. Sixty-seven articles reported clinical outcomes. The most common country of article origin was the United States (n = 62), followed by Canada (n = 8) and France (n = 7). The most common topics were spinal metastases (n = 35), intramedullary tumors (n = 18), chordoma (n = 17), intradural tumors (n = 7), vertebroplasty/kyphoplasty (n = 7), primary bone tumors (n = 6), and others (n = 10). One researcher had authored 6 studies on the top 100 list, and 7 authors had 3 studies each on this list.

CONCLUSIONS This study identified the 100 most-cited research articles in the area of spinal oncology. The studies highlighted the multidisciplinary and multimodal nature of spinal tumor management. Recognition of historical articles may guide future spinal oncology research.

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KEY WORDS citation analysis; spinal oncology; spine tumors; spine surgery; bibliometrics

IN the last decades, spinal oncology has emerged as a separate subspecialty,¹¹⁴ reflecting years of research focused on innovative techniques for controlling spinal tumors and managing the pain and pathophysiology arising from these types of cancers.⁸⁴ Although management of some diseases may involve few specialists, patients with spinal tumors are usually treated by a multidisciplinary team, including neurosurgeons, orthopedic surgeons, oncologists, radiation oncologists, and neurologists.⁸⁴ Thus, the spinal oncology literature encompasses numerous researchers and countries, specialties, and scientific journals.

Citation analysis is a systematic approach for identifying scientific studies that have a high impact on medicine. This type of analysis has been applied to the literature on general neurosurgery,⁸⁸ orthopedic surgery,⁶⁷ otolaryngology,⁹² urology,⁶⁴ and plastic surgery.⁷⁶ Although bibliometric analyses have been performed on spinal surgery as a whole,⁸⁴ as well as on spinal deformity surgery⁸⁵ and lumbar spine surgery,¹⁰³ little is known about the most frequently cited articles specifically related to spinal oncology.

Therefore, the purpose of this study was to identify the 100 most-cited articles on spinal tumors in an effort to identify important contributions to the literature in this field.

ABBREVIATIONS CY = citations per year.

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Methods

The citation indexing service of Thomson Reuters Web of Science was queried.¹⁰³ The search algorithm ([spine OR spinal OR vertebral] AND [tumor OR neoplasm OR cancer OR metastases]) was used in the “Topic” field to identify articles of interest. The following search parameters were used: 1) articles published in the years 1864–2015, and 2) all languages. The articles retrieved were then sorted in descending order of times cited.

All authors then reviewed the article titles and abstracts to identify the 100 most-cited articles in the area of spinal oncology. Data such as title, authors, author specialty, journal of publication, year of publication, number of citations, article category, and country of origin were recorded. The levels of evidence of the studies were assigned according to therapeutic, prognostic, and diagnostic criteria set by the North American Spine Society (<https://www.spine.org/Portals/0/Documents/ResearchClinicalCare/LevelsOfEvidence.pdf>). Under these criteria, Level I studies correspond to high-quality randomized controlled trials or systematic reviews of Level I randomized trials; Level II studies correspond to lesser-quality randomized controlled trials, prospective comparative studies, or systematic reviews of Level II studies; Level III studies correspond to case-control studies, retrospective comparative studies, or systematic reviews of Level III studies; Level IV studies correspond to case series; and Level V studies correspond to case reports or expert opinions.

To control for year of publication, a citations per year (CY) index was calculated as follows: CY index = total number of article citations/years the article has been published (up to 2015).

Results

Our search algorithm retrieved 157,468 articles, and the top 100 articles on topics related to spinal oncology were identified according to the number of times they were cited by other studies (Table 1). The articles on this top 100 list were cited between 120 (article Nos. 96–100) and 1164 times (top article), and all 100 articles had been collectively cited 20,771 times (with a mean number of citations of 207.7 for each paper). The oldest article on the top 100 list was from 1931, and the most recent from 2008. Ninety-nine articles were written in English, and 1 was written in French. The list comprised 4 Level I evidence studies, 3 Level II evidence studies, 9 Level III evidence studies, 70 Level IV evidence studies, and 2 Level V evidence studies; levels of evidence were not assigned to 12 studies because they were not on therapeutic, prognostic, or diagnostic topics. The top article according to the CY index had been cited 55.2 times per year and was No. 5 on the top 100 list, and the bottom article had been cited 1.61 times per year (No. 72 on the top 100 list). The most prolific decade was the 1990s, with 34 articles on the top 100 list (Table 2).

The top 100 articles were published in 31 different journals, with the *Journal of Neurosurgery* contributing most studies (i.e., 25 articles), followed by *Cancer* and *Spine*, (each having published 12 articles on this list) (Table 3). When we analyzed the articles by study scope

and type, 67 were identified as clinical outcome studies (i.e., case series, retrospective cohort studies, prospective studies, and randomized controlled trials), 9 were review articles (including systematic reviews and meta-analyses), 6 were anatomical or pathological studies, 5 were technical notes, 4 were staging or prognostic studies, 4 were radiology studies, 2 were basic science or animal studies, 2 were case reports, and 1 was an epidemiological study. The most common article topics were spinal metastases (n = 35), followed by intramedullary tumors (n = 18), chordoma (n = 17), intradural tumors (n = 7), vertebroplasty or kyphoplasty (n = 7), primary bone tumors (n = 6), and others (n = 10).

The country with the highest number of articles on the top 100 list was the United States (n = 62), followed by Canada and France, with 8 and 7 articles each, respectively (Table 4). The author with the largest number of articles on the top 100 list was Fred J. Epstein (sometimes cited as Epstein, F.) with 6 articles, followed by K. D. Harrington (United States), Z. L. Gokaslan (United States), K. Tomita (Japan), N. Kawahara (Japan), S. Boriani (Italy), R. Biagini (Italy), and N. Sundaresan (United States), who each had authored or coauthored 3 articles on this list.

Discussion

Spinal oncology has exponentially grown during the last decades, currently involves numerous specialties, and is considered by many a distinct subspecialty.¹¹⁴ In this study, we sought to identify the most-cited 100 articles in spinal oncology, in an effort to gain insight into the history and future directions of spinal tumor research. Not surprisingly, we found that the top 100 most-cited articles were written by authors in a variety of specialties, including neurosurgery, orthopedic surgery, neurology, pathology, radiology, and radiation oncology. In contrast to other research fields in which most high-impact articles are published in only a few journals,⁸⁸ the most-cited articles pertaining to spinal oncology were published in 31 different journals, also reflecting the multidisciplinary nature of spinal tumor research.

The article that had received the most citations on our top 100 list was an anatomical pathology study by Oscar Vivian Batson, in which the author described a valveless venous system (now known as Batson’s plexus) that connects the deep pelvic and thoracic veins to the vertebral venous plexus, a circulation system that most likely is involved in the spread of metastatic disease to the spine.⁸ This article was No. 1 on the list when ranked by the total number of received citations, but it was ranked No. 15 according to the CY index, with 15.52 citations per year since its publication in 1940. The second and third most-cited articles were by French authors, and both studies described vertebroplasty and kyphoplasty, techniques used to treat intractable pain and provide stability to osteoporotic or pathological compression fractures;^{32,51} the description of vertebroplasty for spinal angiomas by Galibert and colleagues was the only article on the list in a language other than English (French in this case). These 2 articles were No. 2 and No. 3 also on the CY index list, and their high ranks on both lists support the assertion

TABLE 1. The top 100 most-cited articles in spinal oncology ranked by number of times cited

Rank	Authors & Year	Article Title	Journal	Specialty	Total No. of Citations	Level of Evidence	CY (rank)
1	Batson, 1940	The function of the vertebral veins and their role in the spread of metastases	<i>Annals of Surgery</i>	Anatomy	1164	NA	15.52 (15)
2	Galibert et al., 1987	Preliminary note on the treatment of vertebral angioma by percutaneous acrylic vertebroplasty	<i>Neurochirurgie</i>	Neuroradiology	1006	IV	35.93 (2)
3	Cotten et al., 1996	Percutaneous vertebroplasty for osteolytic metastases and myeloma: effects of the percentage of lesion filling and the leakage of methylmethacrylate at clinical follow-up	<i>Radiology</i>	Radiology	628	IV	33.05 (3)
4	Gilbert et al., 1978	Epidural spinal-cord compression from metastatic tumor: diagnosis and treatment	<i>Annals of Neurology</i>	Neurology, radiology, & radiation therapy	558	III	15.08 (19)
5	Patchell et al., 2005	Direct decompressive surgical resection in the treatment of spinal cord compression caused by metastatic cancer: a randomised trial	<i>The Lancet</i>	Neurosurgery	552	I	55.20 (1)
6	Weill et al., 1996	Spinal metastases: indications for and results of percutaneous injection of acrylic surgical cement	<i>Radiology</i>	Neuroradiology	487	IV	25.63 (7)
7	Tomita et al., 2001	Surgical strategy for spinal metastases	<i>Spine</i>	Orthopedic surgery	383	IV	27.36 (6)
8	Fourney et al., 2003	Percutaneous vertebroplasty and kyphoplasty for painful vertebral body fractures in cancer patients	<i>Journal of Neurosurgery</i>	Neurosurgery	344	IV	28.67 (5)
9	McCormick et al., 1990	Intramedullary ependymoma of the spinal cord	<i>Journal of Neurosurgery</i>	Neurosurgery	334	IV	13.36 (22)
10	Young et al., 1980	Treatment of spinal epidural metastases. Randomized prospective comparison of laminectomy and radiotherapy	<i>Journal of Neurosurgery</i>	Neurosurgery & radiotherapy	288	I	8.23 (43)
11	Tomita et al., 1997	Total en bloc spondylectomy. A new surgical technique for primary malignant vertebral tumors	<i>Spine</i>	Orthopedic surgery	287	IV	15.94 (13)
12	Higinbotham et al., 1967	Chordoma. Thirty-five-year study at Memorial Hospital	<i>Cancer</i>	Radiology	282	IV	5.88 (62)
13	Dahlin & MacCarty, 1952	Chordoma	<i>Cancer</i>	Neurosurgery & pathology	282	IV	4.48 (84)
14	Barron et al., 1959	Experiences with metastatic neoplasms involving the spinal cord	<i>Neurology</i>	Pathology	279	IV	4.98 (77)
15	Greenberg et al., 1980	Epidural spinal cord compression from metastatic tumor: results with a new treatment protocol	<i>Annals of Neurology</i>	Neurology & radiation therapy	261	IV	7.46 (50)
16	Tokuhashi et al., 1990	Scoring system for the preoperative evaluation of metastatic spine tumor prognosis	<i>Spine</i>	Orthopedic surgery	260	IV	10.40 (33)
17	Sen & Sekhar, 1990	An extreme lateral approach to intradural lesions of the cervical spine and foramen magnum	<i>Neurosurgery</i>	Neurosurgery	255	IV	10.20 (34)
18	Rich et al., 1985	Clinical and pathologic review of 48 cases of chordoma	<i>Cancer</i>	Radiation therapy, pathology, & orthopedic surgery	251	IV	8.37 (42)

(continued)

TABLE 1. The top 100 most-cited articles in spinal oncology ranked by number of times cited (*continued*)

Rank	Authors & Year	Article Title	Journal	Specialty	Total No. of Citations	Level of Evidence	CY (rank)
19	Gerszten et al., 2007	Radical surgery for spinal metastases: clinical experience in 500 cases from a single institution	<i>Spine</i>	Neurosurgery & radiation oncology	246	IV	30.75 (4)
20	McMaster et al., 2001	Chordoma: incidence and survival patterns in the United States, 1973–1995	<i>Cancer Causes & Control</i>	Genetic epidemiology	245	NA	17.50 (11)
21	Tokuhashi et al., 2005	A revised scoring system for preoperative evaluation of metastatic spine tumor prognosis	<i>Spine</i>	Orthopedic surgery	240	III	24.00 (8)
22	Constans et al., 1983	Spinal metastases with neurological manifestations. Review of 600 cases	<i>Journal of Neurosurgery</i>	Neurosurgery	240	IV	7.50 (48)
23	Bergh et al., 2000	Prognostic factors in chordoma of the sacrum and mobile spine: a study of 39 patients	<i>Cancer</i>	Orthopedic surgery & pathology	229	IV	15.27 (17)
24	Maranzano & Latini, 1995	Effectiveness of radiation therapy without surgery in metastatic spinal cord compression: final results from a prospective trial	<i>International Journal of Radiation Oncology, Biology, Physics</i>	Radiation oncology	229	II	11.45 (28)
25	Boriani et al., 1997	Primary bone tumors of the spine. Terminology and surgical staging	<i>Spine</i>	Orthopedic surgery	220	NA	12.22 (25)
26	Chambers & Schwinn, 1979	Chordoma. A clinicopathologic study of metastasis	<i>American Journal of Clinical Pathology</i>	Pathology	201	IV	5.58 (67)
27	Dudeney et al., 2002	Kyphoplasty in the treatment of osteolytic vertebral compression fractures as a result of multiple myeloma	<i>Journal of Clinical Oncology</i>	Orthopedic surgery	197	IV	15.15 (18)
28	Ryu et al., 2001	Image-guided hypo-fractionated stereotactic radiosurgery to spinal lesions	<i>Neurosurgery</i>	Neurosurgery & radiation oncology	197	IV	14.0 (20)
29	Black, 1979	Spinal metastasis: current status and recommended guidelines for management	<i>Neurosurgery</i>	Neurosurgery	197	NA	5.47 (69)
30	Ryu et al., 2003	Image-guided and intensity-modulated radiosurgery for patients with spinal metastases	<i>Cancer</i>	Radiation oncology & neurosurgery	192	IV	16.00 (12)
31	Robertson et al., 1998	Survival and prognostic factors following radiation therapy and chemotherapy for ependymomas in children: a report of the Children's Cancer Group	<i>Journal of Neurosurgery</i>	Multidisciplinary	191	IV	11.24 (30)
32	Wong et al., 1990	Spinal metastases: the obvious, the occult, and the impostors	<i>Spine</i>	Orthopedic surgery & pathology	191	NA	7.64 (45)
33	Sonneland et al., 1985	Myxopapillary ependymoma. A clinicopathologic and immunocytochemical study of 77 cases	<i>Cancer</i>	Neurosurgery & pathology	189	IV	6.30 (59)
34	Cooper & Epstein, 1985	Radical resection of intramedullary spinal cord tumors in adults. Recent experience in 29 patients	<i>Journal of Neurosurgery</i>	Neurosurgery	187	IV	6.23 (60)
35	York et al., 1999	Sacral chordoma: 40-year experience at a major cancer center	<i>Neurosurgery</i>	Neurosurgery, pathology, surgical oncology, & radiation oncology	181	IV	11.31 (29)

(*continued*)

TABLE 1. The top 100 most-cited articles in spinal oncology ranked by number of times cited (continued)

Rank	Authors & Year	Article Title	Journal	Specialty	Total No. of Citations	Level of Evidence	CY (rank)
36	Catton et al., 1996	Chordoma: long-term follow-up after radical photon irradiation	<i>Radiotherapy and Oncology</i>	Radiation oncology, surgical oncology, & oncological pathology	180	IV	9.47 (38)
37	Gokasian et al., 1998	Trans thoracic vertebrectomy for metastatic spinal tumors	<i>Journal of Neurosurgery</i>	Neurosurgery, thoracic surgery, & cardiovascular surgery	179	IV	10.53 (32)
38	Tomita et al., 1994	Total en bloc spondylectomy for solitary spinal metastases	<i>International Orthopaedics</i>	Orthopedic surgery	179	IV	8.52 (39)
39	Yuh et al., 1989	Vertebral compression fractures: distinction between benign and malignant causes with MR imaging	<i>Radiology</i>	Radiology	177	IV	6.81 (53)
40	Harrington, 1981	The use of methylmethacrylate for vertebral-body replacement and anterior stabilization of pathological fracture-dislocations of the spine due to metastatic malignant disease	<i>Journal of Bone & Joint Surgery, American Volume</i>	Orthopedic surgery	175	IV	5.15 (74)
41	Byrne, 1992	Spinal cord compression from epidural metastases	<i>The New England Journal of Medicine</i>	Neurology	174	NA	7.57 (47)
42	Loblaw & Laperriere, 1998	Emergency treatment of malignant extradural spinal cord compression: an evidence-based guideline	<i>Journal of Clinical Oncology</i>	Radiation oncology	171	I	10.06 (35)
43	Harrington, 1986	Metastatic disease of the spine	<i>Journal of Bone & Joint Surgery, American Volume</i>	Orthopedic surgery	169	NA	5.83 (65)
44	Suit et al., 1982	Definitive radiation therapy for chordoma and chondrosarcoma of base of skull and cervical spine	<i>Journal of Neurosurgery</i>	Radiation medicine	169	IV	5.12 (75)
45	Bataille & Sany, 1981	Solitary myeloma: clinical and prognostic features of a review of 114 cases	<i>Cancer</i>	Rheumatology	169	III	4.97 (78)
46	Barone & Elvidge, 1970	Ependymomas. A clinical survey	<i>Journal of Neurosurgery</i>	Neurology & neurosurgery	169	IV	3.76 (91)
47	Epstein et al., 1993	Adult intramedullary spinal cord ependymomas: the result of surgery in 38 patients	<i>Journal of Neurosurgery</i>	Neurosurgery	167	IV	7.59 (46)
48	Algra et al., 1991	Detection of vertebral metastases: comparison between MR imaging and bone scintigraphy	<i>Radiographics</i>	Radiology, health sciences, & clinical oncology	166	III	6.92 (52)
49	Spetzler et al., 2002	Modified classification of spinal cord vascular lesions	<i>Journal of Neurosurgery</i>	Neurosurgery	164	NA	12.62 (24)
50	Sundaresan et al., 1985	Treatment of neoplastic epidural cord compression by vertebral body resection and stabilization	<i>Journal of Neurosurgery</i>	Neurosurgery	164	IV	5.47 (70)
51	Baker et al., 1990	Benign versus pathologic compression fractures of vertebral bodies: assessment with conventional spin-echo, chemical-shift, and STIR MR imaging	<i>Radiology</i>	Radiology & orthopedic surgery	162	III	6.48 (58)
52	Guidetti et al., 1981	Long-term results of the surgical treatment of 129 intramedullary spinal gliomas	<i>Journal of Neurosurgery</i>	Neurosurgery	160	IV	4.71 (81)

(continued)

TABLE 1. The top 100 most-cited articles in spinal oncology ranked by number of times cited (continued)

Rank	Authors & Year	Article Title	Journal	Specialty	Total No. of Citations	Level of Evidence	CY (rank)
53	Cummings et al., 1983	Chordoma: the results of megavoltage radiation therapy	<i>International Journal of Radiation Oncology, Biology, Physics</i>	Radiation oncology	159	IV	4.97 (79)
54	Ehni & Love, 1945	Intraspinal lipomas: report of cases, review of the literature, and clinical and pathologic study	<i>Archives of Neurology & Psychiatry</i>	Neurosurgery	158	IV	2.26 (98)
55	Chang et al., 2007	Phase I/II study of stereotactic body radiotherapy for spinal metastasis and its pattern of failure	<i>Journal of Neurosurgery: Spine</i>	Radiation oncology, neurosurgery, radiation physics, biostatistics, & symptom research	154	II	19.25 (10)
56	Cooper, 1989	Outcome after operative treatment of intramedullary spinal cord tumors in adults: intermediate and long-term results in 51 patients	<i>Neurosurgery</i>	Neurosurgery	152	IV	5.85 (64)
57	Sundaresan et al., 1979	Spinal chordomas	<i>Journal of Neurosurgery</i>	Neurosurgery, radiation therapy, & pathology	152	IV	4.22 (87)
58	Dupuy et al., 2000	Radiofrequency ablation of spinal tumors: temperature distribution in the spinal canal	<i>American Journal of Roentgenology</i>	Radiology	150	NA	10.00 (36)
59	Bach et al., 1990	Metastatic spinal cord compression. Occurrence, symptoms, clinical presentation and prognosis in 398 patients with spinal cord compression	<i>Acta Neurochirurgica</i>	Oncology, neurology, & neurosurgery	149	IV	5.96 (61)
60	Yamada et al., 2008	High-dose, single-fraction image-guided intensity-modulated radiotherapy for metastatic spinal lesions	<i>International Journal of Radiation Oncology, Biology, Physics</i>	Radiation oncology, neurosurgery, medical physics, & biostatistics	148	IV	21.14 (9)
61	Constantini et al., 2000	Radical excision of intramedullary spinal cord tumors: surgical morbidity and long-term follow-up evaluation in 164 children and young adults	<i>Journal of Neurosurgery</i>	Neurosurgery, neurology, & pathology	146	IV	9.73 (37)
62	Fox & Onofrio, 1993	The natural history and management of symptomatic and asymptomatic vertebral hemangiomas	<i>Journal of Neurosurgery</i>	Neurosurgery	144	IV	6.55 (57)
63	Cohen et al., 1989	Malignant astrocytomas of the spinal cord	<i>Journal of Neurosurgery</i>	Neurosurgery & neurooncology	142	IV	5.46 (71)
64	Boriani et al., 2006	Chordoma of the mobile spine: fifty years of experience	<i>Spine</i>	Orthopedic surgery	141	IV	15.67 (14)
65	Hamilton et al., 1995	Preliminary clinical experience with linear accelerator-based spinal stereotactic radiosurgery	<i>Neurosurgery</i>	Neurosurgery & radiation oncology	141	IV	7.05 (51)
66	Findlay, 1984	Adverse effects of the management of malignant spinal cord compression	<i>Journal of Neurology, Neurosurgery & Psychiatry</i>	Neurosurgery	141	III	4.55 (83)
67	Vujovic et al., 2006	Brachyury, a crucial regulator of notochordal development, is a novel biomarker for chordomas	<i>Journal of Pathology</i>	Biomedical research, oral pathology, neural development, & orthopedic surgery	139	NA	15.44 (16)
68	Levy et al., 1982	Spinal cord meningioma	<i>Journal of Neurosurgery</i>	Neurosurgery	136	IV	4.12 (88)

(continued)

TABLE 1. The top 100 most-cited articles in spinal oncology ranked by number of times cited (continued)

Rank	Authors & Year	Article Title	Journal	Specialty	Total No. of Citations	Level of Evidence	CY (rank)
69	Rades et al., 2005	Evaluation of five radiation schedules and prognostic factors for metastatic spinal cord compression	<i>Journal of Clinical Oncology</i>	Radiation oncology	135	III	13.50 (21)
70	Bauer & Wedin, 1995	Survival after surgery for spinal and extremity metastases. Prognostication in 241 patients	<i>Acta Orthopædica Scandinavica</i>	Orthopedic surgery	135	III	6.75 (54)
71	Edelson et al., 1972	Intramedullary spinal cord metastases. Clinical and radiographic findings in nine cases	<i>Neurology</i>	Neurology	135	IV	3.14 (96)
72	Kernohan et al., 1931	Intramedullary tumors of the spinal cord: A review of fifty-one cases with an attempt at histologic classification	<i>Archives of Neurology & Psychiatry</i>	Pathology	135	IV	1.61 (100)
73	Wise et al., 1999	Complication, survival rates, and risk factors of surgery for metastatic disease of the spine	<i>Spine</i>	Orthopedic surgery	134	IV	8.38 (41)
74	Harrington, 1984	Anterior cord compression and spinal stabilization for patients with metastatic lesions of the spine	<i>Journal of Neurosurgery</i>	Orthopedic surgery	134	IV	4.32 (85)
75	Weiss, 1955	A metastasizing ependymoma of the cauda equina	<i>Cancer</i>	NA	134	V	6.70 (56)
76	Solero et al., 1989	Spinal meningiomas: review of 174 operated cases	<i>Neurosurgery</i>	Neurosurgery	132	IV	5.08 (76)
77	Epstein et al., 1992	Adult intramedullary astrocytomas of the spinal cord	<i>Journal of Neurosurgery</i>	Neurosurgery	131	IV	5.70 (66)
78	Volpe & Mazabraud, 1983	A clinicopathologic review of 25 cases of chordoma (a pleomorphic and metastasizing neoplasm)	<i>American Journal of Surgical Pathology</i>	Pathology	131	IV	4.09 (89)
79	Boriani et al., 1996	En bloc resections of bone tumors of the thoracolumbar spine. A preliminary report on 29 patients	<i>Spine</i>	Orthopedic surgery	128	IV	6.74 (55)
80	Sundaresan et al., 1991	Treatment of neoplastic spinal cord compression: results of a prospective study	<i>Neurosurgery</i>	Neurosurgery	128	II	5.33 (73)
81	Fuchs et al., 2005	Operative management of sacral chordoma	<i>Journal of Bone & Joint Surgery, American Volume</i>	Orthopedic surgery & surgical pathology	127	IV	12.70 (23)
82	Murphy & Deramond, 2000	Percutaneous vertebroplasty in benign and malignant disease	<i>Neuroimaging Clinics of North America</i>	Radiology	127	NA	8.47 (40)
83	Bruce & Schut, 1979	Spinal lipomas in infancy and childhood	<i>Childs Brain</i>	Neurosurgery	126	IV	3.50 (93)
84	Eimoto et al., 1978	Plasma cell granuloma (inflammatory pseudotumor) of the spinal cord meninges: report of a case	<i>Cancer</i>	Neurosurgery	126	V	3.41 (94)
85	Livingston & Perrin, 1978	The neurosurgical management of spinal metastases causing cord and cauda equina compression	<i>Journal of Neurosurgery</i>	Neurosurgery	125	IV	3.38 (95)
86	Sørensen et al., 1990	Metastatic epidural spinal cord compression. Results of treatment and survival	<i>Cancer</i>	Oncology, neurology, & neurosurgery	124	IV	4.96 (80)
87	Cosgrove et al., 1988	Cavernous angiomas of the spinal cord	<i>Journal of Neurosurgery</i>	Neurosurgery	124	IV	4.59 (82)
88	Laredo et al., 1986	Vertebral hemangiomas: radiologic evaluation	<i>Radiology</i>	Radiology	124	IV	4.28 (86)
89	Stark et al., 1982	Spinal metastases. A retrospective survey from a general hospital	<i>Brain</i>	Neurology & clinical epidemiology	124	IV	3.76 (90)

(continued)

TABLE 1. The top 100 most-cited articles in spinal oncology ranked by number of times cited (*continued*)

Rank	Authors & Year	Article Title	Journal	Specialty	Total No. of Citations	Level of Evidence	CY (rank)
90	Weigel et al., 1999	Surgical management of symptomatic spinal metastases. Postoperative outcome and quality of life	Spine	Orthopedic surgery	123	IV	7.69 (44)
91	Cristante & Herrmann, 1994	Surgical management of intramedullary spinal cord tumors: functional outcome and sources of morbidity	Neurosurgery	Neurosurgery	123	IV	5.86 (63)
92	Gerszten et al., 2004	CyberKnife frameless stereotactic radiosurgery for spinal lesions: clinical experience in 125 cases	Neurosurgery	Neurosurgery & radiation oncology	122	IV	11.09 (31)
93	Mullan et al., 1966	The use of an anterior approach to ventrally placed tumors in the foramen magnum and vertebral column	Journal of Neurosurgery	Neurosurgery & otolaryngology	122	IV	2.49 (97)
94	Coman & deLong, 1951	The role of the vertebral venous system in the metastasis of cancer to the spinal column; experiments with tumor-cell suspensions in rats and rabbits	Cancer	Pathology	122	NA	1.91 (99)
95	Herman et al., 1993	Analysis of 153 patients with myelomeningocele or spinal lipoma reoperated upon for a tethered cord. Presentation, management and outcome	Pediatric Neurosurgery	Neurosurgery	121	IV	5.50 (68)
96	Loblaw et al., 2005	Systematic review of the diagnosis and management of malignant extradural spinal cord compression: Cancer Care Ontario Practice Guidelines Initiative's Neuro-Oncology Disease Site Group	Journal of Clinical Oncology	Radiation oncology & medicine	120	I	12.00 (26)
97	Klimo et al., 2005	A meta-analysis of surgery versus conventional radiotherapy for the treatment of metastatic spinal epidural disease	Neuro-Oncology	Neurosurgery, family & preventive medicine, & spinal oncology	120	III	12.00 (27)
98	Cheng et al., 1999	Lumbosacral chordoma. Prognostic factors and treatment	Spine	Orthopedic surgery	120	IV	7.50 (49)
99	Bjornsson et al., 1993	Chordoma of the mobile spine. A clinicopathologic analysis of 40 patients	Cancer	Surgical pathology & neurosurgery	120	IV	5.45 (72)
100	Epstein & Epstein, 1982	Surgical treatment of spinal cord astrocytomas of childhood. A series of 19 patients	Journal of Neurosurgery	Neurosurgery	120	IV	3.64 (92)

NA = not assigned.

TABLE 2. Decades of publication

Decade	No. of Articles (n = 100)
1930s	1
1940s	2
1950s	3
1960s	2
1970s	9
1980s	26
1990s	34
2000s	23

that both of these studies made a significant impact on the management of pathological compression fractures. Notably, vertebroplasty and kyphoplasty were also the focus of articles that were ranked No. 6 and 8 according to the CY index; in both studies, the authors examined the role of these techniques in the treatment of pathological fractures due to metastatic disease.

Two randomized controlled trials were among the top 10 articles on the top 100 list. A trial by Young et al. published in 1980 investigated the outcomes among patients with metastatic epidural spinal cord compression treated with laminectomy plus radiotherapy versus patients treated with radiotherapy alone; the authors reported that the 2 treatment modalities do not significantly differ in providing pain relief or in improving ambulation or sphincter function.¹²³ This trial led to the general belief that outcomes after radiotherapy alone can be equivalent to those after laminectomy without instrumentation. Several years later, Patchell and colleagues reported outcomes of “direct decompressive surgery,” in which the pathological compression (most often located anteriorly to the spinal canal) was addressed anteriorly rather than posteriorly via a laminectomy.⁸⁷ The findings of this trial indicated a sig-

TABLE 3. Journals of publication

Journal	No. of Articles (n = 100)
<i>Journal of Neurosurgery</i> *	25
<i>Cancer</i>	12
<i>Spine</i>	12
<i>Neurosurgery</i>	10
<i>Radiology</i>	5
<i>Journal of Clinical Oncology</i>	4
<i>International Journal of Radiation Oncology, Biology, Physics</i>	3
<i>Journal of Bone and Joint Surgery, American Volume</i>	3
<i>Annals of Neurology</i>	2
<i>Archives of Neurology and Psychiatry</i>	2
<i>Neurology</i>	2
Others†	20

* Also includes *Journal of Neurosurgery: Spine*, a separate journal that started publication in 1999 (1 article on the top 100 list was from *JNS: Spine*).

† These include journals that each contributed 1 article to the top 100 article list.

TABLE 4. Countries of article origin

Country of Origin	No. of Articles (n = 100)
United States	62
Canada	8
France	7
Italy	6
Japan	6
Germany	3
United Kingdom	3
Denmark	2
Sweden	2
Netherlands	1

nificant treatment difference: patients who underwent direct decompression plus radiotherapy were more likely to walk after treatment and retain the ability to walk longer distances than patients who underwent only radiation.⁸⁷ The study by Patchell et al. had received 552 citations, and was one of the few articles on our top 10 list published in a high-impact factor medical journal (*The Lancet*). More importantly, however, this article was ranked No. 1 according to the CY index, with 55.2 citations per year since its publication in 2005; this highlights the impact this study had on the management of metastatic epidural spinal cord compression.

Another noteworthy article on our top 10 list was the study by Tomita et al. (from Japan), which was ranked No. 7 on the regular list and No. 6 on the CY index list (with 27.36 citations per year since 2001), and in which the authors described a surgical strategy to approach spinal metastases.¹¹² This strategy was based on those reported in several other studies on the top 100 list, mainly the initial report of en bloc spondylectomy for spinal tumors also by Tomita et al. (articles No. 11 and 38) and of the Tokuhashi scoring system (article No. 16). When examining studies by research topic, we found that more than one-third of the articles had a focus on spinal metastases, a disease condition that is the most common type of spinal tumor and observed in 36% of patients who die of cancer.¹²⁰

The second most common topic among the 100 most-cited articles was intramedullary tumors. Although these tumors account for only 2%–4% of all CNS tumors,⁹⁵ 18 articles on the topic of intramedullary tumors were on the top 100 list; these articles focused on outcomes after surgery for ependymoma, cavernous angioma, gliomas, and other tumors. Research focused on chordoma was the third most common area on the top 100 list, with 17 articles (articles No. 12, 13, 18, 20, 23, 26, 35, 36, 44, 53, 57, 64, 67, 78, 81, 98, and 99) investigating the genes involved in chordoma, outcomes after surgery or radiation for chordoma, epidemiology of this disease, and other chordoma-related topics. Chordoma has an estimated incidence of 0.08 per 100,000 cases, and is considered the most common primary malignant bone tumor of the sacrum and mobile spine.⁷⁹ Although relatively rare, significant efforts have been directed toward identifying a cure for this disease. Current research has focused on stereotactic body radiotherapy, proton-beam therapy, and novel agents such as nilotinib,

dasatinib, and imatinib (all tyrosine kinase inhibitors) to treat chordoma patients.^{17,18}

The most prolific decade was the 1990s with 34 articles. Eighty-three of the 100 articles were published after 1980; this observation is similar to findings by Steinberger et al. who examined the top 100 articles published on lumbar spine surgery.¹⁰³ The oldest article on our top 100 list was from 1931 by the Irish-American pathologist James Watson Kernohan and colleagues (article No. 72), in which the authors described pathological findings of intramedullary tumors.⁶⁸ The most recent was from 2008 by radiation oncologist Yamada and colleagues (article No. 60), in which the authors examined the effect of high-dose, single-fraction, image-guided, intensity-modulated radiotherapy for local tumor control in patients with metastatic spinal lesions.¹²¹ This article was No. 60 on the top 100 list and No. 9 according to the CY index (21.14 CY since 2008).

Although authors from the United States contributed most of the studies to the top 100 list (i.e., 62), it is of note that authors from 9 other countries also contributed. When we examined the articles for individual authors, we found that Fred J. Epstein was an author on 6 articles on the list, all focused on intramedullary tumors (articles No. 34, 47, 61, 63, 77, and 100); 7 other authors appeared 3 times each on this list.

According to the level-of-evidence grading, 70% of the articles were Level IV evidence studies, and only 4% were high-quality Level I evidence studies. Even though this observation implied scarce high-quality evidence for management of spinal tumors, the challenges of conducting randomized controlled surgical trials must be acknowledged. Such studies require multicenter collaborations, a lot of personnel, large funding, and patients' consent to receiving either an experimental intervention or no intervention. Additionally, we also observed very few Level III evidence studies (case-control studies or retrospective comparative studies), which may be the next step in spinal oncology research. Level III studies are less challenging to conduct than randomized trials, but they allow for multivariable analyses or direct comparison of interventions. We also note that the lower representation of higher-level-evidence studies on the top 100 list does not necessarily mean that these studies have not been frequently conducted—it may simply imply that these types of studies may have not been cited as many times as studies with lower levels of evidence.

To identify temporal trends in spinal tumor treatments, studies reporting on particular techniques were stratified by time published (Table 5). Resection (either subtotal or gross total) was the main topic in articles published in the 1930s and 1940s, and the combination of surgery plus radiation therapy began to be reported in 1950. This treatment modality then became the mainstay of treatment for spinal tumors up to the 1990s when en bloc resection was shown to achieve superior outcomes compared with intralesional or subtotal resection. Likewise, the introduction of vertebroplasty and kyphoplasty did not happen until the 1980s. Last, frequently cited studies reporting on radiosurgery and photon therapy for spinal tumors were published in the 1990s and 2000s.

As mentioned above, spinal oncology is a dynamic field, and the articles identified in this study reflected that dynamism. Ranging from anatomical pathology studies to randomized controlled trials to systematic reviews, the top 100 most-cited articles focused on topics such as metastatic spinal tumors, primary vertebral column tumors, radiation oncology, surgical techniques, intramedullary tumors, staging and scoring systems, and many other areas. The fact that many distinct specialties and journals were represented among the studies on this list is very interesting and supports the notion that spinal tumors are best treated in a multidisciplinary and multimodal fashion.¹¹⁴

Advances in genetics-based treatments,³⁷ radiosurgery,¹⁷ proton-beam therapy,^{2,86} immunotherapy,¹⁸ and minimally invasive surgery,^{36,38,70,81} among others, will be an important part of the future of spinal oncology. Treatments involving wild-type neurofibromatosis 2 gene insertion, oncolytic viruses, and transfer of gene-silencing ribonucleic acid have all shown promising results in vitro for meningiomas.³⁷ Stereotactic body radiotherapy (radiosurgery) has been used as a first-line treatment for metastatic lesions, after failure of conventional radiotherapy, after separation surgery, and as first-line treatment for primary tumors and has shown promising results in each approach.¹⁷ Recently, proton-beam therapy has gained attention because it can deliver high doses of energy to a small tissue volume; clinical studies have shown high local tumor control and overall patient survival rates, particularly for chordoma.^{80,86}

The aforementioned tyrosine kinase inhibitors are currently being investigated for the treatment of chordoma,¹⁸ other immunotherapeutic agents have also been investigated for metastatic melanoma to the spine.²⁰ Last, minimally

TABLE 5. Spinal tumor treatment strategies stratified by decade of publication*

Topic	Decade of Publication							
	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s
VP/KP	0	0	0	0	0	2	2	3
Surgery	1	1	1	0	3	5	6	1
Surgery + RT	0	0	1	2	4	12	12	4
En bloc resection	0	0	0	0	0	0	3	2
RT	0	0	0	0	0	3	2	0
Radiosurgery	0	0	0	0	0	0	1	6
Photon therapy	0	0	0	0	0	0	1	0

RT = radiotherapy; VP/KP = vertebroplasty/kyphoplasty.

* The data represent number of articles.

invasive surgery has been shown to provide outcomes in terms of neurological recovery similar to outcomes of traditional open surgery for vertebral thoracic metastases causing acute myelopathy;⁸¹ other studies have also examined the role of minimally invasive surgery on intradural tumors.⁵² Although each of these techniques has shown favorable results, patients will most likely have best outcomes when treated by a multidisciplinary team that uses a combination of multimodal strategies.

Limitations

This study has several limitations. First, some studies have suggested that citation analyses may favor older studies, since these studies had more time to accumulate citations.^{56,96} For example, it could be argued that clinical studies such as that by Patchell et al.⁸⁷ on direct decompressive surgery plus radiotherapy have much more clinical “impact” than the anatomical study by Batson,⁸ and yet the latter had more than double the number of citations. For this reason, in an attempt to control for this potential bias, we utilized the CY index. When we ranked the studies according to the CY index, the study by Patchell et al. jumped to No. 1, and the top 10 articles on the CY list included those on topics such as vertebroplasty/kyphoplasty, radiotherapy, and radiosurgery. Second, although Web of Science has been used for citation analysis, we note that this index does not always include citations from textbooks or journals written in languages other than English.⁸⁸ Third, although we ranked articles by number of citations, we excluded some studies in a subjective manner, and it may be possible that other relevant articles were missed. Last, the number of times an article has been cited does not directly reflect its quality. As shown in this study, most articles were Level IV evidence studies, and only 4 were Level I evidence studies.

Conclusions

In this study, the 100 most-cited articles in spinal oncology were examined, and important contributions from various authors, specialties, and countries were identified. More than one-third of the research in these articles was focused on spinal metastases, followed by intramedullary tumors and chordoma. The top 100 articles were published in 31 different journals, reflecting the multidisciplinary nature of spinal tumor care. Recognition of important historical contributions to this field may guide future investigations into spinal oncology.

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Disclosures

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Author Contributions

Conception and design: Caro-Osorio, De la Garza-Ramos. Acquisition of data: De la Garza-Ramos, Benvenuti-Regato. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: Caro-Osorio. Approved the final version of the manuscript on behalf of all authors: Caro-Osorio. Statistical analysis: De la Garza-Ramos. Study supervision: Caro-Osorio.

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