Original Article

Traumatic spinal cord and spinal column injuries: A bibliometric analysis of the 200 most cited articles

ABSTRACT

Study Design: Bibliometric analysis.

Objectives: This study aimed to highlight the 200 most influential articles related to traumatic spinal cord and spinal column injuries and provide an insight of past and current global trends in spinal trauma research.

Methods: The Web of Science database was used to identify the top 200 most cited articles on the topic of traumatic spinal cord injury (SCI) and spinal column injuries between using a prespecified algorithm. The articles were manually reviewed; bibliometrics were collected on title, first and corresponding authors' country, institution, journal, publication year, and citation data.

Results: The search string yielded 30,551 articles during 1977–2019. The average time from the publication was 19.5 years. A total of 1356 authors contributed to 67 different journals, the top 200 most cited articles amassing a total of 88,115 citations and an average 440.6 citations. The United States of America (USA) contributed the most with 110 articles; the top institution was the University of Toronto with 34 publications. Most studies focused on basic science research on SCI. Keyword analysis revealed the most commonly used keywords: SCI, inflammation, apoptosis, incidence/prevalence, and regeneration; four word-clusters were identified. Institutions from the USA and Canada collaborated the most and two major and two minor institutional collaboration subnetworks were identified. Co-citation analysis detected three main clusters of authors.

Conclusion: This overview of the most cited articles on traumatic spinal cord and spinal column injuries provides insight into the international spinal trauma community and the terrain in this field, potentially acting as a springboard for further collaboration development.

Keywords: Bibliometric, spinal column injury, spinal cord injury, spinal injury, spinal trauma

INTRODUCTION

The majority of injuries to the spinal column and spinal cord occur as a result of blunt or penetrating trauma in the context of road traffic accidents, falls, sport-related injuries, and assaults.[1] Traumatic spinal cord injury (tSCIs) and/or traumatic spinal column injuries can present high mortality and morbidity rates involving various degree of motor, sensory and/or autonomic dysfunction depending on severity, location, and management options.[1-3] The complex mechanistic, anatomical and biomechanical characteristics of the spinal column, combined with the large number of injury patterns according to the level of injury and classification system used, have inevitably led to challenges in reproducibility of preclinical injury models and clinical translation.[1,4] This has created huge variability in treatment

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options, patient outcomes, education and research output and emphasizes the need for the continuous development of universally accepted guidelines and experimental protocols. Ultimately, spinal trauma has been widely recognized as a global health priority in the last decade owing to the huge physical, psychological, socioeconomic, and work-related burden; it places on patients, their families, health-care systems, and society.[5-8]

The devasting consequences of SCI including loss of functional independence, high rates of mortality and morbidity, and the combination with staggering financial health-care costs, signify the pressing need for better prevention and treatment strategies.[9] Most acute spinal injuries have been reported to happen in healthy, young males.[1] However, provided the global population will continue to rise, the absolute number of patients with spinal injuries is also expected to increase, particularly in the elderly where more chronic spinal injury is prevalent instead, such as degenerative cervical myelopathy.[10] Given the shifts in trends and variations according to age, regional, demographic and cultural backgrounds, and injury mechanisms, it is imperative to monitor and further analyze these trends to help coordinate and plan future research and strategies on a global scale.

Aim

The aim of this current bibliometric analysis is to highlight and present the 200 most prominent and influential research articles on the topic of traumatic spinal cord and traumatic spinal column injury to provide a more comprehensive picture of global trends in spinal injury research, valuable both to academics in the field and for advocacy, future projects, but also to inform policy-makers.

MATERIALS AND METHODS

No institutional approval and informed consent was required for this study as it constitutes a literature-based analysis.

Database search strategy

In July 2022, a prespecified, title-specific algorithm was used to identify the articles in the Web of Science (WoS) database on the topic of traumatic spinal cord and traumatic spinal column injuries. The exact algorithm used is available in full in Appendix 1. The following language and category filters were used: (1) Language filter: English language, (2) Article category filter: "Article" (original works), "Review." This resulted in the automatic exclusion of other article categories such as letters to the editor, errata and conference abstracts. After sorting by total citation count, the 200 most cited works were manually chosen, after the exclusion of articles that were specifically concerned with the topic of osteoporosis-related fractures (management not usually performed by surgical specialties). The bibliometric data of the 200 most cited articles were extracted in a ".txt" file form.

Data analysis

The bibliometric analysis of the 200 most cited studies was performed using the bibliometrix R package and the biblioshiny web application.[11] The titles and abstracts of the chosen articles were manually reviewed to find the total citation count as per the "Google Scholar" database and to sort the articles in one of the following thematic categories:

(1) Basic science studies on SCI (including pathophysiology and experimental models); (2) basic science studies on spinal column injuries (including pathophysiology, experimental models); (3) Epidemiology and classification studies on SCI; (4) Epidemiology and classification studies on spinal column injuries; (5) Studies on the pre-hospital management of SCI; (6) Studies on the pre-hospital management of spinal column injuries; (7) Studies on the in-hospital management of SCI (including surgical and nonsurgical management); (8) Studies on the in-hospital management of spinal column injuries (including surgical and non-surgical management); (9) Studies on the rehabilitation and long-term management of patients with SCI; and (10) Studies on the rehabilitation and long-term management of patients with spinal column injuries.

RESULTS

Database search

The WoS database search yielded 30,551 results after the application of the aforementioned filters. Subsequently, the authors manually reviewed the titles and abstracts of the most cited articles and excluded studies that were solely focusing on the topic of osteoporotic fractures, resulting in the 200 most cited articles concerning spinal cord and spinal column trauma.

Basic article characteristics

The articles were published between 1977 and 2019 with an average time from publication of 19.5 years. More than half of the articles (111/200, 55.5%) were published during the 1997–2006 decade. Overall, 1356 authors contributed to those articles, published in 67 scientific journals. The 200 most cited articles amassed a total of 88,115 citations with an average number of 440.6 citations per document. The majority of the articles were original studies (161/200, 80.5%), while the rest were literature reviews (39/200, 19.5%). Table 1 presents the main characteristics of the 200 most cited articles.

Table 1: Basic characteristics of the 200 most cited articles on the topic

Rank according to WoS citation count	Title	First author	Journal	YOP	Corresponding author's country	Total citations WoS	Total citations Google Scholar	Total citations per year (based on WoS citations)
1	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 Study	Bracken	*NEJM*	1990	US	1839	3407	55.73
2	Chondroitinase ABC promotes functional recovery after spinal cord injury	Bradbury	*Nature*	2002	UK	1739	2648	82.81
3	Reference for the 2011 revision of the International Standards for Neurological Classification of Spinal Cord Injury	Kirshblum	*J Spinal Cord Medicine*	2011	US	1505	543	125.42
4	The three column spine and its significance in the classification of acute thoracolumbar spinal injuries	Denis	*Spine*	1983	US	1350	4534	33.75
5	International Standards for Neurological and Functional Classification of Spinal Cord Injury	Maynard	*Spinal Cord*	1997	US	1293	2228	49.73
6	Graded histological and locomotor outcomes after spinal cord contusion using the NYU weight-drop device versus transection	Basso	*Experimental Neurology*	1996	US	1157	1825	42.85
7	Review of the secondary injury theory of acute spinal cord trauma with emphasis on vascular mechanisms	Tator	*J Neurosurgery*	1991	Canada	1141	1876	35.66
8	Targeting recovery: Priorities of the spinal cord-injured population	Anderson	*J Neurotrauma*	2004	US	1136	1854	59.79
9	Reactive astrocytes protect tissue and preserve function after spinal cord injury	Faulkner	*J Neuroscience*	2004	US	1101	1747	57.95
10	CNS plasticity and assessment of forelimb sensorimotor outcome in unilateral rat models of stroke, cortical ablation, parkinsonism and spinal cord injury	Schallert	*Neuropharmacology*	2000	US	1027	1437	44.65
11	Administration of methylprednisolone for 24 or 48 h 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	Bracken	*JAMA*	1997	US	964	2030	37.08
12	Apoptosis and delayed degeneration after spinal cord injury in rats and monkeys	Crowe	*Nature Medicine*	1997	US	921	1441	35.42
13	Human embryonic stem cell-derived oligodendrocyte progenitor cell transplants remyelinate and restore locomotion after spinal cord injury	Keirstead	*J Neuroscience*	2005	US	900	1533	50.00
14	Repertoire of microglial and macrophage responses after spinal cord injury	David	*Nat Rev Neuroscience*	2011	Canada	869	1212	72.42
15	Epidemiology, demographics, and pathophysiology of acute spinal cord injury	Sekhon	*Spine*	2001	Australia	840	1733	38.18
16	Functional recovery following traumatic spinal cord injury mediated by a unique polymer scaffold seeded with neural stem cells	Teng	*PNAS*	2002	US	751	1200	35.76
17	Neuronal and glial apoptosis after traumatic spinal cord injury	Liu	*J Neuroscience*	1997	US	743	1173	28.58
18	Therapeutic interventions after spinal cord injury	Thuret	*Nat Rev Neuroscience*	2006	UK	738	1197	43.41
19	Cellular inflammatory response after spinal cord injury in sprague-dawley and lewis rats	Popovich	*J Comparative Neurology*	1997	US	720	1084	27.69
20	Incidence, prevalence and epidemiology of spinal cord injury: What learns a worldwide literature survey?	Wyndaele	*Spinal Cord*	2006	Belgium	680	1402	40.00
21	Conditional ablation of Stat3 or Socs3 discloses a dual role for reactive astrocytes after spinal cord injury	Okada	*Nature Medicine*	2006	Japan	664	964	39.06
22	Neural stem cells constitutively secrete neurotrophic factors and promote extensive host axonal growth after spinal cord injury	Lu P	*Experimental Neurology*	2003	US	662	1127	33.10

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Rank according to WoS citation count	Title	First author	Journal	YOP	Corresponding author's country	Total citations WoS	Total citations Google Scholar	Total citations per year (based on WoS citations)
23	Inflammation and its role in neuroprotection, axonal regeneration and functional recovery after spinal cord injury	Donnelly	*Experimental Neurology*	2008	US	653	1027	43.53
24	STAT3 is a critical regulator of astrogliosis and scar formation after spinal cord injury	Herrmann	*J Neuroscience*	2008	US	623	909	41.53
25	Objective clinical assessment of motor function after experimental spinal cord injury in the rat	Rivlin	*J Neurosurgery*	1977	Canada	616	945	13.39
26	Recovery from spinal cord injury mediated by antibodies to neurite growth inhibitors	Bregman	*Nature*	1995	US	597	961	21.32
27	A longitudinal study of the prevalence and characteristics of pain in the first 5 years following spinal cord injury	Siddall	*Pain*	2003	Australia	596	955	29.80
28	A monitored contusion model of spinal cord injury in the rat	Hruner	*J Neurotrauma*	1992	US	585	871	18.87
29	Plasticity of motor systems after incomplete spinal cord injury	Raineteau	*Nat Rev Neuroscience*	2001	Switzerland	574	927	26.09
30	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 needed for therapeutic clinical trials	Fawcett	*Spinal Cord*	2007	UK	573	862	35.81
31	Early versus delayed decompression for traumatic cervical spinal cord injury: Results of the surgical timing in acute spinal cord injury study	Fehlings	*PLOS ONE*	2012	Canada	570	958	51.82
32	Spinal-cord injury	Mcdonald	*Lancet*	2002	US	570	1056	27.14
33	cAMP and Schwann cells promote axonal growth and functional recovery after spinal cord injury	Pearse	*Nature Medicine*	2004	US	558	812	29.37
34	Long-distance growth and connectivity of neural stem cells after severe spinal cord injury	Lu P	*Cell*	2012	US	557	791	50.64
35	Human neural stem cells differentiate and promote locomotor recovery in spinal cord-injured mice	Cummings	*PNAS*	2005	US	556	900	30.89
36	Botulinum-A toxin for treating detrusor hyperreflexia in spinal cord injured patients: A new alternative to anticholinergic drugs? preliminary results	Schurch	*J Urology*	2000	Switzerland	554	973	24.09
37	Infiltrating blood-derived macrophages are vital cells playing an anti-inflammatory role in recovery from spinal cord injury in mice	Shcechter	*PLOS MED*	2009	Israel	543	823	38.79
38	Recent trends in mortality and causes of death among persons with spinal cord injury*,**	De Vivo	*Arch Phys Med Rehab*	1999	US	543	1049	22.62
39	Depletion of hematogenous macrophages promotes partial hindlimb recovery and neuroanatomical repair after experimental spinal cord injury	Popovich	*Experimental Neurology*	1999	US	542	799	22.58
40	Efficacy and safety of balloon kyphoplasty compared with nonsurgical care for vertebral compression fracture: A randomized controlled trial	Wardlaw	*Lancet*	2009	UK	541	1008	38.64
41	Self-assembling nanofibers inhibit glial scar formation and promote axon elongation after spinal cord injury	Tysseling-Mattiace	*J Neuroscience*	2008	US	537	757	35.80
42	Global prevalence and incidence of traumatic spinal cord injury	Singh	*Clinical Epidemiology*	2014	Canada	536	942	59.56
43	Cellular delivery of neurotrophin-3 promotes corticospinal axonal growth and partial functional recovery after spinal cord injury	Grill	*J Neuroscience*	1997	US	534	784	20.54
44	Acute spinal cord injury, part I: Pathophysiologic mechanisms	Dumont	*Clinical Neuropharmacology*	2001	Canada	530	917	24.09

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Rank according to WoS citation count	Title	First author	Journal	YOP	Corresponding author's country	Total citations WoS	Total citations Google Scholar	Total citations per year (based on WoS citations)
45	Traumatic spinal cord injury	Ahuja	*Nat Rev Dis Primers*	2017	Canada	527	840	87.83
46	Methylprednisolone or naloxone treatment after acute spinal cord injury: 1-year follow-up data	Bracken	*J Neurosurgery*	1992	US	518	977	16.71
47	A sham-controlled, phase II trial of transcranial direct current stimulation for the treatment of central pain in traumatic spinal cord injury	Fregni	*Pain*	2006	US	498	800	29.29
48	Recovery of supraspinal control of stepping via indirect propriospinal relay connections after spinal cord injury	Courtine	*Nature Medicine*	2008	US	496	710	33.07
49	Regeneration of dorsal column fibers into and beyond the lesion site following adult spinal cord injury	Neumann	*Neuron*	1999	US	494	741	20.58
50	Restoring voluntary control of locomotion after paralyzing spinal cord injury	van den Brand	*Science*	2012	Switzerland	493	755	44.82
51	Effect of eliminating compensation for pain and suffering on the outcome of insurance claims for whiplash injury	Cassidy	*NEJM*	2000	Canada	486	864	21.13
52	Incidence, prevalence, costs, and impact on disability of common conditions requiring rehabilitation in the United States: Stroke, spinal cord injury, traumatic brain injury, multiple sclerosis, osteoarthritis, rheumatoid arthritis, limb loss, and back pain	Ma	*Arch Phys Med Rehab*	2014	US	481	877	53.44
53	The ReWalk powered exoskeleton to restore ambulatory function to individuals with thoracic-level motor-complete spinal cord injury	Esquenazi	*Am J Phys Med Rehab*	2012	US	479	823	43.55
54	The load sharing classification of spine fractures	McCormack	*Spine*	1994	US	476	1448	16.41
55	Activated microglia contribute to the maintenance of chronic pain after spinal cord injury	Hains	*J Neuroscience*	2006	US	475	654	27.94
56	Epidemiology of traumatic spinal cord injury: Trends and future implications	Devivo	*Spinal Cord*	2012	US	470	866	42.73
57	Current status of acute spinal cord injury pathophysiology and emerging therapies: Promise on the horizon	Rowland	*Neurosurgery Focus*	2008	Canada	470	811	31.33
58	Delayed transplantation of adult neural precursor cells promotes remyelination and functional neurological recovery after spinal cord injury	Karimi-Abdolrezaee	*J Neuroscience*	2006	Canada	468	731	27.53
59	Spinal cord injury in rat: Treatment with bone marrow stromal cell transplantation	Chopp	*NeurorReport*	2000	US	465	881	20.22
60	The International Standards Booklet for neurological and functional classification of spinal cord injury	Ditunno	*Paraplegia*	1994	US	462	881	15.93
61	From basics to clinical: A comprehensive review on spinal cord injury	Silva	*Progress in Neurobiology*	2014	Portugal	450	729	50.00
62	Secondary injury mechanisms in traumatic spinal cord injury: A nugget of this multiply cascade	Oyinbo	*Acta Neurobiologiae Experimentalis*	2011	Nigeria	446	761	37.17
63	Spinal cord injury reveals multilineage differentiation of ependymal cells	Meletis	*PLOS Biology*	2008	Sweden	444	671	29.60
64	Posttraumatic inflammation following spinal cord injury	Hausmann	*Spinal Cord*	2003	Switzerland	442	676	22.10
65	Glial scar borders are formed by newly proliferated, elongated astrocytes that interact to corral inflammatory and fibrotic cells via STAT3-dependent mechanisms after spinal cord injury	Wanner	*J Neuroscience*	2013	US	439	652	43.90
66	A prospective assessment of mortality in chronic spinal cord injury	Garshick	*Spinal Cord*	2005	US	430	728	23.89

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Rank according to WoS citation count	Title	First author	Journal	YOP	Corresponding author's country	Total citations WoS	Total citations Google Scholar	Total citations per year (based on WoS citations)
67	The global map for traumatic spinal cord injury epidemiology: Update 2011, global incidence rate	Lee	*Spinal Cord*	2014	Australia	429	855	47.67
68	The pathology of human spinal cord injury: Defining the problems	Norenberg	*J Neurotrauma*	2004	US	419	695	22.05
69	Experimental modeling of spinal cord injury: Characterization of a force-defined injury device	Scheff	*J Neurotrauma*	2003	US	412	608	20.60
70	Inhibition of astroglial nuclear factor kappa B reduces inflammation and improves functional recovery after spinal cord injury	Brambilla	*J Experimental Medicine*	2005	US	411	606	22.83
71	Global, regional, and national burden of traumatic brain injury and spinal cord injury, 1990–2016: a systematic analysis for the global burden of disease study 2016	James	*Lancet Neurology*	2019	US	406	397	101.50
72	The chondroitin sulfate proteoglycans neurocan, brevican, phosphacan, and versican are differentially regulated following spinal cord injury	Jones	*Experimental Neurology*	2003	US	406	651	20.30
73	P2X7 receptor inhibition improves recovery after spinal cord injury	Wang	*Nature Medicine*	2004	US	404	575	21.26
74	Microtubule stabilization reduces scarring and causes axon regeneration after spinal cord injury	Hellal	*Science*	2011	Germany	403	536	33.58
75	Locomotor training after human spinal cord injury: A series of case studies	Behmran	*Physical Therapy and Rehabilitation Therapy*	2000	US	403	773	17.52
76	Mortality, morbidity, and psychosocial outcomes of persons spinal cord injured >20 years ago	Whiteneck	*Paraplegia*	1992	US	402	777	12.97
77	The role of excitotoxicity in secondary mechanisms of spinal cord injury: A review with an emphasis on the implications for white matter degeneration	Park	*J Neurotrauma*	2004	Canada	401	633	21.11
78	Transplantation of in vitro-expanded fetal neural progenitor cells results in neurogenesis and functional recovery after spinal cord contusion injury in adult rats	Ogawa	*J Neuroscience Research*	2002	Japan	400	728	19.05
79	Recovery of motor function after spinal-cord injury – a randomized, placebo-controlled trial with GM-1 ganglioside	Geisler	*NEJM*	1991	US	398	683	12.44
80	Minocycline treatment reduces delayed oligodendrocyte death, attenuates axonal dieback, and improves functional outcome after spinal cord injury	Stirling	*J Neuroscience*	2004	Canada	394	615	20.74
81	Long-term medical complications after traumatic spinal cord injury: A regional model systems analysis	McKinley	*Arch Phys Med Rehab*	1999	US	393	715	16.38
82	Traumatic spinal cord injury induces nuclear factor-κB activation	Bethea	*J Neuroscience*	1998	US	393	583	15.72
83	NG2 is a major chondroitin sulfate proteoglycan produced after spinal cord injury and is expressed by macrophages and oligodendrocyte progenitors	Jones	*J Neuroscience*	2002	US	389	591	18.52
84	Quantitative analysis of cellular inflammation after traumatic spinal cord injury: Evidence for a multiphasic inflammatory response in the acute to chronic environment	Beck	*Brain*	2010	US	385	560	29.62
85	Cardiovascular consequences of loss of supraspinal control of the sympathetic nervous system after spinal cord injury	Teasell	*Arch Phys Med Rehab*	2000	Canada	385	671	16.74
86	A systematic review of cellular transplantation therapies for spinal cord injury	Tetzlaff	*J Neurotrauma*	2011	Canada	384	615	32.00

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Rank according to WoS citation count	Title	First author	Journal	YOP	Corresponding author's country	Total citations WoS	Total citations Google Scholar	Total citations per year (based on WoS citations)
87	Review of current evidence for apoptosis after spinal cord injury	Beattie	*J Neurotrauma*	2000	US	382	599	16.61
88	Cardiovascular disease in spinal cord injury: An overview of prevalence, risk, evaluation, and management	Myers	*Am J Phys Med Rehab*	2007	US	381	676	23.81
89	Macrophage activation and its role in repair and pathology after spinal cord injury	Gensel	*Brain Research*	2015	US	379	558	47.38
90	Cell transplantation therapy for spinal cord injury	Assinck	*Nature Neuroscience*	2017	Canada	377	519	62.83
91	Matrix metalloproteinases limit functional recovery after spinal cord injury by modulation of early vascular events	Noble	*J Neuroscience*	2002	US	373	500	17.76
92	Degenerative and regenerative mechanisms governing spinal cord injury	Profyris	*Neurobioloy of Disease*	2004	Australia	370	567	19.47
93	Spinal instability as defined by the three-column spine concept in acute spinal trauma	Denis	*Clin Orthop Relat Res*	1984	US	370	1282	9.49
94	Therapeutic potential of appropriately evaluated safe-induced pluripotent stem cells for spinal cord injury	Tsuji	*PNAS*	2010	Japan	369	598	28.38
95	AOSpine thoracolumbar spine injury classification system: Fracture description, neurological status, and key modifiers	Vaccaro	*Spine*	2013	US	368	584	36.80
96	Down-regulation of the potassium-chloride cotransporter KCC2 contributes to spasticity after spinal cord injury	Boulenguez	*Nature Medicine*	2010	France	363	536	27.92
97	Laufband locomotion with body weight support improved walking in persons with severe spinal cord injuries	Wernig	*Paraplegia*	1992	Germany	361	673	11.65
98	Grafted human-induced pluripotent stem-cell–derived neurospheres promote motor functional recovery after spinal cord injury in mice	Nori	*PNAS*	2011	Japan	359	565	29.92
99	Automated quantitative gait analysis during overground locomotion in the rat: its application to spinal cord contusion and transection injuries	Hamers	*J Neurotrauma*	2001	Netherlands	358	535	16.27
100	Spinal cord injury without radiographic abnormalities in children	Pang	*J Neurosurgery*	1982	US	358	799	8.73
101	Sensory hypersensitivity occurs soon after whiplash injury and is associated with poor recovery	Sterling	*Pain*	2003	Australia	355	536	17.75
102	Methylprednisolone or tirilazad mesylate administration after acute spinal cord injury: 1-year follow up	Bracken	*J Neurosurgery*	1998	US	354	667	14.16
103	Activation of the caspase-3 apoptotic cascade in traumatic spinal cord injury	Springer	*Nature Medicine*	1999	US	352	531	14.67
104	Targeted neurotechnology restores walking in humans with spinal cord injury	Wagner	*Nature*	2018	Switzerland	351	545	70.20
105	Autologous olfactory ensheathing cell transplantation in human spinal cord injury	Feron	*Brain*	2005	Australia	347	579	19.28
106	Spinal cord contusion in the rat: Behavioral analysis of functional neurologic impairment	Gale	*Experimental Neurology*	1985	US	347	557	9.13
107	ProNGF induces p75-mediated death of oligodendrocytes following spinal cord injury	Beattie	*Neuron*	2002	US	343	568	16.33
108	Whiplash injury	Barnsley	*Pain*	1994	Australia	343	688	11.83
109	Efficacy of methylprednisolone in acute spinal cord injury	Bracken	*JAMA*	1984	US	338	729	8.67

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110	Apoptosis after traumatic human spinal cord injury	Emery	*J Neurosurgery*	1998	US	337	637	13.48
111	The relationships among the severity of spinal cord injury, residual neurological function, axon counts, and counts of retrogradely labeled neurons after experimental spinal cord injury	Fehlings	*Experimental Neurology*	1995	Canada	336	525	12.00
112	Chapter 4 cell death in models of spinal cord injury	Beattie	*Progress in Brain Research*	2002	US	334	516	15.90
113	Update on the pathophysiology and pathology of acute spinal cord injury	Tator	*Brain Pathology*	1995	Canada	334	582	11.93
114	Quality of life and traumatic spinal cord injury	Westgren	*Arch Phys Med Rehab*	1998	Sweden	331	619	13.24
115	Evidence for spinal cord hypersensitivity in chronic pain after whiplash injury and in fibromyalgia	Banic	*Pain*	2004	Switzerland	329	542	17.32
116	Methylprednisolone for acute spinal cord injury: An inappropriate standard of care	Hurlbert	*J Neurosurgery*	2000	Canada	327	650	14.22
117	Guidelines for the conduct of clinical trials for spinal cord injury as developed by the ICCP panel: Clinical trial outcome measures	Steeves	*Spinal Cord*	2007	Canada	326	455	20.38
118	Rho activation patterns after spinal cord injury and the role of activated Rho in apoptosis in the central nervous system	Dubreuil	*J Cell Biol*	2003	Canada	326	462	16.30
119	Endogenous repair after spinal cord contusion injuries in the rat☆,☆☆	Beattie	*Experimental Neurology*	1997	US	324	495	12.46
120	Systemic deletion of the myelin-associated outgrowth inhibitor Nogo-A improves regenerative and plastic responses after spinal cord injury	Simonen	*Neuron*	2003	Switzerland	322	539	16.10
121	Effectiveness of automated locomotor training in patients with chronic incomplete spinal cord injury: A multicenter trial	Wirz	*Arch Phys Med Rehab*	2005	Switzerland	321	597	17.83
122	Spinal fractures in patients with ankylosing spinal disorders: A systematic review of the literature on treatment, neurological status and complications	Westerveld	*Eur Spine J*	2009	Netherlands	319	576	22.79
123	Chondroitinase ABC promotes sprouting of intact and injured spinal systems after spinal cord injury	Barritt	*J Neuroscience*	2006	UK	319	484	18.76
124	Systemic administration of an antagonist of the ATP-sensitive receptor P2X7 improves recovery after spinal cord injury	Peng	*PNAS*	2009	US	317	428	22.64
125	Long-term exercise training in persons with spinal cord injury: Effects on strength, arm ergometry performance and psychological well-being	Hicks	*Spinal Cord*	2003	Canada	315	609	15.75
126	Apoptosis of microglia and oligodendrocytes after spinal cord contusion in rats	Shuman	*J Neuroscience Research*	1997	US	314	473	12.08
127	Traumatic spinal cord injury in the United States, 1993–2012	Jain	*JAMA*	2015	US	313	497	39.12
128	Assessing walking ability in subjects with spinal cord injury: Validity and reliability of 3 walking tests	Van Hedel	*Arch Phys Med Rehab*	2005	Switzerland	312	478	17.33
129	Etiology and incidence of rehospitalization after traumatic spinal cord injury: A multicenter analysis	Cardenas	*Arch Phys Med Rehab*	2004	US	310	541	16.32
130	Effects of botulinum a toxin on detrusor-sphincter dyssynergia in spinal cord injury patients	Dykstra	*J Urology*	1988	US	309	546	8.83

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131	Pathology of experimental spinal cord trauma. II. Ultrastructure of axons and myelin	Balentine	*Laboratory Investigation*	1978	US	308	291	6.84
132	Neuroprotection by minocycline facilitates significant recovery from spinal cord injury in mice	Wells	*Brain*	2003	Canada	305	494	15.25
133	Recombinant human erythropoietin counteracts secondary injury and markedly enhances neurological recovery from experimental spinal cord trauma	Gorio	*PNAS*	2002	Italy	303	543	14.43
134	Causes of death during the first 12 years after spinal cord injury	De Vivo	*Arch Phys Med Rehab*	1993	US	303	591	10.10
135	Oligodendroglial apoptosis occurs along degenerating axons and is associated with FAS and p75 expression following spinal cord injury in the rat	Casha	*Neuroscience*	2001	Canada	302	512	13.73
136	BDNF-expressing marrow stromal cells support extensive axonal growth at sites of spinal cord injury	Lu	*Experimental Neurology*	2005	US	300	536	16.67
137	A brain–spine interface alleviating gait deficits after spinal cord injury in primates	Capogrosso	*Nature*	2016	Switzerland	299	491	42.71
138	Axonal regrowth after spinal cord transection in adult zebrafish	Becker	*J Comparative Neurology*	1997	Switzerland	298	422	11.46
139	Systemically administered interleukin-10 reduces tumor necrosis factor-alpha production and significantly improves functional recovery following traumatic spinal cord injury in rats	Bethea	*J Neurotrauma*	1999	US	296	485	12.33
140	Traumatic spinal cord injury-repair and regeneration	Ahuja	*Neurosurgery*	2017	Canada	295	465	49.17
141	Anesthetic potency is not altered after hypothermic spinal cord transection in rats	Rampil	*Anaesthesiology*	1994	US	294	501	10.14
142	The health and life priorities of individuals with spinal cord injury: A systematic review	Simpson	*J Neurotrauma*	2012	Canada	293	385	26.64
143	Axonal regeneration and functional recovery after complete spinal cord transection in rats by delayed treatment with transplants and neurotrophins	Coumans	*J Neuroscience*	2001	US	293	457	13.32
144	Long-term survival in spinal cord injury: A 50 years investigation	Frankel	*Spinal Cord*	1998	UK	293	639	11.72
145	Passive or active immunization with myelin basic protein promotes recovery from spinal cord contusion	Hauben	*J Neuroscience*	2000	Israel	292	475	12.70
146	Spinal cord injury is accompanied by chronic progressive demyelination	Totoiu	*J Comparative Neurology*	2005	US	291	467	16.17
147	Upper extremity pain in the postrehabilitation spinal cord injured patient	Sie	*Arch Phys Med Rehab*	1992	US	291	576	9.39
148	Expression of pro-inflammatory cytokine and chemokine mRNA upon experimental spinal cord injury in mouse: An *in situ* hybridization study	Bartholdi	*Eur J Neuroscience*	1997	Switzerland	290	474	11.15
149	Factors influencing body composition in persons with spinal cord injury: A cross-sectional study	Spungen	*J Applied Physiology*	2003	US	289	446	14.45
150	Combinatorial therapy with neurotrophins and cAMP promotes axonal regeneration beyond sites of spinal cord injury	Lu	*J Neuroscience*	2004	US	287	472	15.11

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Table 1: Contd...

Rank according to WoS citation count	Title	First author	Journal	YOP	Corresponding author's country	Total citations WoS	Total citations Google Scholar	Total citations per year (based on WoS citations)
151	Traumatic spinal cord injury: An overview of pathophysiology, models and acute injury mechanisms	Alizadeh	*Frontiers in Neurology*	2019	Canada	286	507	71.50
152	The biology of regeneration failure and success after spinal cord injury	Tran	*Physiological Reviews*	2018	UK	286	397	57.20
153	A global perspective on spinal cord injury epidemiology	Ackery	*J Neurotrauma*	2004	Canada	286	555	15.05
154	Cellular morphology of chronic spinal cord injury in the cat: Analysis of myelinated axons by line-sampling	Blight	*Neuroscience*	1983	US	285	434	7.12
155	The etiology of missed cervical spine injuries	Davis	*J Trauma*	1993	US	284	496	9.47
156	Neurotrophic factors increase axonal growth after spinal cord injury and transplantation in the adult rat	Bregman	*Experimental Neurology*	1997	US	283	489	10.88
157	Spasticity after spinal cord injury	Adams	*Spinal Cord*	2005	Canada	282	592	15.67
158	A demographic profile of new traumatic spinal cord injuries: Change and stability over 30 years	Jackson	*Arch Phys Med Rehab*	2004	US	282	594	14.84
159	Incidence of spinal cord injury worldwide: A systematic review	van den Berg	*Neuroepidemiology*	2010	Spain	281	564	21.62
160	Role of neutrophils in spinal cord injury in the rat	Taoka	*Neuroscience*	1997	Japan	280	397	10.77
161	Pregabalin in central neuropathic pain associated with spinal cord injury: A placebo-controlled trial	Siddall	*Neurology*	2006	Australia	278	519	16.35
162	Modulation of the proteoglycan receptor PTP promotes recovery after spinal cord injury	Lang	*Nature*	2015	US	277	387	34.62
163	Inflammation and apoptosis: Linked therapeutic targets in spinal cord injury	Beattie	*Trends in Molecular Medicine*	2004	US	277	378	14.58
164	Brain-derived neurotrophic factor in astrocytes, oligodendrocytes, and microglia/macrophages after spinal cord injury	Dougherty	*Neurobioloy of Disease*	2000	US	277	470	12.04
165	Antioxidant therapies in traumatic brain and spinal cord injury	Bains	*Biochim Biophys Acta*	2012	US	276	441	25.09
166	Functional regeneration of respiratory pathways after spinal cord injury	Alilain	*Nature*	2011	US	275	377	22.92
167	Transplantation of human neural stem cells for spinal cord injury in primates	Iwanami	*J Neuroscience Research*	2005	Japan	273	474	15.17
168	Vascular events after spinal cord injury: Contribution to secondary pathogenesis	Mautes	*Physical Therapy and Rehabilitation Therapy*		Germany	273	475	11.87
169	Osteoporosis after spinal cord injury	Garland	*J Orthopaedic Research*	1992	US	273	492	8.81
170	Quality of life after spinal cord injury: A meta analysis of the effects of disablement components	Dijkers	*Spinal Cord*	1997	US	272	605	10.46
171	Pathogenesis and pharmacological strategies for mitigating secondary damage in acute spinal cord injury	Amar	*Neurosurgery*	1999	US	271	534	11.29
172	Systemic administration of epothilone B promotes axon regeneration after spinal cord injury	Ruschel	*Science*	2015	Germany	270	349	33.75
173	Minocycline inhibits contusion-triggered mitochondrial cytochrome c release and mitigates functional deficits after spinal cord injury	Teng	*PNAS*	2004	US	270	392	14.21
174	Exercise recommendations for individuals with spinal cord injury	Jacobs	*Sports Medicine*	2004	US	270	544	14.21

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Table 1: Contd...

Rank according to WoS citation count	Title	First author	Journal	YOP	Corresponding author's country	Total citations WoS	Total citations Google Scholar	Total citations per year (based on WoS citations)
175	Mechanisms underlying the recovery of urinary bladder function following spinal cord injury	de Groat	*J of the Autonomic Nervous System*	1990	US	270	427	8.18
176	Etiology and clinical course of missed spine fractures	Reid	*J Trauma*	1987	Canada	270	474	7.50
177	Nogo-66 receptor prevents raphespinal and rubrospinal axon regeneration and limits functional recovery from spinal cord injury	Kim	*Neuron*	2004	US	269	449	14.16
178	Altered sodium channel expression in second-order spinal sensory neurons contributes to pain after peripheral nerve injury	Hains	*J Neuroscience*	2003	US	269	428	13.45
179	Complete spinal cord injury treatment using autologous bone marrow cell transplantation and bone marrow stimulation with granulocyte macrophage-colony stimulating factor: Phase I/II clinical trial	Yoon	*Stem Cells*	2007	South Korea	266	459	16.62
180	Transplantation of mesenchymal stem cells promotes an alternative pathway of macrophage activation and functional recovery after spinal cord injury	Nakajima	*J Neurotrauma*	2012	Japan	265	417	24.09
181	Safety and tolerance of the ReWalk™ exoskeleton suit for ambulation by people with complete spinal cord injury: A pilot study	Zeilig	*J Spinal Cord Medicine*	2012	Israel	265	485	24.09
182	Involuntary stepping after chronic spinal cord injury: Evidence for a central rhythm generator for locomotion in man	Calancie	*Brain*	1994	US	265	484	9.14
183	Survey of the needs of patients with spinal cord injury: Impact and priority for improvement in hand function in tetraplegics	Snoek	*Spinal Cord*	2004	Netherlands	264	440	13.89
184	Rats and mice exhibit distinct inflammatory reactions after spinal cord injury	Sroga	*J Comparative Neurology*	2003	US	263	404	13.15
185	The effects of methylprednisolone and the ganglioside GM1 on acute spinal cord injury in rats	Constantini	*J Neurosurgery*	1994	US	263	440	9.07
186	Transient blockade of the CD11d/CD18 integrin reduces secondary damage after spinal cord injury, improving sensory, autonomic, and motor function	Gris	*J Neuroscience*	2004	Canada	262	373	13.79
187	Locomotor recovery in spinal cord-injured rats treated with an antibody neutralizing the myelin-associated neurite growth inhibitor Nogo-A	Merkler	*J Neuroscience*	2001	Canada	262	417	11.91
188	Dizziness and unsteadiness following whiplash injury: Characteristic features and relationship with cervical joint position error	Treleaven	*J Rehabilitation Medicine*	2003	Australia	261	505	13.05
189	Relationship of life satisfaction to impairment, disability, and handicap among persons with spinal cord injury living in the community	Fuhrer	*Arch Phys Med Rehab*	1992	US	261	511	8.42
190	Physical and psychological factors predict outcome following whiplash injury	Sterling	*Pain*	2005	Australia	260	412	14.44
191	Blockade of Nogo-66, myelin-associated glycoprotein, and oligodendrocyte myelin glycoprotein by soluble Nogo-66 receptor promotes axonal sprouting and recovery after spinal injury	Li	*J Neuroscience*	2004	US	259	429	13.63
192	Epidemiology of incident spinal fracture in a complete population	Hu	*Spine*	1996	Canada	259	521	9.59
193	Recovery of motoneuron and locomotor function after spinal cord injury depends on constitutive activity in 5-HT2C receptors	Murray	*Nature Medicine*	2010	Canada	258	370	19.85
194	The subaxial cervical spine injury classification system: A novel approach to recognize the importance of morphology, neurology, and integrity of the disco-ligamentous complex	Vaccaro	*Spine*	2007	US	258	476	16.12

Contd...

Table 1: Contd...

Rank according to WoS citation count	Title	First author	Journal	YOP	Corresponding author's country	Total citations WoS	Total citations Google Scholar	Total citations per year (based on WoS citations)
195	Recent advances in pathophysiology and treatment of spinal cord injury	Hulsebosch	*Advances in Physiology Education*	2002	US	258	480	12.29
196	Combined medical and surgical treatment after acute spinal cord injury: Results of a prospective pilot study to assess the merits of aggressive medical resuscitation and blood pressure management	Vale	*J Neurosurgery*	1997	US	258	469	9.92
197	The sygen multicenter acute spinal cord injury study	Geisler	*Spine*	2001	US	254	506	11.55
198	Scoliosis research society. Multicenter spine fracture study	Gertzbein	*Spine*	1992	US	254	784	8.19
199	Nogo-A antibody improves regeneration and locomotion of spinal cord–injured rats	Liebscher	*Annals of Neurology*	2005	Switzerland	253	415	14.06
200	Axonal plasticity and functional recovery after spinal cord injury in mice deficient in both glial fibrillary acidic protein and vimentin genes	Menet	*PNAS*	2003	France	253	359	12.65

WoS - Web of Science; YOP - Year of publication; ICCP - ???; cAMP - ???; PTPσ - ???

Table 2: Corresponding author's countries

Country	Number of articles
United States of America	110
Canada	33
Switzerland	13
Australia	10
Japan	7
United Kingdom	7
Germany	4
Israel	3
Netherlands	3
France	2
Sweden	2
Belgium	1
Italy	1
South Korea	1
Nigeria	1
Portugal	1
Spain	1

Table 3: Academic institutions with members that contributed in at least 10 studies

Affiliations	Number of articles
University of Toronto	34
Ohio State University	29
University of Miami	23
Keio University	20
University of British Columbia	20
Yale University	16
Harvard University	14
University of California Irvine	14
University of California Los Angeles	14
University of California San Diego	14
University of Washington	13
Tehran University of Medical Sciences	12
Kermanshah University of Medical Sciences	10
University of Queensland	10
University of Zurich	10

Article categories

More than half (116/200, 58%) of the articles were sorted in "Category 1: Basic science studies on SCI." "Category 3: Epidemiology and classification studies on SCI" included 18/200 (9%) studies, "Category 4: Epidemiology and classification studies on spinal column injuries" included 6/200 (3%) studies, "Category 7: Studies on the in-hospital management of SCI" included 24/200 (12%) studies, "Category 8: Studies on the in-hospital management of spinal column injuries" included 5/200 (2.5%) studies. Finally, "Category 9: Studies on the rehabilitation and long-term management of patients with SCI" included 55/200 (27.5%) studies and "Category 10: Studies on the rehabilitation and long-term management of patients with spinal column

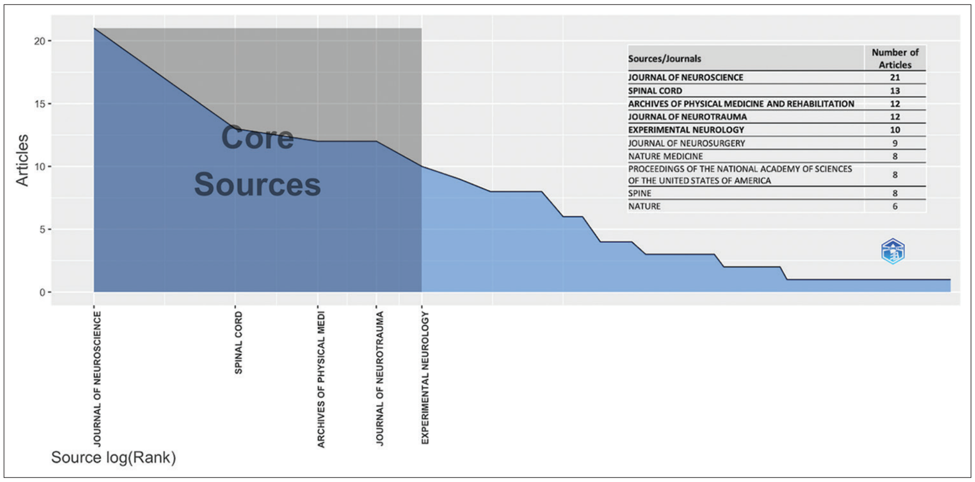

Figure 1: Bradford's law. Sources in the highlighted grey area are those with a particular interest on the topic as indicated by the number of highly cited publications

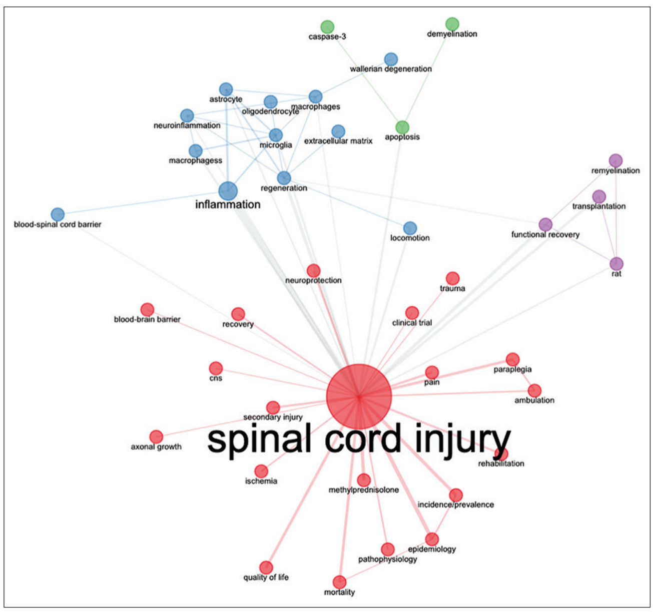

Figure 2: Clusters of keywords. Figure presenting the association between the most commonly used keywords

injuries" included 1/200 (0.5%) studies. Categories "2: Basic science studies on SCI", "5: Studies on the prehospital management of SCI" and "6: Studies on the prehospital management of spinal column injuries" did not include any studies. Eighteen studies were included in more than one category.

Authorship analysis

Based on the corresponding author's affiliation, authors from the United States of America (USA) contributed more than half (110/200, 55%) of the 200 most cited articles, followed by Canada (33/200, 16.5%). In fact, 199/200 articles were contributed by the authors residing in "High-Income Countries" as per "The World Bank."[12]

Table 4: Most important and impactful authors on the topic

Name	Number of articles	Total number of citations
Fehlings MG	17	8365
Tuszynski MH	9	4034
Young W	8	6017
Beattie MS	8	4052
Bresnahan JC	7	3775
Nakamura M	7	2964
Bracken MB	6	5306
Schwab ME	6	2298
Wilberger JE	5	4808
Perot PL	5	4013
Shepard MJ	5	4013
Tator CH	5	3720
Okano H	5	2065
Toyama Y	5	2065
Jones LL	5	2044
Devivo MJ	5	1991
Dietz V	5	1794

Table 5: Most commonly used keywords

Author's keywords	Occurrences
Spinal cord injury	79
Inflammation	15
Apoptosis	13
Incidence/prevalence	10
Regeneration	10
Epidemiology	9
Functional recovery	7
Microglia	7
Astrocyte	6
Macrophages	6

Only one corresponding author was affiliated with an institution in a "Lower Middle-Income Country" (Nigeria). The breakdown for all articles is presented in Table 2. When considering all authors, the University of Toronto

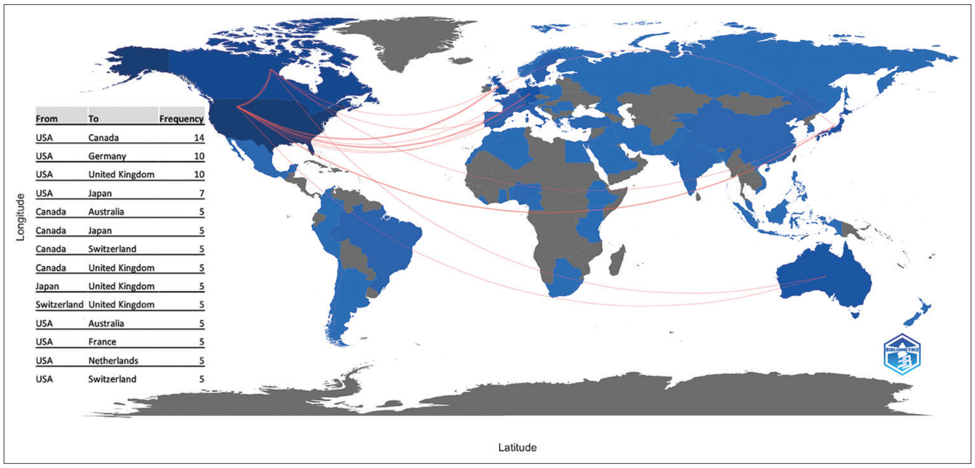

Figure 3: Collaborations between countries. Figure highlighting the collaborations between countries

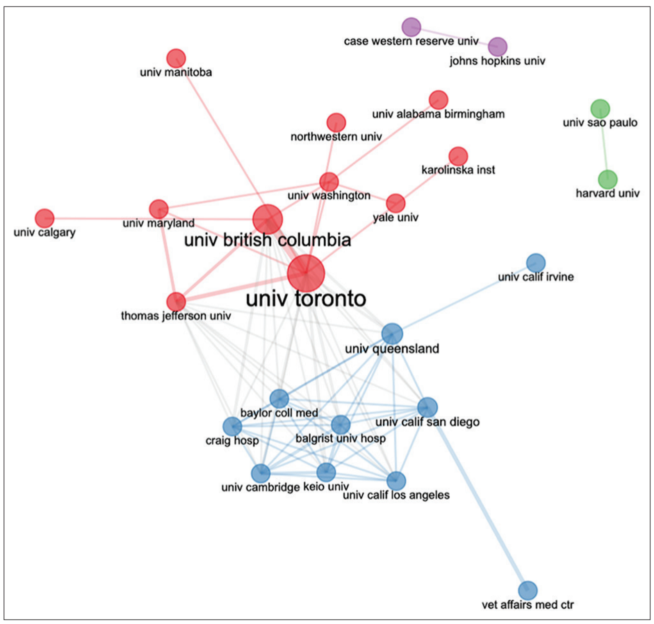

Figure 4: Clusters of collaborating institutions. Figure highlighting the collaborations between institutions

was the institution represented in the highest number of articles with 34, followed by Ohio State University ($n = 29$) and the University of Miami ($n = 23$). Table 3 presents all institutions with affiliated authors with contributions in at least ten of the articles. Table 4 presents the names of all authors with at least five publications amongst the 200 most cited articles, alongside the total number of articles contributed and the total number of citations that those articles have received.

Journal publication analysis

The five journals which published the most articles were the "Journal of Neuroscience" (https://www.jneurosci.org/) with 21/200 (10.5%) articles, the "Spinal Cord" journal (https://www.nature.com/sc/) with 13/200 (6.5%) articles, the "Archives of Physical Medicine and Rehabilitation" (https://www.archives-pmr.org/) and the "Journal of Neurotrauma" (https://home.liebertpub.com/publications/journal-of-neurotrauma/39/overview) with 12/200 (6%) articles each, and the "Experimental Neurology" journal (https://www.sciencedirect.com/journal/experimental-neurology) with 10/200 (5%) articles. According to Bradford's law[13] [Figure 1], the aforementioned journals have published more than one-third of the 200 most cited articles (68/200, 34%).

Keywords analysis

Table 5 presents the 10 most commonly used keywords used by the authors for their articles. As expected, "spinal cord injury" was by far the most commonly used keyword. It was followed by "inflammation", "apoptosis", "incidence/prevalence," and "regeneration". Analysis of author's keywords revealed four word-clusters [Figure 2]. The bigger cluster included words such as "spinal cord injury," "epidemiology," "incidence/prevalence," "mortality," "quality of life." The second cluster contained words such as "inflammation", "regeneration", "microglia," and "astrocyte."

Collaborations analysis

Figure 3 illustrates the collaborations between countries (minimum collaboration frequency = 5) in the selected 200 most cited articles. A considerable number of collaborations was revealed between the USA and Canada ($n = 14$), Germany ($n = 10$), UK ($n = 10$), and Japan ($n = 7$).

Analysis of institutional collaborations [Figure 4] revealed two major and two minor collaboration subnetworks. The first major subnetwork included 11 universities, all from North America (USA and Canada) except Karolinska University from Sweden. The second major subnetwork included 10 institutions from USA, Japan, UK, Australia, and Switzerland.

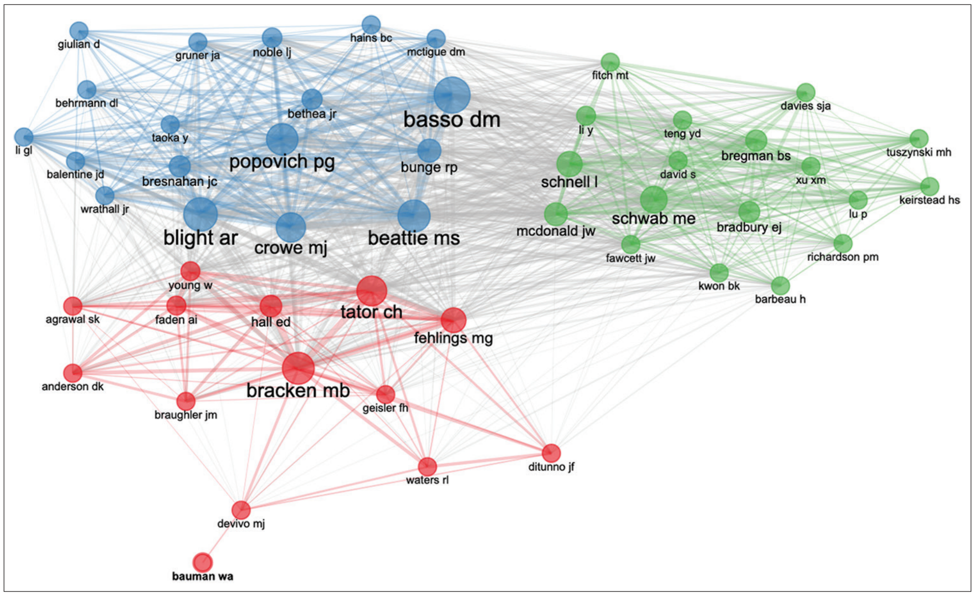

Figure 5: Co-citation analysis, highlighting co-citation networks

Co-citation analysis was implemented to discern the topic relationships between the articles based on citation lists. Three clusters of authors were identified and are presented in Figure 5. The first cluster (red) included 14 authors, whereas the second (blue) and the third (green) included 18 authors each.

DISCUSSION

This bibliometric analysis highlights the 200 most prominent articles published up until 2022 and dealing with the subject of traumatic spinal cord and spinal column injuries, thus enabling the identification of the most impactful work on the topic as well as the evaluation of knowledge gaps that could fuel future research efforts, advocacy, and policy design.

With a total of 88,115 citations and an average of 440.6 citations per article among the 200 most cited articles, research in the themes of traumatic spinal cord and column injury has resulted in some highly impactful studies. Most articles were published at the start of the 21st century, which seems to be related to advancements/discoveries in the fields of stem cell biology, spinal cord plasticity, and related biotechnology.[14]

More than half of the articles in this bibliometric analysis focused on preclinical studies on SCI, which may reflect the limitations in the reproducibility (difficulty of applying pre-clinical concepts in clinical research) of experimental models and subsequent difficulties in conducting clinical studies, owing to the concerns in safety and efficacy.[15,16] Another contributing factor may be the limited number of replication studies that act as confirmation of a certain methodology or therapeutic drug, owing to lack of funding, reluctance to perform such studies, and difficulty in co-operation between research groups. In turn, this can affect the funding and generation of highly impactful clinical research as seen by the relatively low proportion of clinical studies in our bibliometric analysis.[2,16] Finally, this could also be explained, in part, by the fact that clinical research tends to receive less citations than basic-science research.[17,18] Nevertheless, there were some clinical studies too that scored well in this analysis, demonstrating the continuous efforts in translating basic to clinical science and toward finding meaningful treatment options for SCI. Interestingly, most of the yielded results involving clinical studies actually focused on SCI (48.5%), with only a few involving spinal column injuries (6%). This discrepancy may be due to the complexity of the spinal column and the various injury patterns that can occur, making the development of standardized experimental protocols challenging; as well as the lack of well-established international datasets on spinal column injuries available for researchers worldwide.[1,4,19] Furthermore, the relatively low number of spinal column studies could be attributed to our search strategy, as our algorithm searched for both spinal cord and spinal column studies in tandem.

This analysis confirms that most of the authors of the highly influential work on the subject reside in North America or Europe. There are several factors that may contribute to regional imbalances. The shortage of neurosurgeons in Africa and some parts of Asia compared to North America and Europe is well known.[20,21] In addition, the latter regions benefit from better resourced health-care systems, a plethora of prestigious academic facilities, larger information technology infrastructures to be able to report and store data, and greater availability of diagnostic equipment.[22] This further emphasizes the lack of epidemiological, basic science, and clinical studies conducted in low- and middle-income countries,[23] where the fewer clinicians per capita are proportionally busier with clinical rather than academic work.

Unsurprisingly, the top five journals included in this analysis have contributed 34% of the 200 most cited articles, and originate in the US and Europe, with a focus on preclinical and clinical neuroscience, neurotrauma, and rehabilitation. A collaboration analysis also revealed that international research networks exist between various institutions in the US, Canada, Europe, and Japan. Although a hopeful step toward better management of spine trauma, there is a huge and growing need to address the global burden of spine trauma on society through greater collaboration between low-income, low-middle-income, and high-income countries, establishment of research and data networks, and provision of training through educational programmes and international conferences.[6-8,24]

Most cited articles

The most cited article included in this analysis was published in 1990 by Bracken *et al*. and is titled "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 Study." This was a landmark study (1839 citations on WoS, 3407 citations in Google Scholar) that suggested the use of methylprednisolone for 24 h in SCI patients presenting within 8 h of injury, something that was initially widely adopted. In the following decades, this has become and still remains a highly controversial topic, as many questions were raised regarding the adverse effects of steroids and the validity of the study, with many subsequent studies producing conflicting results.[25-27] This ultimately led to most guidelines not recommending routine use of methylprednisolone in SCI patients and highlights the need for more robust clinical trial designs and further research into the pharmacological options for SCI.[28]

The second article to be featured and the most cited in "Category 1: Basic science studies on SCI" is by Bradbury *et al*. (2002) and is titled "Chondroitinase ABC promotes functional recovery after spinal cord injury." It was demonstrated that chondroitin sulphate proteoglycans are inhibitory molecules produced at sites of central nervous system injury and that these can be degraded using chondroitinase ABC (ChABC) to promote axon regeneration, plasticity and recovery in rats. The "ChABC for Spinal Injury Therapy consortium" is currently working towards making human clinical trials possible. Unfortunately, two decades later on there is still some way to go before this is possible.[29]

The third most cited article is the reference for the 2011 revision of the International Standards for Neurological Classification of SCI.[30] This classification, which is revised periodically,[31] constitutes the gold standard method for the assessment and documentation of SCI. It is to be expected that the reference for such an important classification system ranks in the top 3 most cited articles on the topic of spine trauma.

The fourth most cited article in this list and the most cited of the spinal column trauma-related literature is by Francis Denis, an orthopedic surgeon in the US.[32] His work on "The three column spine and its significance in the classification of acute thoracolumbar spinal injuries" was widely used before more modern classification systems evolved, such as the "AOSpine thoracolumbar spine injury classification system: Fracture description, neurological status, and key modifiers," which is another article included in this analysis.[33]

While we focused on the 200 most cited articles in the traumatic spinal column and spinal cord literature, it is worth noting that Li *et al*. have recently published a bibliometric analysis including only SCI articles from 1999 to 2019.[34] Similarly to our findings, USA was the most impactful country, with the University of Toronto contributing the most articles. Both bibliometric analyses revealed the same most cited author (MG Fehlings), whereas the Spinal Cord journal was the first and second most cited journal in the aforementioned study and our current bibliometric analysis, respectively. While the Li *et al*. study focused only on SCI, we highlight some important research efforts in the field of spinal column trauma.

Future research perspectives

Over the last decades, great progress has been made in elucidating the complex mechanisms surrounding spinal cord and spinal column injuries. However, the absence of clinically proven treatments for SCI, as well as persisting differences and a lack of consensus in relation to guidelines and research methodologies across the international community suggest that there is still a great deal to be done before clinical translation is achieved.[35] Some of the bibliometric trends that emerged in our analysis include a decline in stem cell research in the last decade (2010-2019), with most articles (>70%) published before 2010, along with an emerging interest in rehabilitation/walking after SCI using assistive devices (e.g., ReWalk Exoskeleton).

Moreover, the proportion of publications by European and Australasian (Israel, Australia, Japan, South Korea) countries from 1977 to 2003 (top 50% of most cited articles) to 2003–2019 (bottom 50% of most cited articles) increased by 69% and 50%, respectively, whilst North America has seen a drop by 21%. Meanwhile, only one African country (Nigeria) has been featured in our analysis, in 2011, with no representation by South America, India or China. Given the huge populations and absolute numbers of SCI patients in these countries, there is significant potential to amplify SCI research output and create more collaboration research networks.[36] Many patients and scientists alike have expressed their frustration regarding these shortcomings and advocate for greater cooperation and patient involvement to help set future research agendas.[37] In addition, growing evidence suggests that combined approaches, which can be guided by patient priorities, may be more effective than single therapeutic interventions at addressing the short-term and long-term complications arising in SCI patients.[38] Priority setting partnerships, clinical trial design, patient recruitment and participation, international collaboration, and accessibility to research are some of the key areas that need to be addressed before clinical translation is possible.[16,36,39] www.SciTrials.org is a website that enables users (patients and healthcare professionals) to identify past, present and future clinical trials on various topics related to traumatic SCI.[40]

Limitations

We acknowledge limitations in our bibliometric analysis. As a consequence of using WoS for database search, articles not indexed in WoS were automatically omitted. However, WoS is the preferred database to use as per the Biblioshiny app developers.[11] Some level of language-based selection bias may have been introduced as a result of our decision to only include studies written in English. We aimed to present only the top 200 most cited articles, thus many high-quality papers with lower citation counts may have been missed despite their impact on the community. Inevitably, some recent articles were not captured owing to the expected lower total citation counts of those more recently published studies. The first author and their corresponding country were used which may not accurately reflect global collaborative trends due to the remaining authors not being accounted for. Nevertheless, we believe that this analysis captures a realistic snapshot of trends in the literature relevant to spinal trauma research.

CONCLUSION

This bibliometric analysis provides a comprehensive overview of the most cited studies in the field of traumatic spinal research, including both spinal cord and spinal column injuries. Such information is useful for both service planning and delivery as well as advocacy, policy, novel project design, and hopefully a springboard for further collaborative investment, financial as well as organizational.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. van Den Hauwe L, Sundgren PC, Flanders AE. Spinal Trauma and Spinal Cord Injury (SCI). In: Hodler, J., Kubik-Huch, R., von Schulthess, G. (eds) Diseases of the Brain, Head and Neck, Spine 2020–2023. IDKD Springer Series. Springer, Cham. 2020. doi: 10.1007/978-3-030-38490-6_19.
2. Ahuja CS, Wilson JR, Nori S, Kotter MR, Druschel C, Curt A, *et al.* Traumatic spinal cord injury. Nat Rev Dis Primers 2017;3:17018.
3. Pope AM, Tarlov AR. Disability in America: Toward a National Agenda for Prevention. 2201 Consitution Avenue: National Academy Press; 1991. Available from: https://eric.ed.gov/?id=ED336892. [Last accessed on 2022 Oct 18].
4. Chhabra HS, Kaul R, Kanagaraju V. Do we have an ideal classification system for thoracolumbar and subaxial cervical spine injuries: What is the expert's perspective? Spinal Cord 2015;53:42-8.
5. Badhiwala JH, Wilson JR, Fehlings MG. Global burden of traumatic brain and spinal cord injury. Lancet Neurol 2019;18:24-5.
6. Marchesini N, Rubiano AM, Sala F, Demetriades AK, Alves OL. Secondary damage management of acute traumatic spinal cord injury in low and middle-income countries: A survey on a global scale (part III). Brain Spine 2022;2:101694.
7. Marchesini N, Demetriades AK, Alves OL, Sala F, Rubiano AM. Exploring perspectives and adherence to guidelines for adult spinal trauma in low and middle-income healthcare economies: A survey on barriers and possible solutions (part I). Brain Spine 2022;2:100932.
8. Demetriades AK, Marchesini N, Alves OL, Rubiano AM, Sala F. A survey on the early management of spinal trauma in low and middle-income countries: From the scene of injury to the diagnostic phase (part II). Brain Spine 2022;2:101185.
9. Barbiellini Amidei C, Salmaso L, Bellio S, Saia M. Epidemiology of traumatic spinal cord injury: A large population-based study. Spinal Cord 2022;60:812-9.
10. Paudel KP, Panta S, Thapa SK, Thapa S. Traumatic spinal injury among patients with spinal injuries admitted to the spine unit of a tertiary care centre: A descriptive cross-sectional study. JNMA J Nepal Med Assoc 2022;60:335-9.
11. Aria M, Cuccurullo C. Bibliometrix: An R-tool for comprehensive science mapping analysis. J Informetr 2017;11:959-75.
12. WDI – The World by Income and Region. Available from: https://datatopics.worldbank.org/world-development-indicators/the-world-by-income-and-region.html. [Last accessed on 2022 Oct 08].
13. Bradford SC. Documentation. London: Crosby Lockwood and Son Ltd; 1948.
14. Guérout N. Plasticity of the injured spinal cord. Cells 2021;10:1886.
15. Silva NA, Sousa N, Reis RL, Salgado AJ. From basics to clinical: A comprehensive review on spinal cord injury. Prog Neurobiol 2014;114:25-57.
16. Schaffran B, Bradke F. Reproducibility – The key towards clinical implementation of spinal cord injury treatments? Exp Neurol

2019;313:135-6.
17. Ke Q. The citation disadvantage of clinical research. J Informetr 2020;14:100998.
18. Donner P, Schmoch U. The implicit preference of bibliometrics for basic research. Scientometrics 2020;124:1411-9.
19. Dvorak MF, Wing PC, Fehlings MG, Vaccaro AR, Itshayek E, Biering-Sorensen F, *et al.* International spinal cord injury spinal column injury basic data set. Spinal Cord 2012;50:817-21.
20. El-Fiki M. African neurosurgery, the 21st-century challenge. World Neurosurg 2010;73:254-8.
21. Cripps RA, Lee BB, Wing P, Weerts E, Mackay J, Brown D. A global map for traumatic spinal cord injury epidemiology: Towards a living data repository for injury prevention. Spinal Cord 2011;49:493-501.
22. Kumar R, Lim J, Mekary RA, Rattani A, Dewan MC, Sharif SY, *et al.* Traumatic spinal injury: Global epidemiology and worldwide volume. World Neurosurg 2018;113:e345-63.
23. GBD 2016 Traumatic Brain Injury and Spinal Cord Injury Collaborators. Global, regional, and national burden of traumatic brain injury and spinal cord injury, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet Neurol 2019;18:56-87.
24. Dewan MC, Rattani A, Fieggen G, Arraez MA, Servadei F, Boop FA, *et al.* Global neurosurgery: The current capacity and deficit in the provision of essential neurosurgical care. Executive summary of the global neurosurgery initiative at the program in global surgery and social change. J Neurosurg 2018;130:1055-64.
25. Pointillart V, Petitjean ME, Wiart L, Vital JM, Lassié P, Thicoipé M, *et al.* Pharmacological therapy of spinal cord injury during the acute phase. Spinal Cord 2000;38:71-6.
26. Matsumoto T, Tamaki T, Kawakami M, Yoshida M, Ando M, Yamada H. Early complications of high-dose methylprednisolone sodium succinate treatment in the follow-up of acute cervical spinal cord injury. Spine (Phila Pa 1976) 2001;26:426-30.
27. Evaniew N, Noonan VK, Fallah N, Kwon BK, Rivers CS, Ahn H, *et al.* Methylprednisolone for the treatment of patients with acute spinal cord injuries: A propensity score-matched cohort study from a Canadian multi-center spinal cord injury registry. J Neurotrauma 2015;32:1674-83.
28. Zhang Y, Li AA, Xiao SN, Zhong NS, Tong WL, Wang SJ, *et al*. A bibliometric analysis of publications on spinal cord injury treatment with glucocorticoids using VOSviewer. Front Public Health 2022;10:907372.
29. CHASE IT | Spinal Research. Available from: https://spinal-research.org/chase-it. [Last accessed on 2022 Oct 08].
30. Kirshblum SC, Waring W, Biering-Sorensen F, Burns SP, Johansen M, Schmidt-Read M, *et al.* Reference for the 2011 revision of the international standards for neurological classification of spinal cord injury. J Spinal Cord Med 2011;34:547-54.
31. ASIA and ISCoS International Standards Committee. The 2019 revision of the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI)-What's new? Spinal Cord 2019;57:815-7.
32. Denis F. The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine (Phila Pa 1976) 1983;8:817-31.
33. Vaccaro AR, Oner C, Kepler CK, Dvorak M, Schnake K, Bellabarba C, *et al.* AOSpine thoracolumbar spine injury classification system: Fracture description, neurological status, and key modifiers. Spine (Phila Pa 1976) 2013;38:2028-37.
34. Li Y, Wei B, Zhong Y, Feng H, Wu H. A bibliometric analysis of global research on spinal cord injury: 1999-2019. Spinal Cord 2022;60:281-7.
35. Dietz VA, Roberts N, Knox K, Moore S, Pitonak M, Barr C, *et al.* Fighting for recovery on multiple fronts: The past, present, and future of clinical trials for spinal cord injury. Front Cell Neurosci 2022;16:977679.
36. Blight AR, Hsieh J, Curt A, Fawcett JW, Guest JD, Kleitman N, *et al.* The challenge of recruitment for neurotherapeutic clinical trials in spinal cord injury. Spinal Cord 2019;57:348-59.
37. van Middendorp JJ, Allison HC, Ahuja S, Bracher D, Dyson C, Fairbank J, *et al.* Top ten research priorities for spinal cord injury: The methodology and results of a British priority setting partnership. Spinal Cord 2016;54:341-6.
38. Griffin JM, Bradke F. Therapeutic repair for spinal cord injury: Combinatory approaches to address a multifaceted problem. EMBO Mol Med 2020;12:e11505.
39. Shah M, Peterson C, Yilmaz E, Halalmeh DR, Moisi M. Current advancements in the management of spinal cord injury: A comprehensive review of literature. Surg Neurol Int 2020;11:2.
40. Spinal Cord Injury Trials. Available from: https://scitrials.org/. [Last accessed on 2022 Oct 12].

APPENDIX

Appendix 1: Exact algorithm used for database search

TI=("spinal cord injur*" OR "traumatic myelopathy" OR "post-traumatic myelopathy" OR "post traumatic myelopathy" OR "spinal cord contusion" OR "spinal cord laceration" OR "spinal cord transection" OR "spinal cord trauma" OR "traumatic spine" OR "traumatic spinal" OR "traumatic vertebral" OR "spine trauma" OR "spinal trauma" OR "vertebral trauma" OR "vertebral column trauma" OR "spinal column trauma" OR "spine injur*" OR "spinal injur*" OR "vertebral injur*" OR "vertebral column injur*" OR "spinal column injur*" OR "spine fracture*" OR "spinal fracture*" OR "vertebral fracture*" OR "vertebral column fracture*" OR "spinal column fracture*" OR "spine compression fracture*" OR "spinal compression fracture" OR "vertebral compression fracture*" OR "vertebral column compression fracture*" OR "spinal column compression fracture*" OR "spine burst fracture*" OR "spinal burst fracture" OR "vertebral burst fracture*" OR "vertebral column burst fracture*" OR "spinal column burst fracture*" OR "spine dislocation" OR "spinal dislocation*" OR "vertebral dislocation*" OR "spinal column dislocation*" OR "vertebral column dislocation*" OR "spine displacement" OR "spinal displacement*" OR "vertebral displacement *" OR "spinal column displacement*" OR "vertebral column displacement*" OR "spine subluxation*" OR "spinal subluxation*" OR "vertebral subluxation*" OR "spinal column subluxation*" OR "vertebral column subluxation*" OR "whiplash injur*" OR "hangman fracture*" OR "hangman's fracture*" OR "chance fracture*").

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