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Direct Cost of Illness for Spinal Cord Injury: A Systematic Review

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Abstract

Study Design: Systematic review.

Objective: Providing a comprehensive review of spinal cord injury cost of illness studies to assist health-service planning.

Methods: We conducted a systematic review of the literature published from Jan. 1990 to Nov. 2020 via Pubmed, EMBASE, and NHS Economic Evaluation Database. Our primary outcomes were overall direct health care costs of SCI during acute care, inpatient rehabilitation, within the first year post-injury, and in the ensuing years.

Results: Through a 2-phase screening process by independent reviewers, 30 articles out of 6177 identified citations were included. Cost of care varied widely with the mean cost of acute care ranging from $290 to $612,590; inpatient rehabilitation from $19,360 to $443,040; the first year after injury from $32,240 to $1,156,400; and the ensuing years from $4,490 to $251,450. Variations in reported costs were primarily due to neurological level of injury, study location, methodological heterogeneities, cost definitions, study populations, and timeframes. A cervical level of the injury, ASIA grade A and B, concomitant injuries, and in-hospital complications were associated with the greatest incremental effect in cost burden.

Conclusion: The economic burden of SCI is generally high and cost figures are broadly higher for developed countries. As studies were only available in few countries, the generalizability of the cost estimates to a regional or global level is only limited to countries with similar economic status and health systems. Further investigations with standardized methodologies are required to fill the knowledge gaps in the healthcare economics of SCI.

Keywords

spinal cord injuries, paraplegia, quadriplegia, cost of illness

Introduction

Global Burden of Disease Study estimated that in 2016 the annual global incidence of traumatic spinal cord injury (SCI) was 0.93 million (0.78-1.16 million), with an age-standardized incidence rate of 13 (11-16) per 100,000 population.[1] SCI incidence is relatively low compared with other chronic diseases; however, the consequences are disproportionally high. SCI results in significant physical and psychosocial burdens for individuals, their relatives, and for the health, social, and medico-social systems as a whole.[2] In addition to the physical and psychosocial trauma, the economic burden is substantial, predominantly due to permanent disability, the occurrence of the injury in younger ages, increased health care costs as well

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as higher rates of morbidity and premature mortality.[3,4] In the United States, for example, the national costs attributable to SCI-related hospitalizations in 2009 estimated at approximately $1.7 billion.[5]

Given the high economic burden of the disease and with the challenges of budget crises, information on the cost of care is necessary to provide optimal care to individuals with SCI. Cost of illness studies are primarily conducted to raise awareness for the financial burden of diseases, provide evidence for funding for care, and identify potential opportunities to design additional research and more efficient services.[6] Investigations into the economic burden of SCI are inconsistent, often have limited to specific regions, databases, population groups, a subgroup of patients with SCI (specific level of injury, certain etiology), or different periods of care (e.g. acute hospitalization, first year).[7] So there is a need for a comprehensive synthesis of previous research and assessment of the components and drivers of cost variation. This study aims to provide an updated, comprehensive review of previous research on the cost of treating SCI from the payer's perspective in different countries. In doing so, we considered the variation in reported costs according to country, trauma subgroups, predictors of cost, and the costing methods employed. Finally, we tried to address the existing discrepancies in the literature related to the costs of SCI to be considered in future researches.

Methods

A systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[8] Using the keywords "costs and cost analysis," "Economics," "Spinal Cord Injuries," "Paraplegia," "Quadriplegia," and "Spinal Cord," a comprehensive literature search was performed in PubMed EMBASE, and NHS Economic Evaluation Database via Cochrane Library for articles published between January 1990 and November 2020. The exact search strategy and keywords for each database are available in Supplementary file 1. There were no restrictions on language or publication status. Additionally, the reference list of each eligible article was screened to find additional articles.

Selection Method and Data Extraction

We searched for all cost of illness studies that reported overall direct costs of care for SCI. Direct costs include medical costs, which are typically associated with medical resource utilization and include in-patient, out-patient, and pharmaceutical services within the health care system,[9] and non-medical costs, which represent the costs associated with non-prescribed supplies and equipment, transportation, meals for patients, and caregivers, etc. Two reviewers independently screened the title and abstract of each paper to identify potentially eligible studies. We then selected studies that met the eligibility criteria for full-text evaluation. Discrepancies regarding the eligibility of studies were resolved through the decision of a third reviewer and group discussion. The required data was then extracted by 2 authors and entered into predefined sheets. The extracted information included the title and first author's name, year of publication, study duration, design, sample size, setting (hospital/local/national) and location, participant characteristics including the level of SCI (cervical, thoracic, lumbosacral), clinical presentation (tetraplegia, paraplegia), cost currency, and direct costs of care for SCI (Table 1).

Eligibility Criteria and Risk of Bias

Our primary outcome was to determine health care costs of SCI during 1) acute care, from index admission to the first discharge to any location other than transfer to acute care in another hospital, 2) inpatient rehabilitation 3) the first year post-injury, and 4) ensuing years; both regardless and stratified by the extent of neurological deficit. Secondary outcomes were to determine components and drivers of cost. All studies with at least 10 cases that reported either any of the primary outcomes were included in the study. Studies reporting indirect costs, a subcategory of costs, costs through modeling/extrapolation methods, and studies from a common database except for the latest one were not included. Furthermore, studies with a population of mainly vertebral column injuries without concomitant SCI and those that were only pediatric were excluded. All currencies were converted to US dollars (USD) using foreign exchange rates provided by the Federal Reserve System, the Central bank of the United States[10] and were adjusted to Nov. 2020 values using the Consumer Price Index by the U.S. Bureau of Labor Statistics.[11] Global Domestic Products (GDP) per capita from the year of the currency for each study were obtained from the World Bank website.[12] For critical appraisal, We used a slightly adjusted form of the checklist developed by Public Health Wales Observatory Evidence Service[13] based on a study by Larg A and Moss J.[14] The final statement had 13 items relating to analytical framework, methodology, analysis, and reporting (Supplementary file2). Each item in the checklist was given a score of −1, 0, or 1, with a score of 1 if the item was appropriately fulfilled.

Results

General Findings

The search identified 6,177 studies, which was reduced to 5,306 after the removal of duplicates. An evaluation of titles and abstracts resulted in the removal of 5,204 articles. The remaining 102 studies underwent full-text assessment for eligibility. Seventy-two studies were excluded based on various reasons, mainly due to a lack of data on our primary outcomes, incompatible care period, inclusion of vertebral column injuries without concomitant SCI, and absence of original data (Figure 1). The list of excluded articles at full-text assessment and Reasons of exclusion are presented in Supplementary file 2. Finally, the remaining 30 studies were included here. Most studies originated in North America (the U.S.: 15 studies,[15-29]

Table 1. Characteristics of Included Studies.

Study	Country, time-frame	Study type	Participants	Participants data source	Participants identification	Source of cost data	Costing approach	Details on cost items
New and Jackson 2010	Australia 2003-2004	Retro. Cohort	564 (170 traumatic and 394 nontraumatic)	Database from public hospitals included in the Victorian Cost Weights Study	ICD-10-AM	Victorian Department of Human Services (VDHS) costing database	Top-down, Diagnosis-Related Group	Medical, nursing, allied health, and pharmacy
Vaikuntam et al, 2019	Australia 2013-2016	Retro. Cohort	534 ≥ 16 year-olds with acute TSC	NSW Admitted Patient Data Collection (APDC) and Emergency Department Data Collection	ICD-10-AM	NSW Activity-based Funding District Network Return Data	Bottom-up, Activity-based	Costs incurred by health service providers, except staff salaries and operation costs, for all emergency department (ED) and admitted hospital separations
Dryden et al, 2004	Canada 1992-1994	Retro. Cohort	233 with TSCI	Alberta Health Care Insurance Stakeholder Registry	ICD-9-CM	Cost List for Manitoba Health Services (adjusted for Alberta which provides an average cost per day for each RDRG, and Claims database	Top-down, Diagnosis Related Group, and actual costs of physician services abstracted from the Claims database	Hospitalizations, physician services, home care services, long-term admissions, and occurrence of secondary complications. The initial hospitalization included acute care hospitalization and inpatient rehabilitation.
Bradbury et al, 2008	Canada NS	Retro. Cohort	10 SCI without traumatic brain injury	Spinal Cord Rehabilitation Program of Toronto Rehabilitation Institute	NS	Hospital records	Top-down Resource Utilization Group (RUG) (based on FIM)	Clinician workload, nursing, physiotherapy, occupational therapy, rehabilitation therapy, and speech language pathology
Mac-Thiong et al, 2012	Canada 2000-2011	Retro. Cohort	477 with TSCI	Quebec Trauma Registry	ICD-9-CM	Quebec Trauma Registry and Niveau Intensité Relative des Ressources Utilisées index (NIRRU1)	Top-down, Diagnosis Related Group (based on NIRRU)	All resources related to hospitalization.
Munce et al, 2013	Canada 2003-2004 & 2005-2006	Retro. Cohort	559 with TSCI	Rick Hansen Foundation database	ICD-10	Resource intensity weight and provincial average cost from Ontario Ministry of Health and Long-Term Care (MOHLTC), and patients discharge abstracts	Top-down, Diagnosis Related Group	Acute inpatient, ED, hospital rehabilitation, complex continuing care1, home health care services, and physician but not medication costs
Radhakrishna et al, 2014	Canada 1997-2007	Retro. Cohort	481 who sustained SCI from motor vehicle accident	Quebec Trauma Registry (RTQ2)	Using the terms spinal cord injury and motor vehicle collisions	Quebec Medical Insurance Agency (RAMQ3), and Quebec Provincial Automobile Insurer (SAAQ4)	Top-down, Per-diem Quebec hospital cost	Initial hospitalization (including therapy, imaging, medication, surgery, and the hospitals fixed costs), practitioners fees, medications, environmental modifications, and personal aides
Richard-Denis et al 2017	Canada 2008-2014	Retro. Cohort	116 with motor-complete (AIS A, B) cervical SCI	Individuals admitted to a level 1 SCI-specialized trauma center	–	Hospital database and Niveau Intensité Relative des Ressources Utilisées index (NIRRU)	Top-down, Diagnosis Related Group (based on NIRRU)	The NIRRU index includes all resources related to hospitalization. Physician fee and costs related to the spine surgery and tracheostomy placement were not available.
Porgo et al, 2019	Canada 2019	Retro. Cohort	614 ≥ 16-year-olds admitted to adult trauma centers	Quebec trauma registry	–	Hospital financial reports (AS-471) for the 2016 fiscal year	Bottom-up Activity-based	Non-physician personnel, services and materials costs in ED, medical ward, OR, ICU, imaging, and para-clinical services. drugs, laboratory tests, blood products, and physician fees were not included
Li et al, 2011	China 2002	Retro. Cohort	710 with TSCI	Information Center of Beijing Health Bureau	Using the term paraplegia or tetraplegia in Chinese language	Information Center of Beijing Health Bureau	Top-down	NS
Jiménez-Avila et al, 2012	Mexico 2004-2007	Retro. Cohort	34 ≥ 16-year-olds with complete cervical SCI	Individuals with a diagnosis of complete cervical spinal cord injury	–	Hospital records	Bottom-up (charges)	The cost calculation was done considering bed days, specialty consultation, laboratory, X-ray, axial computed tomography, MRI, and surgery.

(continued)

Table 1. (continued)

Study	Country, time-frame	Study type	Participants	Participants data source	Participants identification	Source of cost data	Costing approach	Details on cost items
Kawu et al, 2011	Nigeria 2009	Pros. Cohort	34 cases with SCI	Spinal cord injured adults at the University of Abuja Hospital	–	Hospital bills paid on discharge	Bottom-up (charges)	Nursing/medical care, accommodation, bed fees, drugs, laboratory charges and operative procedures; But not hospital staff and physicians fees, and medical equipment costs
Tsai et al, 2005	Taiwan 1998-2000	Retro. Cohort	184 with cervical SCI	Bureau of National Health Insurance (BNHI) database	ICD-9-CM	Annual in-patient expenses information system of the BNHI	Top-down	Total in-patient and medical order items
Yang et al, 2008	Taiwan 2000-2003	Retro. Cohort	15,510 with acute TSCI	National Health Insurance (NHI) database	ICD-9-CM	National Health Insurance Bureau (NHIB) datasets, including monthly claim summary for inpatient claims, inpatient expenditures by admissions and details of inpatient orders	Top-down	The datasets including details of inpatient orders, monthly claim summary for inpatient claims and inpatient expenditures by admissions were selected.
Lessing et al, 2020	Tanzania 2016-2019	Retro. Cohort	125 > 14 year-olds	Muhimbili Orthopaedic Institute database	–	Hospital records	Bottom-up Activity-based	The sum of direct costs during admission. For nonoperative patients calculated by adding the cost of initial imaging, LOS, OR fee, surgical implants, and postop. imaging
Price et al, 1994	USA 1989	Retro. Cohort	376 with TSCI	Population-based statewide surveillance system	ICD-9-CM	Estimated or actual charges for acute care and rehabilitation hospitalization	Bottom-up (charges)	All charges of acute care and rehabilitation except physician services, outpatient rehabilitation, emergency transportation and later admissions
Johnson et al, 1996	USA 1989	Retro. Cohort	115 with TSCI	Colorado Spinal Cord Injury Early Notification System (ENS)	ICD-9	Participants were asked about the names of all providers and billing information was obtained from providers.	Bottom-up (hospital or outpatient charges)	Medical services, medical supplies and equipment, in-home care, and the names of providers. Providers are asked for Billing information
Chan et al, 1997	USA 1987-1994	Retro. Cohort	NS, discharges from rehab hospitals (non-acute rehab)	Medicare billing records and selected hospital cost reports	–	Records of hospital charges on Medicare	Bottom-up (charges)	NS
Cifu et al, 1999	USA, 1988-1996	Retro. Cohort	2,099 adults with tetraplegia TSCI	National Model Spinal Cord Injury Systems program	Individuals with paraplegia SCI	Hospital billing records	Bottom-up (estimated or actual hospital bills)	Acute care and inpatient rehabilitation
Cifu et al, 1999	USA 1988-1996	Retro. Cohort	2,169 adult persons with paraplegia TSCI	National Model Spinal Cord Injury Systems program	Individuals with paraplegia SCI	Hospital billing records	Bottom-up Activity-based (estimated or actual hospital charges)	Acute care and inpatient rehabilitation
McKinley et al, 2001	USA 1992-1999	Retro. Cohort	172 rehabilitation inpatients (86 with TSCI and 86 nontraumatic SCI)	National Model Spinal Cord Injury Systems program compiled on the NIDRR7 SCI Database	NS	Actual rehabilitation hospital charges for each patient	Bottom-up (charges)	Nursing, occupational therapy, physiatry and related medical services, physical therapy, psychologic and neurologic assessment, recreational therapy, and social services
Seel et al, 2001	USA 1988-1998	Retro. Cohort	180 adults with paraplegia	National Model Spinal Cord Injury Systems program compiled on the NIDRR5 SCI Database	–	Actual hospital charges for each patient	Bottom-up (charges)	
Smith et al, 2003	USA 1993-1999	Retro. Cohort	47 with SCI Caused by Gunshot wounds	National Rehabilitation Hospital	Nonacute rehabilitative care recipients	Completed bills for 12 of the 47 persons	Bottom-up (rehabilitation hospital charges)	NS

(continued)

Table 1. (continued)

Study	Country, time-frame	Study type	Participants	Participants data source	Participants identification	Source of cost data	Costing approach	Details on cost items
Webster et al, 2004	USA 1989-1999	Retro. Cohort	62 with work-related tetraplegia	The workers compensation database	Cross-referencing NCCI codes specific to: body part injured and injury type with relevant word search terms in the accident description	Compensation insurer data source covering 8-10% of the US private workers compensation market	Top-down	Initial hospitalization, acute rehabilitation, subsequent hospital and rehabilitation readmissions, outpatient services (i.e., physician and therapy visits, diagnostic services), pharmacy and medical supplies, vehicle and home modifications, personal care attendants, and ambulance/assisted transportation.
French et al, 2007	USA 2005	Retro. Cohort	675 veterans with SCI	Veterans Health Administration (VHA) administrative database	Non-ventilator dependent wheelchair user veterans with SCI over 2 years	The Decision Support System National Data Extracts (DSS-NDE)	Bottom-up Activity-based (DSS provided costs)	All outpatient and inpatient care i.e. hospitalization and surgery, medications, radiology, laboratory, nursing care, prosthetics, rehabilitation, and nursing home care
Yu et al, 2008	USA 1999-2001	Retro. Cohort	1,181 veterans with SC	VA National Patient Care Databases (NPCDs)	ICD-9	VA Health Economics Resource Center Average Cost File (ACF)	Top-down Medicare's Diagnosis Related Group	Inpatient and outpatient care at VA facilities
DeVivo et al, 2011	USA 2000-2006	Retro. Cohort	1,676 with SCI	National SCI Statistical Center (NSCISC) database	A random sample of 508 treated from 1973 to 1988 and 227 newly injured in 1989	Charges reflect the average amount billed to individuals or third parties	Bottom-up	Inpatient acute care and rehabilitation, emergency medical services, nursing home, outpatient services, physician fees, equipment, environmental modifications, medications, supplies, attendant care, vocational rehabilitation
Deutsch et al, 2011	USA 2002-2006	Retro. Cohort	2919 > 64 Medicare fee-for-service cases	Medicare claims and assessment data files	ICD-9-CM	Patient-level Medicare billing (ie, claims) records (Medicare Provider Analysis and Review file)	Top-down (The total amount paid to the rehabilitation hospital)	Part A services
Krause et al, 2019	USA 2011-2015	Retro. Cohort	303	State-wide SCI Surveillance System Registry	ICD-9-CM	South Carolina Revenue and Fiscal Affairs, Health and Demographics records	Bottom-up (acute hospital care charges)	Costs related to health care utilization for ED visits and hospitalizations.
Sikka et al, 2019	USA, 2003-2014	Retro. Cohort	591 with TSCI	Trauma registry data merged with the regional hospital registry database (DFWHC)6	ICD-9	DFWHC database	Bottom-up (acute hospital care charges)	NS

1 Niveau Intensité Relative des Ressources Utilisées index (NIRRU); relative intensity of resources, 2 Registre des traumatismes du Québec, 3 Régie de l'assurance maladie du Québec, 4 Société de l'assurance automobile du Québec, 5 National Institute on Disability, Independent Living and Rehabilitation Research (NIDRR), 6 Dallas-Fort Worth Hospital Council.

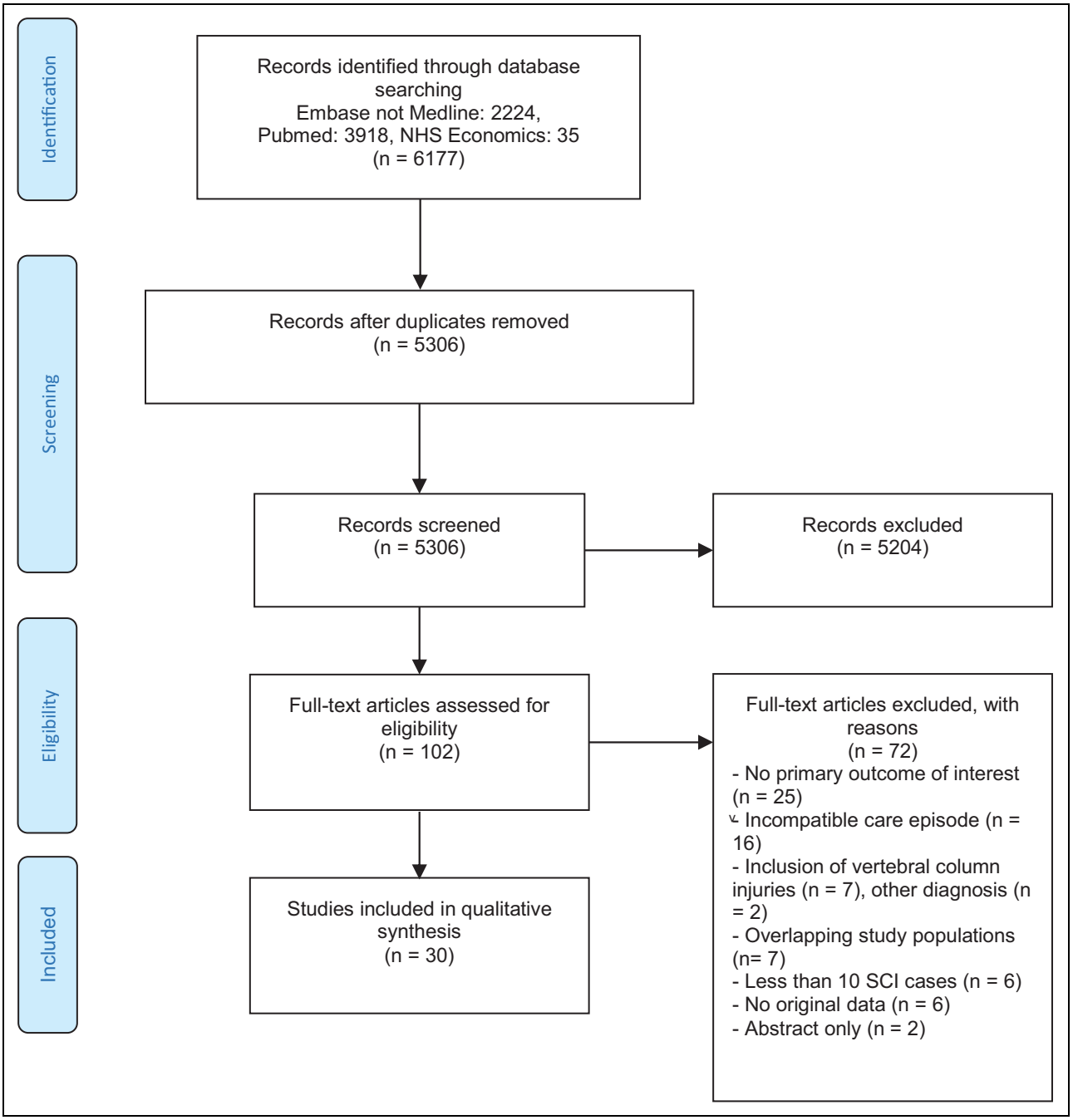

Figure 1. PRISMA 2009 flow diagram.

and Canada: 7[30-36]); and the rest were conducted in Australia,[37,38] China,[39] Mexico,[40] Nigeria,[41] Taiwan,[42,43] and Tanzania.[44] Sample sizes ranged from 34 to 15,510, and settings varied from hospital-based to nationwide. The methodologies, cost perspectives, and sources of cost data varied considerably among studies; with 13 studies took a top-down approach, and the rest including most of the U.S. studies used bottom-up approaches. The characteristics of the included articles are summarized in Table 1.

The cost of care varied widely with the mean cost of acute care ranging from $290[41] to $612,590,[26] inpatient rehabilitation from $19,536[17] to $443,044,[22] the first year after index injury costs from $32,238[30] to $1,156,406,[26] and the ensuing years following the first year from $4,392[17] to $200,810[26] (Table 1). Scores for critical appraisal ranged from −4 to 11 points with a median score of 5. Results of the quality assessment of each study are presented in Supplementary file 2.

Acute Care

A total of 21 studies reported the mean cost of hospital acute care in 8 countries. The lowest costs were found in Nigeria,[41]

Tanzania,[44] China,[39] and Taiwan[42,43] ($290 to $4,860). A study from Mexico reported the mean cost of acute care for complete cervical SCI to be $29,940.[40] In Australia, the cost of acute care varied from $42,600 for cases with paraplegia to $63,134 for quadriplegia.[38] The costs in Canada ranged from $39,330 for incomplete paraplegia to $138,620 for complete quadriplegia.[30,34] Richard-Denis et al showed the mean cost of acute care in a specialized SCI center for individuals with motor-complete SCI was $10,120 for early transfer and $15,443 if transferred after surgery, but omitted all costs related to the spine surgery and tracheostomy as well as physician fees.[35] Although the highest figures were reported in the U.S., which ranged from $73,850 for Asia Impairment Score (AIS) group D, E to $612,590 for C1-C4 AIS A, B, C cases,[15,17-19,21,26,29] these figures were charges rather than actual costs (Table 2). The average charges for acute care of SCI regardless of the neurologic category was reported from $92,220 to $337,400 in the U.S.[17,26,29] The corresponding costs were $29,550 to $61,180 in Australia[37,38] and $9,980 to $34,202 in Canada.[32,33,36] The acute care costs as a percentage of the GDP per capita were variable from 68% to 110% for Australia, 47% to 73% for Canada, 281% to 590% for the US, and from 12% to 123% for low-to-middle income countries (LMIC) (Table 3).

Inpatient Rehabilitation

In Canada, the average reported cost of inpatient rehabilitation for all injury categories was reported as $106,890[33] and $180,460.[31] The corresponding charges in the U.S. were reported to range from $19,540 for people with AIS D, E injuries to $433,044 for people with quadriplegia,[17,22] and from $32,220 to $190,620 for inpatient charges regardless of neurologic category.[26,27]

First-Year After Index Injury

Similar to inpatient rehabilitation, studies reporting costs of the first year after injury were confined to Canada and the U.S. In Canada, the mean first-year costs ranged from $32,240 for incomplete paraplegia to $167,640 for complete quadriplegia.[30,34] Another study reported a mean total cost of $119,870 for all neurologic injury levels.[33] However, in the U.S., mean first-year total charges ranged from $111,780 for AIS D, E patients to $1,156,410 for AIS A, B, C injuries of C1-C4 level.[17,23,26] The mean charges of the first year without considering injury level were $119,870 in Canada[33] and between $300,880 and $634,500 in the U.S.[17,26]

Ensuing Years

Two studies from Canada and 6 from the U.S. reported the cost of care for the years following the first year. In Canada, average annual costs varied from $6,260 for lumbar lesions to $86,720 for complete cervical SCI.[30,34] In the U.S., annual charges varied from $4,490 for AIS D, E injuries to $251,450 for AIS A, B, C injuries of C1-C4 (Table 2).[17,23,26] The mean annual charges regardless of the neurologic level of injury varied widely, from $17,950 to $96,750 (Table 3).[17,26,28] Using data from the Veterans Health Administration (VA), French et al[24] reported mean annual costs of all outpatient and inpatient care were $28,540 while Yu et al[25] obtained $37,630 for the second year before the end of life and $93,540 for the final year. It should be pointed out that the former study only included the cost of services provided by the VA. Consequently, the cost for attendant care, which was shown to be the single largest long-term cost item for persons with SCI, was not included. Additionally, ventilator-dependent cases were not included in the former study; therefore the average annual costs were possibly underestimated.

Components and Determinants of the Cost of Care

Several studies provided additional information on demographic and clinical factors that were associated with reported acute care costs. Four of these studies were conducted in Australia[35,38] and Canada[32,33] and one in Taiwan.[42] We summarized statistically significant predictors of higher treatment costs in Table 4. In the developed setting, after adjustment for other factors, a cervical level of the injury, ASIA grade A and B, concomitant injuries, and complication development showed the greatest incremental effect in costs. Both surgical delay (>24 h) and delayed transfer to a specialized SCI center were associated with incremental costs of 6300$ and 6093$, respectively. Other factors that showed significant relation to higher costs were age (continuous and age >70), female sex, and higher injury severity scores. Nevertheless gender,[32,38] age groups,[38] and charlston index[33] were not reported to have a significant effect on total costs in some of these analyses. Among studies from LMIC, Tsai et al[42] showed a male sex and medical center compared to metropolitan hospitals as control were associated with higher costs.

The most important contributors to health spending in the first year were initial hospitalization (range: 30% to 53%) followed by inpatient rehabilitation (range: 30% to 58%). After inpatient acute care and rehabilitation, inpatient readmission constituted the greatest proportion of total health care costs. Attendant care, followed by re-hospitalization, were the 2 most substantial drivers of recurring total costs after postoperative year one.

Discussion

We systematically reviewed the direct cost of illness for individuals with SCI from countries with different socioeconomic development levels. This review included 30 studies, most of which were conducted in North America. There is a paucity of literature in Europe and LMICs. The current research has considerable variation in methodology, cost descriptions, and study timeframes, providing a wide array of cost of illness estimates. Despite these differences in cost estimates, we found that health care costs for patients with SCI are substantial. Since the currently published data is not available in most

Table 2. Average Direct Health Care Costs/Charges* Per Case Stratified by Neurologic Level of SCI.

Ref.	Study, year	Country	Tetraplegia (C1-C8)		Paraplegia (T1-S5)		AIS D
			Incomplete	Complete	Incomplete	Complete	
			Mean ± SD (median) costs per case in 2020 USD				
	Acute hospital care						
37	Vaikuntam et al, 2019	Australia	63,134 ± 80,609 (36,706)		T1-T12: 71,030 ± 80,722 (51,238) L1-L5: 42,601 ± 70,059 (24,558)		–
29	Dryden et al§, 2004	Canada	39,330	133,192	T1-T12: 30,395 Lumbar/CES: 41,173	T1-T12: 91,835	-
33	Radhakrishna et al, 2014	Canada	46,714	138,621	C8-T6: 49,504 T7-L1: 40,201 L2-S5: 55,588	C8-T6: 67,319 T7-L1: 44,257	-
34	Richard-Denis et al, 2017	Canada	–	SCI center: (10,120) NS center: (15,443)	–	–	–
39	Jiménez-Ávila, 2012	Mexico	–	29,941	–	–	–
41	Tsai et al, 2005	Taiwan	C1-C4: 2,765 ± 4,442 SD		–	–	–
14	Price et al, 1994	USA	(35,594)*	(145,226)*	(37,743)*	(67,808)*	–
16	Johnson et al, 1996	USA	C1-C4 AIS A-C: 206,643 (152,275)* C5-C8 AIS A-C: 230,937 (154,844)*		AIS A-C: 150,895 (122,864)*		73,847 (39,503)* (AIS D, E)
17	Cifu et al, 1999	USA	131,450*		–	–	–
18	Cifu et al, 1999	USA	–	–	100,030*		–
20	Seel et al, 2001	USA	–	–	81,840 to 108,876		–
25	DeVivo et al, 2011	USA	C1-C4 AIS A-C: 612,590* C5-C8 AIS A-C: 437,922*		AIS A-C: 311,726*		207,316*
28	Sikka et al, 2019	USA	(84,002)*		(111,922)*		
	Rehabilitation						
14	Price et al, 1994	USA	(57,048)	(43,930)	(39,439)	(38,306)	–
16	Johnson et al, 1996	USA	C1-C4 AIS A-C: 240,848 (184,491)* C5-C8 AIS A-C: 264,932 (223,351)*		AIS A-C AIS A-C: 127,124 (107,152)*		19,536 (0)* (AIS D, E)
17	Cifu et al, 1999	USA	159,610*		–	–	–
18	Cifu et al, 1999	USA	–	–	98,176*		–
20	Seel et al, 2001	USA	–	–	85,514 to 102,734		–
21	Smith et al, 2003	USA	443,044*		T1-T12: 109,116* L1-L5: 77,329*		–
25	DeVivo et al, 2011	USA	C1-C4 AIS A-C: 347,215* C5-C8 AIS A-C: 261,155*		T1-S1 AIS A-C: 161,690*		119,363*

(continued)

Table 2. (continued)

Ref.	Study, year	Country	Tetraplegia (C1-C8)		Paraplegia (T1-S5)		AIS D
			Incomplete	Complete	Incomplete	Complete	
			Mean ± SD (median) costs per case in 2020 USD				
			First year				
29	Dryden et al, 2004	Canada	42,093	138,996	T1-12: 32,238 L1-L5/CES: 43,476	T1-12: 96,348	-
33	Radhakrishna et al, 2014	Canada	60,058	167,637	C8-T6: 61,334 T7-L1: 47,326 L2-S5: 73,248	C8-T6: 102,534 T7-L1: 75,425	-
16	Johnson et al, 1996	USA	C1-C4 AIS A-C: 689,091 (577,669)* C5-C8 AIS A-C: 643,908 (447,814)*		AIS A-C: 344,808 (276,569)*		111,783 (78,456)* (AIS D, E)
22	Webster et al, 2004	USA	C1-C4 AIS A-C: 847,784 (859,873)* C5-C8 AIS A-C: 651,328 (583,324)*		–	–	268,993 (252,370)*
25	DeVivo et al, 2011	USA	C1-C4 AIS A-C: 1,156,406* C5-C8 AIS A-C: 835,604*		T1-S1 AIS A-C: 563,590*		377,407*
			Ensuing years				
29	Dryden et al, 2004	Canada	14,553	49,371	T1-T12: 14,737 L1-L5/CES: 6,263	T1-T12: 22,750	-
33	Radhakrishna et al, 2014	Canada	17,514	86,719	C8-T6: 10,260 T7-L1: 7,201 L2-S5: 14,861	C8-T6: 53,923 T7-L1: 35,478	-
16	Johnson et al, 1996	USA	C1-C4 AIS A-C: 251,452 (95,518)* C5-C8 AIS A-C: 131,535 (40,716)*		AIS A-C: 39,761 (33,512)*		4,492 (1,763)* (AIS D, E)
22	Webster et al, 2004	USA	C1-C4 AIS A-C: 197,967 (202,501)* C5-C8 AIS A-C: 194,945 (157,165)*		–	–	51,380 (42,313)*
23	French et al, 2007	USA	29,492	37,753	T1-T12: 22,374 L1-L5: 23,400	T1-T12: 27,881 L1-L5: 30,857	–
24	Yu et al, 2008	USA	Last year: 106,240 (67,700) The year before: 45,490 (15,720)		Last year: 99,130 (55,160) The year before: 45,490 (17,380)		
25	DeVivo et al, 2011	USA	C1-C4 AIS A-C: 200,810* C5-C8 AIS A-C: 123,190*		AIS A-C: 74,658*		45,840*

Numbers are presented as Mean ± SD when available, numbers inside parenthesis represent Medians instead of mean, e.g. Mean (Median).
* Charges instead of costs, § included both the initial acute care and inpatient rehabilitation.
§ included both the initial acute care and inpatient rehabilitation.

Table 3. Average Direct Health Care Costs/charges* Per Case.

Ref.	Study	country	Cost of care. Mean (Median) Mean ± SD (median) costs per case in 2020 USD	Mean cost / GDP per capita (%)
			Acute hospital care	
36	New and Jackson, 2010	Australia	Traumatic: $54,718 (24,254)	126
			Nontraumatic: $18,700 (10,066)	43
			All: $29,555 (11,300)	68
37	Vaikuntam et al, 2019	Australia	$61,187 ± 79,992 (36,706)	110
31	Mac-Thiong, 2012	Canada	ALL: $28,682 ± 20,475	47
			< 24 h surgical delay: 24,370 ± 16,375	40
			> 24 h surgical delay: 29,727 ± 21,237	49
32	Munce, 2013	Canada	$35,457 ± 45,760	73
35	Porgo et al, 2019	Canada	($9,980) IQR: (6,096-17,633)	–
38	Li, 2011	China	$4,860	123
40	Kawu et al, 2011	Nigeria	$290	13
42	Yang et al, 2008	Taiwan	$2,485 ± 4,661	12
43	Lessing et, al 2020	Tanzania	Operative: $757	69
			Nonoperative: $219	20
16	Johnson et al, 1996	USA	$132,525 (86,480)*	281
25	DeVivo et al, 2011	USA	$337,400*	59
28	Sikka et al, 2019	USA	($92,220)* IQR: 43,390-171,750	–
			Rehabilitation	
32	Munce, 2013	Canada	$106,895 ± 74,088	273
30	Bradbury et al, 2008	Canada	$180,464 ± 125,067	353
15	Chan et al, 1997	USA	$78,969*	156
16	Johnson et al, 1996	USA	$105,972 (54,727)*	224
19	McKinley et al, 2001	USA	Nontraumatic: $38,029*	77
			Traumatic: $99,916*	201
25	DeVivo et al, 2011	USA	$190,620*	333
26	Deutsch et al, 2011	USA	$32,222 ± 21,317 (28,814)	55
			First Year	
32	Munce et al, 2013	Canada	$119,867	248
16	Johnson et al, 1996	USA	$300,875 (216,963)*	638
25	DeVivo et al, 2011	USA	$634,496*	1101
			Ensuing years	
16	Johnson et al, 1994	USA	$52,758 (7,066)*	743
23	French et al, 2007	USA	$28,581	49
24	Yu et al, 2008	USA	Last year: 93,543 (59,541)	–
			The year before: 37,628 (12,240)	
25	DeVivo et al, 2011	USA	$96,746*	169
27	Krause et al, 2019	USA	$17,953*	29

* Charges instead of costs.

countries, any generalizability of the results to a regional or global level can only be limited to states with similar economic status and health care systems. Our results demonstrated that cost figures were broadly higher for the developed countries compared with the rest of the world. Of note, we only included studies that reported direct costs of care in the SCI population.

In a review article on the health economics of the SCI conducted among war veterans, Furlan et al[45] reported that the cost of care varied from $30,770 to $62,563 in 2016 USD, which in general was greater than the health care costs for other chronic diseases. The authors found the ratio of costs of inpatient care to total health care (50.6% to 80.4%) was greater than the ratio of outpatient care costs (13% to 43.5%), and outpatient pharmacy costs (2.1% to 10.3%) to total health care. The most significant determinants of the cost of care were the presence of pressure ulcers, cervical level of injury, period time (i.e. first-year post-injury and end-of-life year), and more severe SCI. Likewise, our results demonstrated severity, level of injury, and development of in-hospital complications were the main origins of costs.

The disparities in reported health care costs between articles included in our review can be partially explained by different

Table 4. Predictors of Higher Treatment Costs.

Ref.	Variables	Incremental cost in 2020 USD
	Age	
31	continuous	142$ (41-243)
32	> 70	2,532$ (751-4,630)
	Gender	
32	Female	1,252$ (119-2,243)
41	Female	−1285.2
31	Neurological level cervical	11,327$ (7,484-15,170)
37	Charlson Index	2,979$ (833-5,724)
31	Injury Severity Score	582$ (385-780)
31	ASIA grade	
	A	9,865$ (4,851-14,878)
	B	11,764$ (6,538-16,991)
	C	4,419$ (−939-9777)
	D	0
32	Traumatic brain injury	1,805$ (233-5,778)
37	Additional injury	
	one	6,300
	2 or more	27,524
34	Care pathway;	
	admission to SCI center ≥24 h	6,093$ (1,370-10,816)
31	Surgical delay	
	Continuous	17.8$ (6.1-29.3)
	> 24 h	6,300$ (10,460-2,140)
32	Complication development	4,995$ (108-9,881)
34		6,518$ (4,525-8,801)
41	Accreditation	
	Medical centers	3,681.1
	Community hospitals	−312.5

* Statistically significant factors associated with an increase/decrease in. Costs that were identified by a multiple regression analysis.

study objectives that possibly contributed to variations in study participants and clinical heterogeneity. They can also be attributed to the major methodological differences in cost calculation methods. Research has shown that approaches used for estimating health care costs including per diem, diagnosis-related (case-mix) groups, and activity-based costing (micro-costing) methods particularly in countries with a single-payer health care system such as Australia and Canada, can remarkably under or overestimate real costs in cases with major injuries.[46-48] Furthermore, differences in cost items considered in the cost calculation can be another potential driver of disparities in reported figures (Table 1).

The highest health care costs for patients with SCI were found in studies from the US that reported charges instead of actual costs. How hospitals in the U.S. set their prices and how they are paid by different third-party payers or self-paying individuals are covered in layers of complex negotiation and accounting. U.S. hospitals are often paid by several distinct third-party payers, each with a distinct set of rules for payment contracted independently with each insurer.[49] Accordingly, hospitals in the U.S. were paid only around 35% of the total bill charged to a patient and billed charges are generally higher than true costs. DeVivo et al[26] highlighted the wide disparity between estimates of charges and costs. Charges were 3 times greater than estimated costs for acute care and 2 times greater for inpatient rehabilitation and first-year costs. Moreover, medical care expenditures in the U.S. are approximately twice as much as in other high-income countries. Higher prices for workforce, goods, pharmaceuticals, and administrative costs account for the major differences in overall health spending between the U.S. and other high-income countries.[50] Conversely, the lowest health spending was reported in studies from the developing world, likely due to lower prices and treatment intensity resulting in lower resource utilization. Although acute care costs as a percentage of GDP per capita were considerable for all countries, there was a trend toward higher costs in developed countries. This can be partially explained by different care strategies such as a lower rate of surgical treatment and implementing conservative treatment in low-income countries.

The different time spans between studies also contributed to variations in reported health care costs for patients with SCI. Using data from the National Spinal Cord Injury Statistical Center (NSCISC), Fiedler et al reported that yearly charges for acute care increased from $34,072 to $89,615 and total charges increased from $125,176 to $177,415 in 1997 USD from 1973 to 1997.[51] Asemota et al also presented recent evidence showing increasing trends in total charges in older-adults with cervical SCI analyzing The Nationwide Inpatient Sample (NIS) from 2001 to 2010.[52] Since advances in medicine and rehabilitation have improved survival among patients with extreme injuries,[53] health expenditures have increased substantially over the past few decades. Advances in surgical technology and improvement in internal fixation devices have increased the number of surgical procedures involving surgical decompression of the spine and have partially caused increasing costs.[54] This does not include incentives to reduce total care spending and rehabilitation utilization and reimbursement in the U.S. Therefore, it is unjustified to compare health spending in different timeframes. Hospital-associated factors (e.g. level of the trauma center, specified centers, volume, indirect or delayed transfer, and treatment protocols) and major epidemiological and demographic differences in SCI populations between the studies could also be potential sources of difference in healthcare spending.

For the predictors of higher treatment costs, level and severity of the injury and in-hospital complications were major determinants of cost. Urinary-related secondary complications followed by respiratory complications and pressure injuries were the major secondary complications during acute care treatment.[38] Pressure ulcer in individuals with SCI remains a common yet preventable complication. The average monthly cost of pressure ulcer management in a community-dwelling SCI population was $4,745 (2011 Canadian dollars).[55] Hospitalization costs were also related to a surgical delay of >24 h. Furthermore, acute care costs were comparatively less expensive if patients admitted to a specialized SCI center within 24 h from injury. Previous studies have suggested that early decompression of the spinal cord and early inpatient rehabilitation are cost-effective, and are associated with favorable outcomes.[56,57]

Early recognition, appropriate prehospital care, and timely transfer to an SCI center are essential to receive specialist care and reduce preventable complications.[58]

Healthcare costs in the first year post-injury were higher than the following years. The largest proportion of total healthcare costs in the first year post-injury involved initial hospitalization, inpatient rehabilitation, and inpatient readmission.[33] During the following years after the first year, attendant care followed by re-hospitalization was the most substantial driver of recurring total costs. Samsa et al[59], in a study of the patterns of inpatient admissions among a cohort of veterans with SCI, found that the incidence of re-hospitalization decreased more in years 2 to 5 after injury but more slowly thereafter. Another study of VA patients showed that among the SCI population, one-half of the recurring costs after the first year post-injury were associated with inpatient care.[24] Jaglal et al[60] showed that the main causes of secondary complications after index discharge were musculoskeletal, respiratory, gastrointestinal, and urological disorders. Although the inpatient and attendant service costs are an important part, durable medical equipment, and home modification costs are also major constituents of the total costs during the years following the first postoperative year.

Limitations

Our review had some inherent limitations. Firstly, data was not available in most parts of the world. Secondly, our review showed considerable variability in the costs and cost calculations of SCI cases. There was no unified definition for the cost of care, and literature consisted of different methods of cost calculation. Furthermore, methodological and reporting heterogeneities were common, which complicated the comparison of the results between publications. Moreover, it was not practical to extract the results and conduct a meta-analysis.

Conclusion

Healthcare costs associated with SCI have broad heterogeneity among different countries due to the definition of cost of care, different time horizons, level and severity of the injury, and health system structure. Therefore, generalizing these health care costs to a regional or global level requires careful consideration. However, the life-long economic cost of SCI is extremely high. Since inconsistencies in the method of conducting studies and limited reporting detail have complicated interpretation and limited studies usefulness, future investigations should follow standard guides for methodology. Published standards on conducting cost of illness studies are available to encourage uniformity.[14,61,62] A methodology guide designed particularly for SCI studies based on these publications could make the best use of a cost of illness studies for SCI. Further studies on the cost of care for individuals with SCI are needed to assist patients, healthcare providers, administrators, and policymakers in making better decisions concerning resource allocation based on the anticipated costs. Moreover, cost-effectiveness studies are essential to identify the efficacy of different interventions and care pathways when planning for optimal care for SCI cases.

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Supplemental Material

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