The 100 most cited articles in metastatic spine disease

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OBJECTIVE Despite the growing neurosurgical literature, a subset of pioneering studies have significantly impacted the field of metastatic spine disease. The purpose of this study was to identify and analyze the 100 most frequently cited articles in the field.

METHODS A keyword search using the Thomson Reuters Web of Science was conducted to identify articles relevant to the field of metastatic spine disease. The results were filtered based on title and abstract analysis to identify the 100 most cited articles. Statistical analysis was used to characterize journal frequency, past and current citations, citation distribution over time, and author frequency.

RESULTS The total number of citations for the final 100 articles ranged from 74 to 1169. Articles selected for the final list were published between 1940 and 2009. The years in which the greatest numbers of top-100 studies were published were 1990 and 2005, and the greatest number of citations occurred in 2012. The majority of articles were published in the journals *Spine* (15), *Cancer* (11), and the *Journal of Neurosurgery* (9). Forty-four individuals were listed as authors on 2 articles, 9 were listed as authors on 3 articles, and 2 were listed as authors on 4 articles in the top 100 list. The most cited article was the work by Batson (1169 citations) that was published in 1940 and described the role of the vertebral veins in the spread of metastases. The second most cited article was Patchell's 2005 study (594 citations) discussing decompressive resection of spinal cord metastases. The third most cited article was the 1978 study by Gilbert that evaluated treatment of epidural spinal cord compression due to metastatic tumor (560 citations).

CONCLUSIONS The field of metastatic spine disease has witnessed numerous milestones and so it is increasingly important to recognize studies that have influenced the field. In this bibliographic study the authors identified and analyzed the most influential articles in the field of metastatic spine disease.

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KEY WORDS metastatic spine disease; spine tumor; bibliographic; literature analysis

THE clinical management of metastatic diseases of the spine is often debatable due to a lack of consensus regarding appropriate therapies. Throughout the growing body of neurosurgical literature addressing the subject, particular studies have significantly contributed to knowledge of the field. Due to the wealth of research articles relating to metastatic spine disease, critically important work often gets overlooked. Methods that help quantify the impact of scientific articles have been previously described.^{30,80} One such tool, citation analysis, is based on the principle that the greater an article's influence, the more frequently it would be cited. In this report, we use citation analysis to identify the 100 most cited scientific articles that pertain to metastatic disease of the spine.

Methods

All databases and journals included in Thomson Reuters Web of Science were used to identify eligible studies.

The literature query was conducted using the following search command: (spine or spinal or vertebral or column or canal) and (primary or metastatic or metastasis or neoplas* or tumor*).

The search was performed using the "basic search" feature under the "title" category and included all articles published before 2016. The initial search yielded 19,831 results. The search results were then sorted on the basis of decreasing citation count.

Upon review of the title and abstract of the articles from the search output, and elimination of the impertinent articles, we identified the top 150 most cited articles on metastatic spine disease. We extended our search to beyond the top 100 articles in order to allow for replacing articles that might be excluded due to excessive self-citation. Only 2 papers^{66,75} were excluded on the basis of having a large percentage of self-citations (> 40% of the total number of citations being in other works by authors of those papers). The remaining articles were ranked based on citation count,

ABBREVIATIONS MESCC = metastatic epidural spinal cord compression.

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FIG. 1. Graph displaying the number of top 100 articles published each year from 1940 through 2015.

and the top 100 most cited articles were included in the final list.

Results

A total of 19,831 articles matched our search criteria. Based on title and abstract review, the 100 most cited articles relevant to metastatic spine disease were selected. The top 100 articles, including their authors and year of publication, article topic, article summary, article type, level of evidence, number of citations, citations in the past year (2015), and citation rate (average citations per year) are shown in Table 1. The total number of citations for the final 100 articles ranged from 74 to 1169, with an average of 148.4 citations per article. The oldest article was published in 1940 by Batson⁹ and described the role of vertebral veins in metastatic spread to the spine. The most recent article was the 2009 study by Rose et al.,⁷¹ evaluating the risk of fracture after image-guided intensity-modulated radiation therapy. The most productive publication years were 1990 and 2005, with 7 articles having been published in each year (Fig. 1). Articles were published in 40 different journals (Fig. 2). The most studies were published in the journal *Spine* (15), followed by *Cancer* (11), and the *Journal of Neurosurgery* (9). Eighty-three first authors contributed to articles on the final list. Eleven authors were credited with having multiple articles on the list. Two of these 11 individuals, Tomita^{90–93} and Harrington,^{41–44} were listed as authors in 4 articles on the final list.

The most frequently cited article was also the earliest publication in the list, the above-mentioned article by Batson, published in 1940 in the *Annals of Surgery*⁹ and describing the architecture of the vertebral veins and their role in the metastatic spread of tumors. This article has been consistently cited since its publication, receiving the most citations (27) in 1997 (Fig. 3). The second most cited

article was the 2005 article by Patchell et al.,⁶⁵ which assessed the efficacy of decompressive surgery for spinal cord compression due to metastatic cancer. Citations of this article peaked in 2012, with 92 citations in that year alone (Fig. 4). The 1978 study by Gilbert et al.,³⁶ published in *Annals of Neurology*, is the third most cited article. This study discusses diagnostic criteria and treatment options for patients with epidural spinal cord compression due to metastatic tumor. This article was most cited in 1985, with 28 citations during that year (Fig. 5).

We defined citation rate as the number of citations per year. The ranking of citation rates for each article on the final list is shown in Table 2. The 2005 study by Patchell et al. had the highest overall citation rate, with an average of 54.0 citations per year.⁶⁵ This was followed by the 2007 article by Gerszten et al.³³ (28.6 citations per year) on radiosurgery for spinal metastases and the 2001 article by Tomita et al.⁹¹ (22.7 citations per year), which discussed a novel prognostic scoring system for surgical management of spinal metastases.

We also measured the number of citations an article received during the past year (2015). The article cited most frequently was written by Patchell et al. and published in 2005 and was cited 98 times during 2015.⁶⁵ We also performed a linear regression to determine the relationship between an article's total number of citations and the number of times it was cited in the previous year. Our results determined that the total number of citations of an article correlates with the number of times it was cited in the preceding year (Fig. 6).

Discussion

Neurosurgical literature is replete with novel studies that, while helpful in advancing the field, pose burdens for physicians in their pursuit to identify studies that have sig-

TABLE 1. Top 100 articles in metastatic spine disease based on total number of citations

Rank	Authors & Year	Article Topic	Article Summary	Article Type	Level of Evidence	Citations	Citations in Past Year	Citation Rate (Rank)
1	Batson, 1940	Other	Anatomical vascular basis of spread of abdominopelvic malignancies to the spine	Original research	NA	1169	25	15.4 (9th)
2	Patchell et al., 2005	Comparison of mgmt options	In pts w/ spinal cord compression, decompressive surgery plus postop radiotherapy is superior to radiotherapy alone	RCT, multicenter	I	594	98	54.0 (1st)
3	Gilbert et al., 1978	Review	Reviews Dx & Tx of epidural compression due to metastatic spine disease	Retrospective comparative study	III	560	10	14.7 (10th)
4	Weill et al., 1996	Surgery	Pain & instability due to metastatic spine disease can be treated effectively by vertebroplasty	Case series	IV	445	14	22.3 (4th)
5	Tomita et al., 2001	Surgery	Proposes a prognostic scoring system for mgmt of spinal metastases	Case series	IV	341	60	22.7 (3rd)
6	Young et al., 1980	Surgery	Laminectomy followed by radiation is as effective as radiation only for mgmt of epidural spinal metastases	RCT, multicenter	I	289	8	8.0 (34th)
7	Barron et al., 1959	Autopsy	Descriptive analysis of 127 autopsies of pts w/ metastatic spine disease	Case series	IV	279	3	4.9 (62nd)
8	Greenberg et al., 1980	Comparison of mgmt options	Proposes use of high-dose steroids combined w/ radiotherapy for mgmt of cord compression	Case series	IV	260	3	7.2 (42nd)
9	Gerszten et al., 2007	Radiation	Propose single-fraction radiosurgery to improve long-term palliation especially for pts w/ solitary metastasis	Prospective cohort study	II	257	37	28.6 (2nd)
10	Constans et al., 1983	Natural history	Descriptive analysis of authors' experience w/ 600 cases of spinal metastases	Case series	IV	242	7	7.3 (38th)
11	Tokuhashi et al., 2005	Prognosis	Proposes a prognostic scoring system for mgmt of spinal metastases	Semi-prospective cohort study	III	237	66	21.5 (5th)
12	Tokuhashi et al., 1990	Prognosis	Proposes a prognostic scoring system for mgmt of spinal metastases	Case series	IV	232	14	8.9 (28th)
13	Maranzano & Latini, 1995	Comparison of mgmt options	Outcome for pts w/ metastatic spinal cord compression treated w/ RT plus steroids, & in select cases in combination w/ surgery	Prospective cohort study	II	232	30	11.0 (18th)
14	Black, 1979	Review	Guideline for mgmt of spinal metastases	Review	V	198	5	5.4 (58th)
15	Ryu et al., 2003	Radiation	Proposes radiosurgery to be effective for mgmt of spinal metastases especially for solitary lesions	Case series	IV	193	11	16.1 (8th)
16	Wong et al., 1990	General	Pathologic & radiologic review of spine of 832 pts w/ pre-mortem Dx of spinal metastasis	Case series	NA	192	22	7.4 (37th)
17	Gokaslan et al., 1998	Surgery	Outcome of anterior approach for corpectomy & stabilization for metastases limited to thoracic spine	Case series	IV	186	14	10.3 (23rd)
18	Harrington, 1981	Surgery	Outcome of corpectomy & use of methylmethacrylate for VB replacement for mgmt of fracture due to spinal metastases	Case series	IV	181	4	5.2 (60th)
19	Byrne et al., 1992	Review	Review of contemporary knowledge on spinal cord compression due to epidural metastases	Review	V	175	6	7.3 (39th)
20	Harrington et al., 1986	Review	Review of contemporary knowledge on metastatic spine disease	Review	V	173	6	5.8 (53rd)
21	Yamada et al., 2008	Radiation	Proposes radiosurgery to be effective & safe for mgmt of spinal metastases	Case series	IV	171	33	21.4 (6th)

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Rank	Authors & Year	Article Topic	Article Summary	Article Type	Level of Evidence	Citations	Citations in Past Year	Citation Rate (Rank)
22	Chang et al., 2007	Radiation	Proposes stereotactic body radiotherapy to be safe & effective for mgmt of spinal metastases	Phase I/II clinical trial	II	167	22	18.6 (7th)
23	Algra et al., 1991	Radiology	MRI is superior to bone scintigraphy in detection of vertebral metastases	Prospective cohort study	II	165	0	6.6 (46th)
24	Bach et al., 1990	Natural history	Descriptive analysis of authors' experience w/ 398 cases of spinal metastases	Case series	IV	153	4	5.9 (52nd)
25	Bauer & Wedin, 1995	Prognosis	Proposes prognostic model for survival in pts w/ spinal metastases after surgery	Retrospective comparative study	III	152	27	7.2 (40th)
26	Tomita et al., 1994 ⁹⁰	Surgery	Outcomes of total en bloc spondylectomy in pts w/ lumbar & thoracic spinal metastases	Case series	IV	149	13	6.8 (44th)
27	Wise et al., 1999	Surgery	Outcome of surgical intervention in pts w/ spinal metastases	Case series	IV	145	18	8.5 (30th)
28	Rades et al., 2005	Comparison of mgmt options	Comparison of different RT schedules	Retrospective comparative study	III	145	17	13.2 (12th)
29	Edelson et al., 1972	Intramedullary metastases	Descriptive analysis of 9 cases of intramedullary spinal cord metastases	Case series	IV	138	2	3.1 (85th)
30	Harrington, 1984	Surgery	Outcome of corpectomy & use of methylmethacrylate for VB replacement for mgmt of fracture due to spinal metastases	Case series	IV	135	1	4.2 (69th)
31	Weigel et al., 1999	Surgery	Outcome of surgical mgmt of spinal metastases	Case series	IV	133	10	7.8 (35th)
32	Klimo et al., 2005	Comparison of mgmt options	Comparison of outcomes of surgery alone versus radiation alone for mgmt of spinal metastases	Review, meta-analysis	III	127	13	11.5 (16th)
33	Livingston & Perrin, 1978	Surgery	Outcome of surgical mgmt of 100 consecutive pts w/ spinal metastases	Case series	IV	126	2	3.3 (82nd)
34	Wang et al., 2004	Surgery	Outcome of posterolateral transpedicular approach in single stage in pts w/ epidural metastatic spine tumors	Case series	IV	126	15	10.5 (21st)
35	Stark et al., 1982	Natural history	Descriptive analysis of authors' experience in managing 131 pts w/ spinal metastases	Survey	IV	125	10	3.7 (78th)
36	Barragán-Campos et al., 2006	Surgery	Complications of vertebroplasty in 117 pts w/ spinal metastases	Case series	IV	125	1	12.5 (13th)
37	Sørensen et al., 1990	Natural history	Outcome for pts w/ epidural spinal metastases causing cord or cauda equina compression	Case series	IV	124	0	4.8 (64th)
38	Helweg-Larsen et al., 2000	Prognosis	Study of prognostic value of multiple variables on survival & gait in 153 pts w/ spinal metastases causing cord compression	Prospective cohort study	II	121	6	7.6 (36th)
39	Schaberg & Gainer, 1985	Natural history	Frequency & natural history of disseminated carcinoma to the vertebral column	Case series	IV	118	12	3.8 (74th)
40	Maranzano et al., 2005	Comparison of mgmt options	Comparison of 2 radiotherapy regimens in pts w/ metastatic spinal cord compression	RCT, multicenter	II	118	6	10.7 (19th)
41	Erich & Davis, 1978	Glioblastoma metastases	Clinical & pathologic characteristics of 5 pts w/ metastases of glioblastoma to the spine	Case series	IV	114	2	3.0 (88th)

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Rank	Authors & Year	Article Topic	Article Summary	Article Type	Level of Evidence	Citations	Citations in Past Year	Citation Rate (Rank)
42	Avrahami et al., 1989	Radiology	Describes utility of MRI in Dx of spinal metastases	Case series	IV	114	6	4.2 (68th)
43	van der Linden et al., 2005	Prognosis	Proposes a scoring model to predict overall survival in pts w/ spinal metastases	RCT	I	114	19	10.4 (22nd)
44	Klimo & Schmidt, 2004	Review	Review of surgical mgmt of spinal metastases	Review	V	114	8	9.5 (26th)
45	Sundaresan et al., 2002	Surgery	Outcome of surgical intervention in pts w/ solitary metastatic spine disease	Case series	IV	114	21	8.1 (32nd)
46	Ibrahim et al., 2008	Surgery	Quality of life outcome of surgical intervention in pts w/ spinal bony metastases	Prospective cohort study, multicenter	II	113	21	14.1 (11th)
47	Vecht et al., 1989	Comparison of mgmt options	Comparison of effectiveness of different steroid dose scheduling in pain relief in pts w/ spinal metastases	RCT	II	113	3	4.2 (72nd)
48	Akeyson & McCutcheon, 1996	Surgery	Outcome spondylectomy, VB reconstruction, & posterior stabilization in pts w/ multi-level thoracolumbar spinal metastases	Case series	IV	111	11	5.6 (54th)
49	Scoville et al., 1967	Surgery	Outcome of use of acrylic plastic for VB replacement in animal model & 3 pts	Case report	IV	111	1	2.3 (95th)
50	Vertosick & Selker, 1990	Glioblastoma metastases	Case series of 11 pts w/ metastatic spread of glioblastoma to the spine	Case series	IV	109	8	4.2 (71st)
51	Dunn et al., 1980	Surgery	Outcome of surgical mgmt of pts w/ spinal epidural metastases	Case series	IV	107	1	3.0 (90th)
52	Grem et al., 1985	Intramedullary metastases	Review of 5 new & 50 previously reported cases of intramedullary spinal cord metastases	Case series, review	III	107	1	3.5 (81st)
53	Castillo et al., 2000	Radiology	Comparison of diffusion-weighted MRI versus non-contrast MRI in Dx of vertebral metastases	Case control	III	104	5	6.5 (47th)
54	Ryu et al., 2004	Radiation	Descriptive analysis of tumor & pain control after radiosurgery for spinal metastases	Case series	IV	103	8	8.6 (29th)
55	Wright, 1963	Surgery	Outcome of surgery for mgmt of spinal epidural metastases	Case series	IV	102	10	1.9 (98th)
56	Blisky et al., 2000	Surgery	Outcome of posterolateral transpedicular approach w/ circumferential fusion in pts w/ spinal metastases	Case series	IV	102	14	6.4 (49th)
57	Ghogawala et al., 2001	Radiation	In pts undergoing surgical intervention for metastatic spinal cord compression, preop radiation increases risk of wound complications	Case series	IV	102	6	6.8 (43rd)
58	Weissman, 1988	Review	Review of steroid therapy for mgmt of brain metastases & epidural spinal metastases causing cord compression	Review	V	102	3	3.6 (80th)
59	Gerszten et al., 2005	Radiation	Stereotactic radiosurgery is an effective modality for mgmt of pts w/ spinal metastases w/ renal cell carcinoma	Case series	IV	102	8	9.3 (27th)
60	Tomita et al., 1983	Radiation	Outcome of RT in pts w/ spinal epidural metastases w/ complete myelographic block	Case series	IV	102	0	3.1 (87th)
61	Enkaoua et al., 1997	Prognosis	Evaluation of Tokuhashi score as prognostic tool in pts w/ spinal metastases	Case series	IV	100	6	5.3 (59th)

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Rank	Authors & Year	Article Topic	Article Summary	Article Type	Level of Evidence	Citations	Citations in Past Year	Citation Rate (Rank)
62	Arguello et al., 1990	Other	Description of sequential events that result in spread of primary tumor to the spine in an animal model	Original research	V	99	3	3.8 (73rd)
63	Gibbs et al., 2007	Radiosurgery	Outcome of image-guided robotic radiosurgery in 74 pts w/ spinal metastases	Case series	IV	99	4	11.0 (17th)
64	DeWald et al., 1985	Surgery	Proposes prophylactic spinal stabilization for pain relief & neurological status improvement in pts w/ metastatic spine disease	Case series	IV	97	3	3.1 (86th)
65	Schiff & O'Neill, 1996	Intramedullary metastases	Descriptive analysis of authors' experience in mgmt of 40 pts w/ intra-medullary spinal metastases	Case series	IV	97	2	4.9 (63rd)
66	Chang et al., 2004	Radiation	CT-guided stereotactic body radiotherapy is a safe & effective mgmt option for pts w/ spinal metastases	Prospective cohort study	II	97	2	8.1 (33rd)
67	Gellad et al., 1990	Radiology	Preop embolization reduces intraoperative blood loss in pts w/ vascular spinal metastases undergoing surgery	Case series	IV	96	2	3.7 (76th)
68	Rodichok et al., 1981	Other	Proposes a clinical & radiological decision-making process to improve early Dx of epidural spine metastases	Prospective cohort study	II	96	0	2.7 (92nd)
69	Taneichi et al., 1997	Prognosis	Proposes a prognostic model to predict VB collapse in thoracolumbar spinal metastases	Case series	IV	95	13	5.0 (61st)
70	Milker-Zabel et al., 2003	Radiation	Fractionated conformal & intensity-modulated RT are effective & safe in Tx of recurrent vertebral metastases	Case series	IV	94	8	7.2 (41st)
71	Bilsky et al., 1999	Review	Review of Dx & mgmt of metastatic spinal tumor	Review	V	94	3	5.5 (55th)
72	Sioutos et al., 1995	Prognosis	Study of factors that affect survival in pts w/ spinal metastases	Case series	IV	93	12	4.4 (65th)
73	Harrington, 1988	Surgery	Outcome of anterior decompression & stabilization in pts w/ pathologic fractures of the spine due to metastases	Case series	IV	92	0	3.3 (83rd)
74	Zhou et al., 2002	Radiology	Imaging characteristics of benign & metastatic vertebral compression fractures based on diffusion MRI	Case series	IV	91	6	6.5 (48th)
75	Rodriguez & Dinapoli, 1980	Review	Review of clinical presentation & mgmt of spinal cord compression due to epidural metastases	Review	V	89	1	2.5 (94th)
76	Helweg-Larsen, 1996	Natural history	Descriptive analysis of authors' experience in mgmt of 153 pts w/ metastatic spinal cord compression	Prospective cohort study	II	88	1	4.4 (66th)
77	Connolly et al., 1996	Intramedullary metastases	Case series of 3 pts w/ intramedullary spinal metastases	Case report, review	IV	87	3	4.4 (67th)
78	Hirabayashi et al., 2003	Surgery	Outcome of palliative surgery in 81 pts w/ spinal metastases	Case series	IV	87	6	6.7 (45th)
79	Böhm & Huber, 2002	Surgery	Outcome of surgical mgmt of 18 pts w/ metastatic spine disease	Case series	IV	86	9	6.1 (50th)
80	Rose et al., 2009	Radiation	Study of factors that predict vertebral fracture after RT to the spine	Case series	IV	86	21	12.3 (14th)
81	Fornasier & Horne, 1975	Autopsy	Utility of radiography for detection of spinal metastases at autopsy	Case series	IV	85	4	2.1 (96th)
82	Witham et al., 2006	Review	Review of surgical mgmt of MESCC	Review	V	85	15	8.5 (31st)
83	Tatsui et al., 1996	Prognosis	Impact of primary tumor type & timing of Dx of spinal metastasis on survival rate in pts w/ metastatic spine disease	Case series	IV	84	2	4.2 (70th)

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Rank	Authors & Year	Article Topic	Article Summary	Article Type	Level of Evidence	Citations	Citations in Past Year	Citation Rate (Rank)
84	Byun et al., 2002	Radiology	Successful therapy of vertebral bone metastases appears as decreased signal intensity on diffusion-weighted MRI	Case control	III	83	7	5.9 (51st)
85	Helweg-Larsen & Sørensen, 1994	Other	Description of signs & Sx w/ which pts w/ spinal metastases present	Case series	IV	82	4	3.7 (75th)
86	Maranzano et al., 1991	Radiation	Outcome of RT in pts w/ metastatic spinal cord compression	Prospective cohort study	II	82	2	3.3 (84th)
87	Sahgal et al., 2009	Radiation	Stereotactic body RT is effective & safe for Tx of previously irradiated spinal metastases	Case series	IV	82	15	11.7 (15th)
88	Carmody et al., 1989	Radiology	Comparison of MRI & myelography to detect spinal metastases	Case series	IV	81	16	3.0 (89th)
89	Tomita et al., 1994 ⁹²	Surgery	Outcome of 2-step total en bloc spondylectomy & combined anterior-posterior decompression in 24 pts w/ solitary spinal metastasis	Case series	IV	81	0	3.7 (77th)
90	White et al., 1971	Surgery	Outcome of decompressive laminectomy in 226 pts w/ metastatic spinal cord compression	Case series	IV	80	5	1.8 (99th)
91	Cole & Patchell, 2008	Review	Review of Dx & mgmt of metastatic spinal cord compression	Review	V	78	0	9.8 (25th)
92	Gynning et al., 1961	Radiology	Utility of radiostronium in localization of & response to hormonal & RT for spinal metastases from primary breast cancer	Case series	IV	77	12	1.4 (100th)
93	Sundaresan et al., 1995	Surgery	Outcome of surgical mgmt of metastatic spinal cord compression	Case series	IV	77	0	3.7 (79th)
94	Jellinger et al., 1979	Autopsy	Series of 7 autopsy cases of intramedullary spinal metastases	Review	IV	76	3	2.1 (97th)
95	Smoker et al., 1987	Radiology	Comparison of MRI & myelography to detect spinal metastases	Case series	IV	76	1	2.6 (93rd)
96	Herneth et al., 2002	Radiology	Utility of apparent diffusion coefficient in detecting vertebral metastases & pathologic compression fractures	Case series	IV	75	0	5.4 (56th)
97	Rades et al., 2002	Prognosis	Evaluation of prognostic value of time of motor deficit development before RT in predicting functional outcome	Prospective cohort study	II	75	4	5.4 (57th)
98	Bartels et al., 2008	Review	Review of Tx options for spinal epidural metastases	Review	V	74	4	10.1 (24th)
99	Kaemmerlen et al., 1989	Surgery	Evaluation of prognostic value of time of motor deficit development before RT in predicting functional outcome	Review	V	74	1	2.8 (91st)
100	Leithner et al., 2008	Prognosis	Review of Tx options for spinal epidural metastases	Retrospective comparative study	III	74	15	10.6 (20th)

Dx = diagnosis; mgmt = management; NA = not available; pts = patients; RCT = randomized controlled trial; RT = radiation therapy; Sx = symptoms; Tx = treatment; VB = vertebral body.

FIG. 2. Graph displaying the number of top 100 articles published by each journal.

nificantly impacted neurosurgical practice. Our aim was to identify the 100 most cited articles on metastatic spine disease. These frequently cited articles provide insight into the founding and development of the field, as well as current trends. In this study we performed citation analysis, wherein we measure the impact of articles, authors, and journals based on the number of times a work has been cited.

The most cited article in metastatic spine disease was Batson's 1940 article in the *Annals of Surgery*.⁹ In this landmark study, the author provides an anatomical explanation for the dissemination of spinal tumors from abdominopelvic primary tumors. In this paper, Batson described the anatomical distribution of the vertebral venous system in detail and, based on data from vessel injection experiments whereby dissemination was tracked, proposed an

explanation for the metastatic spread of tumors from the abdomen or pelvis to the spine. This study has been consistently cited since publication in 1940, with a total of 1169 citations, and it received the greatest number of citations in 1998. Batson's work is considered a "classic," and some suggest that older papers are more likely to be cited.⁵⁴

The second most cited article was the 2005 paper by Patchell et al., which sought to determine the role of surgery in the treatment of metastatic epidural spinal cord compression (MESCC).⁶⁵ In their prospective randomized trial, the authors demonstrated that decompressive surgery followed by postoperative radiotherapy resulted in improved patient outcomes (i.e., retention of the ability to walk) compared with radiotherapy alone. The results indicate that surgery followed by radiotherapy may well be the

FIG. 3. Graph displaying citations per year of Batson's 1940 article titled "The function of the vertebral veins and their role in the spread of metastases."⁹

FIG. 4. Graph displaying citations per year for the 2005 article by Patchell et al. titled "Direct decompressive surgical resection in the treatment of spinal cord compression caused by metastatic cancer: a randomised trial."⁶⁵

most effective treatment for MESCC. Despite not being the most cited article overall, the study is accumulating citations at a rapid pace. Since its publication in 2005, it has been cited 594 times, with an average of 54 citations per year. This is comparatively faster than the Batson study, which has received an average of 15.4 citations per year. Although recent, the influence of the Patchell et al. study is demonstrated by the rate with which this paper has been cited in the neurosurgical literature.

The third most cited article was written by Gilbert et al. and published in 1978.³⁶ In this report, the authors compared the efficacy of radiotherapy alone versus laminectomy followed by radiotherapy for spinal cord compression due to extradural tumors. They concluded that radiotherapy alone was as effective as laminectomy plus radiotherapy in treating epidural spinal cord compression caused by metastatic cancer. Based on these results, surgical treatment (i.e., laminectomy) for MESCC was

FIG. 5. Graph displaying the citations per year for the 1978 article by Gilbert et al. titled "Epidural spinal cord compression from metastatic tumor: diagnosis and treatment."³⁶

TABLE 2. Top 100 articles on metastatic spine disease ranked on the basis of citation rate (citations per year)

Rank	Article	Citation Rate
1	Patchell et al., 2005	54.0
2	Gerszten et al., 2005	28.6
3	Tomita et al., 2001	22.7
4	Weill et al., 1996	22.3
5	Tokuhashi et al., 2005	21.5
6	Yamada et al., 2008	21.4
7	Chang et al., 2007	18.6
8	Ryu et al., 2003	16.1
9	Batson, 1940	15.4
10	Gilbert et al., 1978	14.7
11	Ibrahim et al., 2008	14.1
12	Rades et al., 2005	13.2
13	Barragán-Campos et al., 2006	12.5
14	Rose et al., 2009	12.3
15	Sahgal et al., 2009	11.7
16	Klimo et al., 2005	11.5
18	Gibbs et al., 2007	11.0
17	Maranzano et al., 1991	11.0
19	Maranzano et al., 2005	10.7
20	Leithner et al., 2008	10.6
21	Wang et al., 2004	10.5
22	van der Linden et al., 2005	10.4
23	Gokaslan et al., 1998	10.3
24	Bartels et al., 2008	10.1
25	Cole & Patchell, 2008	9.8
26	Klimo & Schmidt, 2004	9.5
27	Gerszten et al., 2007	9.3
28	Tokuhashi et al., 1990	8.9
29	Ryu et al., 2004	8.6
30	Wise et al., 1999	8.5
31	Witham et al., 2006	8.5
33	Chang et al., 2004	8.1
32	Sundaresan et al., 1995	8.1
34	Young et al., 1980	8.0
35	Weigel et al., 1999	7.8
36	Helweg-Larsen, 1996	7.6
37	Wong et al., 1990	7.4
39	Byrne, 1992	7.3
38	Constans et al., 1983	7.3
41	Bauer & Wedin, 1995	7.2
40	Greenberg et al., 1980	7.2
42	Milker-Zabel et al., 2003	7.2
44	Ghogawala et al., 2001	6.8
43	Tomita et al., 1994 ⁹²	6.8
45	Hirabayashi et al., 2003	6.7
46	Algra et al., 1991	6.6
47	Castillo et al., 2000	6.5
48	Zhou et al., 2002	6.5

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TABLE 2. Top 100 articles on metastatic spine disease ranked on the basis of citation rate (citations per year)

Rank	Article	Citation Rate
49	Bilsky et al., 1999	6.4
50	Böhm & Huber, 2002	6.1
51	Bach et al., 1990	5.9
52	Byun et al., 2002	5.9
53	Harrington, 1984	5.8
54	Akeyson & McCutcheon, 1996	5.6
55	Bilsky et al., 2000	5.5
56	Black, 1979	5.4
57	Herneth et al., 2002	5.4
58	Rades et al., 2002	5.4
59	Enkaoua et al., 1997	5.3
60	Harrington, 1988	5.2
61	Taneichi et al., 1997	5.0
62	Barron et al., 1959	4.9
63	Schiff & O'Neill, 1996	4.9
64	Sørensen et al., 1990	4.8
67	Connolly et al., 1996	4.4
66	Helweg-Larsen et al., 2000	4.4
65	Sioutos et al., 1995	4.4
69	Avrahami et al., 1989	4.2
68	Harrington, 1986	4.2
72	Tatsui et al., 1996	4.2
70	Vecht et al., 1989	4.2
71	Vertosick et al., 1990	4.2
74	Arguello et al., 1990	3.8
73	Schaberg & Gainor, 1985	3.8
76	Gellad et al., 1990	3.7
77	Helweg-Larsen & Sørensen, 1994	3.7
75	Stark et al., 1982	3.7
79	Sundaresan et al., 2002	3.7
78	Tomita et al., 1983	3.7
80	Weissman, 1988	3.6
81	Grem et al., 1985	3.5
83	Harrington, 1981	3.3
82	Livingston et al., 1978	3.3
84	Maranzano et al., 1995	3.3
87	DeWald et al., 1985	3.1
85	Edelson et al., 1972	3.1
86	Tomita et al., 1994 ⁹⁰	3.1
90	Carmody et al., 1989	3.0
89	Dunn et al., 1980	3.0
88	Erlich & Davis, 1978	3.0
91	Kaemmerlen et al., 1989	2.8
92	Rodichok et al., 1981	2.7
93	Smoker et al., 1987	2.6
94	Rodriguez & Dinapoli, 1980	2.5
95	Scoville et al., 1967	2.3

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TABLE 2. Top 100 articles on metastatic spine disease ranked on the basis of citation rate (citations per year)

Rank	Article	Citation Rate
96	Fornasier & Horne, 1975	2.1
97	Jellinger et al., 1979	2.1
98	Wright, 1963	1.9
99	White et al., 1971	1.8
100	Gynning et al., 1961	1.4

deemed unnecessary. However, the work by Patchell and colleagues challenged this notion by demonstrating the efficacy of decompressive surgery for management of MESCC.

Among the most frequently cited articles, publication dates ranged from 1940 (for Batson's article) to as recent as 2009 (for the study by Rose et al., which evaluated the risk of fracture following single fraction image-guided intensity-modulated radiation therapy for spinal metastases⁷¹). Articles relating to the topic of metastatic spine disease have become increasingly frequent, with most articles having been published in 1990 and 2005. The reason underlying these publication trends is not fully understood. An argument could be made that historical developments in the neurosurgical field, such as novel technologies or techniques, could be responsible for certain publication trends. For example, our data show a dramatic rise in the number of top 100 articles published during the 1980s. During this time, the first MRI of the spine was performed, and publication trends may reflect the emergence of this technology.

If an article were indeed influential, as measured by number of citations, we reasoned that it would continue to have an impact on current practice. One would expect that influential articles would continue to be cited as new articles in the field emerge. To address this we analyzed the relationship of the number of citations within the preceding year (2015) as a function of total number of citations of an article. As predicted, we found a positive correlation between these 2 factors, suggesting that impactful studies are more likely to be referenced by recently published articles and continue to influence current work.

The largest number of articles pertaining to metastatic spine disease were published in the journal *Spine*. It is important to note that a journal's contribution to a particular field may be the result of the number of years it has been in circulation and/or the frequency with which it is published. *Spine* is a biweekly peer-reviewed journal and thus its appearance on the top 100 list may reflect the frequency of publication. Furthermore, journals or articles that cover multiple disciplines, will at times attract a larger reader base, which can increase the exposure of an article. Other authors have studied the effect of degree of disciplinary on citation impact and have found this relationship to be complex.¹⁰⁷

Although citation analysis is a powerful tool for measuring an article's impact, citation count alone does not completely reveal an article's influence on the field. Self-citation is arguably the most confounding factor influenc-

FIG. 6. Correlation between an article's total citations and number citations in the past year (2015).

ing citation analysis.^{51,59} For different reasons, authors may cite their own papers, which increases citation numbers and the eventual impact of their article. This can skew citation analysis, as it becomes difficult to distinguish between articles that are frequently referenced due to their impact on the field and those that are frequently self-cited. Within our final list, nearly all articles were cited by 1 or more of their authors in subsequent publications at least once. For most articles, self-citations comprised a small fraction of the total citations. In some cases, a considerable percentage of the total citations were made by the articles' authors. More detailed analysis is warranted to determine the prevalence of self-citation and its influence on an article's impact. Another limitation of citation analysis is the concept of "obliteration by incorporation," which is based on the idea that information from "classic" papers is cited less frequently as it is absorbed into the body of existing knowledge.⁶³ Other limitations that have been described elsewhere include "incomplete citations," whereby certain citations are made as a means to persuade the reader rather than recognize work that has contributed to the field.⁵⁴ It is important that future studies address how these factors influence citation trends and that a novel method—one that accounts for these factors—is developed to improve our system for classifying the impact of an article.

Conclusions

Although citation analysis does not address the quality of a scientific report, it serves as a reliable tool for determining the impact that an article, author, and journal has had on the scientific community. In this study we have attempted to develop a resource with detailed information on the 100 most cited articles on metastatic spine disease. We provide insights into the historical development and recent advances within the field.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Hamilton, Cohen, Alan. Acquisition of data: Cohen, Alan. Analysis and interpretation of data: Hamilton, Cohen. Drafting the article: Cohen, Alan, Zhou. Critically revising the article: Hamilton, Cohen, Alan. Reviewed submitted version of manuscript: Hamilton, Cohen, Alan. Approved the final version of the manuscript on behalf of all authors: Hamilton. Statistical analysis: Cohen. Study supervision: Hamilton.

Supplemental Information

Videos

Video Abstract. <https://vimeo.com/172402982>.

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