The 100 most cited spine articles

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Abstract

Purpose Spine-related research has evolved dramatically during the last century. Significant contributions have been made by thousands of authors. A citation rank list has historically been used within a particular field to measure the importance of an article. The purpose of this article is to report on the 100 most cited articles in the field of spine.

Methods Science Citation Index Expanded was searched for citations in 27 different journals (as of 30 November 2010) chosen based on the relevance for all cited spine publications. The top 100 most cited articles were identified. Important information such as journal, date, country of origin, author, subspecialty, and level of evidence (for clinical research) were compiled.

Results The top 100 publications ranged from 1,695 to 240 citations. Fifty-three articles were of the lumbar, 17 were of the thoracolumbar, and 15 of the cervical spine. Eighty-one of the articles were clinical and 19 were basic science in nature. Level of evidence varied for the clinical papers, however, was most commonly level IV (34 of 81 articles). Notably, the 1990–1999 decade was the most productive period with 43 of the top 100 articles published during this time.

Conclusions Identification of the most cited articles within the field of spine recognizes some of the most important contributions in the peer-reviewed literature. Current investigators may utilize the aspects of their work to guide and direct future spine-related research.

Keywords Citation analysis · Spine surgery · Publications

Introduction

The care of spinal disorders has dramatically evolved since the early part of the twentieth century as a consequence of significant contributions and ideas. Landmark publications have led to improvements in surgical technique, protocols for pain control, and the management of patients with difficult clinical conditions. The establishment of a citation rank list has been often utilized in other specialties of medicine to identify those works that have had the greatest intellectual influence.

When a peer-reviewed article references another publication, a “citation” is received. Citation analysis involves ranking and evaluating an article or journal based on the number of citations that it receives. In addition to determining the most frequently cited articles, this analysis is also used to rank journals in terms of impact. Multiple medical fields have used a rank list to determine the impact of articles and journals within its specialty, such as otolaryngology [1, 2], emergency medicine [3, 4], dermatology [5–7], general surgery [8], trauma surgery [9], plastic surgery [10], physical medicine and rehabilitation [11], urology [12], ophthalmology [13], obstetrics and gynecology [14], critical care [15, 16], anesthesiology [17], neurosurgery [18], orthopedics [19–21], pediatric orthopedics

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[22], and orthopedic trauma [23]. However, to date, no analysis has been made for those in spine care. Although the significance of citation analysis remains a topic of debate, proponents point out that this method provides the only objective method to determine the significance of an article or journal [16, 24, 25]. In fact, many libraries, universities, and government agencies have used the citation analysis of an author to determine tenure appointments or research funding [16, 24, 26–29].

Unlike other medical specialties, the literature in spine encompasses many different fields including neurosurgery, orthopedic surgery, anesthesiology, radiology, and physical therapy, just to name a few. Consequently, the identification of publications that deal with spinal disorders must include journals from a wide array of sources. The first publications likely appeared in the Transactions of the American Orthopaedic Association and Journal of Neurosurgery, first published in 1887 and 1944, respectively. In 1976, *Spine* began publication, which was the first dedicated spine journal. Since then, the evolution of surgical, rehabilitative, and interventional treatments have led to manuscripts in over 25 different journals. The Institute for Scientific Information (ISI), which has compiled data since 1945, utilizes the “Science Citation Index Expanded” system to track citation information for these manuscripts. The purpose of this study was to identify and characterize the most frequently cited articles in the field of spine. We hypothesized that the results of our study would demonstrate that randomized-controlled studies with a high level of evidence would be of the most frequently cited, reflecting their significant impact on clinical practice within the field of spine care.

Materials and methods

In November 2010, we searched the Science Citation Index of the ISI from 1945 to 2010 for article citations in the following subject categories: “Orthopedics”, “Neurosciences”, “Neurology”, “Rehabilitation”, “Sports Sciences”, “Medicine, General and Internal” and “Radiology, Nuclear Medicine, and Medical Imaging”. The above categories included all terms that within the Science Citation Index that were relevant to spinal disorders. References were then evaluated for pertinence to the natural history, diagnosis, and/or management of spinal disorders by three independent reviewers. Furthermore, from this list, a total of 27 journals that regularly published literature pertaining to spine were identified (Table 1). Using a previously published protocol [20], the “cited reference search” (a component of Science Citation Index) command was used for each of these journals to identify the most frequently cited articles. The compilation of both of these lists was

Table 1 List of 27 journals utilized for citation analysis for publications in spine surgery

Journal titles
American Journal of Neuroradiology
American Journal of Roentgenology
Clinical Biomechanics
Clinical Journal of Pain
Clinical Orthopaedics and Related Research (CORR)
European Spine Journal
Journal of Neurosurgery
Journal of Pediatric Orthopaedics
Journal of Spinal Disorders ^a
Journal of Spinal Disorders and Techniques
Journal of Trauma
Journal of the American Medical Association (JAMA)
Journal of Bone and Joint Surgery—American Volume (JBJS-Am)
Journal of Bone and Joint Surgery—British Volume (JBJS-Br)
Journal of Neurosurgery—Spine
Journal of Vascular and Interventional Radiology
Lancet
New England Journal of Medicine (NEJM)
Neurosurgical Review
Neurosurgery
Orthopaedic Clinics of North America
Pain
Physical Therapy
Radiology
Regional Anesthesia and Pain Medicine
Spine
The Spine Journal

^a *Journal of Spinal Disorders* became *Journal of Spinal Disorders and Techniques* in 2002

again evaluated for relevance to spine care. One hundred percent agreement of the relevance led to inclusion of a publication. Articles felt to be irrelevant to the management of spinal disorders or that were non-specific to the field of spine care were excluded.

The top 100 cited spine-related publications were retrieved and reviewed. The journal title, year of publication, authors’ names, and geographic location of primary author were recorded. Articles were categorized by study type [clinical or basic science (“basic science” articles included all in vitro, pre-clinical, and biomechanical studies)]. Level of evidence was assigned for each of the clinical articles according to the *Journal of Bone and Joint Surgery (American Edition)* guidelines [30] (Fig. 2) by two independent reviewers. Review articles were further categorized by subtype (general clinical review, systematic clinical review, basic science review). Articles were also categorized by anatomic focus (cervical, lumbar,

Fig. 1 Number of articles per decade of publication. The most common decade was 1990–1999 with 43 articles, followed by 1980–1989 with 25 articles

thoracolumbar, or entire spine), patient population (adult or pediatric), and subspecialty (degenerative, developmental spine pathology, oncology, trauma, rehabilitation, deformity, rheumatologic, and pertaining to the general field of spine care). Articles were further categorized into a novel classification, diagnostic method, and/or procedure, when applicable.

Results

The 100 most cited spine articles were published from 1954 to 2004, with number of citations ranging from 244 to 1,695 (Table 2) in a total of 13 journals. Four articles had over 1,000 citations at the time of literature search. The decade responsible for the largest number of articles was 1990–1999 with 43 articles, followed by 1980–1989 with 25 articles (Fig. 1). The journal *Spine* was responsible for the largest number of articles (55 articles), followed by *Journal of Bone and Joint Surgery (American Edition)* with 22 articles. The remaining journals (*Journal of the American Medical Association*, *American Journal of Neuroradiology*, *Radiology*, *Lancet*, *New England Journal of Medicine*, *Journal of Bone and Joint Surgery—British*, *Journal of Neurosurgery*, *Physical Therapy*, *Journal of Spinal Disorders*, *Clinical Biomechanics*, and *Orthopaedic Clinics of North America*) each published six or fewer articles in the top 100 list.

Investigators from American institutions authored 60 of the top 100 articles while European centers published 29 articles. Authors from Canadian and Australian institutions produced 8 and 3 articles respectively. Articles from Europe came from seven regions—UK (11 articles), Netherlands (6 articles), Sweden (5 articles), France (3 articles), Norway (2 articles), Denmark and Switzerland (1 article each).

Ninety-one articles reported findings from the adult population, while seven articles involved pediatric patients. Clinical research publications were the most common type (81 articles), followed by basic science (19 articles). Among the clinical studies, 67 were original research and 14 clinical reviews (9 general reviews and 5 systematic reviews). Seventeen of the basic science articles were original research and 2 were reviews. For the 81 clinical research articles, the most common level of evidence was IV (34 articles) (Fig. 2). A total of 19 articles were either level I or II studies.

Degenerative disease of the spine was the most common subspecialty topic with 49 articles (Table 3). Articles discussing trauma (20 articles) and spinal deformity (4 articles) were also represented. The lumbar spine was the most common anatomic area reported with 53 articles. The other common anatomic regions included the thoracolumbar spine (17 articles), cervical spine (15 articles), and the entire spine (15 articles). Twenty of the top 100 articles discussed a new surgical technique or classification system. These articles include “The Anterior Approach for Removal of Ruptured Cervical Disks” [31] by Cloward, “The Treatment of Certain Cervical Spine Disorders by Anterior Removal of the Intervertebral Disc and Interbody Fusion” [32] by Smith and Robinson and “Treatment of Scoliosis—Correction and Internal fixation by Spine Instrumentation” [33] by Harrington. The most frequently listed first, last, and total authors are listed in Table 4.

Discussion

Spinal disorders are treated by multiple specialties that encompass ideas and research from orthopedic surgery, neurosurgery, rehabilitative medicine, and pain management. Major contributions to the field have helped to shape modern treatment protocols and improve outcomes for patients who suffer from these conditions. The recognition of this work is important in helping current clinician-investigators understand and design future research. To our knowledge, this is the first report of the most frequently cited articles in the field of spinal disorders.

Our list recognizes some of the classic papers of spine care; ones that have made long-lasting and “game-changing” contributions to the field. It is important to recognize that this list is composed of articles that address various topics and span across multiple disciplines. One example was in 1987, when a new treatment paradigm for low back pain [34] was established, demonstrating the harm of prolonged bed rest and benefits from the controlled activity for these patients. In another, the first report of the alarmingly high incidence of abnormal lumbar MRI findings in asymptomatic patients occurred in 1990, leading to a more

Table 2 Top 100 cited articles in the field of spine surgery

Rank	Article	Subspecialty	Type of paper	Citations
1	Black DM, Cummings SR, Karpf DB, et al. Randomised trial of effect of alendronate on risk of fracture in women with existing vertebral fractures. Fracture Intervention Trial Research Group. <i>Lancet</i> 1996;348:1535–41	Trauma	Clinical Outcomes	1695
2	Ettinger B, Black DM, Mitlak BH, et al. Reduction of vertebral fracture risk in postmenopausal women with osteoporosis treated with raloxifene: results from a 3-year randomized clinical trial. Multiple Outcomes of Raloxifene Evaluation (MORE) Investigators. <i>JAMA</i> 1999;282:637–45	Trauma	Clinical Outcomes	1428
3	Harris ST, Watts NB, Genant HK, et al. Effects of risedronate treatment on vertebral and nonvertebral fractures in women with postmenopausal osteoporosis: a randomized controlled trial. Vertebral Efficacy With Risedronate Therapy (VERT) Study Group. <i>JAMA</i> 1999;282:1344–52	Trauma	Clinical Outcomes	1013
4	Roland M, Morris R. A study of the natural history of back pain. Part I: development of a reliable and sensitive measure of disability in low-back pain. <i>Spine (Phila Pa 1976)</i> 1983;8:141–4	Degenerative	Questionnaire Development	1127
5	Boden SD, Davis DO, Dina TS, Patronas NJ, Wiesel SW. Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects. A prospective investigation. <i>J Bone Joint Surg Am</i> 1990;72:403–8	Degenerative	Diagnostic Imaging	773
6	Cloward RB. The anterior approach for removal of ruptured cervical disks. <i>J Neurosurg</i> 1958;15:602–17	Degenerative	Surgical Technique	767
7	Jensen MC, Brant-Zawadzki MN, Obuchowski N, Modic MT, Malkasian D, Ross JS. Magnetic resonance imaging of the lumbar spine in people without back pain. <i>N Engl J Med</i> 1994;331:69–73	Degenerative	Diagnostic Imaging	709
8	Waddell G. 1987 Volvo award in clinical sciences. A new clinical model for the treatment of low-back pain. <i>Spine (Phila Pa 1976)</i> 1987;12:632–44	Degenerative	Clinical Outcomes	595
9	Denis F. The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. <i>Spine (Phila Pa 1976)</i> 1983;8:817–31	Trauma	Classification	593
10	Tator CH, Fehlings MG. Review of the secondary injury theory of acute spinal cord trauma with emphasis on vascular mechanisms. <i>J Neurosurg</i> 1991;75:15–26	Trauma	Basic Science	564
11	Jensen ME, Evans AJ, Mathis JM, Kallmes DF, Cloft HJ, Dion JE. Percutaneous polymethylmethacrylate vertebroplasty in the treatment of osteoporotic vertebral body compression fractures: technical aspects. <i>AJNR Am J Neuroradiol</i> 1997;18:1897–904	Trauma	Surgical Technique	502
12	Weber H. Lumbar disc herniation. A controlled, prospective study with ten years of observation. <i>Spine (Phila Pa 1976)</i> 1983;8:131–40	Degenerative	Clinical Outcomes	493
13	Smith GW, Robinson RA. The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion. <i>J Bone Joint Surg Am</i> 1958;40-A:607–24	Degenerative	Surgical Technique	490
14	Biering-Sorensen F. Physical measurements as risk indicators for low-back trouble over a one-year period. <i>Spine (Phila Pa 1976)</i> 1984;9:106–19	Rehabilitation	Physical Exam Technique	487
15	Ware JE, Jr. SF-36 health survey update. <i>Spine (Phila Pa 1976)</i> 2000;25:3130–9	General Spine	Questionnaire Development	484
16	Bigos SJ, Battie MC, Spengler DM, et al. A prospective study of work perceptions and psychosocial factors affecting the report of back injury. <i>Spine (Phila Pa 1976)</i> 1991;16:1–6	Degenerative	Clinical Outcomes	459
17	Linton SJ. A review of psychological risk factors in back and neck pain. <i>Spine (Phila Pa 1976)</i> 2000;25:1148–56	Degenerative	Epidemiology	438
18	Deyo RA, Battie M, Beurskens AJ, et al. Outcome measures for low back pain research. A proposal for standardized use. <i>Spine (Phila Pa 1976)</i> 1998;23:2003–13	Degenerative	Questionnaire Development	428
19	Frymoyer JW, Pope MH, Clements JH, Wilder DG, MacPherson B, Ashikaga T. Risk factors in low-back pain. An epidemiological survey. <i>J Bone Joint Surg Am</i> 1983;65:213–8	Degenerative	Epidemiology	421
20	Meunier PJ, Roux C, Seeman E, et al. The effects of strontium ranelate on the risk of vertebral fracture in women with postmenopausal osteoporosis. <i>N Engl J Med</i> 2004;350:459–68	Trauma	Clinical Outcomes	411

Table 2 continued

Rank	Article	Subspecialty	Type of paper	Citations
21	Cotten A, Dewatre F, Cortet B, et al. Percutaneous vertebroplasty for osteolytic metastases and myeloma: effects of the percentage of lesion filling and the leakage of methyl methacrylate at clinical follow-up. <i>Radiology</i> 1996;200:525–30	Oncology	Surgical Technique	400
22	Fairbank JC, Pynsent PB. The Oswestry Disability Index. <i>Spine (Phila Pa 1976)</i> 2000;25:2940–52; discussion 52	General Spine	Questionnaire Development	398
23	Harrington PR. Treatment of scoliosis. Correction and internal fixation by spine instrumentation. <i>J Bone Joint Surg Am</i> 1962;44-A:591–610	Deformity	Surgical Technique	391
24	Waddell G, McCulloch JA, Kummel E, Venner RM. Nonorganic physical signs in low-back pain. <i>Spine (Phila Pa 1976)</i> 1980;5:117–25	Degenerative	Physical Exam Technique	389
25	Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. <i>Spine (Phila Pa 1976)</i> 1996;21:2640–50	Degenerative	Basic Science	386
26	Verbiest H. A radicular syndrome from developmental narrowing of the lumbar vertebral canal. <i>J Bone Joint Surg Br</i> 1954;36-B:230–7	Degenerative	Clinical Description	385
27	Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. <i>J Bone Joint Surg Am</i> 1974;56:1663–74	Trauma	Classification	383
28	Rivlin AS, Tator CH. Objective clinical assessment of motor function after experimental spinal cord injury in the rat. <i>J Neurosurg</i> 1977;47:577–81	Trauma	Basic Science	380
29	Banwart JC, Asher MA, Hassanein RS. Iliac crest bone graft harvest donor site morbidity. A statistical evaluation. <i>Spine (Phila Pa 1976)</i> 1995;20:1055–60	General Spine	Clinical Outcomes	379
30	van Tulder MW, Koes BW, Bouter LM. Conservative treatment of acute and chronic nonspecific low back pain. A systematic review of randomized controlled trials of the most common interventions. <i>Spine (Phila Pa 1976)</i> 1997;22:2128–56	Degenerative	Clinical Outcomes	375
31	Zdeblick TA. A prospective, randomized study of lumbar fusion. Preliminary results. <i>Spine (Phila Pa 1976)</i> 1993;18:983–91	Degenerative	Clinical Outcomes	374
32	van Tulder M, Furlan A, Bombardier C, Bouter L. Updated method guidelines for systematic reviews in the cochrane collaboration back review group. <i>Spine (Phila Pa 1976)</i> 2003;28:1290–9	General Spine	Clinical Outcomes	370
33	Frymoyer JW, Cats-Baril WL. An overview of the incidences and costs of low back pain. <i>Orthop Clin North Am</i> 1991;22:263–71	Degenerative	Epidemiology	369
34	Panjabi MM. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. <i>J Spinal Disord</i> 1992;5:383–9; discussion 97	General Spine	Basic Science	361
35	Buckwalter JA. Aging and degeneration of the human intervertebral disc. <i>Spine (Phila Pa 1976)</i> 1995;20:1307–14	Degenerative	Basic Science	355
36	Beaton DE, Bombardier C, Guillemin F, Ferraz MB. Guidelines for the process of cross-cultural adaptation of self-report measures. <i>Spine (Phila Pa 1976)</i> 2000;25:3186–91	General Spine	Clinical Outcomes	351
37	Holdsworth F. Fractures, dislocations, and fracture-dislocations of the spine. <i>J Bone Joint Surg Am</i> 1970;52:1534–51	Trauma	Classification	350
38	Bracken MB, Shepard MJ, Collins WF, Jr., et al. Methylprednisolone or naloxone treatment after acute spinal cord injury: 1-year follow-up data. Results of the second National Acute Spinal Cord Injury Study. <i>J Neurosurg</i> 1992;76:23–31	Trauma	Clinical Outcomes	344
39	Spitzer WO, Skovron ML, Salmi LR, et al. Scientific monograph of the Quebec Task Force on Whiplash-Associated Disorders: redefining “whiplash” and its management. <i>Spine (Phila Pa 1976)</i> 1995;20:1S–73S	Trauma	Clinical Outcomes	343
40	Weill A, Chiras J, Simon JM, Rose M, Sola-Martinez T, Enkaoua E. Spinal metastases: indications for and results of percutaneous injection of acrylic surgical cement. <i>Radiology</i> 1996;199:241–7	Oncology	Clinical Outcomes	340
41	Andersson GB. Epidemiologic aspects on low-back pain in industry. <i>Spine (Phila Pa 1976)</i> 1981;6:53–60	Degenerative	Epidemiology	340
42	Wiesel SW, Tsourmas N, Feffer HL, Citrin CM, Patronas N. A study of computer-assisted tomography. I. The incidence of positive CAT scans in an asymptomatic group of patients. <i>Spine (Phila Pa 1976)</i> 1984;9:549–51	Degenerative	Diagnostic Imaging	339
43	Garfin SR, Yuan HA, Reiley MA. New technologies in spine: kyphoplasty and vertebroplasty for the treatment of painful osteoporotic compression fractures. <i>Spine (Phila Pa 1976)</i> 2001;26:1511–5	Trauma	Surgical Technique	331

Table 2 continued

Rank	Article	Subspecialty	Type of paper	Citations
44	Lieberman IH, Dudeney S, Reinhardt MK, Bell G. Initial outcome and efficacy of “kyphoplasty” in the treatment of painful osteoporotic vertebral compression fractures. <i>Spine (Phila Pa 1976)</i> 2001;26:1631–8	Trauma	Surgical Technique	328
45	Panjabi MM. The stabilizing system of the spine. Part II. Neutral zone and instability hypothesis. <i>J Spinal Disord</i> 1992;5:390–6; discussion 7	General Spine	Basic Science	328
46	Barr JD, Barr MS, Lemley TJ, McCann RM. Percutaneous vertebroplasty for pain relief and spinal stabilization. <i>Spine (Phila Pa 1976)</i> 2000;25:923–8	Trauma	Clinical Outcomes	327
47	Bohlman HH. Acute fractures and dislocations of the cervical spine. An analysis of three hundred hospitalized patients and review of the literature. <i>J Bone Joint Surg Am</i> 1979;61:1119–42	Trauma	Clinical Outcomes	327
48	Deyo RA, Tsui-Wu YJ. Descriptive epidemiology of low-back pain and its related medical care in the United States. <i>Spine (Phila Pa 1976)</i> 1987;12:264–8	Degenerative	Epidemiology	325
49	King HA, Moe JH, Bradford DS, Winter RB. The selection of fusion levels in thoracic idiopathic scoliosis. <i>J Bone Joint Surg Am</i> 1983;65:1302–13	Deformity	Surgical Technique	319
50	Patrick DL, Deyo RA, Atlas SJ, Singer DE, Chapin A, Keller RB. Assessing health-related quality of life in patients with sciatica. <i>Spine (Phila Pa 1976)</i> 1995;20:1899–908; discussion 909	Degenerative	Clinical Outcomes	309
51	Brooks AL, Jenkins EB. Atlanto-axial arthrodesis by the wedge compression method. <i>J Bone Joint Surg Am</i> 1978;60:279–84	Trauma	Surgical Technique	309
52	Roland M, Fairbank J. The Roland-Morris Disability Questionnaire and the Oswestry Disability Questionnaire. <i>Spine (Phila Pa 1976)</i> 2000;25:3115–24	General Spine	Questionnaire Development	307
53	Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. <i>Clin Biomech (Bristol, Avon)</i> 1996;11:1–15	Degenerative	Basic Science	307
54	Burton AK, Tillotson KM, Main CJ, Hollis S. Psychosocial predictors of outcome in acute and subchronic low back trouble. <i>Spine (Phila Pa 1976)</i> 1995;20:722–8	Degenerative	Clinical Outcomes	305
55	Kurz LT, Garfin SR, Booth RE, Jr. Harvesting autogenous iliac bone grafts. A review of complications and techniques. <i>Spine (Phila Pa 1976)</i> 1989;14:1324–31	General Spine	Clinical Outcomes-Review Article	298
56	Summers BN, Eisenstein SM. Donor site pain from the ilium. A complication of lumbar spine fusion. <i>J Bone Joint Surg Br</i> 1989;71:677–80	General Spine	Clinical Outcomes	298
57	Frymoyer JW, Pope MH, Costanza MC, Rosen JC, Goggin JE, Wilder DG. Epidemiologic studies of low-back pain. <i>Spine (Phila Pa 1976)</i> 1980;5:419–23	Degenerative	Epidemiology	297
58	O’Sullivan PB, Phytz GD, Twomey LT, Allison GT. Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. <i>Spine (Phila Pa 1976)</i> 1997;22:2959–67	Rehabilitation	Clinical Outcomes	296
59	Marras WS, Lavender SA, Leurgans SE, et al. The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders. The effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury. <i>Spine (Phila Pa 1976)</i> 1993;18:617–28	Degenerative	Basic Science	288
60	van Tulder MW, Assendelft WJ, Koes BW, Bouter LM. Method guidelines for systematic reviews in the Cochrane Collaboration Back Review Group for Spinal Disorders. <i>Spine (Phila Pa 1976)</i> 1997;22:2323–30	General Spine	Clinical Outcomes	286
61	McBroom RJ, Hayes WC, Edwards WT, Goldberg RP, White AA, 3rd. Prediction of vertebral body compressive fracture using quantitative computed tomography. <i>J Bone Joint Surg Am</i> 1985;67:1206–14	Trauma	Diagnostic Imaging/Basic Science	285
62	Klennerman L, Slade PD, Stanley IM, et al. The prediction of chronicity in patients with an acute attack of low back pain in a general practice setting. <i>Spine (Phila Pa 1976)</i> 1995;20:478–84	Degenerative	Epidemiology	283
63	Herkowitz HN, Kurz LT. Degenerative lumbar spondylolisthesis with spinal stenosis. A prospective study comparing decompression with decompression and intertransverse process arthrodesis. <i>J Bone Joint Surg Am</i> 1991;73:802–8	Degenerative	Clinical Outcomes	283
64	Olmarker K, Rydevik B, Nordborg C. Autologous nucleus pulposus induces neurophysiologic and histologic changes in porcine cauda equina nerve roots. <i>Spine (Phila Pa 1976)</i> 1993;18:1425–32	Degenerative	Basic Science	281

Table 2 continued

Rank	Article	Subspecialty	Type of paper	Citations
65	Bailey RW, Badgley CE. Stabilization of the cervical spine by anterior fusion. <i>J Bone Joint Surg Am</i> 1960;42-A:565–94	General Spine	Surgical Technique	279
66	Lee CK. Accelerated degeneration of the segment adjacent to a lumbar fusion. <i>Spine (Phila Pa 1976)</i> 1988;13:375–7	Degenerative	Clinical Outcomes	278
67	Roaf R. A Study of the Mechanics of Spinal Injuries. <i>Journal of Bone and Joint Surgery-British Volume</i> 1960;42:810–23	Trauma	Basic Science	278
68	Morris JM. Role of the Trunk in Stability of the Spine. <i>Journal of Bone and Joint Surgery-American Volume</i> 1961;43:314–5	General Spine	Basic Science	277
69	Hoffer MM, Feiwell E, Perry R, Perry J, Bonnett C. Functional ambulation in patients with myelomeningocele. <i>J Bone Joint Surg Am</i> 1973;55:137–48	Developmental	Clinical Outcomes	274
70	Ranawat CS, O’Leary P, Pellicci P, Tsairis P, Marchisello P, Dorr L. Cervical spine fusion in rheumatoid arthritis. <i>J Bone Joint Surg Am</i> 1979;61:1003–10	Rheumatology	Clinical Outcomes	269
71	Rosenblum B, Oldfield EH, Doppman JL, Di Chiro G. Spinal arteriovenous malformations: a comparison of dural arteriovenous fistulas and intradural AVM’s in 81 patients. <i>J Neurosurg</i> 1987;67:795–802	Developmental	Clinical Outcomes	267
72	Bovim G, Schrader H, Sand T. Neck pain in the general population. <i>Spine (Phila Pa 1976)</i> 1994;19:1307–9	Degenerative	Epidemiology	265
73	Thompson JP, Pearce RH, Schechter MT, Adams ME, Tsang IK, Bishop PB. Preliminary evaluation of a scheme for grading the gross morphology of the human intervertebral disc. <i>Spine (Phila Pa 1976)</i> 1990;15:411–5	Degenerative	Classification/Basic Science	265
74	Fritzell P, Hagg O, Wessberg P, Nordwall A. 2001 Volvo Award Winner in Clinical Studies: Lumbar fusion versus nonsurgical treatment for chronic low back pain: a multicenter randomized controlled trial from the Swedish Lumbar Spine Study Group. <i>Spine (Phila Pa 1976)</i> 2001;26:2521–32; discussion 32–4	Degenerative	Clinical Outcomes	263
75	Wilke HJ, Neef P, Caimi M, Hoogland T, Claes LE. New in vivo measurements of pressures in the intervertebral disc in daily life. <i>Spine (Phila Pa 1976)</i> 1999;24:755–62	General Spine	Basic Science	260
76	Koes BW, van Tulder MW, Ostelo R, Kim Burton A, Waddell G. Clinical guidelines for the management of low back pain in primary care: an international comparison. <i>Spine (Phila Pa 1976)</i> 2001;26:2504–13; discussion 13–4	Degenerative	Primary Care Guidelines	259
77	Saal JS, Franson RC, Dobrow R, Saal JA, White AH, Goldthwaite N. High levels of inflammatory phospholipase A2 activity in lumbar disc herniations. <i>Spine (Phila Pa 1976)</i> 1990;15:674–8	Degenerative	Basic Science	259
78	Mayer TG, Gatchel RJ, Kishino N, et al. Objective assessment of spine function following industrial injury. A prospective study with comparison group and one-year follow-up. <i>Spine (Phila Pa 1976)</i> 1985;10:482–93	Degenerative	Clinical Outcomes	259
79	Hilibrand AS, Carlson GD, Palumbo MA, Jones PK, Bohlman HH. Radiculopathy and myelopathy at segments adjacent to the site of a previous anterior cervical arthrodesis. <i>J Bone Joint Surg Am</i> 1999;81:519–28	Degenerative	Clinical Outcomes	259
80	Lonstein JE, Carlson JM. The prediction of curve progression in untreated idiopathic scoliosis during growth. <i>J Bone Joint Surg Am</i> 1984;66:1061–71	Deformity	Clinical Outcomes	259
81	McCarron RF, Wimpee MW, Hudkins PG, Laros GS. The inflammatory effect of nucleus pulposus. A possible element in the pathogenesis of low-back pain. <i>Spine (Phila Pa 1976)</i> 1987;12:760–4	Degenerative	Basic Science	258
82	Kelsey JL, White AA, 3rd. Epidemiology and impact of low-back pain. <i>Spine (Phila Pa 1976)</i> 1980;5:133–42	Degenerative	Epidemiology	258
83	Nachemson A, Morris JM. In Vivo Measurements of Intradiscal Pressure. Discometry, a Method for the Determination of Pressure in the Lower Lumbar Discs. <i>J Bone Joint Surg Am</i> 1964;46:1077–92	Degenerative	Basic Science	258
84	Lindstrom I, Ohlund C, Eek C, et al. The effect of graded activity on patients with subacute low back pain: a randomized prospective clinical study with an operant-conditioning behavioral approach. <i>Phys Ther</i> 1992;72:279–90; discussion 91–3	Rehabilitation	Clinical Outcomes	258
85	Boden SD, McCowin PR, Davis DO, Dina TS, Mark AS, Wiesel S. Abnormal magnetic-resonance scans of the cervical spine in asymptomatic subjects. A prospective investigation. <i>J Bone Joint Surg Am</i> 1990;72:1178–84	Degenerative	Diagnostic Imaging	256

Table 2 continued

Rank	Article	Subspecialty	Type of paper	Citations
86	Boden SD, Zdeblick TA, Sandhu HS, Heim SE. The use of rhBMP-2 in interbody fusion cages. Definitive evidence of osteoinduction in humans: a preliminary report. <i>Spine (Phila Pa 1976)</i> 2000;25:376–81	Degenerative	Clinical Outcomes	255
87	Turner JA, Ersek M, Herron L, Deyo R. Surgery for lumbar spinal stenosis. Attempted meta-analysis of the literature. <i>Spine (Phila Pa 1976)</i> 1992;17:1–8	Degenerative	Clinical Outcomes-Review	255
88	Lenke LG, Betz RR, Harms J, et al. Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. <i>J Bone Joint Surg Am</i> 2001;83-A:1169–81	Deformity	Classification	254
89	McGill SM, Norman RW. Partitioning of the L4-L5 dynamic moment into disc, ligamentous, and muscular components during lifting. <i>Spine (Phila Pa 1976)</i> 1986;11:666–78	General Spine	Basic Science	253
90	Macnab I. Negative disc exploration. An analysis of the causes of nerve-root involvement in sixty-eight patients. <i>J Bone Joint Surg Am</i> 1971;53:891–903	Degenerative	Clinical Outcomes	253
91	Fischgrund JS, Mackay M, Herkowitz HN, Brower R, Montgomery DM, Kurz LT. 1997 Volvo Award winner in clinical studies. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective, randomized study comparing decompressive laminectomy and arthrodesis with and without spinal instrumentation. <i>Spine (Phila Pa 1976)</i> 1997;22:2807–12	Degenerative	Clinical Outcomes	252
92	Cote P, Cassidy JD, Carroll L. The Saskatchewan Health and Back Pain Survey. The prevalence of neck pain and related disability in Saskatchewan adults. <i>Spine (Phila Pa 1976)</i> 1998;23:1689–98	Degenerative	Epidemiology	251
93	Roy SH, De Luca CJ, Casavant DA. Lumbar muscle fatigue and chronic lower back pain. <i>Spine (Phila Pa 1976)</i> 1989;14:992–1001	Degenerative	Diagnostic Testing	251
94	Esses SI, Sachs BL, Dreyzin V. Complications associated with the technique of pedicle screw fixation. A selected survey of ABS members. <i>Spine (Phila Pa 1976)</i> 1993;18:2231–8; discussion 8–9	General Spine	Clinical Outcomes	248
95	Fredrickson BE, Baker D, McHolick WJ, Yuan HA, Lubicky JP. The natural history of spondylolysis and spondylolisthesis. <i>J Bone Joint Surg Am</i> 1984;66:699–707	Developmental	Epidemiology	248
96	Hoffman JR, Mower WR, Wolfson AB, Todd KH, Zucker MI. Validity of a set of clinical criteria to rule out injury to the cervical spine in patients with blunt trauma. National Emergency X-Radiography Utilization Study Group. <i>N Engl J Med</i> 2000;343:94–9	Trauma	Diagnostic Imaging	247
97	Symon L, Kuyama H, Kendall B. Dural arteriovenous malformations of the spine. Clinical features and surgical results in 55 cases. <i>J Neurosurg</i> 1984;60:238–4	Developmental	Clinical Outcomes	245
98	Hoogendoorn WE, van Poppel MN, Bongers PM, Koes BW, Bouter LM. Systematic review of psychosocial factors at work and private life as risk factors for back pain. <i>Spine (Phila Pa 1976)</i> 2000;25:2114–25	Degenerative	Epidemiology	244
99	Kang JD, Georgescu HI, McIntyre-Larkin L, Stefanovic-Racic M, Donaldson WF, 3rd, Evans CH. Herniated lumbar intervertebral discs spontaneously produce matrix metalloproteinases, nitric oxide, interleukin-6, and prostaglandin E2. <i>Spine (Phila Pa 1976)</i> 1996;21:271–7	Degenerative	Basic Science	244
100	Hides JA, Stokes MJ, Saide M, Jull GA, Cooper DH. Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. <i>Spine (Phila Pa 1976)</i> 1994;19:165–72	Rehabilitation	Diagnostic Imaging	244

critical evaluation of the correlation of degenerative changes and pain [35]. Articles describing classic surgical techniques are also included in this list. These articles include the description of the exposure of the anterior cervical spine, a surgical approach used on a daily basis, which was first described in 1958 [31, 32]. In addition to the above clinical articles, it is also essential to recognize numerous contributions from the realm of basic science and from other disciplines, such as physical medicine and

rehabilitation. This includes research that has provided insight into the efficacy of graded activity for patients with subacute low back pain [36].

Analysis of the most frequently cited articles has provided a list of publications that have been recognized for either describing novel procedures and classification systems or for reporting the results of original research. Both types of publication have received equal attention in our analysis as each has advanced the field of spine care in a

Fig. 2 Level of evidence distribution for clinical studies. Utilizing the Journal of Bone and Joint Surgery—American guidelines, designation was made by two independent reviewers. Level IV evidence was most common with 34 articles. There were nine level I studies included. Journal of Bone and Joint Surgery (American) guidelines: level I, high quality randomized-controlled trial; level II, lesser quality randomized-controlled trial (<80 % follow-up, no blinding, improper randomization) or prospective comparative study; level III, case-control or retrospective comparative study; level IV, case series; level V, expert opinion

Table 3 Number of articles by subspecialty

Subspecialty	Articles
Degenerative	49
Trauma	20
General to the field of “spine care”	16
Rehabilitation	4
Deformity	4
Developmental/congenital	4
Oncology	2
Rheumatology	1

unique way. While original research studies have received multiple citations based on their reporting of the outcomes of a particular intervention, publications that have described procedures and classification systems have provided the necessary tools needed for other investigators to undertake meaningful clinical and basic science studies. For example, without the description of the SF-36 or the Oswestry Disability Index, many clinical studies on the outcome of interventions for spinal pathology may not have been possible or, at the least, may not have had the same impact as they have achieved. Both types of articles have contributed to the field of spine care and both deserve mention among the “Top 100 Most Cited Spine Articles”.

There were nine articles in our study that met level I evidence criteria. Notably, the top three most frequently cited articles in spine surgery are all level I studies (Table 2). Unquestionably, the quality of spine research

Table 4 Number of authorships of a top 100 most frequently cited spine article

Description	Author name
Most frequent first author	Van Tulder, M.W. (3)
	Frymoyer, J.W. (3)
	Boden, S.D. (3)
Most frequent last author	Bouter, L. (4)
Most frequent co-author	Koes, B.W. (5)
	Bouter, L. (4)
	Deyo, R.A. (4)
	Genant, H.K. (4)
	Van Tulder, M.W. (4)
	Waddell, G. (4)
	Boden, S.D. (3)
	Frymoyer, J.W. (3)
	Kurz, L.T. (3)
	Nachemson, A.L. (3)
	Roland, M. (3)
	Wiesel, S.W. (3)

continues to improve with each decade that passes. For example, the fact that eight of the nine level I studies have a publication of date after 1990 indicates that both investigators and readers are recognizing the scientific strength of a prospective, randomized, controlled protocol. It is likely that when this study is repeated a decade from now, an even higher percentage of level I studies will be included. With health care reform demanding the emphasis of evidence-based medicine and comparative effectiveness research in spine care, these types of studies will be increasingly important in advancing treatment.

Lefaivre et al. [20] reported the 100 most frequently cited journal articles within the field of orthopedic surgery. In comparison, the composition of these studies was similar in research type (81 clinical—spine, 76 clinical—orthopedic) and level of evidence (34 level IV—spine, 42 level IV—orthopedic). However, the most productive decade reported in Lefaivre et al. [20] was 1980–1989 with 36 and second most in 1970–1979 with 23 articles. In contrast, our data for spine surgery (1990–1999 with 43 articles and 1980–1989 with 25 articles) suggest that the most influential contributions have come more recently. This could be attributed to a more recent rapid evolution in the treatment of, improvement in the quality of research for, and/or higher publication rate for spinal disorders.

Our analysis determined that the journal *Spine* produced the largest number of articles within the “Top 100 Most Cited Spine Articles”. However, when evaluating the contribution of various journals, it is essential to evaluate multiple factors. One particular factor is the frequency of publication. Bimonthly journals will publish a greater

number of articles than those of journals that publish less frequently and will therefore have published a larger number of articles and have a greater chance that one of their articles will be frequently cited. The other primary factor is the duration of time that each journal has been in circulation. Articles and journals that have been in circulation for a longer period of time will have had more opportunity to have been cited by other authors. For example, journals with favorable impact factors, including *The Spine Journal* and the *European Spine Journal* were not cited as contributors of articles within the “Top 100 Most Cited Spine Articles”. Their exclusion is largely a product of their relatively recent inception dates (*The Spine Journal* in 2001 and *European Spine Journal* in 1992) as opposed to any comment toward the quality of the journal. It would be expected that the source journals of the most frequently cited articles in spine care would be quite different if performed again in 10 years.

There were limitations to our study. One was that the Science Citation Index Expanded did not track citations for articles published prior to 1945. Omission of important articles published prior to this date is entirely possible. Furthermore, because “spine” is not 1 of the 200 subject categories predetermined in Science Citation Index Expanded, we used multiple pertinent categories to arrive at our final list. Although we attempted to capture all articles on spine surgery in the literature including those in general medical journals, it is impossible to confirm that every relevant article ever published was discovered. Furthermore, we chose to exclude journals that historically publish basic science studies that may have applications to spine surgery. Inclusion of these journal articles would have presented substantial controversy regarding the relevance of studies specifically to spinal disorders. For example, the classic article “Bone Formation by Autoinduction” by the late Marshall Urist [37] in *Science* in 1965 led to the discovery of bone morphogenetic protein and had been cited over 2,600 times. We chose to exclude studies such as these because their applicability was not specific for spine surgery, but rather to broader areas such as “bone healing”. A final set of limitations involves the intrinsic controversies of citation analysis. Some authors have opined that the number of citations that an article receives is not necessarily a reflection of the quality of research [38, 39]. Furthermore, the analysis fails to account for self-citation, has language bias toward English and against that of a competitor, and journal bias where the work is submitted [17, 23, 28]. An additional bias is the “obliteration by incorporation” effect. Older publications are subject to the “obliteration by incorporation” effect [40]. This refers to the documented phenomenon that exists where older publications are no longer cited with the same frequency as their findings become incorporated into the field’s

current body of knowledge. Due to this effect, this analysis ranked the articles based on the total number of citations received as opposed to the number of citations received in the current year alone. If the number of citations in the current year was used as the ranking criteria, it was hypothesized that the “obliteration by incorporation effect” would have produced an unfair relative increase in citations for more recent articles as composed to fewer citations for many “classic articles” that have a much earlier publication date.

Despite the intrinsic limitations, citation analysis provides an objective and quantitative measure of the impact that an article has on its respective field. The identification of the top 100 most cited articles related to the care of spine patients recognizes the historical advances of this field and allows insight into the types of articles that have provided these advances. It serves to highlight the contributions from various disciplines and responsible authors within the field of spine care. This analysis also provides direction for future research by demonstrating the power of well-organized randomized-controlled trials and their ability to have a meaningful impact despite their recent publication date. This was demonstrated by the finding that, despite having a publication date being within the last 20 years, the top 3 articles in our list of 100 most frequently cited articles reported on the result of a randomized-controlled trial [41–43].

Conflict of interest None.

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