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Review Article

The 100 Classic Papers in Spinal Deformity Surgery

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Abstract

Study Design: Bibliometric review of the literature.
Objective: To identify and analyze the top 100 cited articles in spinal deformity surgery.
Summary of Background Data: The field of spinal deformity surgery is an ever-growing and complex field that owes its development to the work and visions of many dedicated individuals.
Methods: The authors searched the Thomson Reuters Web of Knowledge for citations of all articles relevant to scoliosis and spinal deformity surgery. The number of citations, authorship, year, journal, and country and institution of publication were recorded for each article.
Results: The most cited article was the 2001 work by Lenke et al. describing a new 2-dimensional classification system of adolescent idiopathic scoliosis used to determine the appropriate vertebral levels to be included in an arthrodesis. The second most cited was Harrington's 1962 article describing the first instrumented method for the treatment of scoliosis. The third most cited article was the 1983 study by King et al. recommending specific vertebral levels for inclusion into spinal arthrodesis. Most articles originated in the United States (62), and most were published in *Spine* (32). Most were published in the 1990s (28), and the 3 most common topics, in descending order, were adolescent idiopathic scoliosis (28), spinal instrumentation (18), and surgical complications (5). Author Suk had 5 articles in the top 100 list, whereas authors Kim, Liljenqvist, Lonstein, and Weinstein had 3 each. Washington University in St. Louis had 7 articles in the top 100 list.
Conclusions: This report's identification of the 100 classic articles in spinal deformity surgery allows insight into the development and trends of this challenging subspecialty of spine surgery. Furthermore, this article identifies individuals who have contributed the most to the advancement of spinal deformity surgery and the body of knowledge used to guide evidence-based clinical decision making in spinal deformity surgery today.

Keywords: Top 100 articles; Scoliosis; Adolescent idiopathic scoliosis; Spinal deformity

Introduction

The subspecialty of spinal deformity surgery is an ever evolving, dynamic specialty that owes its advancements to many individuals and their pioneering works that have shaped the way we practice spinal deformity surgery today. One way to distinguish and honor these individuals is through recognizing the importance of their scientific publications. This is the first study to analyze and quantify the most highly cited articles in spinal deformity surgery and to measure their relevant impact on the entire spinal deformity literature.

A citation is an alphanumeric expression that acknowledges the relevance given by the author to the work of others on a topic of discussion in which the citation appears [1]. The primary goal of a citation is to credit authors on the work they previously published. The greater the number of citations an author has, the more esteemed that author becomes in the field of practice. Citation analysis is used to determine the relative importance of medical journals by means of the impact factor, which is determined from the

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Table 1
Top 100 articles in spinal deformity, by first author.

Rank	First Author	Citations	Rank	First Author	Citations	Rank	First Author	Citations
1	Lenke, LG [11]	490	35	Risser, JC [45]	170	69	Boos, N [79]	125
2	Harrington, PR [12]	473	36	Belmont, PJ [46]	167	70	Vedantam, R [80]	124
3	King, HA [13]	444	37	Lonstein, JE [47]	164	71	Asher, R [81]	122
4	Lonstein, JE [14]	360	38	Lenke, LG [48]	160	72	Youkilis, AS [82]	122
5	Bernhardt, M [15]	316	39	Rowe, DE [49]	159	73	Stokes, IAF [83]	121
6	Suk, SI [16]	299	40	Aebi, M [50]	157	74	Mehta, MH [84]	120
7	Nuwer, MR [17]	274	41	Brooks, HL [51]	152	75	Newton, PO [85]	120
8	Kim, YJ [18]	272	42	Lowe, TG [52]	150	76	Emami, A [86]	120
9	Bergofsky, EH [19]	271	43	Dubousset, J [53]	147	77	Suk, SI [87]	120
10	Nachemson, AL [20]	270	44	Kim, YJ [54]	146	78	James, JI [88]	119
11	Wynne-Davies, R [21]	260	45	Ponseti, IV [55]	145	79	Dwyer, AF [89]	119
12	Legaye, J [22]	259	46	Wilber, RG [56]	145	80	Fon, GT [90]	119
13	Nash, CL [23]	251	47	Emans, JB [57]	144	81	Lagrone, MO [91]	118
14	Warren, MP [24]	242	48	Winter, RB [58]	142	82	Ransford, AO [92]	118
15	Macewen, GD [25]	234	49	Engler, GL [59]	142	83	Nilsonne, U [93]	117
16	Boyd, SG [26]	233	50	Dommisse, GF [60]	141	84	Allen, BL [94]	117
17	Suk, SI [27]	231	51	Bunnell, WP [61]	141	85	Hamill, CL [95]	117
18	Glassman, SD [28]	229	52	Asher, M [62]	141	86	Schwab, FJ [96]	117
19	Cochran, T [29]	226	53	Suk, SI [63]	140	87	Aaro, S [97]	115
20	Ponseti, IV [30]	222	54	Campbell, RM [64]	140	88	Richards, BS [98]	115
21	Schlegel, JD [31]	221	55	Nachemson, AL [65]	138	89	Machida, M [99]	114
22	Liljenqvist,UR [32]	216	56	Luque, ER [66]	138	90	Merloz, P [100]	114
23	Morrissy, RT [33]	210	57	Roussouly, P [67]	138	91	Akbarnia, BA [101]	114
24	Rogala, EJ [34]	206	58	Shands, AR [68]	136	92	Sahlstrand, T [102]	113
25	Carman, DL [35]	204	59	Ellis, ER [69]	134	93	Lonstein, JE [103]	113
26	Haher, TR [36]	197	60	Passuti, N [70]	134	94	Weinstein, SL [104]	113
27	Weinstein, SL [37]	185	61	Bunnell, WP [71]	133	95	Carr, WA [105]	112
28	Betz, RR [38]	185	62	Riseborough, EJ [72]	132	96	Leatherman, KD [106]	111
29	Stokes, IAF [39]	184	63	Lee, SM [73]	132	97	Thompson, JP [107]	109
30	Weinstein, SL [40]	178	64	Roaf, R [74]	129	98	Liljenqvist, UR [108]	109
31	McMaster, MJ [41]	177	65	Suk, SI [75]	128	99	Kosmopoulos, V [109]	109
32	Kim, YJ [42]	177	66	Myers, MA [76]	127	100	Machida, M [110]	108
33	Collis, DK [43]	175	67	McDonnell, MF [77]	126			
34	Dickson, RA [44]	171	68	Liljenqvist, UR [78]	126			

ratio of the number of citations in the current year to articles published in the journal in the 2 preceding years, divided by the number of citable items published in the same 2 years [2-4]. The impact factor has emerged as the marker of the quality and rank of a journal.

Recent publications identified the top 100 articles in orthopedic surgery [1] and pediatric orthopedic surgery [5]. Multiple other studies exist examining publication history in the fields of otolaryngology [6], dermatology [7], critical care [8], plastic surgery [9], and general surgery [10].

The goal of this study was to identify the top 100 articles relevant to spinal deformity surgery and published in surgical and non–surgery-related journals through an extensive search of the literature using methods validated in other similar, previously published studies.

Materials and Methods

The current authors used the Thomson Reuters Web of Knowledge, a research platform that provides bibliographic database services, to search for citations of all articles from 1900 to 2013 relevant to scoliosis and spinal deformity surgery and published in surgical and nonsurgical journals. The decision about which journals to search was made with the use of the Thomson Reuters Journal Citation Report database, which ranks journals according to impact factor.

The researchers used search limits and sorting options in the Thomson Reuters Web of Knowledge to rank all articles from each journal according to the number of citations. The results were then carefully reviewed and only those relevant to scoliosis and spinal deformity surgery were selected. The 100 articles that matched the search criteria were then further analyzed, and the title, first author, journal and year of publication, number of citations, and country and institution of origin were recorded.

Results

A total of 38,193 articles matched the search criteria. Of those, 584 were cited ⩾ 100 times. Table 1 lists the top 100 articles, their first author, and their corresponding number of citations. The top article was cited 490 times, the 100th article was cited 108 times, and the mean number of citations for the top 100 articles was 171.1. The articles were published between 1950 and 2007. The oldest article was by Ponseti and Friedman [55], published in 1950. The

Table 2
Publication dates.

Decade	No. of Papers
1950s	6
1960s	8
1970s	10
1980s	24
1990s	28
2000s	24

newest article was published in 2007 by Kosmopoulos and Schizas [109]. More than three quarters of the top 100 cited articles were published after 1980, with the 1990s producing the largest number of highly cited articles published (28%) (Table 2). The top 100 articles were published in 18 journals, with the top 3 journals publishing 78% of the articles (Table 3). The top journal was *Spine*, with 36 articles, followed by the *Journal of Bone and Joint Surgery, American Volume*, with 32 articles, and the *Journal of Bone and Joint Surgery, British Volume*, with 10 articles. The 3 most popular categories published were adolescent idiopathic scoliosis (AIS) with 28 articles, spinal instrumentation with 18, and surgical complications with 5 (Table 4). For publications published after the year 2000, the most common topics were spinal instrumentation, followed by AIS, and adult scoliosis. A total of 81 first authors contributed to the top 100 articles. Only 5 were credited with $\geqslant$ 3 publications and only 1, Suk, had 5 publications in the top 100 (Table 5). The top articles originated from 15 different countries; the United States was the most prolific (62%) (Table 6). There were 68 institutions responsible for the top cited articles; Washington University in St. Louis contributed the most, with 7 publications in the top 100 (Table 7).

Discussion

This article identifies the authors and topics that have made the most impact on the practice of spinal deformity surgery over the course of the past century and the beginning of this one. By identifying these classic works, insight is gained into the history, development, and current trends in spinal deformity surgery. The findings of this study identified the articles responsible for the most important developments in this field.

Table 3
Top journals of publication.

Journal	Impact factor*	Articles, n
Spine	2.159	36
Journal of Bone and Joint Surgery, American Volume	3.234	32
Journal of Bone and Joint Surgery, British Volume	2.735	10
European Spine Journal	2.133	4
Acta Orthopaedica	2.736	3
Clinical Orthopaedics and Related Research	2.787	3

* As of July 31, 2012.

The most cited article in deformity surgery is the classic 2001 work by Lenke et al. [11] describing a new 2-dimensional classification system of AIS incorporating 3 components: curve type, a lumbar spine modifier, and a sagittal thoracic modifier that prioritizes providing details of curvatures in different anatomic surfaces to explain the precise intensity of scoliosis. This new classification method has been shown to have higher interobserver agreement scores and noninferior postoperative results compared with the previously accepted classification method of King et al. [13].

The second most cited article was from 1962, by Paul Harrington [12], describing a new method for the treatment of scoliosis in which a metal system of rods and hooks is implanted, and distraction and compression forces are applied to correct the curve and stabilize the treated segments in the correct position by skeletal fixation. This rod and hook system, known today as the Harrington rod, was the first device designed to straighten and immobilize the spine from inside the body. The Harrington rod system was the reference standard for scoliosis surgery for over 20 years before it became obsolete.

The third most cited article was the work of King et al. [13] describing the first classification system to help guide surgical treatment of AIS. This system was based on the location of coronal deformity, the clinical appearance of the regional curves, and the relative flexibility of the regional curves. This classification system was widely accepted and seemed to offer reliable fusion guidelines when used with Harrington distraction instrumentation, the standard AIS instrumentation used in the early 1980s.

Adolescent idiopathic scoliosis was the most popular topic in the top 100 articles, with 28 studies dedicated to its understanding, natural history, and conservative and surgical management. Two of the 3 most highly cited articles, those of King et al. [13] and Lenke et al. [11], described classification systems to help guide surgical treatment of AIS. The fourth most cited article, by Lonstein and Carlson [14], which was published in 1984, described the prediction of curve progression in untreated idiopathic scoliosis. The 10th most cited article was from 1995, by Nachemson and Peterson [20], and described different nonsurgical treatment of AIS. Long-term follow-up and prognosis in untreated AIS were described by Weinstein et al. [40], and that study ranked 30th on the list. Dickson et al. [44] (34th) described the pathogenesis of AIS in 1984. The Risser sign was introduced in 1958 and was the 35th most cited article [45].

The top 100 articles identified in this work correspond with major surgical advances over the past half century. The first spinal instrumentation for the treatment of spinal deformity was introduced by Paul Harrington [12] and was described in 1962, which earned him the third spot on the top 100 list. Although the Harrington rod system allowed

Table 4
Most popular topics, ranked by numbers of articles.

Category	Articles, n
Adolescent idiopathic scoliosis	28
Instrumentation	18
Complications	5
Congenital scoliosis	4
Intraoperative neurophysiological monitoring	4
Anatomy	3
Epidemiology	3
Scoliosis	3

for significant coronal plane correction, it was ineffective in correcting rotational deformity and caused flattening in the sagittal plane, leading to flatback syndrome in cases where instrumentation was applied to the lower lumbar spine. In 1975, Eduardo Luque [66] introduced segmental spinal instrumentation using contoured rods and sublaminar wires. The Luque method provided a more rigid internal fixation and allowed for coronal and sagittal plane correction, but lacked a derotative effect in the thoracic spine. Cotrel and Dubousset, in 1984, described a system using 2 rods and multiple hooks that allowed the surgeon to contour the rods and correct the deformity in all 3 planes. In 1995, Suk et al. [16] described the safe and effective use of thoracic pedicle screws that allowed for a more powerful correction of spinal deformity in the coronal, sagittal, and axial planes. This work by Suk et al. was ranked sixth in the top 100 articles in spinal deformity surgery. In 2002, Suk et al. [75] described the posterior vertebral column resection technique as an alternative to combined anterior-posterior surgery to treat severe deformities with limited flexibility, which further improved the correction capabilities of spinal deformity with surgery.

The third most common topic published in the top 100 spinal deformity articles was surgical complications. As in every surgical specialty, complications and their avoidance remain an important topic of discussion and research. In spinal deformity surgery, intraoperative spinal cord injury is a relatively uncommon but devastating complication. This has led to the development and increased use of intraoperative monitoring techniques, a topic with 4 publications in the top 100 and an important area of continued research.

Table 5
Top authors and topics of publication.

First author	Articles, n	Topic
Suk SI	5	Adolescent idiopathic scoliosis, instrumentation, vertebral column resection
Kim YJ	3	Adolescent idiopathic scoliosis, instrumentation
Liljenqvist UR	3	Adolescent idiopathic scoliosis, instrumentation
Lonstein JE	3	Adolescent idiopathic scoliosis, scoliosis screening, Milwaukee bracing
Weinstein SL	3	Adolescent idiopathic scoliosis

Table 6
Countries of origin.

Country of origin	Articles, n
United States	62
South Korea	7
Sweden	6
France	4
United Kingdom	4
Switzerland	3
Germany	3
Japan	3
Australia	2
Belgium	1
India	1
Canada	1
Mexico	1
Scotland	1
South Africa	1

The oldest article, by Ponseti and Friedman [55], published in 1950, described the course of the most common patterns of idiopathic curvature of the spine and offered some basis for the prognosis with any given curve. The most recent article, by Kosmopoulos and Schizas [109], was a meta-analysis of the literature evaluating the accuracy and the postoperative methods used for the assessment of pedicle screw placement in the human spine; it ranks 97th on the list. The 100th article on the list is by Machida et al. [110], evaluating the pathogenesis of idiopathic scoliosis in an experimental animal model.

Of the top-cited articles, 24 were published before 1980. Previous works suggested that the older an article is, the more likelihood it has of being cited [111]. However, this may not be completely true, because one of the more important problems of this type of analysis is the ‘‘obliteration by incorporation’’ phenomenon [112]. This describes the process whereby data from truly classic articles becomes cited less frequently they are absorbed into the body of current knowledge. It has been described that some of the truly classic articles can sometimes be found referenced in some of the top-cited publications [111]. Another limitation of this study was the inability to assess the true ‘‘lead’’ author of each article. For this reason, the first author was assumed to be the primary contributor to the work, and this was used to create the ranking of authors according to the number of publications. One last limitation

Table 7
Top institutions of origin of articles.

Institution	Location	Articles, n
Washington University in St. Louis	St. Louis, MO, USA	7
Inje University	Gimhae, South Korea	5
University of Minnesota	Minneapolis, MN, USA	4
Dupont Institute	Wilmington, DE, USA	3
University of Gothenburg	Gothenburg, Sweden	3
University of Iowa	Iowa City, IA, USA	3

to this study was the problem of "incomplete citing," which is described as the erroneous manner in which some citations are made in an effort to convince or persuade the readership of that particular journal, instead of giving credit to those who most significantly influenced the work [113].

To the current authors' knowledge, this article is the first to identify the 100 classic articles in spinal deformity surgery. This study provides unique insight into the development and trends of this challenging subspecialty within spine surgery in the 20th and early 21st centuries. This work identifies individuals who have made the greatest contributions to the ever-growing body of knowledge that guides everyday clinical decision making in the field of spinal deformity surgery. Furthermore, the classic articles identified in this study are the ones that have had the most impact and, as such, will be the most remembered.

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