


# Spinal cord injury: a review of the most-cited publications

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## Abstract

**Purpose** The objective of this study was to identify and review the most-cited articles on spinal cord injury (SCI). Citation analyses showcase the relative influence of individual articles in a given field. In addition to distinguishing publications of particular quality and impact and well-developed areas of the literature, citation analyses allow for an understanding of the direction in which a field of research is headed.

**Methods** A multi-disciplinary bibliographic index was used to identify the 50 SCI articles with the most lifetime citations, and the 50 SCI articles with the highest annual citation rates. Studies were categorized into one of six categories based on their primary focus: treatment, pathology/natural history, predictor of outcome, methods, epidemiology, or assessment measure.

**Results** We report that 40.0 and 56.0 % of SCI papers with the most lifetime citations and highest annual citation rates, respectively, were systematic reviews or meta-analyses, indicating that some of the most referenced papers in SCI are not primary publications. Further, there appears to be a greater international presence in SCI research. In the highest annual citation rate cohort, 14.0 % of papers were a

product of international collaboration, 50.0 % were published by outside of the United States, and the average year of publication was  $2005 \pm 5.4$ ; the comparable numbers for papers that comprised the highest lifetime citation cohort were, respectively, 8.0, 28.0 %, and  $1998 \pm 9.2$ . Treatment and pathology/natural history of SCI were a common research focus in both citation cohorts, consistent with ongoing efforts to better understand and manage this injury. **Conclusions** This comprehensive review provides a cross-sectional summary and bibliometric analysis of some of the most influential literature in SCI, and compliments existing systematic reviews and meta-analysis in the field by establishing which areas of the literature are growing and which have been well developed.

**Keywords** Spinal cord injury · SCI · Citation analysis · Review

## Introduction

Spinal cord injury (SCI) is recognized as one of the most disabling and expensive health conditions [1]. Globally, over two million individuals live with the sequela of SCI, including physical, social, psychological, and emotional impairments that often extend beyond affected individuals to their families, friends, employers, community and health care system [2–4]. Although the costs of SCI vary by factors such as injury severity, it has been estimated that the lifetime cost of SCI for an individual injured by age 25 in the United States can exceed 2 million dollars [5]. Unfortunately, SCI impacts perceived quality of life and may also reduce post-injury life expectancy [6, 7].

Given the burden of this injury, recently, many efforts have been made to improve the ability to prevent, manage,

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and treat SCI. Consider that standardized traumatic injury reporting is being supported by international coalitions to allow for the global aggregation of SCI data to inform future prevention initiatives [8], or that multiple efforts are being made to understand how pharmacological intervention and/or clinical and applied therapies can improve post-SCI outcomes [9, 10]. The field of SCI is, therefore, experiencing a tremendous amount of growth, and it will continue to evolve as more questions on how to prevent or improve outcome following SCI are answered.

While it is understood that SCI has been the subject of extensive scholarship, it remains difficult to objectively assess the relative impact of individual publications in this field. Citation analyses compliment systematic reviews and meta-analyses in a field by reviewing the literature through a lens that measures the influence of individual publications in the science. This is achieved by examining the number of times individual publications are cited; deeper analysis of citation data facilitates an understanding of the current trends in a field as well as the areas of a literature that are well developed [11–13].

To complement existing systematic reviews and meta-analyses in SCI, we conducted a citation analysis with the purpose of identifying: (1) the most widely cited articles in SCI, and (2) the articles with the highest annual citation rate, to determine research trends in this field.

## Methods

### Sources

Publish or Perish was produced by Professor Anne-Will Harzing of the University of Melbourne and developed by Tarma Software Research. Publish or Perish is a free, publically available program that extracts and analyzes citation information in Google Scholar to yield a variety of citation metrics and bibliometric data (e.g., h-index, journal impact metrics) [14]. Google Scholar offers a more comprehensive coverage in the arts and humanities while still covering the sciences [15].

### Search strategy and study selection

In June 2015, we conducted a search using Publish or Perish to identify highly cited articles in SCI. The keyword search used the four following terms: spinal cord injury, spinal cord injuries, spinal cord trauma, and spinal cord traumas. The year of publication was unrestricted. The results for each keyword were arranged largest number of citations to lowest. The outcomes for each keyword were compiled into a single spreadsheet where the most frequently cited articles were identified. The data was also

sorted according to annual citation rates (i.e., citations/year) on Publish or Perish. Because our focus is on highly cited and publically available articles on spinal cord injury, the search was not extended to any other databases or gray literature.

### Inclusion and exclusion criteria

To identify the top 50 results from the broad list of studies generated by our search criteria, we manually examined each of the results to include studies relevant to our search and to exclude out-of-scope publications. The inclusion criteria for this comprehensive review were articles whose primary focus was on SCI. The exclusion criteria were (1) articles in languages other than English; (2) articles that were not peer-reviewed (e.g., books, book chapters, reviews, commentaries, consensus statements/guidelines, corrections and conference proceedings); (3) articles whose full texts were not electronically accessible or available for download articles; and (4) articles focused on topics extraneous to SCI.

### Assessing the articles

Two reviewers independently extracted all pertinent information for each eligible article. Raw data on subject variables such as author names, title of work, year of publication, number of citations, type of cited journal, journal of publication, country of correspondence, product of international collaboration were presented in Harzing's Publish or Perish. Moreover, we used number of citation in Publish or Perish to identify the articles ranked from no. 1 to no. 50. The articles were organized by design (case-series, comparative, cross-sectional, prospective cohort, randomized control trial, retrospective cohort, review, animal model). Finally, we categorized each paper as belonging to one of six general categories: treatment; pathology/natural history; predictor of outcome; methods; epidemiology; or assessment measure.

### Degree of agreement between assessors

Inter-rater agreement was evaluated using Cohen's kappa for inter-rater correlation [16]. All of the data were entered and coded by the first rater in an electronic database. A second rater was provided a random sample of 20 % of the first rater's data. The first rater coded the articles independently of the second rater. The identical process was conducted by the second rater. Inter-observer agreement was achieved for both citation cohorts ( $n = 100$ ). Cohen's kappa was situated between 0.89 and 0.96, indicating a close agreement between both observers for both citation groups.

## Data analysis and reporting

We reported the study according to PRISMA guidelines (Fig. 1) [8]. Descriptive studies and analysis were performed using Stata version 11.0 [17].

## Results

The distribution of papers into categories and sub-categories is shown in Tables 1, 2, 3 and 4. The topics addressed in the articles with the most lifetime citations included: pathology (20/50, 40.0 %); treatment (20/50, 40.0 %); epidemiology (5/50, 10.0 %); predictor of outcome (3/50, 6.0 %); methods (1/50, 2.0 %); assessment measure (1/50, 2.0 %). The foci of the papers with the most annual citation rates were: pathology (21/50, 42.0 %); treatment (21/50, 42.0 %); epidemiology (5/50, 10.0 %); predictor of outcome (1/50, 2.0 %); assessment measure (2/50, 4.0 %). Comparison of the top-cited articles included in the two cohorts—articles with the most absolute citations

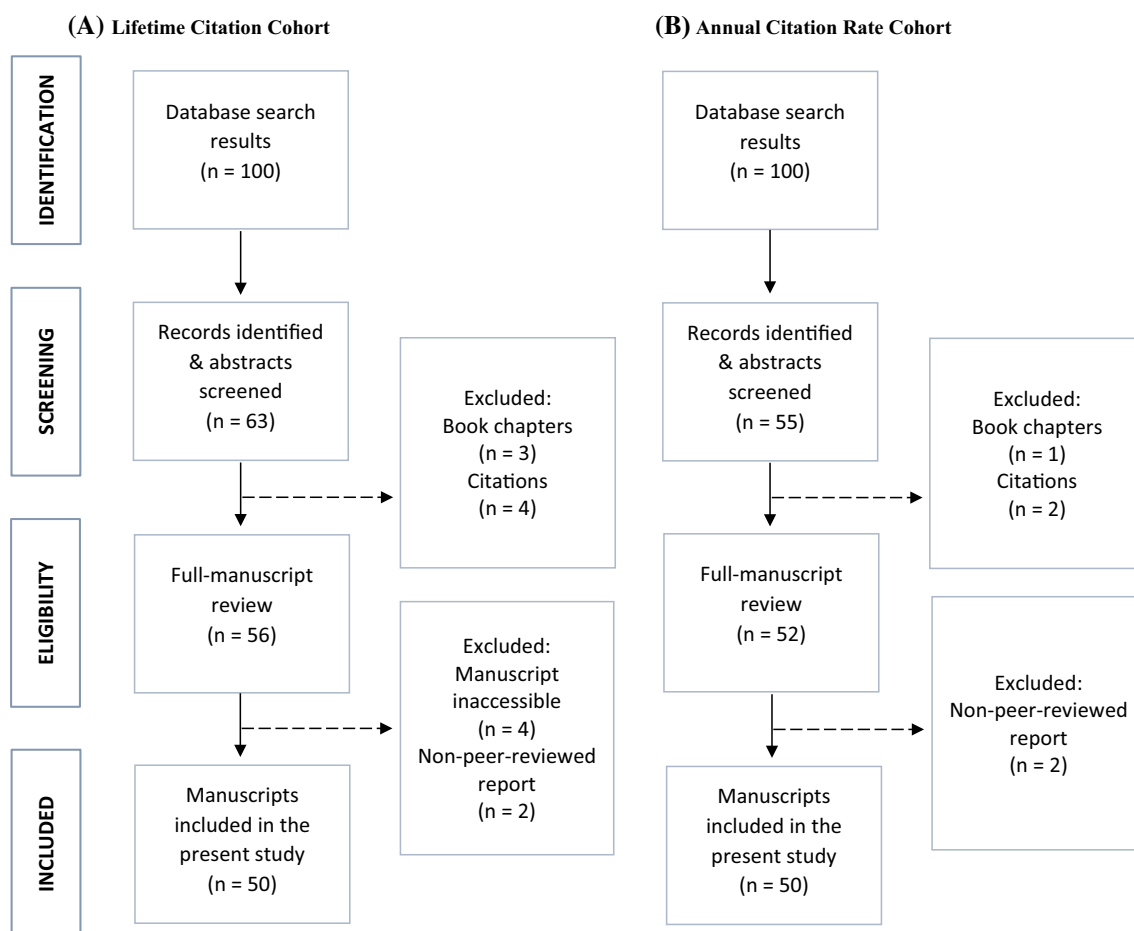
and annual citations—revealed that there were 24 publications (24/50, 48.0 %) identified by both citation groups.

All of the papers with the most lifetime citations were published during a 50-year time period (1954–2008) (see Fig. 2). The number of highly cited articles increased significantly after 1995. Most SCI papers with the highest annual citation rates were published over a 15-year span at the onset of the 1990s. The lifetime and annual citation rate cohorts were, respectively, authored by average of 6.0 and 7.9 collaborators.

## Classification of papers by category

### *Pathology/natural history*

The most significant research interest, this category included any papers characterizing exclusively the natural course and processes of the injury. There were 20 (20/50, 40.0 %) articles in this category of the most frequently cited articles in SCI. The majority of the articles (15/20, 75.0 %) dealt with animal subjects, a smaller number (3/



**Fig. 1** Flow diagram representing the study selection process for the **a** lifetime cohort and **b** annual citation rate cohort

**Table 1** SCI publications with the highest lifetime citation rates ( $n = 50$ )

Rank	First author	Study title	Year of publication	Number of citations	Topic/focus
1	M.B. Bracken	A randomized, controlled trial of methylprednisolone or naloxone in the treatment of acute spinal-cord injury: results of the second national acute spinal cord injury...	1990	2395	Treatment
2	E.J. Bradbury	Chondroitinase ABC promotes functional recovery after spinal cord injury	2002	1534	Treatment (review)
3	M.B. Bracken	...hours or tirilazad mesylate for 48 h in the treatment of acute spinal cord injury: results of the third national acute spinal cord injury randomized controlled trial	1997	1335	Treatment
4	C.H. Tator	Review of the secondary injury theory of acute spinal cord trauma with emphasis on vascular mechanisms	1991	1142	Pathology/natural history (review)
5	M.J. Crowe	Apoptosis and delayed degeneration after spinal cord injury in rats and monkeys	1997	978	Pathology/natural history (review)
6	H.S. Keirstead	Human embryonic stem cell-derived oligodendrocyte progenitor cell transplants remyelinate and restore locomotion after spinal cord injury	2005	934	Treatment
7	L.H.S. Sekhon	Epidemiology, demographics, and pathophysiology of acute spinal cord injury	2001	867	Epidemiology (review)
8	Y.D. Teng	Functional recovery following traumatic spinal cord injury mediated by a unique polymer scaffold seeded with neural stem cells	2002	813	Treatment (review)
9	X.Z. Liu	Neuronal and glial apoptosis after traumatic spinal cord injury	1997	813	Pathology/natural history
10	J.R. Faulkner	Reactive astrocytes protect tissue and preserve function after spinal cord injury	2004	813	Pathology/natural history (review)
11	T. Schallert	CNS plasticity and assessment of forelimb sensorimotor outcome in unilateral rat models of stroke, cortical ablation, parkinsonism and spinal cord injury	2000	806	Pathology/natural history (review)
12	B.S. Bregman	Recovery from spinal cord injury mediated by antibodies to neurite growth inhibitors	1995	729	Treatment (review)
13	P. Lu	Neural stem cells constitutively secrete neurotrophic factors and promote extensive host axonal growth after spinal cord injury	2003	727	Pathology/natural history (review)
14	P.G. Popovich	Cellular inflammatory response after spinal cord injury in sprague? Dawley and Lewis rats	1997	712	Pathology/natural history (review)
15	M.B. Bracken	Methylprednisolone or naloxone treatment after acute spinal cord injury: 1-year follow-up data: results of the second National Acute Spinal Cord Injury Study	1992	686	Treatment
16	M. Chopp	Spinal cord injury in rat: treatment with bone marrow stromal cell transplantation	2000	680	Treatment (review)
17	A.S. Rivlin	Objective clinical assessment of motor function after experimental spinal cord injury in the rat	1977	639	Methods (review)
18	J. Michael	Recent trends in mortality and causes of death among persons with spinal cord injury	1999	594	Predictor of outcome (review)
19	M. Wyndaele	Incidence, prevalence and epidemiology of spinal cord injury: what learns a worldwide literature survey?	2006	582	Epidemiology
20	R. Grill	Cellular delivery of neurotrophin-3 promotes corticospinal axonal growth and partial functional recovery after spinal cord injury	1997	582	Pathology/natural history (review)
21	K.A. Moore	Partial peripheral nerve injury promotes a selective loss of GABAergic inhibition in the superficial dorsal horn of the spinal cord	2002	571	Pathology/natural history
22	D.D. Pearse	cAMP and Schwann cells promote axonal growth and functional recovery after spinal cord injury	2004	545	Pathology/natural history
23	D. Pang	Spinal cord injury without radiographic abnormalities in children	1982	542	Pathology/natural history
24	M. Celik	Erythropoietin prevents motor neuron apoptosis and neurologic disability in experimental spinal cord ischemic injury	2002	527	Pathology/natural history (review)

**Table 1** continued

Rank	First author	Study title	Year of publication	Number of citations	Topic/focus
25	S. Thuret	Therapeutic interventions after spinal cord injury	2006	524	Methods (review)
26	P.G. Popovich	Depletion of hematogenous macrophages promotes partial hindlimb recovery and neuroanatomical repair after experimental spinal cord injury	1999	519	Pathology/natural history (review)
27	O. Raineteau	Plasticity of motor systems after incomplete spinal cord injury	2001	515	Pathology/natural history (review)
28	R.C. Schneider	The syndrome of acute central cervical spinal cord injury: with special reference to the mechanisms involved in hyperextension injuries of cervical spine	1954	494	Predictor of outcome
29	F.H. Geisler	Recovery of motor function after spinal-cord injury—a randomized, placebo-controlled trial with GM-1 ganglioside	1991	482	Treatment
30	A.L. Behrman	Locomotor training after human spinal cord injury: a series of case studies	2000	469	Treatment
31	M.B. Bracken	...or tirilazad mesylate administration after acute spinal cord injury: 1-year follow-up: results of the third national acute spinal cord injury randomized controlled trial	1998	464	Treatment
32	A. Wernig	Laufband locomotion with body weight support improved walking in persons with severe spinal cord injuries	1992	457	Treatment (review)
33	M.B. Bracken	Efficacy of methylprednisolone in acute spinal cord injury	1984	456	Treatment
34	S. Neumann	Regeneration of dorsal column fibers into and beyond the lesion site following adult spinal cord injury	1999	450	Pathology/natural history (review)
35	R.J. Hurlbert	Methylprednisolone for acute spinal cord injury: an inappropriate standard of care	2000	433	Methods (review)
36	D.M. Basso	Basso mouse scale for locomotion detects differences in recovery after spinal cord injury in five common mouse strains	2006	433	Assessment measure
37	E. Emery	Apoptosis after traumatic human spinal cord injury	1998	432	Pathology/natural history
38	P.J. Siddall	A longitudinal study of the prevalence and characteristics of pain in the first 5 years following spinal cord injury	2003	430	Epidemiology
39	S. Karimi-Abdolrezaee	Delayed transplantation of adult neural precursor cells promotes remyelination and functional neurological recovery after spinal cord injury	2006	428	Treatment (review)
40	S. Okada	Conditional ablation of Stat3 or Socs3 discloses a dual role for reactive astrocytes after spinal cord injury	2006	426	Pathology/natural history (review)
41	W.D. Kalsbeek	The national head and spinal cord injury survey: major findings.	1980	421	Epidemiology (review)
42	R.J. Dumont	Acute spinal cord injury, part I: pathophysiologic mechanisms	2001	420	Pathology/natural history (review)
43	W.O. McKinley	Long-term medical complications after traumatic spinal cord injury: a regional model systems analysis	1999	417	Epidemiology (review)
44	J.R. Bethea	Traumatic spinal cord injury induces nuclear factor- $\kappa$ B activation	1998	417	Treatment (review)
45	A. Gorio	Recombinant human erythropoietin counteracts secondary injury and markedly enhances neurological recovery from experimental spinal cord trauma	2002	416	Treatment (review)
46	D.P. Stirling	Minocycline treatment reduces delayed oligodendrocyte death, attenuates axonal dieback, and improves functional outcome after spinal cord injury	2004	406	Treatment (review)
47	L.L. Jones	NG2 is a major chondroitin sulfate proteoglycan produced after spinal cord injury and is expressed by macrophages and oligodendrocyte progenitors	2002	401	Pathology/natural history (review)
48	H.L. Frankel	Long-term survival in spinal cord injury: a 50 year investigation	1998	398	Predictor of outcome

**Table 1** continued

Rank	First author	Study title	Year of publication	Number of citations	Topic/focus
49	V.M. Tysseling-Mattiace	Self-assembling nanofibers inhibit glial scar formation and promote axon elongation after spinal cord injury	2008	397	Treatment
50	D.J. Donnelly	Inflammation and its role in neuroprotection, axonal regeneration and functional recovery after spinal cord injury	2008	396	Pathology/natural history (review)

20, 15.0 %) used both humans and animals and humans were the focus in two articles (2/20, 10.0 %).

Ten of the pathological studies (10/50, 20.0 %) in SCI were ranked among the top 50 papers with the highest annual citation rates. Of the 50 SCI articles with the highest annual citation rates, the subject of 21 (42.0 %) was pathology. Similarly, the majority of the pathological papers in this cohort used animal models of injury (14/21, 66.7 %) while seven studies (7/21, 33.3 %) used both animal and human models.

#### Treatment

Papers in this category assigned exposures or interventions for SCI. There were 20 papers (20/50, 40.0 %) in the top 50 articles in this category. The articles primarily involved human subjects (10/18, 55.6 %), followed by seven treatment studies using animal subjects (7/18, 38.9 %) and one using both human and animal samples (1/18, 5.6 %). A smaller number of the treatment studies (6/18, 33.3 %) were randomized control trials. Most treatment articles used molecular therapies (10/18, 55.6 %).

There were 21 studies (21/50, 42.0 %) belonging to the treatment group with the most annual citation counts. Moreover, nine in this group (9/50, 18.0 %) garnered a position amongst the top 50 SCI papers with the highest annual citation rates. Three randomized control trials (3/50, 6.0 %) were found among the SCI treatment studies with the highest annual citation rates. The majority of these papers focused on cellular interventions and used mostly animal models of injury (10/19, 52.6 %). Four papers (4/19, 21.1 %) used human subjects and five (5/19, 26.3 %) used both humans and animals.

#### Methods

While not assigning interventions or treatments, papers in this category discussed or theorized therapies for SCI. One paper in the SCI papers with the highest lifetime citations was among the group with the highest annual citation rates (1/50, 2.0 %).

#### Predictor of outcome

This category comprised articles investigating causal relationships between a variable and outcome at a later point. Out of the 50 top-cited SCI articles, three (3/50, 6.0 %) studied predictors of outcome. Two of the studies (2/3, 66.7 %) used SCI (or its features) as a predictor (i.e., independent variable) of clinical outcome, while the other used SCI as an outcome (i.e., dependent variable) and examined factors that predicted SCI. All these studies used human subjects. One of the studies (1/3, 33.3 %) used retrospective cohorts and was a review assessing the survivorship after SCI, while one was a comparative study (1/3, 33.3 %) and the latter assessed features of secondary injury of the spinal cord (33.3 %).

One of the articles (1/3, 33.3 %) was common between the 50 papers with the highest lifetime and annual citations and was the only of its type in the papers with the most annual citations. It investigated SCI on human subjects.

#### Epidemiology

The 50 most-cited articles in SCI articles comprised three epidemiological studies (5/50, 10 %). Similarly, four of the 50 articles (5/50, 10.0 %) with the highest annual citations were studies in the epidemiology of SCI.

#### Assessment measure

We extended studies in this category to publications dealing with any aspect of SCI assessment, such as descriptions and classification of the illness as well as measurements of severity. The fewest of any category, there was one study (1/50, 2.0 %) focused on assessment measures from the group of papers with the greatest lifetime citations. The study developed a rating scale of idiosyncratic recovery in mild-to-severe SCI in mouse strains. It subsequently assessed the face, predictive and concurrent validities of the scale in a comparative study of inter-strain differences. The paper was one of two papers (1/2, 50.0 %) among the 50 articles with the highest annual citation rates in SCI. The other assessment measure paper in the cohort of papers

**Table 2** SCI publications with the highest annual citation rates ( $n = 50$ )

Rank	First author	Study title	Year of publication	Number of citations	Annual citation rate (citations/year)	Topic/focus
1	E.J. Bradbury	Chondroitinase ABC promotes functional recovery after spinal cord injury	2002	1541	118.54	Treatment (review)
2	M.B. Bracken	A randomized, controlled trial of methylprednisolone or naloxone in the treatment of acute spinal-cord injury: results of the second national acute spinal cord injury...	1990	2406	96.24	Treatment
3	H.S. Keirstead	Human embryonic stem cell-derived oligodendrocyte progenitor cell transplants remyelinate and restore locomotion after spinal cord injury	2005	939	93.9	Treatment
4	S. David	Repertoire of microglial and macrophage responses after spinal cord injury	2011	313	78.25	Pathology/natural history (review)
5	J.R. Faulkner	Reactive astrocytes protect tissue and preserve function after spinal cord injury	2004	825	75	Pathology/natural history (review)
6	M.B. Bracken	...hours or tirilazad mesylate for 48 h in the treatment of acute spinal cord injury: results of the third national acute spinal cord injury randomized controlled trial	1997	1341	74.5	Treatment
7	R. van den Brand	Restoring voluntary control of locomotion after paralyzing spinal cord injury	2012	211	70.33	Treatment
8	M. Wyndaele	Incidence, prevalence and epidemiology of spinal cord injury: what learns a worldwide literature survey?	2006	593	65.89	Epidemiology
9	P. Lu	Long-distance growth and connectivity of neural stem cells after severe spinal cord injury	2012	193	64.33	Pathology/natural history (review)
10	Y.D. Teng	Functional recovery following traumatic spinal cord injury mediated by a unique polymer scaffold seeded with neural stem cells	2002	818	62.92	Treatment (review)
11	L.H.S. Sekhon	Epidemiology, demographics, and pathophysiology of acute spinal cord injury	2001	872	62.29	Epidemiology (review)
12	O. Tsuji	Therapeutic potential of appropriately evaluated safe-induced pluripotent stem cells for spinal cord injury	2010	310	62	Treatment (review)
13	P. Lu	Neural stem cells constitutively secrete neurotrophic factors and promote extensive host axonal growth after spinal cord injury	2003	731	60.92	Treatment (review)
14	M.J. Devivo	Epidemiology of traumatic spinal cord injury: trends and future implications	2012	178	59.33	Epidemiology (review)
15	S. Thuret	Therapeutic interventions after spinal cord injury	2006	529	58.78	Methods (review)
16	W. Tetzlaff	A systematic review of cellular transplantation therapies for spinal cord injury	2011	235	58.75	Methods (review)
17	R. Shechter	Infiltrating blood-derived macrophages are vital cells playing an anti-inflammatory role in recovery from spinal cord injury in mice	2009	349	58.17	Pathology/natural history (review)
18	V.M. Tysseling-Mattiace	Self-assembling nanofibers inhibit glial scar formation and promote axon elongation after spinal cord injury	2008	402	57.43	Treatment
19	D.J. Donnelly	Inflammation and its role in neuroprotection, axonal regeneration and functional recovery after spinal cord injury	2008	397	56.71	Pathology/natural history (review)
20	M.J. Crowe	Apoptosis and delayed degeneration after spinal cord injury in rats and monkeys	1997	985	54.72	Pathology/natural history (review)
21	T. Schallert	CNS plasticity and assessment of forelimb sensorimotor outcome in unilateral rat models of stroke, cortical ablation, parkinsonism and spinal cord injury	2000	813	54.2	Pathology/natural history (review)
22	D.D. Pearse	cAMP and Schwann cells promote axonal growth and functional recovery after spinal cord injury	2004	549	49.91	Pathology/natural history

**Table 2** continued

Rank	First author	Study title	Year of publication	Number of citations	Annual citation rate (citations/year)	Topic/focus
23	D.M. Basso	Basso Mouse Scale for locomotion detects differences in recovery after spinal cord injury in five common mouse strains	2006	441	49	Assessment measure
24	S. Nori	Grafted human-induced pluripotent stem-cell-derived neurospheres promote motor functional recovery after spinal cord injury in mice	2011	194	48.5	Treatment (review)
25	S. Okada	Conditional ablation of Stat3 or Socs3 discloses a dual role for reactive astrocytes after spinal cord injury	2006	432	48	Treatment (review)
26	C.H. Tator	Review of the secondary injury theory of acute spinal cord trauma with emphasis on vascular mechanisms	1991	1151	47.96	Pathology/natural history (review)
27	S. Karimi-Abdolrezaee	Delayed transplantation of adult neural precursor cells promotes remyelination and functional neurological recovery after spinal cord injury	2006	429	47.67	Treatment (review)
28	J.E. Herrmann	STAT3 is a critical regulator of astrogliosis and scar formation after spinal cord injury	2008	325	46.43	Pathology/natural history
29	M. Chopp	Spinal cord injury in rat: treatment with bone marrow stromal cell transplantation	2000	684	45.6	Treatment (review)
30	X.Z. Liu	Neuronal and glial apoptosis after traumatic spinal cord injury	1997	818	45.44	Pathology/natural history
31	F. Hellal	Microtubule stabilization reduces scarring and causes axon regeneration after spinal cord injury	2011	181	45.25	Pathology/natural history (review)
32	J.W. Fawcett	Guidelines for the conduct of clinical trials for spinal cord injury as developed by the ICCP panel: spontaneous recovery after spinal cord injury and statistical power...	2007	360	45	Assessment measure (review)
33	K.A. Moore	Partial peripheral nerve injury promotes a selective loss of GABAergic inhibition in the superficial dorsal horn of the spinal cord	2002	575	44.23	Pathology/natural history
34	G. Courtine	Recovery of supraspinal control of stepping via indirect propriospinal relay connections after spinal cord injury	2008	306	43.71	Treatment
35	B.C. Hains	Activated microglia contribute to the maintenance of chronic pain after spinal cord injury	2006	369	41	Pathology/natural history
36	M. Celik	Erythropoietin prevents motor neuron apoptosis and neurologic disability in experimental spinal cord ischemic injury	2002	530	40.77	Pathology/natural history (review)
37	K. Meletis	Spinal cord injury reveals multilineage differentiation of ependymal cells	2008	285	40.71	Pathology/natural history
38	J.W. Rowland	Current status of acute spinal cord injury pathophysiology and emerging therapies: promise on the horizon	2008	279	39.86	Pathology/natural history (review)
39	P.G. Popovich	Cellular inflammatory response after spinal cord injury in Sprague-Dawley and Lewis rats	1997	715	39.72	Pathology/natural history
40	F. Fregni	A sham-controlled, phase II trial of transcranial direct current stimulation for the treatment of central pain in traumatic spinal cord injury	2006	356	39.56	Treatment
41	J. Michael	Recent trends in mortality and causes of death among persons with spinal cord injury	1999	600	37.5	Predictor of outcome (review)
42	D.P. Stirling	Minocycline treatment reduces delayed oligodendrocyte death, attenuates axonal dieback, and improves functional outcome after spinal cord injury	2004	410	37.27	Treatment (review)



**Table 2** continued

Rank	First author	Study title	Year of publication	Number of citations	Annual citation rate (citations/year)	Topic/focus
43	K.D. Beck	Quantitative analysis of cellular inflammation after traumatic spinal cord injury: evidence for a multiphasic inflammatory response in the acute to chronic environment	2010	186	37.2	Pathology/natural history
44	O. Raineteau	Plasticity of motor systems after incomplete spinal cord injury	2001	518	37	Pathology/natural history (review)
45	M.E.L. Van den Berg	Incidence of spinal cord injury worldwide: a systematic review	2010	184	36.8	Epidemiology (review)
46	B.S. Bregman	Recovery from spinal cord injury mediated by antibodies to neurite growth inhibitors	1995	730	36.5	Treatment (review)
47	J. Sharp	Human embryonic stem cell-derived oligodendrocyte progenitor cell transplants improve recovery after cervical spinal cord injury	2010	182	36.4	Treatment (review)
48	P.J. Siddall	A longitudinal study of the prevalence and characteristics of pain in the first 5 years following spinal cord injury	2003	435	36.25	Epidemiology
49	P. Boulenguez	Down-regulation of the potassium-chloride cotransporter KCC2 contributes to spasticity after spinal cord injury	2010	181	36.2	Pathology/natural history
50	M. Wirz	Effectiveness of automated locomotor training in patients with chronic incomplete spinal cord injury: a multicenter trial	2005	359	35.9	Treatment (review)

with the most annual citations used human models of injury.

## Discussion

The purpose of this review was to identify well-developed areas of the SCI literature as well as the direction in which this field is heading through a citation analysis. This study compliments SCI systematic reviews and meta-analyses by demonstrating the influence of individual publications in the field.

In publications with the most lifetime citations and highest annual citation rates, animal models of investigation were commonly used (Table 3). More than half of the publications in the highest annual citation rate group were reviews (56.0 %), indicating that many articles that are currently being cited most often present secondary data (Table 3). A greater proportion of publications in the highest citation rate cohort were published outside of the United States than in the lifetime citation cohort (Table 3), suggesting that SCI has gained more international research interest.

The most researched sub-fields of SCI are discussed below; categories comprised of too few publications (i.e., >5) are not discussed due to the limited amount of available data.

## Pathology/natural history

Studies examining the pathology and/or natural history of SCI are an area of significant research interest as demonstrated by the predominance of this category in both citation cohorts. Approximately two-fifths of each cohort was allotted to studies investigating SCI pathology. In view of the step-wise nature of SCI, the observation of focused research interests in pathology suggest that developing our understanding of it is inextricably connected to the prevention, treatment and management of SCI. Research into the pathology and/or natural history of SCI is likely to continue to be common, as this will be necessary to advance and develop treatments for this injury; indeed, recent systematic reviews have identified gaps in knowledge that remain to be bridged [18].

## Treatment

Almost two-fifths of both citation cohorts examined treatment of SCI, demonstrating the research interest in this sub-field. Extensive and varied research efforts into treatment of SCI are not unexpected, given that SCI is associated with a broad range of sequela that require clinical attention [2]. Further, given that treatment approaches for SCI vary considerably (for example, motor impairments may be treated with electrical stimulation, cell therapies,

**Table 3** Characterization of the two cohorts

	SCI publications with the most lifetime citations <i>n</i> (%)	SCI publications with the highest annual citation rates <i>n</i> (%)
Sample		
Animal	25 (50.0)	25 (50.0)
Human	20 (40.0)	10 (20.0)
Both	5 (10.0)	15 (30.0)
Design		
Review	31 (58.0)	33 (66.0)
Animal model	3 (6.0 %)	9 (18.0)
Randomized control trial	7 (14.0 %)	3(6.0)
Comparative	3 (6.0)	4 (8.0)
Cohort	5 (10.0)	1 (2.0)
Case-series	1 (2.0)	0 (0.0)
Country of correspondence		
United States of America	36 (72.0)	25 (50.0)
Canada	4 (8.0)	6 (12.0)
United Kingdom	4 (8.0)	3 (6.0)
Switzerland	2 (4.0)	3 (6.0)
Japan	0 (0.0)	3 (6.0)
Australia	1 (2.0)	2 (4.0)
Turkey	2 (4.0)	1 (2.0)
Belgium	1 (2.0)	1 (2.0)
China	0 (0.0)	1 (2.0)
France	0 (0.0)	1 (2.0)
Germany	0 (0.0)	1 (2.0)
Israel	0 (0.0)	1 (2.0)
Spain	0 (0.0)	1 (2.0)
Sweden	0 (0.0)	1 (2.0)
Product of international collaboration	4 (8.0)	7 (14.0)
Average number of citations	640.9 ± 353.0	554.9 ± 409.4
Average number of authors	6.0 ± 4.0	7.9 ± 5.1
Citation range	2395–396	2406–178
Average year of publication	1998 ± 9.2	2005 ± 5.4

pharmacological intervention, or standard clinician-based physical rehabilitation programs [19], a breadth of treatment options need to be researched. Treatment is expected to be a continued focus in SCI as efforts to develop efficacious therapies for this injury persist.

### Epidemiology

Epidemiological studies comprised approximately 10 % of both citation categories. As in any field, ongoing epidemiological research is necessary to frame the scale of the subject of study. However, future epidemiological research in SCI will be important for understanding how increased access to motor vehicles in developing nations will contribute to an increase in SCI globally. Further, with efforts to collect ‘big data’ on SCI [8], estimates of the incidence and prevalence of

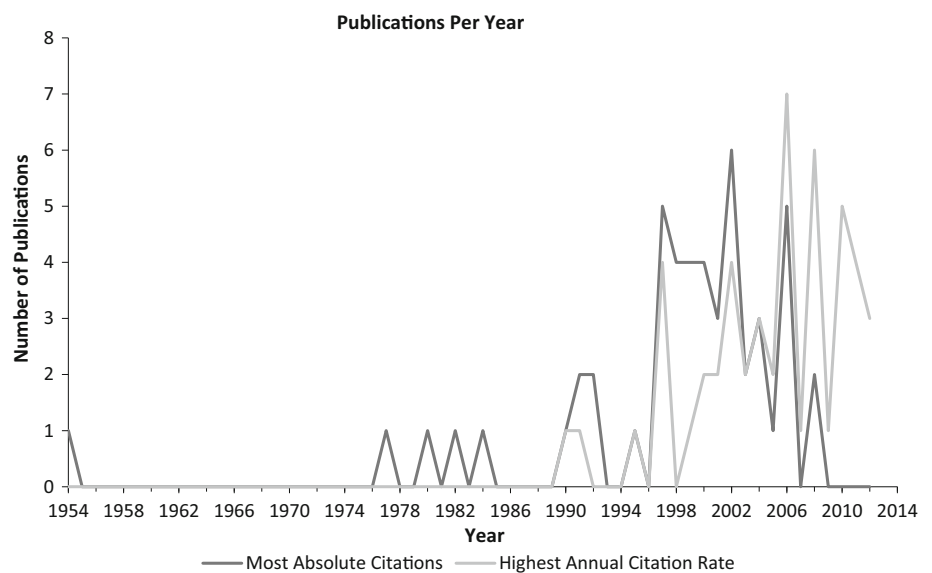
SCI will become more reflective of the global burden of this injury. Future epidemiologic research will be needed to determine the effect of injury prevention initiatives (such as educational interventions in sports or improved automotive safety standards) will affect the scale of SCI.

### Limitations

There are several limitations to this study, fundamental ones of which lie in the attribution of scientific influence on the sole basis of citation analysis. Due to the large volume of literature on SCI, there could be variance in the search results obtained from different literature search programs. Made in the interest of disciplinary inclusivity, our choice to use Google Scholar as the only search engine platform

**Table 4** Categorical division of the two cohorts

Type	SCI publications with the most lifetime citations <i>n</i> (%)	SCI publications with the highest annual citation rates <i>n</i> (%)
Treatment	20 (40.0)	21 (42.0)
Cellular	6 (12.0)	10 (20.0)
Molecular	10 (20.0)	6 (12.0)
Palliative	0 (0.0)	1 (2.0)
Rehabilitative	2 (4.0)	2 (4.0)
Pathology/natural history	20 (40.0)	21 (42.0)
Functional	1 (2.0)	1 (2.0)
Gross	1 (2.0)	1 (2.0)
Histological	9 (18.0)	9 (18.0)
Physiological	9 (18.0)	10 (20.0)
Epidemiology	5 (10.0)	5 (10.0)
Methods		
Clinical	1 (2.0)	0 (0.0)
Predictor of outcome	3 (6.0)	1 (2.0)
Mortality	2 (4.0)	1 (2.0)
Neurological	1 (2.0)	0 (0.0)
Assessment measure	1 (2.0)	2 (4.0)

**Fig. 2** Organization of publications comprising both cohorts by year

may have excluded other relevant and influential papers. The likelihood of inter-database variation is further amplified by the large volume of literature on SCI, which may potentially alter the search outcomes. Similarly, our choice of search terms, albeit focused and restricted to English-published results may have impeded our access to influential articles listed under different search terms or in languages other than English. As well, this may have caused the higher number of articles observed from the USA, UK and Canada, exaggerating the contribution of western countries to the field and inaccurately representing global impact on the subject.

Also, the number 50 represents an arbitrary number of articles, which we chose to examine. Finally, while considerable change is unlikely since the time we conducted the literature search, recent citations of papers in study may change the rankings of top-cited articles and bibliometric data we report. Based on the cross-sectional nature of this review, there was little opportunity for a longitudinal study. It should be noted that other bibliometric measures of citation impact, ones that could be of additional use in future studies of this field, were not assessed in this study. One such example, the m-index, exploits the high and low productivity periods of a researcher's career to reflect their

current scientific utility [20]. As well, compensating for the non-entropic dispersal of citations, the s-index avoids some of the drawbacks of the h-index. Alternatively, Smith suggests the coupled use of non-bibliometric information with bibliometric data (i.e., citation counts) as an alternative indicator of quality [20]. Further citation analyses with alternative impact measures or assessments of citation trends may thus be useful in observing the evolution and emerging trends of this branch of knowledge.

## Conclusion

This bibliometric study identified and characterized the most influential papers in SCI. Our findings show the impact that the articles with the most absolute citations and the articles with the most annual citations have had on the scientific community and the field of SCI. Pathology and/or natural history, treatment, and epidemiology are the areas of primary focus in SCI research. Our findings as well as other indications of influential scholarship could be considered in tandem with patterns and trends over time to best ascertain the history and development of research in the SCI field.

## Compliance with ethical standards

**Conflict of interest** None to declare.

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